

Impact of Code Changes on the Design of RC Frame Structure

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Abstract

The behavior of building frames under different loading conditions and different serviceability and limiting conditions is still under a continuous research process. This study discusses the comparison of two Bangladesh National Building Code (BNBC) code named as BNBC 2006 and BNBC 2020 to grasp an idea of the impact of code changes on Reinforced Cement Concrete (RCC) structures. For this, three buildings are chosen with three different options for each and three different framing conditions for the earlier code (BNBC 2006). All the buildings are in the low seismic zone and high wind zone. The analyses were carried out by the state-of-the-art finite element software using respective design code for the earlier version and for the later version (BNBC 2020). Output results are tabulated in the figures for three buildings for the seismic force and the wind load. Seismic base shear is increased while wind force is reduced for all the three buildings for all the options except option 1 of building 1. Finally, the concrete volumes of the structural items are calculated and are tabulated in the figure. When comparing the results, it is seen that overall cost is reduced by the updated code for this zone.

Keywords

Comparison, BNBC 2006, BNBC 2020, RC Frame, Low Seismic Zone, High Wind Zone

1. Introduction

Civil engineering is a broad field encompassing the planning, design, construction, and maintenance of infrastructure critical to society [1] [2]. It includes specialized sectors such as structural engineering, geotechnical engineering [3] [4], transportation engineering, environmental engineering, water resources engineering, and construction engineering management [5]-[7]. Each sector within civil engineering addresses distinct challenges, yet collectively they contribute to the safety, sustainability, and efficiency of infrastructure systems. Structural engineering, for instance, ensures that buildings and bridges withstand various loads and stresses, while geotechnical engineering deals with soil mechanics and foundation stability [8]-[10]. Transportation engineering focuses on designing and maintaining efficient transportation networks, whereas environmental engineering aims at minimizing ecological impacts and ensuring sustainable practices [11]. Water resources engineering addresses water management, flood control, and irrigation systems, ensuring reliable and efficient water distribution [12]-[14]. Construction engineering management integrates engineering principles with management practices to oversee project timelines, costs, and quality assurance [15]. Detailed analysis in each of these sectors is crucial for identifying potential vulnerabilities, predicting structural behaviors, and ensuring optimal performance under varying conditions. Building codes serve as essential guidelines that standardize analytical approaches, provide minimum safety requirements, and incorporate current best practices from extensive research and real-world experiences [16]-[18]. Hence, the continuous refinement and updating of building codes, such as the BNBC, are indispensable to civil engineering practice, safeguarding public safety, resilience, and sustainable development [19] [20].

Upgradation of Building Codes is a continuous process all over the world. They need to be upgraded regularly based on recent research findings, lessons learned from different events like storms, earthquake, building collapse during or after construction, etc. [21] [22]. The Bangladesh National Building Code (BNBC) is primarily used in Bangladesh to control building construction as well as to maintain and uphold buildings to specific standards [23]. BNBC was first compiled on in 1993 and officially approved in 2006 [24]. The first version was based on Uniform Building Code (UBC 94) for lateral load analysis and American Concrete Institute (ACI-318-99) standards for design code provisions. After that, in 2009, a new committee was formed to update the code. By this time, American codes were changed drastically and so are methods related to the analysis and design of RC Frame structures especially the moment frame structures. In the previous code of BNBC both WSD and USD methods were compiled partially but in the recent code in lieu of the international standards the WSD method is nullified. In analysis part, lateral load calculations methods and their parameter selections have been changed a lot from the state-of-the-art research. Especially the effect of the sub-soil strata in combination with ground acceleration and occupancy category are identified in detail [22].

