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A Comparative Study of BNBC 2006 and BNBC 2020 on the Cost Impact and Lateral Loads of the RC Frame Structure

M. R. Raju[1], Md. F. Haque[2], M. Ahamed[3], I. T. Hossain[4]

[1] Department of Civil Engineering, IUBAT, Bangladesh (mraju.civil@iubat.edu)
[2]Department of Civil Engineering, IUBAT, Bangladesh (mhaque.ce@iubat.edu)
[3]Department of Civil Engineering, RUET, Bangladesh (maruet004@gmail.com)
[4]Department of Civil Engineering, IUBAT, Bangladesh (ishraq.ce@iubat.edu)

Abstract

The Bangladesh National Building Code (BNBC) establishes structural and design parameters standards in response to evolving civil engineering methods, materials, and needs. This study models a ten-storey reinforced concrete (RC) Intermediate Moment Resisting Frame (IMRF) building in seismic zone 2 (Dhaka) using ETABS. Comparing BNBC 2020 and BNBC 2006, the investigation assesses lateral loading effects on story drift, base shear, and cost impact for columns and beams due to earthquakes and wind forces. Notably, BNBC 2020's top displacement values are 34.68% and 23.55% higher in X and Y directions, and wind displacement values are 9.10% and 6.68% higher. Maximum storey drift values for earthquakes are 28.00% and 6.00% higher in X and Y directions in BNBC 2020. BNBC 2020's higher zone coefficient, structural factor, and self-weight yield a 27.53% higher base shear. Observed reinforcement differences between BNBC 2020 and BNBC 2006 underscore the importance of cost evaluation, revealing potential increments of 30.09% for corner columns and 17% for interior columns. BNBC 2020's larger beam reinforcement areas result in around 25.01% higher costs than BNBC 2006.

***Keywords**: Storey Displacement; Storey Drift; BNBC 2006; and BNBC 2020.*

1. Introduction

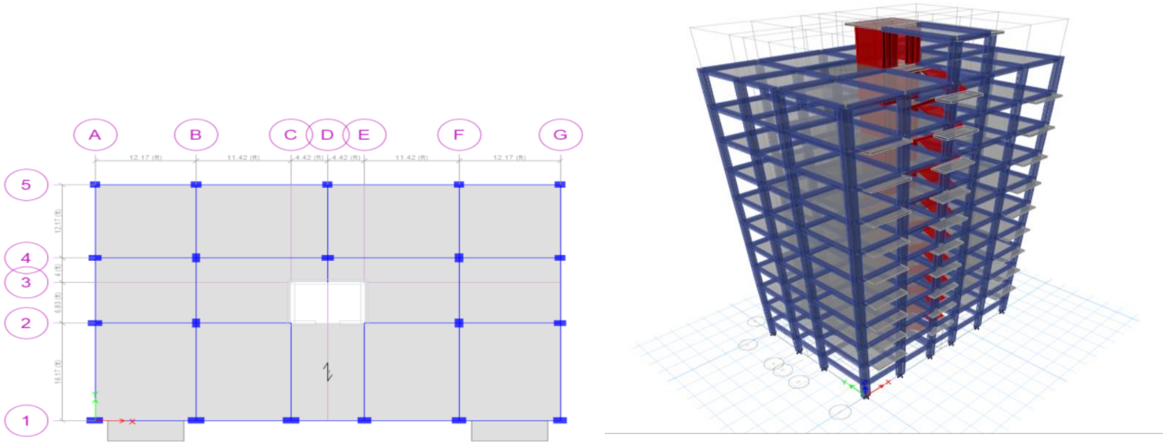
Buildings' seismic design and construction are essential for assuring their safety and resilience because Bangladesh is located in a seismically active area (Ahmed and Kabir, 2021). To enhance seismic performance, BNBC is a regulatory document that offers recommendations for the design and construction of structures in the nation (Shafi, 2010). Two main versions of guidelines, BNBC 2006 and BNBC 2020, which have differing requirements for the design and construction of reinforced concrete (RC) frame structures, have been changed regularly to include current rules. The cost impact and lateral loads are crucial considerations in the design and construction of RC frame structures (Shafi, 2010). The cost impact refers to the changes in construction cost due to the updated provisions of BNBC 2020 compared to BNBC 2006, while the lateral loads refer to the forces exerted on the structure due to lateral loads. Several studies compared lateral load allowances in various versions of the BNBC (Al-Hussaini et al., 2012; Sarraz et al., 2015). Abdullah, Islam, Abu Turab Asif, & Ali (2021) did a comparative research of a reliable and parametric analysis based on BNBC 1993 and BNBC 2020, with the comparison to BNBC 1993 often resulting in a less cost-effective design with a higher safety margin. Also, Abdullah (2020) compared the BNBC 2017 to BNBC 2006 for low-rise residential projects. The analysis concluded that the higher strengthening standards for beams and columns in BNBC 2017 raised construction costs.

