A COMPARATIVE ANALYSIS OF DESIGN PROVISIONS FOR LOW-RISE AND MID-RISE RC BUILDINGS IN MODERATE AND HIGH SEISMIC ZONES AND WIND-PRONE LOCATIONS: A STUDY OF BNBC 1993 AND BNBC 2020

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ABSTRACT

Incorporating advancements in structural engineering knowledge over the past two decades, significant revisions have been implemented in the BNBC 2020. These revisions primarily pertain to the design evaluation of wind and seismic loads. Noteworthy changes have been proposed for design parameters and analysis methodologies, explicitly focusing on wind load and seismic load assessments. Critical aspects such as maximum lateral deflection, section classification, location considerations, and rebar percentages have been redefined in the context of seismic loads. The seismic zoning has undergone recalibration to adjust Peak Ground Acceleration (PGA) values. Alterations are also evident in response reduction factors for structural systems, structural importance factors, and soil-related factors. The modifications extend to wind load considerations as well. Adjustments have been made to the gust response factor, external and internal pressure coefficients, wind speed recording, topographic factors, and terrain exposure levels. A systematic parametric study of Reinforced Concrete (RC) structures was conducted to grasp these alterations comprehensively. The study utilised Finite Element Analysis (FEA) to compare outcomes based on the previous code (BNBC 1993) and the newly gazetted code (BNBC 2020). This study focused on analysing a 10th and 15th-story RCC building located in the cities of Narayanganj, Cox's Bazar, and Habiganj. The research highlights that the primary disparities between the two codes lie in seismic base shear, maximum lateral displacement, wind base shear, maximum lateral displacement, inter-story drift, and rebar percentage. By systematically examining and contrasting the provisions of BNBC 1993 and BNBC 2020, this study provides a lucid perspective on the variations and commonalities between the codes. It emphasises the crucial role of these provisions in ensuring the safety and resilience of RCC buildings across diverse zones.

Keywords:*Seismic Load Assessment, Wind Load Assessment, BNBC 1993, BNBC 2020, Peak Ground Acceleration (PGA), Finite Element Analysis (FEA).*

1. INTRODUCTION

The main differences between the Bangladesh National Building Code (BNBC) of 1993 and 2020 are based on examining seismic and wind loads, which are more complicated than static dead loads. Wind loads have undergone significant modifications in terms of analysis. Specifically, substantial changes have been made to the seismic and wind loads in their analysis. The introduced elements relate to seismic loads, and certain aspects such as seismic zoning, design spectral acceleration, and the system response modification factor have been restructured. The primary goal of this study is to investigate these developments from both structural and economic perspectives. Using ETABS, a finite element analysis program, two codes were employed to analyse structural RCC. ETABS 2016 conducts the study and design of structures with various story heights. This study concentrates on analysing various types of loads encountered in construction, including lateral and gravity loads.

Seismic loading in Bangladesh is known to vary across different seismic zones, primarily influenced by Peak Ground Acceleration (PGA) values. According to the BNBC of 1993, Bangladesh is classified into three distinct seismic zones. Habigonj, Narayangonj, and Cox's Bazar are all situated in different seismic intensity zones. Habigonj falls within a zone characterised by high seismic intensity (Z=0.25), while Narayangonj and Cox's Bazar are located in zones with moderate seismic intensity (Z=0.15).

Based on the BNBC 2020, Bangladesh has been categorised into four distinct seismic zones. Habigonj is located in a region classified as a very severe seismic zone characterised by a high-intensity value (Z=0.36). On the other hand, Cox's Bazar and Narayangonj are situated in the severe seismic zone and moderate seismic zone, respectively. These zones exhibit lower intensity values, with Cox's Bazar having a value of (Z=0.28) and Narayangonj having a value of (Z=0.20).

The BNBC 1993 was the first building code of Bangladesh. The provisions for seismic load design were developed based on experience and knowledge. It has been observed that some research, such as the work of Ali and Choudhury (1994), Atique& Wadud (2001), and Ansary and Sharfuddin (2002), has been carried out since 1993 to enhance the existing building code. This research includes efforts to restructure the seismic zoning code, the soil classification system, and the site-dependent response spectrum.

From this extensive body of research, the House Building Research Institute (HBRI), in collaboration with renowned faculty members from Bangladesh University of Engineering and Technology (BUET) and a few external consultants, was tasked with preparing BNBC 2020. Bari and Khondoker (2007) conducted a comprehensive comparison based on BNBC 1993 with other building codes, focusing on seismic analysis. The research team first introduced the proposed changes to BNBC 1993.