The BNBC 1993 amendments were first recommended by Al-Hussaini, T. M. *et al.* [25]. They thoroughly examined Peak Ground Acceleration (PGA), Spectral Acceleration, a ground classification method, and an on-site response spectrum. They demonstrated that the design and structural analysis provisions of BNBC 1993 need to be significantly improved. The literature on comparative analysis of current codes in Bangladesh and around the world is referenced in the following list. Ahmed M. M., *et al.*, [26] conducted seismic load analysis comparison of BNBC 1993 and BNBC 2017 of an 8 storied hospital building at Sylhet (Very Severe Seismic Intensity zone). The main differences between the BNBC 1993 and 2017 are presented by Sarothi S. Z. *et al.* [27] to explore and measure the modifications in the estimation of both wind and earthquake loads with respect to structural and economic perspective. Using finite element analysis, they analyzed a multistory commercial structure (16.5 m × 24 m) located in Chattogram for both low and high-rise buildings (8 and 16 stories). Because of changes to the zone coefficient (Z), response modification factor (R), and addition of Cs (normalized acceleration response spectrum), seismic base shear has increased in BNBC 2017 relative to BNBC 1993. In contrast, BNBC 1993 displays a higher wind load than BNBC 2017. Based on the analysis results, the design based on the updated code requirements typically results in a higher safety margin and a less economical design than the design according to the prior code. To obtain a precise understanding of improvements, Sakib M. S. *et al.* [28] attempted to conduct a systematic simulation analysis using the finite element technique (FEM) based on the previously proposed (BNBC 1993) and newly proposed (BNBC 2017) codes. They examined two multi-storied buildings (8 and 16 story), 16.5 m x 24.0 m commercial steel building in Chattogram that had a concentric braced framing system and was located on soft to medium stiff clay. They found that the rate of change in base shear value decreases as story height increases due to wind and seismic forces, and that base shear resulting from wind is slightly less in BNBC 2017 than it was in BNBC 1993 due to a lower wind pressure coefficient. According to BNBC 1993 and BNBC 2015, Hassan M. M. *et al.* investigated a comparative assessment of the wind load effect in the city, obstructed, and unobstructed plain territory type zones. To investigate their effects on structural analysis using both codes, they looked at a multistory residential structure (20.0 m × 20.0 m) of 100 m height for three exposure criteria (*i.e.*, Exposure A, Exposure B, and Exposure C). In BNBC 2015, the rate of change in wind thrust relative to the number of stories appears to be more stable. According to BNBC 2015, exposure A is 7% - 12% greater than that of BNBC 1993. However, compared to BNBC 1993, exposure B and C are significantly lower in BNBC 2015 by 2% - 10%. The comparative analysis of wind force offered by BNBC 1993 and BNBC 2010 was studied by Faysal R. M. [29]. The authority has upgraded the wind provision in BNBC 2010 by taking the influence of surrounding structures and building height into account. As a result, it is found that the wind load in urban areas (Exposure A) is considerably higher (7% - 12%) than it was in BNBC 1993. In the meantime, compared to BNBC 1993,

the wind load calculated from this new code for the blocked and unblocked plain territory region (Exposure B and C) is much lower. Imam F. S. *et al.* compared the seismic and wind analysis offered in the BNBC 1993 with the recommendations made in the BNBC 2012 [30]. To identify the structural analysis differences between BNBC 2012 and BNBC 1993, they examined a typical multistory residential building located in Dhaka, with an intermediate moment resisting frame system resting on medium dense soil. The analysis was done for a range of story counts (2 to 18), and it was discovered that maximum drift happens generally at the mid-point of the building. The residential structure's base shear as determined by this new draft code differs greatly, and for wind load alone, BNBC 2012's maximum lateral displacement and inter story drift with respect to number of stories are lower than BNBC 1993's. One of the benefits of using BNBC 2012 for RC building design is that it requires less reinforcement than BNBC 1993, making it a more cost-effective approach. However, this is only relevant for Dhaka city. Bari *et al.* provided illustrations of how certain requirements for the tectonic assessment of building codes are similar in BNBC 1993, BNBC 2010, NBC 2005, and ASCE 7-05 [31]. A seismic safety message for our nation at this location is communicated by this study. According to this study, BNBC 1993 has the least amount of base shear among the recommended values. The base shear values factorized for BNBC 2010 have significantly improved in lower elevated structures ($B \leq 20$ m) throughout the state across its antecedent when compared to BNBC 1993. It is noteworthy that the proposed BNBC 2010 code, which suggests higher base shear values, has improved the earthquake safety factor. Atique and Wadud *et al.* [32] presented an analysis of many design codes (BNBC-93, UBC-91, UBC-97, NBC-83, and Bangladesh Outline Code, 1979) for wind and seismic analysis from around the globe. The study examined the seismic activity of an office building measuring 15.6 m by 15.6 m that is situated in the United States' Zone 3 (UBC), in India's Zone V (NBC-83) and in Bangladesh's Zone 3 (BNBC-93). After analyzing ten, fifteen, twenty, and twenty-five story buildings, it was determined that developed nations increased their seismic safety factor by recommending a higher base shear value. It is notable that the proposed BNBC 2010 code, which suggests higher base shear values, has improved the earthquake safety factor. The seismic design standards in BNBC-93, in comparison to current codes under review, are the least conservative in the building industry and may result in a major loss of life and property in a major earthquake. Abdullah *et al.* used ETABS software to perform a lateral load analysis of two BNBC codes [3] [33]. A ten-story commercial building was selected for a low-medium-high wind zone, and the same process was followed for the seismic analysis. Their analysis predicted a decrease in the cost of construction.