This study examines the cost and lateral load differences in RC frame structures under BNBC 2006 and BNBC 2020, aiding safer design practices in Bangladesh. It informs practitioners on adapting to new regulations for enhanced structural resilience, and future research may explore long-term performance and rule effectiveness in reducing seismic risks.

2. Structural Modeling and Analysis

For the comparative analysis, a conventional ten-story residential building (56'-11" 40'-1") that is geometrically regular in plan was chosen (Figure 1). The structures are assumed to be fixed at a base height of 8 feet, and the floors function as rigid diaphragms with similar member sizes for both codes. According to the BNBC 2006 and

BNBC 2020 codes of practice, the response modification coefficient (R) for the Intermediate Moment Resisting Frame (IMRF) was set at 8 and 5, respectively. The structures have been modeled using ETABS (version 16.2.1) with the same condition and structurally significant factors for two distinct standards (BNBC 2006 and BNBC 2020). Table 1 contains design parameters and equations used to calculate lateral loads and other factors for both standards (BNBC, 2006); (BNBC, 2020).



(a) (b)

Figure 1. (a) Beam and column layout of RC building and (b) 3D of RC building model.

Table 1. Comparison of design parameters of BNBC 2006 and BNBC 2020.

BNBC 2006	**BNBC 2020**
1. The building fundamental period, T= $C_t h_n^{\frac{3}{4}}$ where h in meter. [Section 2.5.6.2]	1. The building period, T= $C_t h_n^m$ where h_n in meter. [section 2.5.7.2]
2. Storey drift, Δ, shall limited as follows: a. $\Delta \leq 0.04h/R \leq 0.0005h$ for $T \leq 0.7$ sec. b. $\Delta \leq 0.03h/R \leq 0.0004h$ for $T \geq 0.7$ c. $\Delta \leq 0.0025h$ for unreinforced masonry structures where, h = height of the building [Section 1.3.4.2]	2. Storey drift, Δ, shall limited as follows: a. $\Delta \leq 0.005h$ for $T \leq 0.7$ sec b. $\Delta \leq 0.004h$ for $T \geq 0.7$ sec. c. $\Delta \leq 0.0025h$ for unreinforced masonary structure where , h= height of the building [Section1.5.6.1]
3. Design lateral force calculated from ESFM method is V = $\frac{ZIC}{R}$ W; where, Z = Earthquake zone coefficient, $C = \frac{1.25\,S}{T^{\frac{2}{3}}}$ and W = the Earthquake weight of the building. [Section 2.5.6.1]	3. Design lateral force calculation from ESFM method is V = $\frac{2}{3}\frac{ZI}{R}C_S$ W: where Z = Earthquake zone coefficient. C_s= Normalized acceleration response spectrum and W = the Earthquake weight of the building (including minimum 25% live load and up to 3 KN/m^2). [Section 2.5.4.3 & 2.5.7.1]
4. Sustained wind pressure at height, z (kN/m^2), q_z= $C_C C_I C_Z V_b^2$ where C_C = Velocity to pressure coefficient, C_I= Structural importance coefficient, C_Z= Combined height and exposure coefficient & V_b = Basic wind speed. [Section 2.4.6.2]	4. Velocity pressure at height z (kN/m^2), q_z = 0.00613 $k_z k_{zt} k_d V^2 I$ where, K_z = Velocity pressure exposure coefficient, K_{zt} = Topographic factor, k_d = Wind directionality factor, V = Basic wind speed & I= Importance factor. [Section 2.4.9.5]