Al-Hussaini and Hossain (2010) demonstrated that BNBC 1993 requires a major upgrade in terms of design and structural analysis provisions. Their study delved into peak ground acceleration (PGA), spectral acceleration, soil classification systems, site-dependent response spectra, and extensively defined seismic design categories. Sakib (2018) conducted a detailed parametric comparison based on BNBC-1993 and BNBC-2017 for steel buildings in another impactful study.

The primary objective of this research project is to conduct a comprehensive comparison of planned parameters in BNBC 2020, focusing on wind and seismic provisions, load combinations, base shear, rebar percentage, maximum lateral displacement, inter-story drift, and rebar percentage. The specific goals include comparing the seismic provisions of BNBC 1993 and BNBC 2020, examining the impact of both wind and seismic load effects on RCC buildings across the two codes, and investigating the effects of these changes on RCC buildings in various zones of Bangladesh.

2. METHODOLOGY

The specific analysis steps were chronologically followed to systematically quantify and record the changes in design through a comparative parametric analysis between BNBC 1993 and BNBC 2017. The distinct analytical approaches to lateral forces in the two codes resulted in pronounced changes in behavioural and structural design. At the conclusion of this analysis, each zone exhibited its own set of characteristic graphs illustrating differences in loading patterns, base shear, lateral maximum deflection, inter-story drift, and rebar percentage. A 10-story and a 15-story building were selected for analysis, situated in Cox's Bazar for the moderate seismic zone, Narayangonj for the moderate seismic zone, and Habigonj for the high seismic zone, presented in Table 1. RCC structures were designed as Intermediate Moment Resisting Frame (IMRF) for BNBC 1993 and Special Moment Resisting Frame for BNBC 2020. Structural analysis was performed for both 10 and 15 stories for the respective codes, utilising ETABS versions 16 and 17.

The following steps were chronologically followed:

- Structural analysis in ETABS
- Structural design in ETABS
- Deflection and stress verification
- Comparison

Table 1: Zone Category Concerning Seismic Intensity

Category	City	Seismic Intensity
Zone-1	Narayangonj	Moderate
Zone-2	Cox's Bazar	Moderate
Zone-3	Habigonj	High

2.1 Modelling and Analysis

The plan area depicted in Figure 1, measuring 95’-6" x 40’-10", results in a total area of 3899.6 square feet, which is a standard plan area for a residential building.

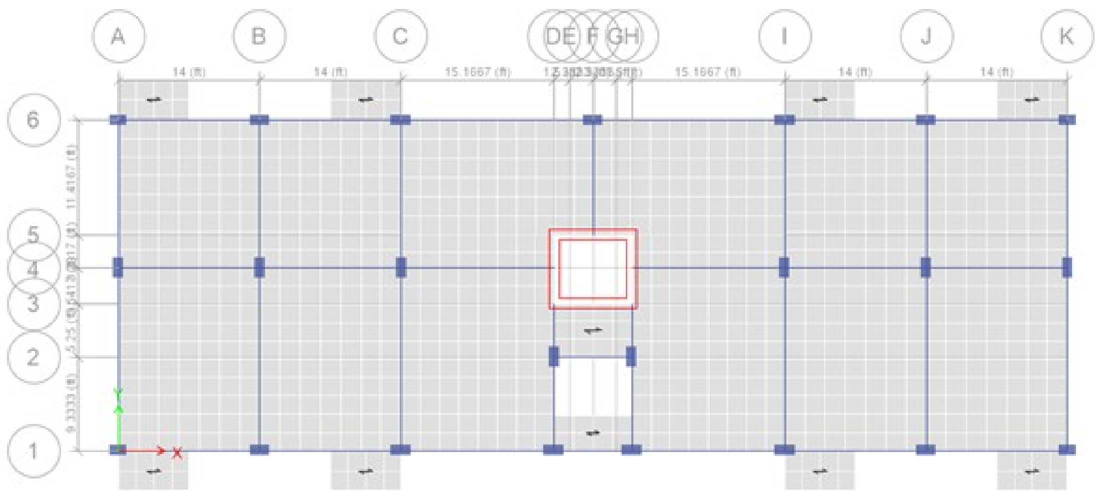

Figure 1: Plan Layout

2.2 Load Analysis

The analysis and design of structures are conducted for gravity loads, encompassing dead loads and live loads. Dead loads consist of the self-weight of the building frame and shell components, floor finish, partition walls, and other superimposed loads. Live loads encompass all temporary loads introduced after the building's construction.

The superimposed dead and live loads used for the analysis are as follows:

- Live load = 3 KN/m²
- Floor Finish = 1.5 KN/m²
- Partition wall = 2.5 KN/m²
- Live load due to lifting machine = 4.79 KN/m²
- Live load due to water tank = 21.30 KN/m²

These loads in ETABS were defined using static load cases. The loading pattern has been adjusted for the same buildings in different zones, considering RCC buildings as per different codes.