In this research, three buildings are analyzed by varying their heights for a location and for a particular soil stratum in both BNBC 2006 and in BNBC 2020 codes. After getting the analysis results, comparisons are made from different factors. Results are tabulated and discussed in the subsequent section with the rea-

soning by references. The moment frame and the moment frame with shear walls are used in this research for one zone only. Further research can be done in other zones by varying framing conditions by varying sub-soil conditions.

2. Modeling and Analysis

Three multistoried buildings situated in the south-western part of Bangladesh were chosen for the study with three possible cases for each of the buildings. The first building is 3-span by 7-bay floor (60 m × 43 m plan area), the second building is 2-span by 17-bay floor (114 m × 12.3 m plan area) and the third building is 5-span by 8-bay floor (70 m × 50 m plan area). For option-01, the ground floor height of the first building is 8.5m and the rest of the floor heights are 4.5 m. In the case of option-02 ground floor height is reduced to 4.5 m to match the other floors height. And in the case of option-03, all the floor heights are reduced to a minimum height of a commercial building which is 3.6 m. In the case of the second building, the ground floor height for option-01 is 6.0 m and the rest of the floor heights are 3.5 m. In the case of option-02, the ground floor height is reduced to 3.5 m to match the other floor height. And in the case of option-03, all the floor heights are reduced to a minimum height of a commercial building which is 3.0 m. For the third building, the ground floor height of option-01 is 11.075 m and the rest of the floor's heights are 5.075 m. In the case of option-02, the ground floor height is reduced to 5.075 m to match the other floor height. And in the case of option-03, all the floor heights are reduced to an average height of a commercial building which is 3.6 m. Line diagrams of the options are shown in **Figure 1**.

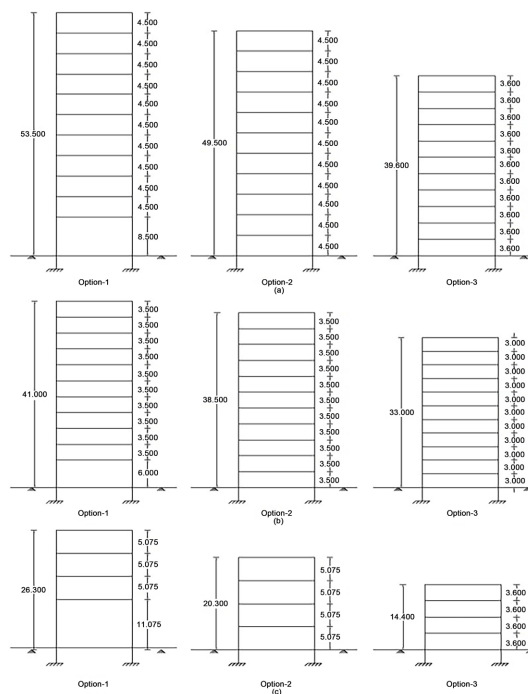


Figure 1. Line diagrams showing different options for the selected structures (a) Building 1 (b) Building 2 (c) Building 3.

Total 36 number of models are developed considering the above criteria and three different framing conditions (OMRF, IMRF, SMRF) for BNBC 2006 and SMRF in the case of BNBC 2020 (Figure 2). In the case of the previous version, considering the earthquake zone any framing condition can be adopted while minimum requirement is special moment resisting frame in the later code for multiple parameters.