5. Design wind pressure at height z (kN/m^2), $P_z = C_G C_p q_z$; Where, C_G = Gust coefficient & C_p= Pressure coefficient. [Section 2.4.6.3]	5. Design wind pressure at height z (kN/m^2), P_z = G$C_p q_z$- q_i(GC_{pi}); Where, G = Gust effect factor C_p =External pressure coefficient, q_i = Velocity pressure for internal pressure determination GC_{pi} Internal pressure coefficient. [Section 2.4.11.2]

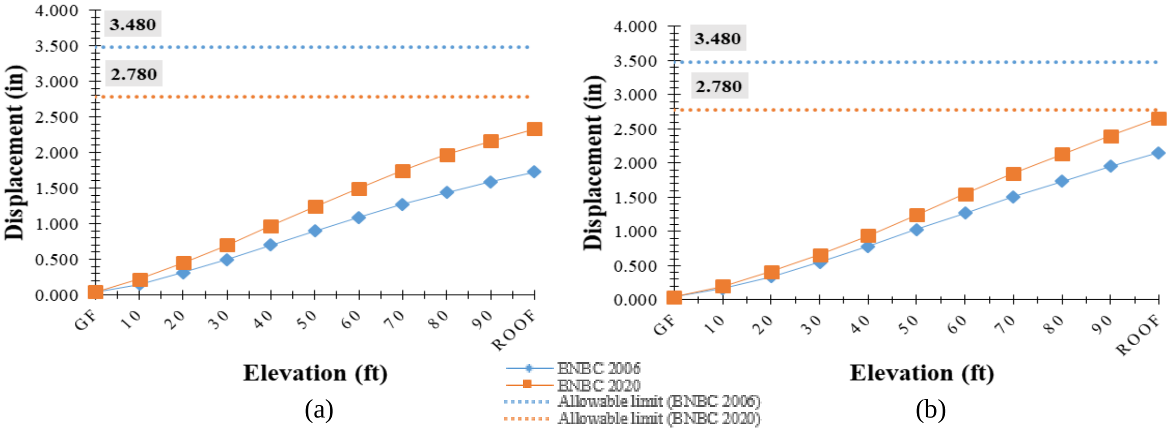
The suggested structure has been examined based on lateral loads, such as wind force and earthquake load, as well as gravity loads, which include live loads and lateral loads. According to BNBC 2020 guidelines, except partition walls, all dead loads—including self-weight, floor finish, and other superimposed loadings—were considered in our study. All dead loads and 25% of all live loads have been taken for the mass source. For earthquake design in Dhaka's earthquake zone II, BNBC 2006 employs a zone coefficient of 0.20, response reduction factor of 5, and importance factor of 1, with site coefficients Fa=1.15 and Fv=1.1725. BNBC 2020 introduces changes: zone factor 0.15, site coefficient 1.5, time period 1.0603, and response modification factor 8, along with a 0.05 eccentricity ratio. Under BNBC 2006, wind design in exposure type B entails a wind speed of 131 mph, using windward and leeward coefficients of 0.8 and 0.5 respectively. For BNBC 2020, exposure type B remains, but adjustments include Kz=1, K_d=0.85, G_f=0.89, and wind speed 147 mph. These design parameters emphasize the differences and updates in BNBC 2006 and BNBC 2020.

3. Results and Discussion

The values of storey displacement, story drift, base shear, and the cost impact of beams and columns are the outcomes of ETABS work and are graphically shown and analyzed in the following.