Table 2: Algorithm for ETABS Lateral Load Scenario Analysis

Code	Load Case	Type	ETABS Analysis
BNBC 1993	EQ_x - EQ_y	Quake	UBC 94
BNBC 2020	EQ_x - EQ_y	Quake	ASCE 7-05
BNBC 1993	W_x - W_y	Wind	UBC 94
BNBC 2020	W_x – W_y	Wind	ASCE 7-05

In Table 2, "EQ_x - EQ_y" represents seismic load in the x and y directions, and "W_x - W_y" represents wind load in the x and y directions. The ETABS analysis methods correspond to the seismic and wind codes specified for each load case.

Parameters of Seismic Load Analysis, Parameters of Wind Load Analysis, and Beam and Column Cross-Sectional Dimensions for BNBC 1993 and BNBC 2020 are represented in Tables 3, 4, and 5 respectively.

Table 3: Parameters of Seismic Load Analysis

Parameter	**Seismic Zone: Narayangonj**		**Seismic Zone: Cox's Bazar**		**Seismic Zone: Habigonj**	
	BNBC 1993	**BNBC 2020**	**BNBC 1993**	**BNBC 2020**	**BNBC 1993**	**BNBC 2020**
Zone Coefficient (Z)	0.15	0.20	0.15	0.28	0.25	0.36
Soil Type	S3	SC	S3	SC	S3	SC
Site Class Coefficient	1.5	1.00	1.5	1.00	1.5	1.00
Structure Importance Factor, I	1.00	1.00	1.00	1.00	1.00	1.00
Time Period, T	$T=C_t(h$¿¿n, where $C_t=0.073$	$T=C_t(h$¿¿r where $C_t=0.0466$	$T=C_t(h$¿¿r, where $C_t=0.073$	$T=C_t(h$¿¿r where $C_t=0.0466$	$T=C_t(h$¿¿n, where $C_t=0.073$	$T=C_t(h$¿¿r where $C_t=0.0466$
Structural System	Intermediate Moment Resisting Frame	Special Moment Resisting Frame	Intermediate Moment Resisting Frame	Special Moment Resisting Frame	Intermediate Moment Resisting Frame	Special Moment Resisting Frame
Response Factor, R	8 (IMRF)	7 (SMRF)	8 (IMRF)	7 (SMRF)	8 (IMRF)	7 (SMRF)
Seismic Design Category	N/A	C	N/A	D	N/A	D

Table 4: Parameters of Wind Load Analysis

Parameter	Wind Zone: Narayangonj		Wind Zone: Cox's Bazar		Wind Zone: Habigonj	
	BNBC 1993	**BNBC 2020**	**BNBC 1993**	**BNBC 2020**	**BNBC 1993**	**BNBC 2020**
Method of Analysis	Surface area method	Analytical Procedure	Surface area method	Analytical Procedure	Surface area method	Analytical Procedure
Basic Wind Speed	200 KN/h	220.21 KN/h	240 KN/h	288 KN/h	180 KN/h	195.3 KN/h
Exposure Type	Exposure: A	Exposure: A	Exposure: C	Exposure: C	Exposure: B	Exposure: B
Occupancy Category	1.00	1.00	1.00	1.00	1.00	1.00
Topographic Factor	1.00	1.00	1.00	1.00	1.00	1.00
Limit of Maximum Deflection	For 100% wind effect	For 75% wind effect	For 100% wind effect	For 75% wind effect	For 100% wind effect	For 75% wind effect

Table 5: Beam and Column Cross-Sectional Dimensions for BNBC 1993 and BNBC 2020

Section Property (inch x inch)	10F (BNBC 1993)	10F (BNBC 2020)	15F (BNBC 1993)	15F (BNBC 2020)
Main Beam	12 x 18	12 x 18	12 x 20	12 x 20
Column External Y-Direction	12 x 20	12 x 20	16 x 25	16 x 25
Column External X-Direction	12 x 20	12 x 20	16 x 25	16 x 25
Corner Column	12 x 20	12 x 20	16 x 25	16 x 25
Internal Column	12 x 24	12 x 24	18 x 30	18 x 30
Grade Beam	12 x 20	12 x 20	12 x 24	12 x 24
Shear Wall	12 x 82	12 x 82	12 x 82	12 x 82

3. RESULT AND DISCUSSION

The results of this analysis, extracted throughout the research, are based on reinforced concrete analysis, which is further subdivided into the following categories:

- Based on Seismic Base Shear
- Based on Wind Base Shear
- Based on Maximum Lateral Deflection
- Based on Maximum Lateral Displacement
- Based on Inter-Story Drift
- Based on Section Comparison

The results of the above parameters are described sequentially in this section.