After modeling the above options in finite element analysis software ETABS, structures are analyzed and designed for dead loads, live loads, wind loads and for seismic force. The dead load includes self-weight of the entire structural element and other superimposed load (e.g., floor finish 1.5 kN/m² and partition wall 2.5 kN/m²). Live loads are varied, ranging from 4 to 10 kN/m² for different floors with respect to the usage category. Wind loads are applied by providing the input parameters relevant to the codes. Design parameters for the wind load analysis are listed in Table 1.

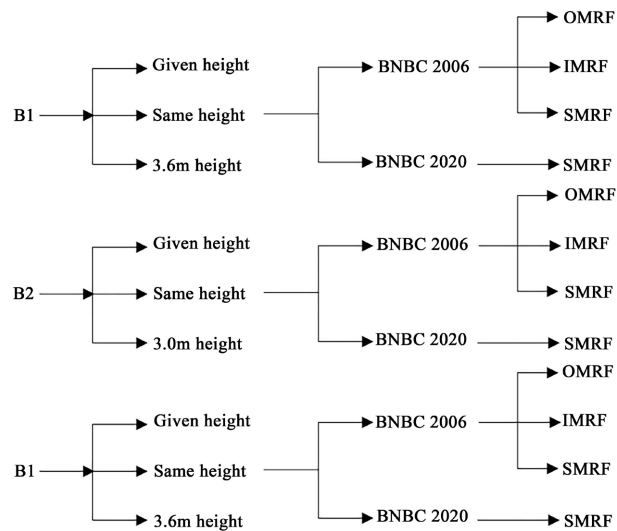


Figure 2. Considerations of the building framing for 3 options.

Table 1. Design parameter—Wind Load Analysis.

Wind load design parameter BNBC 2006	Wind load design parameter BNBC 2020
Analysis Method: Surface Area Method	Analysis Method: Analytical Method
Basic Wind Speed: 252 Km/hr (Fastest mile speed)	Basic Wind Speed: 279 Km/hr (3-s gust wind speed)
Standard Occupancy Structure, IF-1.0	Standard Occupancy Structure, IF- 1.15
Exposure Category-A	Exposure Category-A
Max Deflection Limit—h/500 for 100% Wind effect	Max Deflection Limit—h/500 for 100% Wind effect
ETABS Analysis Algorithm—UBC94	Topographic factor, K_{zt} - 1.00 Directionality Factor, K_d - 0.85 ETABS Analysis Algorithm—ASCE 7-05

Seismic loads are also applied by providing input parameters for the earlier version and for the later version design spectral acceleration (in units of g) is calculated manually and then given the input as user coefficient in the finite element analysis model. Design parameters for seismic analysis are listed in **Table 2**.

Table 2. Design parameter—Seismic Load Analysis.

Seismic load design parameter BNBC 2006	Seismic load design parameter BNBC 2020
Seismic Zone Coefficient, $Z = 0.075$	Seismic Zone Coefficient, $Z = 0.12$
Site Classification = S3	Site Classification = SD
Site Coefficient = 1.5	Site Coefficient = 1.35
Importance Factor = 1.25	Importance Factor = 1.50
Time Period = $C_t h_m^m$	Time Period = $C_t h_m^m$
Frame System—OMRF, IMRF, SMRF	Seismic Design Category: D (High Severity)
Structure Reduction Factor—5, 8, 12	Frame System & Reduction Coefficient— SMRF (R = 8 for B1, R = 7 for B2 & R = 8 for B3)
ETABS Analysis Algorithm—UBC94	ETABS Analysis Algorithm—User Coefficient

For all cases concrete compressive strength (f_c') is considered 30 MPa and rebar yield strength (f_y) is taken as 415 MPa.