3.1 Story Displacement

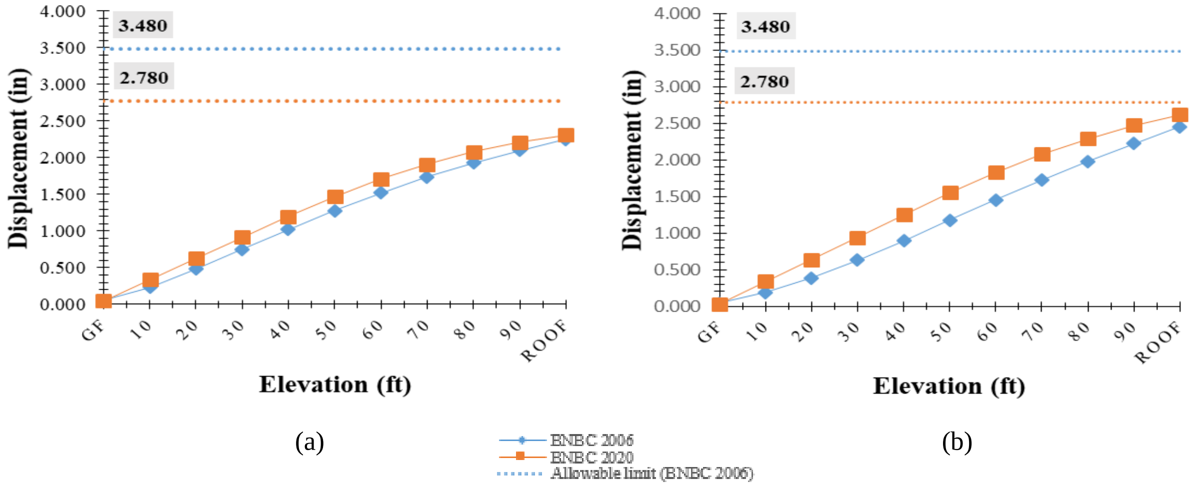
Figure 2 depicts the storey displacement versus elevation of stories graph for BNBC-2006 and BNBC-2020. For both BNBC 2006 (blue line) and BNBC 2020 (orange line), displacement for earthquake loading direction Ey is greater than displacement for earthquake loading direction Ex. The rate of maximum storey displacement according to BNBC 2020 is 34.68% and 23.55% higher than BNBC 2006 in the E_X and E_Y directions, respectively. Due to the earthquake load in both directions, the maximum storey displacement values for BNBC 2006 and BNBC 2020 did not exceed the allowable limit values.



(a) (b)

Figure 2. Storey displacement due to earthquake load; (a) X-direction and (b) Y-direction.

When analyzing the effect of lateral pressures on a building's response, storey displacement is an essential factor to consider. The p-effect can be caused by a significant displacement of the top story, progressively increasing the overturning moment. The wind loads in both directions depicted in Figure 3 caused BNBC 2020 to have a more significant maximum storey displacement than BNBC 2006. Due to the wind load in the Y direction, the increase in wind load for each additional story is more constant in BNBC-2020 compared to BNBC-2006. The maximum storey displacement for BNBC 2020 is 9.10% and 6.68% higher in the X and Y orientations compared to BNBC 2006. The differences in storey displacements between wind and earthquake loads arise due to variations in the nature, magnitude, and direction of these lateral forces acting on the building (Aly and Abburu, 2015).