3.1 Seismic Base Shear

According to the findings presented in Figure 2, it can be observed that there has been an increase in the base shear in BNBC 2020 when compared to BNBC 1993. The research findings indicate an increase in base shear in the Cox's Bazar zone for both buildings, as compared to the standards set by BNBC 1993. Regarding the Habigonj district, it is important to note that it falls within a high seismic zone according to both the BNBC codes. It has been observed that the base shear exhibits a gradual decrease in both buildings when compared to BNBC 1993. In contrast, a notable observation reveals that the base shear value has increased in the case of a 10th story building in Narayangonj. At the same time, a decrease has been observed for a 15th story building, in accordance with the provisions outlined in the code of BNBC 1993.

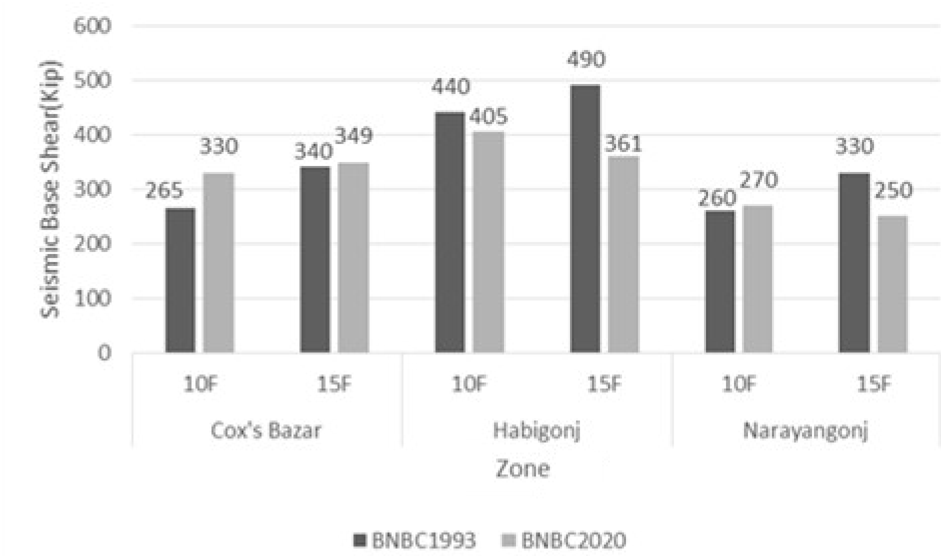

Figure 2: Seismic Base Shear (Kip) vs. Number of Stories

According to Figure 3, it can be observed that the base shear of the structure exhibits significant variations across different zones in relation to BNBC 1993. The seismic base shear of buildings in the respective zones has gradually decreased over time, as observed in accordance with the BNBC 1993 guidelines. Additionally, in Figure 3, it can be observed that the rate of change of seismic base shear varies non-linearly across different zones.

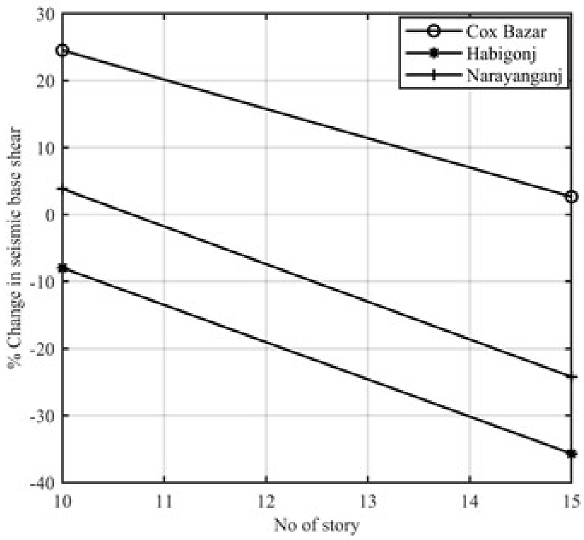

Figure 3: Percent (%) Change in Seismic Base Shear with Respect to BNBC 1993

3.2 Wind Base Sear

Figure 4 illustrates a decrease in base shear in BNBC 2020 compared to BNBC 1993. The analysis findings indicate that BNBC 2020 demonstrates reduced wind base shear values for both the X and Y directions when compared to BNBC 1993. As depicted in Figure 4, it is evident that buildings constructed following the BNBC 2020 exhibit lower wind base shear values compared to structures built in accordance with its previous version.