Seismic provisions are also taken from ASCE-7-05 that is based on Maximum considered earthquake (MCE) as the design basis earthquake. Both the numbers and the distributions of Seismic zoning map are changed in the later version. In BNBC 2006 Seismic Zoning Map gives the design ground motion values based on estimated PGA for a return period of 200 years while it is 2475 years in BNBC 2020. Soil effects are considered by the Site Coefficient S and by the Response Spectrum. A constant normalized acceleration response spectrum is taken in the previous code while it is variable with structure (building) period, site coefficient and the damping correction factor in the later code. The design basis earthquake ground motion is selected at a ground shaking level that is 2/3 of the Maximum considered earthquake (MCE) ground motion (BNBC 2020) [34]. Elastic responses are defined by three different structures (building) period while it is based on one structure period in the previous code. The seismic design category is also introduced, and this is the functions of soil factor, zone coefficient and occupancy category. In the previous version framing condition is dependent upon zone coefficient only. A contribution of the live load for calculating seismic force is taken for all values. The vertical distribution of shear force is transformed from linear to exponential. Deflection amplification factor Cd is introduced. Site class was de-

terminated by SPT value only while it can be determined by SPT value, undrained shear strength value and by shear wave velocity in the later code. Seismic force is already factored in the later version, that's why load factor 1 is used in the load combinations [35].

3. Results and Discussion

In **Figure 3** and **Figure 4** seismic base shear values are depicted for BNBC 2006 and BNBC 2020. Most of the base shear values for BNBC 2020 are greater than the values for BNBC 2006.

Abbreviations and Acronyms

Define abbreviations and acronyms the first time they are used in the text, even after they have been defined in the abstract. Abbreviations such as IEEE, SI, MKS, CGS, sc, dc, and rms do not have to be defined. Do not use abbreviations in the title or heads unless they are unavoidable.

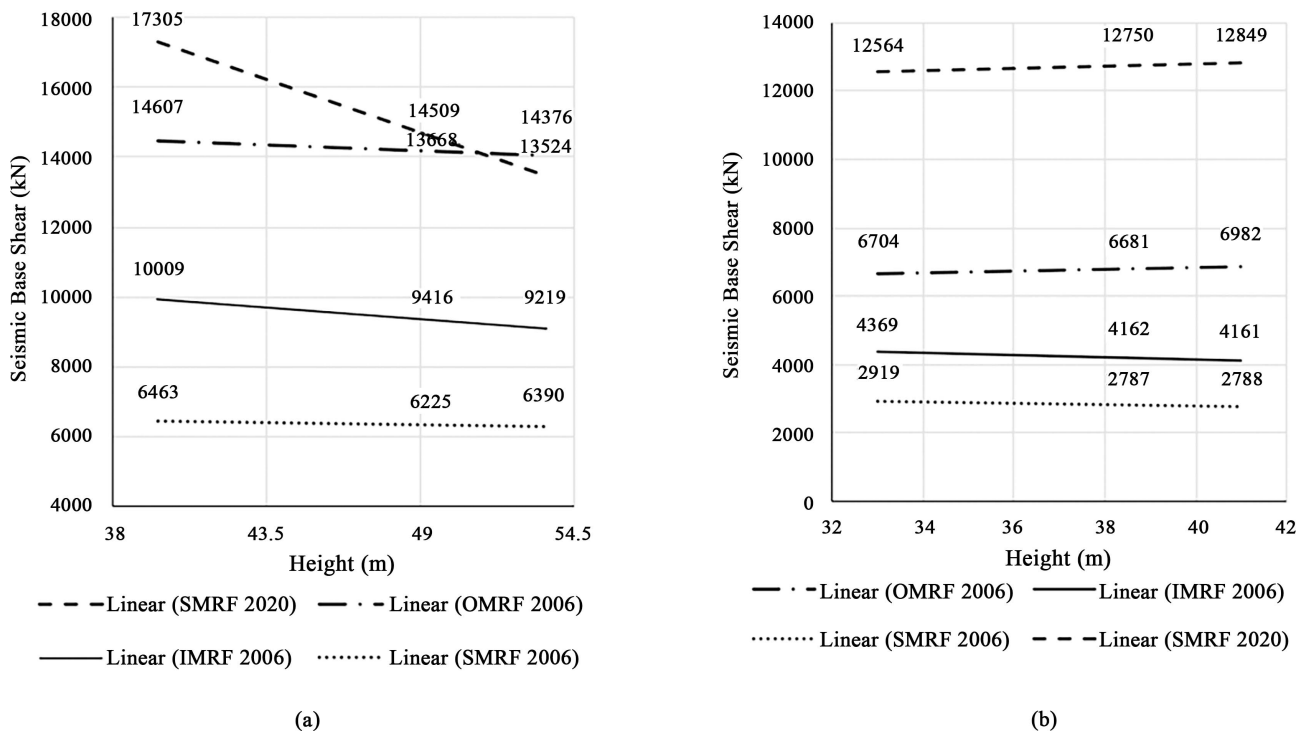


Figure 3. Comparison of seismic base shear for (a) building 1 and (b) building 2.

