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Investigating Structural Behavior of High-Rise Building under Lateral Loads in Bangladesh: A Comparative Study of BNBC 2006 and BNBC 2020

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Abstract

This study compares the Bangladesh National Building Code (BNBC) 2006 and BNBC 2020 to identify changes in design of a multi-story building and analyze its structural behavior under lateral load using ETABS software (version 16.2.1). The parameters used for comparison are seismic and wind forces, lateral displacement, story drift, wind and seismic shear, moment of particular beams and columns, and base shear for seismic forces. The study revealed significant variations in seismic base shear and maximum lateral displacement between the two codes. The maximum story drift for earthquake loading was found at the sixth floor, almost three times greater in both x and y directions for BNBC 2020 compared to BNBC 2006. However, for wind load condition, the maximum story drift was found 22% greater in x direction and 25% greater in y direction for BNBC 2006 compared to BNBC 2020. Additionally, moment values in various beams increased with the earthquake force and were impacted by the additional consideration of live load for seismic weight in BNBC 2020. Wind forces values and corresponding moment values were lower in BNBC 2020. Even though the earthquake force was found to be much higher following BNBC 2020 compared to BNBC 2006, the difference in rebar percentage was negligible when all of the load combinations that existed in both codes were considered for determining the rebar percentage in frame members.

Keywords: *Building Codes; Structural behavior; Lateral Load; ETABS software; Seismic and Wind forces.*

1 Introduction

The seismic vulnerability of reinforced concrete structures necessitates their alignment with earthquake-resistant design standards concerning strength, ductility, and stiffness. The precise arrangement of fundamental building elements significantly impacts the response behavior of laterally loaded structures, with poor placement contributing to earthquake-related damage. Bangladesh, as a densely populated and economically disadvantaged nation, faces even greater challenges from earthquakes compared to industrialized countries. Due to limited contemporary modeling and computational capacity, static analysis is commonly used in Bangladesh and other developing countries. Heightened structures face significant lateral movement from wind loads, potentially causing both structural and non-structural component failures. The objective of safety guidelines is to balance efficiency and security, especially in seismic-prone regions. The Bangladesh National Building Code (BNBC) was revised from 1993 to 2020, incorporating international insights to enhance safety. This article aims to compare wind load and earthquake analysis regulations between BNBC 1993 and BNBC 2020. The study provides designers utilizing BNBC 1993 with a relationship indicating percentage changes in design wind load between the old and new codes, thus aiding their design computations.

2 Modeling and Analysis

This research focuses on a ten-story commercial building in Chittagong, characterized by a geometrically symmetrical layout measuring 220.31ft x 68.47ft. The study aims to examine the impact of wind and seismic loads on the structure using two standards: BNBC 2006 and BNBC 2020. The structural analysis of the building incorporates gravity loads (e.g., living loads, dead loads), wind thrust, and seismic loads, including the building's self-weight, floor finishes, and other superimposed loadings.

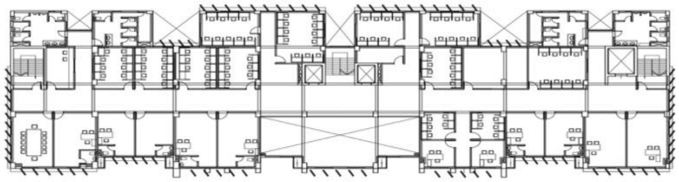

Figure 1. Building Plan View of Typical Floor

The seismic loading calculation technique remains mostly unchanged between the two editions of BNBC, utilizing the Equivalent Lateral Force method and calculating base shear based on factors like seismic zone, structural relevance, and response reduction characteristics. The base shear is determined using the time period and soil type, with BNBC 2020 using the acceleration spectrum coefficient (Cs) and BNBC 2006 utilizing a numerical coefficient (C). Both BNBC versions consider seismic force as a lateral force and employ the equivalent static force method (ESFM) to calculate base shear. The codes specify different values for the response modification coefficient (R) of the Intermediate Moment Resisting Frame (IMRF), with BNBC 2006 setting it at 8 and BNBC 2020 at 5. The study examines wind load using the Surface Area Method from BNBC 2006 and the Analytical Procedure from BNBC 2020. Three-dimensional models of the structure were developed using ETABS software (Version 16.2.1), considering fixed columns at the foundation and accounting for rigid diaphragm movement of the slab. The structure underwent various loads, including dead load, live load, and specially imposed live loads (seismic and wind loads), as per the Bangladesh National Building Code provisions.