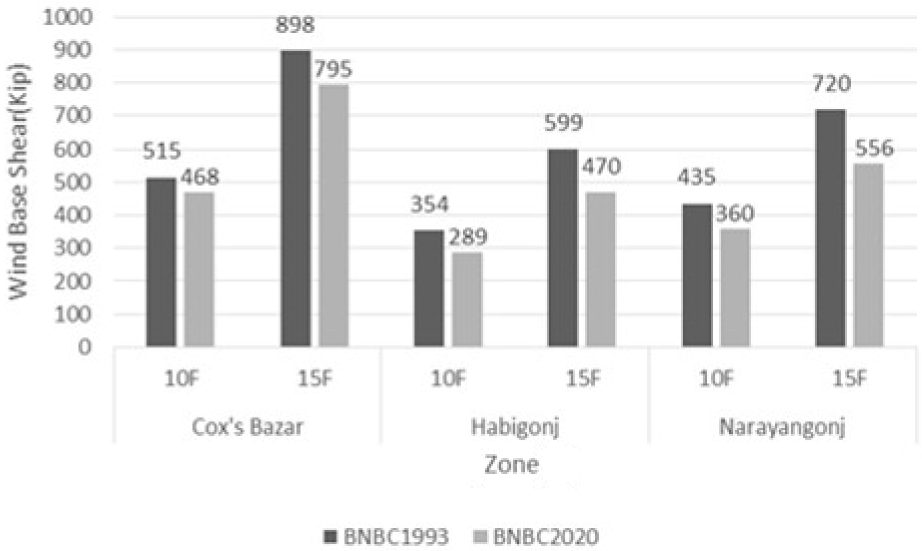

Figure 4: Wind Base Shear (Kip) vs No of Story

The analysis of Figure 5 reveals notable fluctuations in the base shear of the structure across various zones, following the BNBC 1993 guidelines. According to the BNBC 1993 guidelines, there has been a gradual decrease in wind base shear for buildings in their respective zones over time. This observation aligns with the research findings.

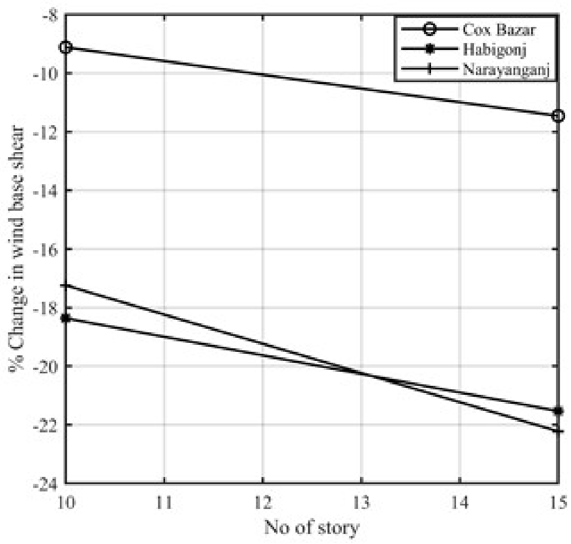

Figure 5: Percent (%) Change in wind Base Shear with Respect to BNBC 1993

3.3 Maximum Seismic Lateral Deflection

The term "maximum lateral deflection" denotes the utmost movement perpendicular to the axial plane of an expansion joint, characterised as a shear motion. This lateral deflection is visually depicted in Figures 6 and 7.

Two distinct characteristics can be observed:

- According to the BNBC 1993, a direct relationship was observed between the height of a building and its seismic lateral deflection in both directions. As the building's height increases, the seismic lateral deflection also increases.
- In the context of the 10th and 15th stories, it is observed that the lateral displacement resulting from seismic base shear is comparatively higher in Habigonj compared to Cox's Bazar and Narayangonj.