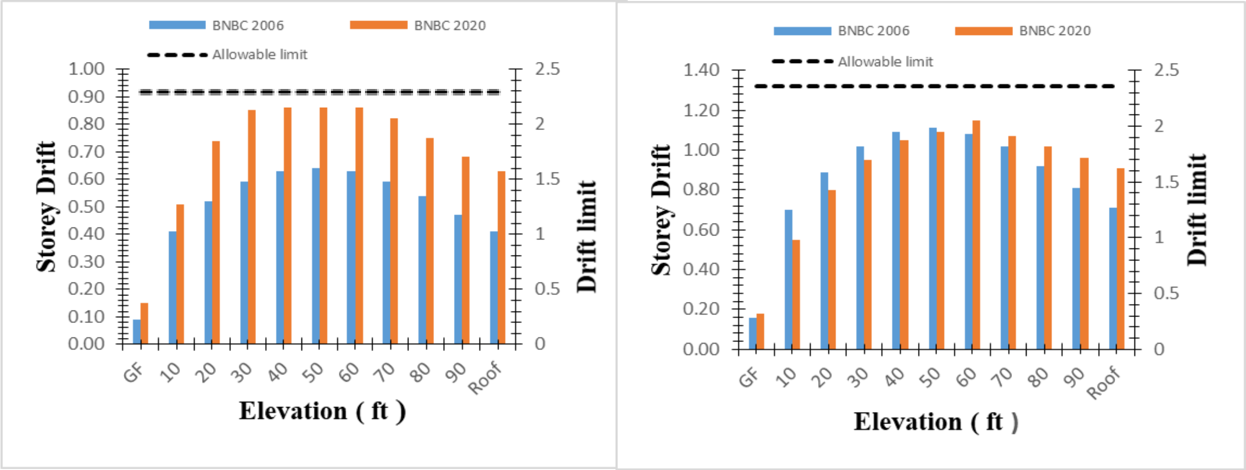


(a) (b)

Figure 3. Storey displacement due to wind load; (a) X-direction and (b) Y-direction.

3.2 Story Drift

The storey drifts are evaluated in the horizontal (EQx) direction, depicted in Figure 4(a). In this context, BNBC 2020 (represented by the orange bar) exhibits notably higher storey drift than BNBC 2006 (the blue bar). A larger story drift signifies increased framing flexibility, which is significant for structural and non-structural elements. Notably, at 50 feet elevation, the maximum storey drifts for BNBC 2006 and 2020 are 0.64 and 0.89, respectively. Figure 4(b) illustrates the maximum and minimum earthquake load values computed in the vertical (EQy) direction. Impressively, BNBC 2020 (orange bar) again presents larger storey drift compared to BNBC 2006 (blue bar). Specifically, at 60 feet elevation, maximum storey drift values are 1.08 for BNBC 2006 and 1.15 for BNBC 2020. Based on the structural moment category and significance factor, the acceptable limit was set at 0.02 hx, where hx is the storey height of the building (American Society of Civil Engineers., 2010). According to the code, the utmost acceptable drift for the proposed building was approximately 2.36 inches. The graph depicts storey drift caused by earthquake loads on both BNBC 2006 and BNBC 2020 axes, where the drift values are less than the permissible limit value. The storey drift is typically higher in the y-direction than the x-direction due to factors like building shape, uneven stiffness, and variations in load distribution (Kewalramani and Syed, 2018).



(a) (b)

Figure 4. Comparison of storey drift due to EQ load; (a) X-direction (b) Y-direction.

3.3 Base Shear

A comparison of the base shear between BNBC 2006 (yellow line) and BNBC 2020 (green line) is shown in Figure 5. The basal shear value of BNBC 2020 is greater than that of BNBC 2006. The x-direction base shear is comparable to the y-direction base shear, where BNBC 2020 is substantially greater than BNBC 2006. Due to increases in zone coefficient (z), structural system factor (R), and self-weight (W), the BNBC-2020 code has a higher base shear than the BNBC-2006 code. BNBC 2020 still proposes lower base shear values than other codes, such as the Indian and American codes, despite modifications to the code. In this regard, additional studies must be conducted.

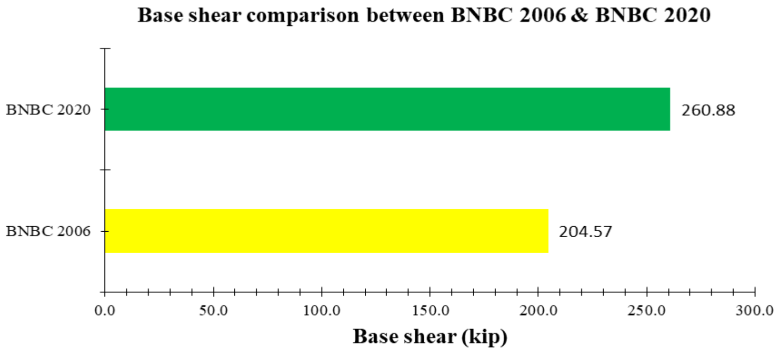


Figure 5. Base shear comparison between BNBC 2006 and BNBC 2020.