3 Result and Discussion

This chapter focuses on the lateral load analysis findings, which include earthquake and wind forces, story displacement, story drift, and beam moments. The discussion focuses on the differences between the BNBC 2006 and BNBC 2020 codes. The chapter uses graphical representations to demonstrate the disparities in outcomes achieved by using both codes, stressing the changes in outcome.

3.1 Comparison of Seismic Load Analysis

In BNBC 2006, seismic zone coefficient had a lower value of 0.15 (zone-II) compared to BNBC 2020 (0.28 for zone-III) for Chittagong.

3.1.1 Earthquake force

The implementation of BNBC 2020 leads to an increased base shear compared to BNBC 2006. This is primarily attributed to adjustments in the zoning map and corresponding higher values specified in BNBC 2020. The variation in the Response Modification Coefficient (R) across different structural systems (ORCMF, IRCMF, SRCMF, and SMRF) further contributes to the significant disparity in base shear. The inclusion of the normalized acceleration response spectrum (Cs) in BNBC 2020 amplifies the base shear. Lower R values in BNBC 2020 result in higher spectral acceleration (Sa), leading to increased seismic base shear.

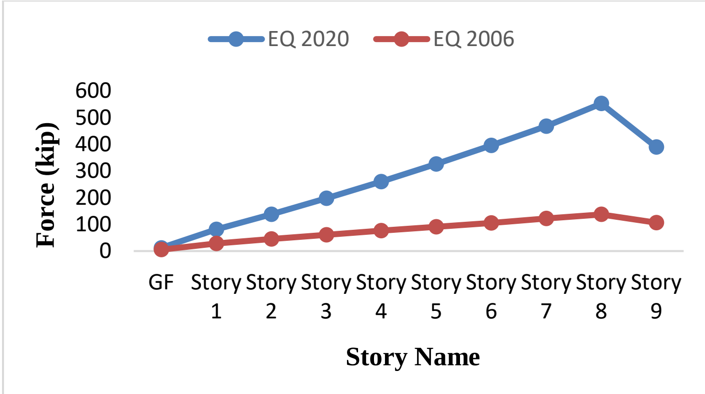

Figure 2. Earthquake Force

Despite the DBE (Design Basis Earthquake) being set at 2/3 of MCE in BNBC 2020, the total base shear rises due to the inclusion of 25% living load as seismic dead weight. Additionally, minor adjustments in building time period and seismic load are observed in BNBC 2020.

3.1.2 Displacement Due to Earthquake Load

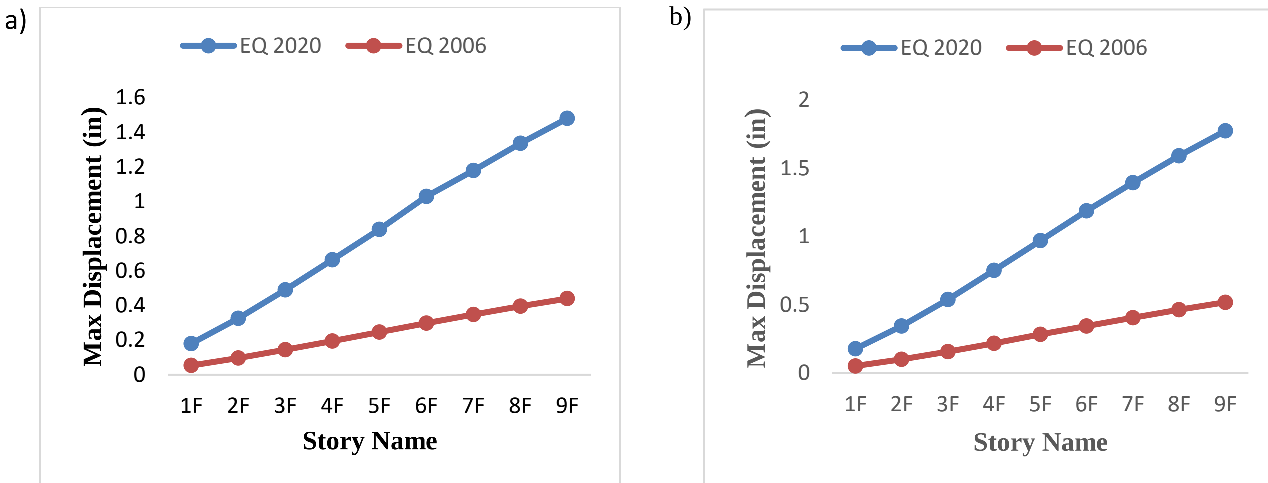

Figure 3. Maximum displacement at different story for earthquake load; (a) X- Direction, (b) Y- Direction

The assessment of top story displacement is crucial when analyzing the response of buildings to lateral loads. Significantly large top story displacement can induce the p-Δ effect and gradually amplify the overturning moment. Through analysis, it is observed that the maximum displacement is greater when applying BNBC 2020 in comparison to BNBC 2006. This disparity can be attributed to the higher earthquake forces calculated under BNBC 2020. The displacement values exhibit a linear increase according to both versions of the BNBC code.