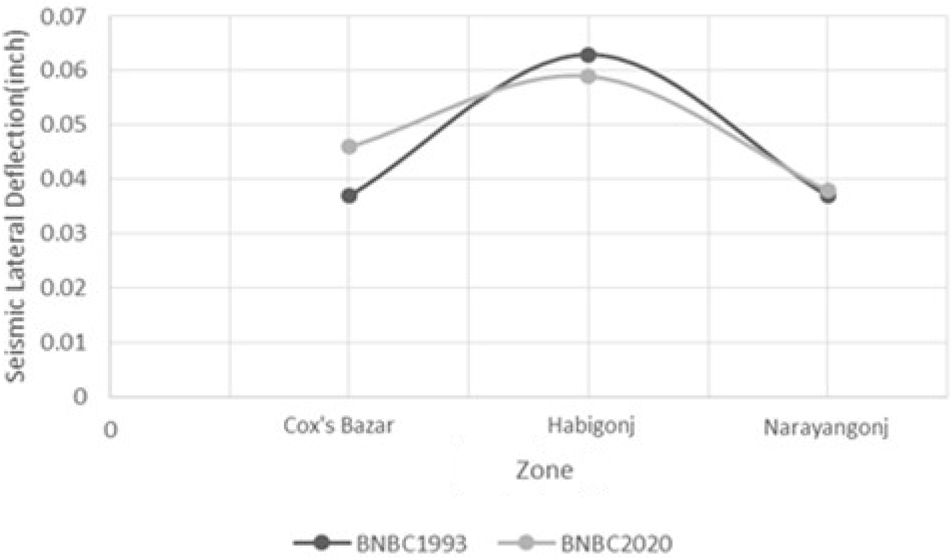

Figure 6: Maximum Seismic Lateral Deflection of 10F Building vs Zones

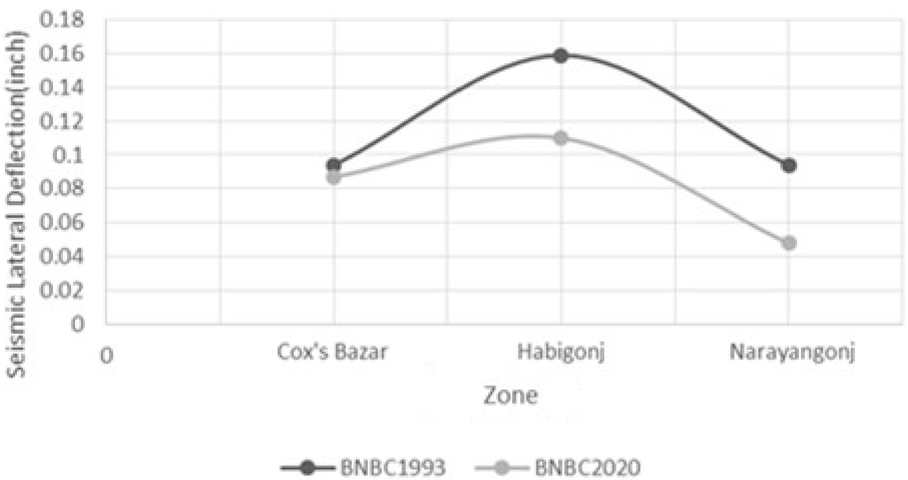

Figure 7: Maximum Seismic Lateral Deflection of 15F Building vs Zones

3.4 Wind Maximum Lateral Displacement

In the analysis conducted by BNBC 1993, it was observed that wind base shear values are higher in both directions, regardless of the height. According to theoretical principles, it can be inferred that the lateral deflection in both the X and Y directions would be greater in BNBC 1993 compared to BNBC 2020, as deflection is directly proportional to base shear. Figures 8 and 9 show that the Habigonj and Narayangonj regions exhibit a higher deflection pattern according to the BNBC 1993 guidelines. However, it is interesting to note that the Cox's Bazar region deviates from the expected theoretical concept, displaying an opposite trend. The analysis reveals an observed increase in deflection patterns as per BNBC 2020.

Moreover, it can be observed that as the height of the structure increases, the set of curves tends to diverge. This suggests that there are greater disparities in lateral displacement between the two codes, particularly for taller buildings. In accordance with the BNBC codes, it has been observed that the displacement value exhibits an upward trend as the height of the building increases across all three zones.