3.4 Effects on Design

3.4.1 Comparison of a Corner and an Interior Column

A corner and interior column were chosen for analysis and design to compare dimensions, bar quantities, and diameters in BNBC 2006 and BNBC 2020. Figure 6 visually illustrates differences in column reinforcement requirements, with BNBC 2020 specifying larger steel areas for both types. BNBC 2020 mandates 2.570 and 2.620 reinforcing areas for corner and interior columns, while BNBC 2006 prescribes 1.80 and 2.16. Observed differences emphasize the need for thorough cost analysis. BNBC 2020's larger steel area leads to more required bars, potentially raising material costs by 30.09% for corner and 17% for interior columns compared to BNBC 2006.

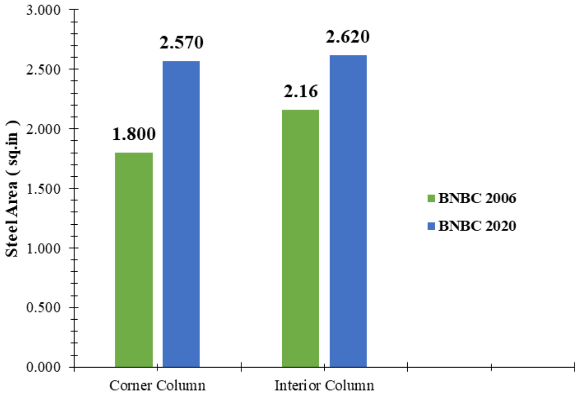


Figure 6. Column reinforcement comparison between BNBC 2006 and BNBC 2020.

3.4.2 Beam Reinforcement Comparison

For the study and design of a beam, top reinforcement and bottom reinforcement for the BNBC-2006 and 2020 codes have been selected to compare beam reinforcement. The top and bottom reinforcement areas of BNBC 2020 are greater than those of BNBC 2006, as seen in Figure 7. The top and bottom reinforcements for the BNBC 2006 are 1.456 and 0.420, respectively. The maximum and bottom reinforcement values, according to BNBC 2020, are 1.772 and 0.572, respectively. There is a notable difference in the total beam reinforcement areas between BNBC 2020 and BNBC 2006, with BNBC 2020 requiring larger areas. This signifies an increase of approximately 25.01% in costs when comparing BNBC 2020 to BNBC 2006.

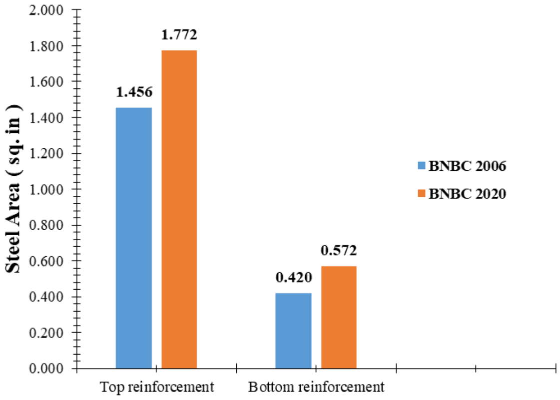


Figure 7. Beam reinforcement comparison between BNBC 2006 and BNBC 2020

4. Conclusions

This study compares lateral loads and cost-effectiveness in Dhaka, Bangladesh, using BNBC 2006 and BNBC 2020. It evaluates drift assessment procedures in both codes, focusing on structural performance control. Lateral displacement is higher under BNBC 2020, influenced by factors like building height. Changes in zone coefficient, structural system factor, and self-weight contribute to BNBC 2020 having additional base shear. Reinforcement requirements between BNBC 2006 and BNBC 2020 highlight the need for meticulous analysis. Larger steel area mandates in BNBC 2020 increase potential construction costs. Differences in required reinforcement emphasize cost evaluation importance. BNBC 2020's increased steel area leads to higher reinforcement quantities, up to 30.09% and 17% cost increments for corner and interior columns. Notable differences in total beam reinforcement highlight approximately 25.01% cost increase in BNBC 2020 compared to BNBC 2006.

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