3.1.3 Story Drift

There is a noticeable disparity in the occurrence of story drift when comparing BNBC 2020 and BNBC 2006. In both the x and y directions, the story drift in BNBC 2020 is approximately three times greater than that in BNBC 2006. Figure 4 demonstrate that the maximum story drift occurs between the fourth and sixth floors, with a gradually increasing zoning coefficient as altitude increases and an upward tendency. For lower zone coefficients, the drift values remain nearly constant from the middle floor to the upper story of the building. The mid-height of the building experiences the maximum story drift. The form of the graph evolves into a semilunar shape as the zone coefficient value grows. All tale drift values obtained from both BNBC 2006 and BNBC 2020 fit within the regulations' permitted range. The permitted limit for story drift is consistent across both codes. The seismic zone coefficient has a strong relationship with the slope of the story drift curve. A smaller zone coefficient equates to a steeper slope. This relationship holds true within a certain range, beyond which the slope change remains relatively constant.

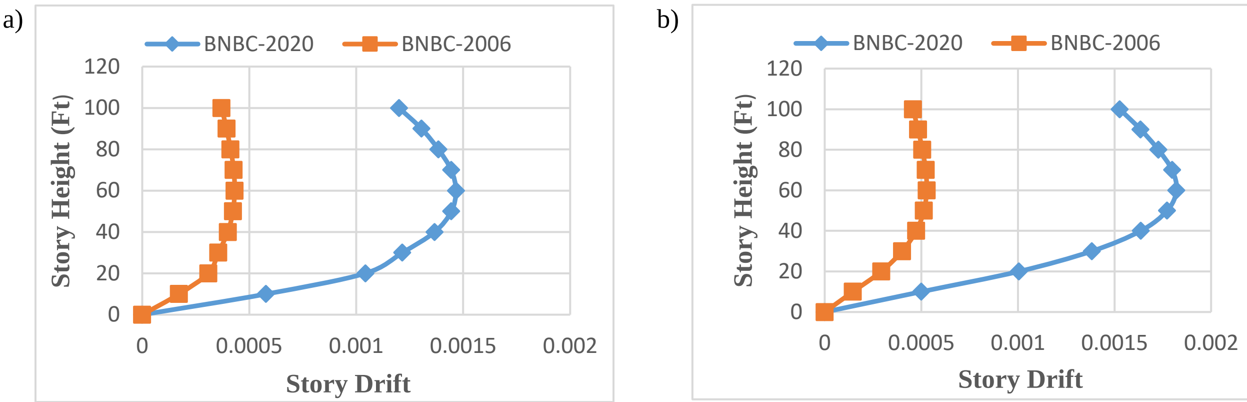

Figure 4. Story drift due to earthquake load; (a) X- Direction, (b) Y- Direction

3.1.4 Variation of moment in Beam

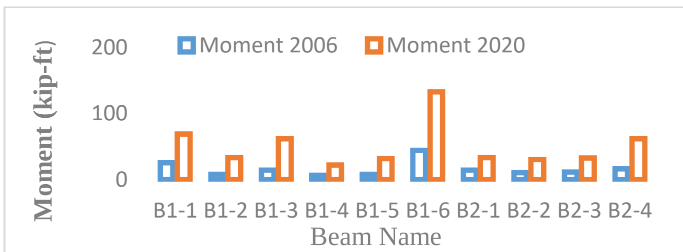

Figure 5. Variations of moment in beam due to earthquake load

The passage discusses the impact of earthquake forces on the shear and moment values of beams. It states that both the shear and moment values of beams increase along with the earthquake force. The study focuses on six external beams (B-1-1 to B-1-6) and four internal beams (B-2-1 to B-2-4) to understand the effect of increased earthquake loads on design values. Comparing the BNBC of 2020 with the BNBC of 2006, the moment values on beams are found to be three times higher in the former. This increase is attributed to the inclusion of live load considerations in seismic weight calculations.