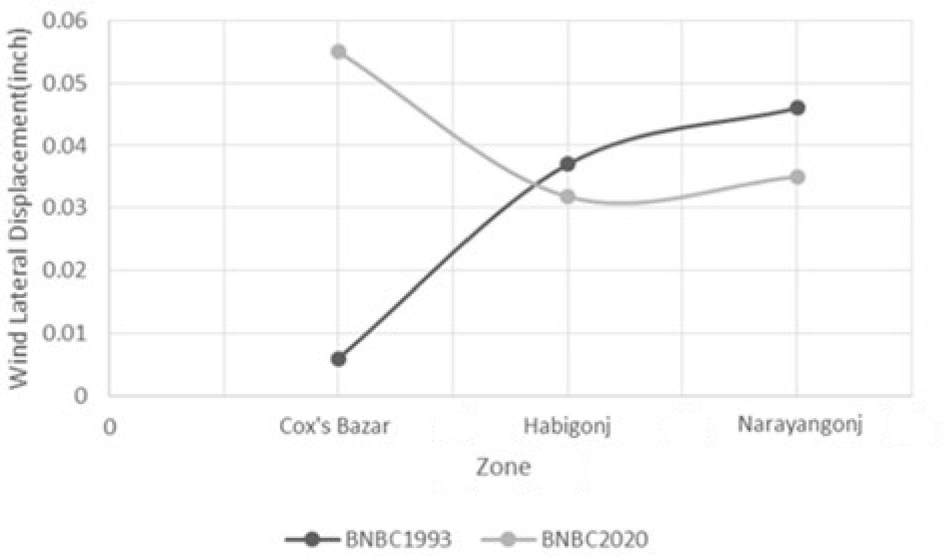

Figure 8: Wind Maximum Lateral Displacement of 10F Building vs Zones

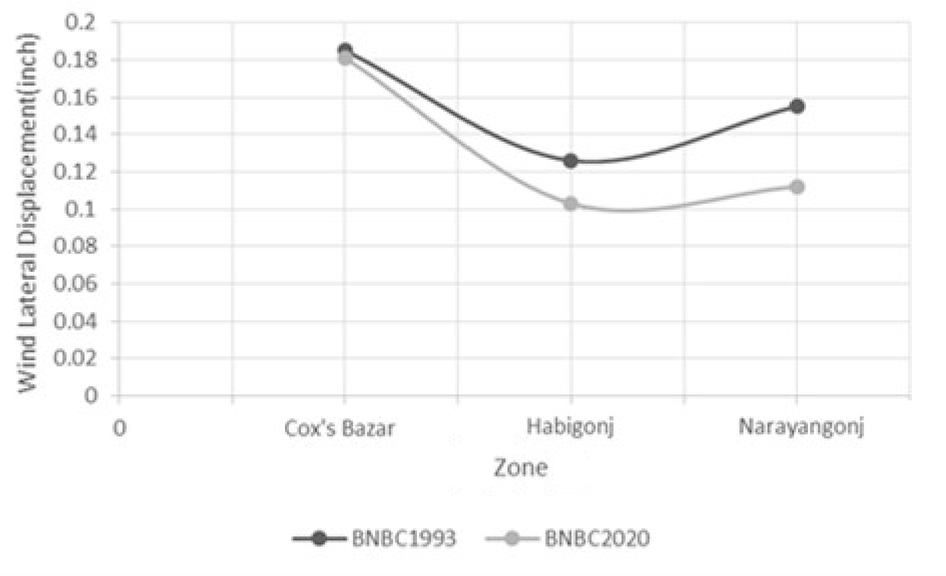

Figure 9: Wind Maximum Lateral Displacement of 15F Building vs Zones

3.5 Inter Story Drift

The concept of inter-story drift refers to the measurement of lateral displacement between two consecutive levels of a building's floors. Generally, there is an observed correlation between the increase in building height and the corresponding increase in lateral load. When a reaction reaches a significant magnitude, it becomes necessary to consider the lateral load effect in the design process explicitly. The analysis of inter-story drift in both old and current building codes traditionally focuses on the top floor of the structure. Table6 presents a comparison of inter-story drifts between the Building Code of Bangladesh BNBC 2020 and BNBC 1993 for three distinct zones.

Table 6: Inter Story Drift Comparison

Code	Cox's Bazar		Narayangonj		Habigonj	
	10F	15F	10F	15F	10F	15F
BNBC 1993	0.082	0.095	0.083	0.096	0.139	0.145
BNBC 2020	0.109	0.112	0.109	0.113	0.172	0.183

3.6 Section Comparison

The shear wall section underwent a notable modification from BNBC 1993 to BNBC 2020. The analysis for the Cox's Bazar, Narayangonj, and Habigonj regions was conducted in accordance with the building codes of BNBC 1993 and BNBC 2020, presented in Figure 10. A comparative analysis between BNBC 2020 and BNBC 1993 shows that there is a higher percentage of column rebar for 10th story buildings in both Cox's Bazar and Narayangonj regions. In contrast, the 15th-story reinforced concrete (RC) building structures within the respective zones demonstrate contrasting characteristics.

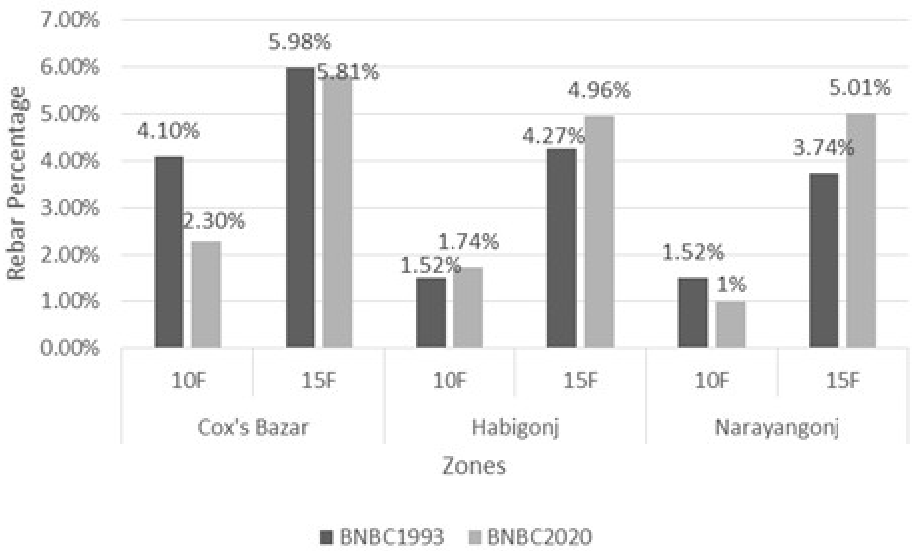

Figure 10: Rebar Percentage between BNBC 1993 & BNBC 2020 vs. No. of Zone

4. CONCLUSIONS

The objective of this study was to assess the modifications implemented in the BNBC 2020, specifically for the Cox's Bazar, Narayangonj, and Habigonj regions. The research findings revealed consistent modifications in various structural parameters, including base shear, lateral displacement, inter-story drift, and section characteristics. The utilisation of this particular sequence of design and analysis has the potential to assist engineers in effectively evaluating the design.