3.2 Comparison of Wind Load Analysis

In the context of wind load, BNBC 2020 demonstrates lower values compared to BNBC 2006, despite having a higher basis wind speed. This can be attributed to two significant factors. Firstly, the gust coefficient (G) in BNBC 2020 has been significantly reduced, almost half of that in BNBC 2006. Secondly, BNBC 2020 divides the pressure coefficient into two categories, windward and leeward sides, with their combined value being considerably lower than that provided by BNBC 2006.

3.2.1 Wind force

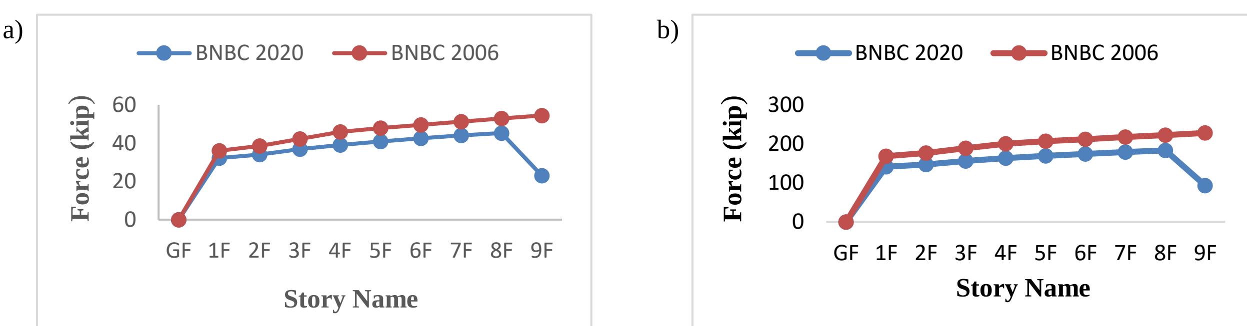

Figure 6. Wind force; (a) X- Direction, (b) Y- Direction

3.2.2 Displacement Due to Wind Load

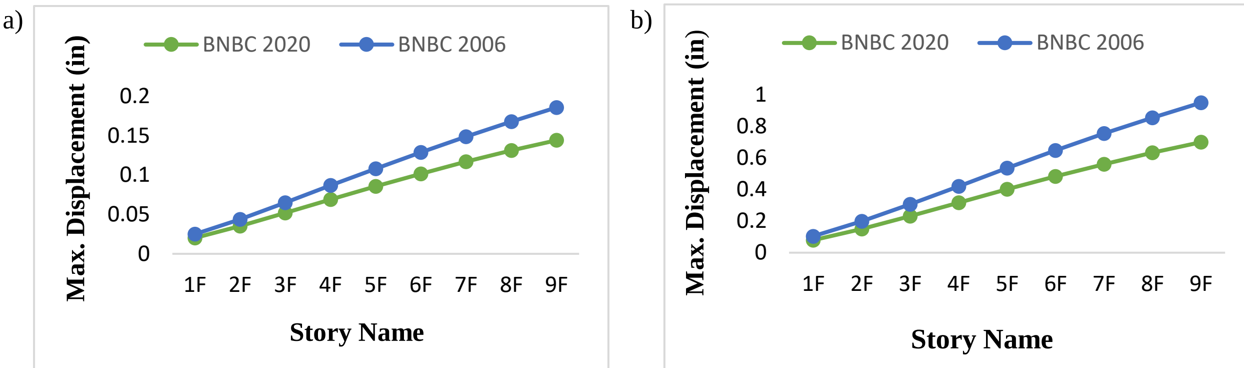

Figure 7. Maximum displacement at different story; (a) X- Direction, (b) Y- Direction