- According to the research, it has been observed that in BNBC 2020, RC structures experience lower wind base shear compared to BNBC 1993.
- According to the research, structures located in Narayangonj and Cox's Bazar experience higher seismic base shear under the BNBC 2020 code compared to the BNBC 1993 code.
- According to the research findings, structures located in Habigonj experience lower seismic base shear under the provisions of BNBC 2020 compared to BNBC 1993.
- The comparison of seismic maximum lateral deflection between the 15th story building under the BNBC 1993 and BNBC 2020 reveals consistently higher values in the former. According to the BNBC 2020, the values assigned to Cox's Bazar and Narayangonj for a 10th-story building are higher compared to the values specified in the BNBC 1993. However, when it comes to Sylhet, it presents a contrasting value. A comparative analysis indicates that BNBC 1993 exhibits a higher valuation compared to BNBC 2020.
- The comparison of wind maximum lateral displacement between the 15th story of buildings designed according to the Bangladesh National Building Code (BNBC) of 1993 and the BNBC of 2020 reveals consistently higher values in the former. According to a comparative analysis, it has been observed that the Building Code of Bangladesh (BNBC) from 1993 assigns higher values for Sylhet and Narayangonj in relation to 10th-story buildings compared to the BNBC of 2020. The findings indicate that Cox's Bazar exhibits a contrasting value, specifically a higher value, compared to BNBC 1993.
- The column steel requirement for BNBC 2020 is generally higher compared to BNBC 1993, with a few exceptions, such as Cox's Bazar and Narayangonj for 10th-story RC buildings.
- In the context of inter-story drift, it has been observed that the values provided by BNBC 2020 consistently exceed those of BNBC 1993.

Potential future research endeavours could explore the following recommendations. A broader and more generalised pattern of change between the two sets of codes could be obtained by including buildings of varying heights and irregular plans. The consistent variations in structural parameters across different regions emphasise the need for a dynamic assessment, considering factors like seismic base shear and lateral displacement, to comprehensively understand the impact of the code changes on diverse building types and locations. The dynamic analysis would provide a more nuanced understanding of structural behaviour, aiding engineers in refining their evaluations and ensuring the effectiveness of the design modifications under the BNBC 2020. Additionally, this study could be extended to encompass time frame analysis and variations in different locations for both sets of codes.

REFERENCES

Ali, M. H., & Choudhury, J. R. (1994, December). Seismic zoning of Bangladesh. In *International Seminar on Recent Developments in Earthquake Disaster Mitigation, Institute of Engineers, Dhaka*.

Al-Hussaini, T. M., Hossain, T. R., & Al-Noman, M. N. (2012). Proposed changes to the geotechnical earthquake engineering provisions of the Bangladesh National Building Code. *Geotechnical Engineering Journal of the SEAGS & AGSSEA*, *43*(2), 1-7.

Ansary, M. A., & Sharfuddin, M. (2002). Proposal for a new seismic zoning map for Bangladesh. *J Civ Eng*, *30*(2), 77-89.

ASCE/SEI. (2005). Minimum Design Loads for Buildings and Other Structures (ASCE/SEI 7-05). American Society of Civil Engineers, Reston, Virginia.

Atique, F., & Wadud, Z. (2001, December). A comparison of BNBC-93 with other building codes with respect to earthquake and wind analysis. In *The Eighth East Asia-Pacific Conference on Structural Engineering and Construction, Nanyang Technological University, Singapore*.

Bari, M. S., &Khondoker, J. U. Seismic forces on buildings: A comparative study of different codes. *Journal of Civil Engineering, Institution of Engineers, Bangladesh, Vol. CE*, *27*, 27(2).

Bangladesh National Building Code, BNBC. (1993). Earthquake Loads, Part 6, Chap. 2.

Bangladesh National Building Code, BNBC. (2020). Earthquake Loads, Part 6, Chap. 2.

Sarothi, S. Z., Sakib, M. S., Hasan, M. A., Akhter, A., Rabbi, T., & Amanat, K. M. Comparative analysis of rc frame structures following bnbc 1993 and 2017 versions of code for high seismic and high wind zone.