3.2.3 Story Drift

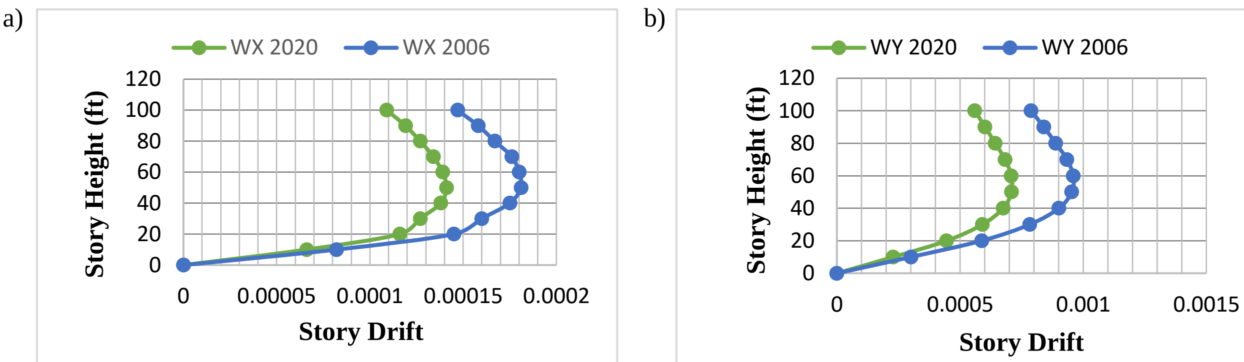

Figure 8. Story drift due to wind load; (a) X- Direction, (b) Y- Direction

3.2.4 Variation of Moment in Beam

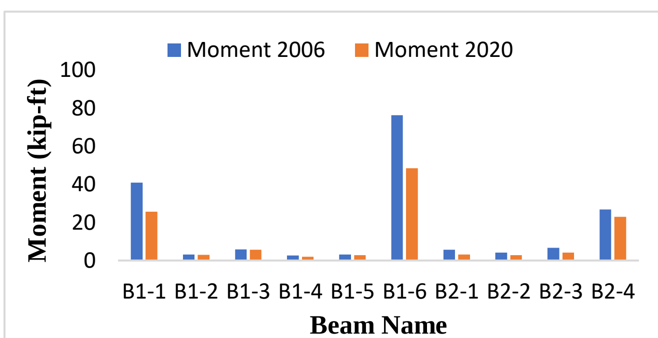

Figure 9. Variations of moment in beam due to wind load

In comparison to earthquake load, the story drift for wind load exhibits a significant similarity, but with lower values for BNBC 2020 as opposed to BNBC 2006 (Figure 8). This difference can primarily be attributed to the load values prescribed by the two codes. As the wind force value is reduced in BNBC 2020, the corresponding moment value is also lower.

3.3 comparison of other cases

Rebar Percentage for column and beam in the limited study of this specific structure has been come out as the followings: The rebar percentages for columns were compared between BNBC 2020 (2.018%) and BNBC 2006 (2.097%), revealing a minor difference. For the 9th floor, beam rebar percentages were examined: BNBC 2020 had positive (0.070%) and negative (0.095%) averages, while BNBC 2006 had higher values (positive: 0.167%, negative: 0.205%). Thus, BNBC 2006 exhibited higher beam rebar percentages compared to BNBC 2020, indicating a noticeable disparity. The calculation of rebar percentage in accordance with both BNBC 2006 and BNBC 2020 involved considering all the load combinations specified in the respective codes.

4 Conclusion

In earthquake-prone Bangladesh, the need to update or renovate buildings constructed according to the BNBC 2006 remains unclear. The introduction of BNBC 2020 signifies a more cautious approach to tectonic design in the country. Notably, the safety margin against higher base shear values for earthquakes has improved, but the requirement for additional reinforcement in low-rise structures may impact the construction design under BNBC 2020. The study identifies several factors, including an increase in seismic zone coefficient (Z), a decrease in response modification coefficient (R), and an increase in normalized response spectrum acceleration (Cs), as contributors to higher seismic base shear in BNBC. It is observed that BNBC 2006 inadequately describes the seismic design base, as BNBC 2020 exhibits significantly larger base shear and story drift. Moreover, there are differences in the vertical dispersion of earthquake force between BNBC 2020 and BNBC 2006. The highest seismic force value was observed at the eighth floor when applying both BNBC 2006 and BNBC 2020. Notably, the seismic force value for BNBC 2020 was approximately four times greater than that of BNBC 2006. The BNBC 2020 has made significant improvements in accounting for adjacent obstacles and structural heights in wind allowance. Consequently, wind loads according to BNBC 2020 are lower compared to BNBC 2006. This reduction in wind force is achieved through adjustments in key factors such as the gust coefficient (G) and wind pressure coefficient in BNBC 2020. Under seismic load, story drift values are over three times higher in BNBC 2020 compared to BNBC 2006, while wind load conditions show no significant change. Moment values in beams increase with earthquake forces, with BNBC 2020 having approximately three times higher moments than BNBC 2006. Rebar percentages in columns remain unchanged between BNBC 2006 and BNBC 2020, but significant variations are observed in beam rebar percentages. Higher values are seen in BNBC 2006 compared to BNBC 2020.

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