In the case of building 1, seismic base shear is approximately 18% greater than the previous code and for building 2 it is approximately 87% greater than BNBC 2006 code provisions (**Figure 3**). In building 3, it is approximately 11% greater than the previous code calculation (**Figure 4**). In **Figure 4(b)** seismic base shear values for all the buildings of all the options are depicted to get a comprehensive picture of shear force variation for different framing conditions.

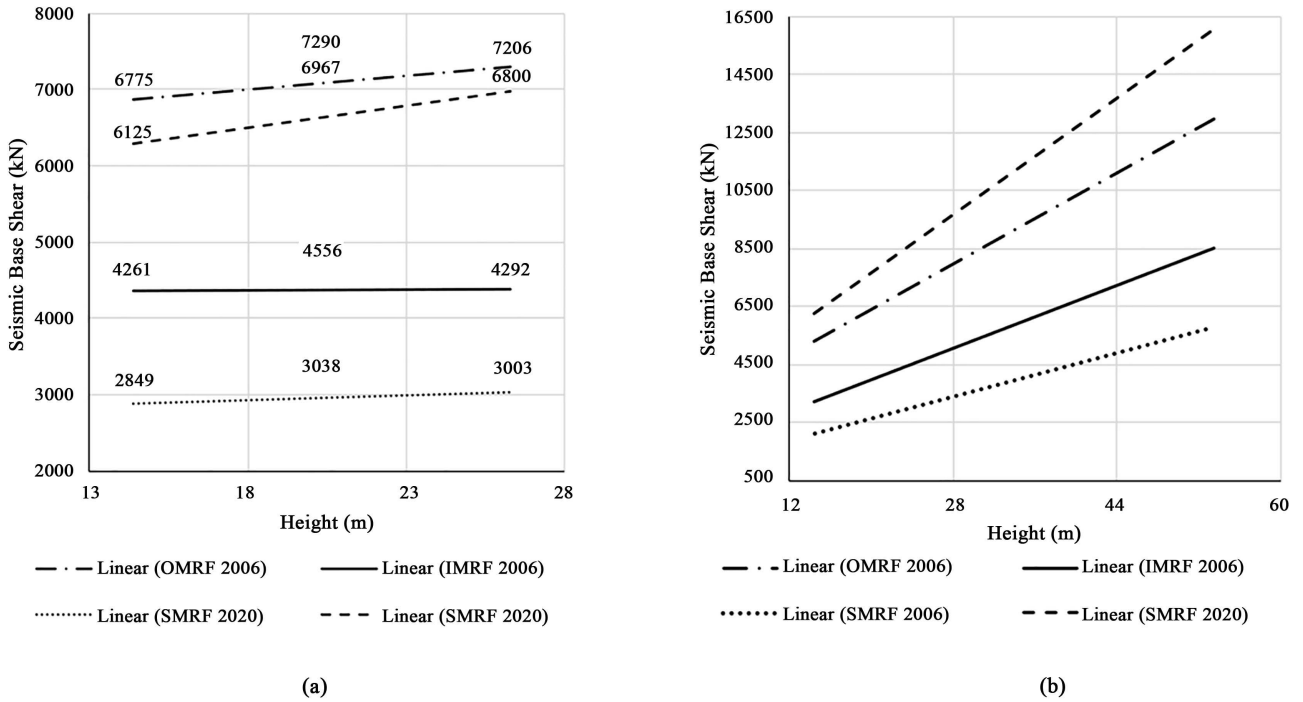


Figure 4. Comparison of seismic base shear for (a) building 3 and (b) all the buildings.

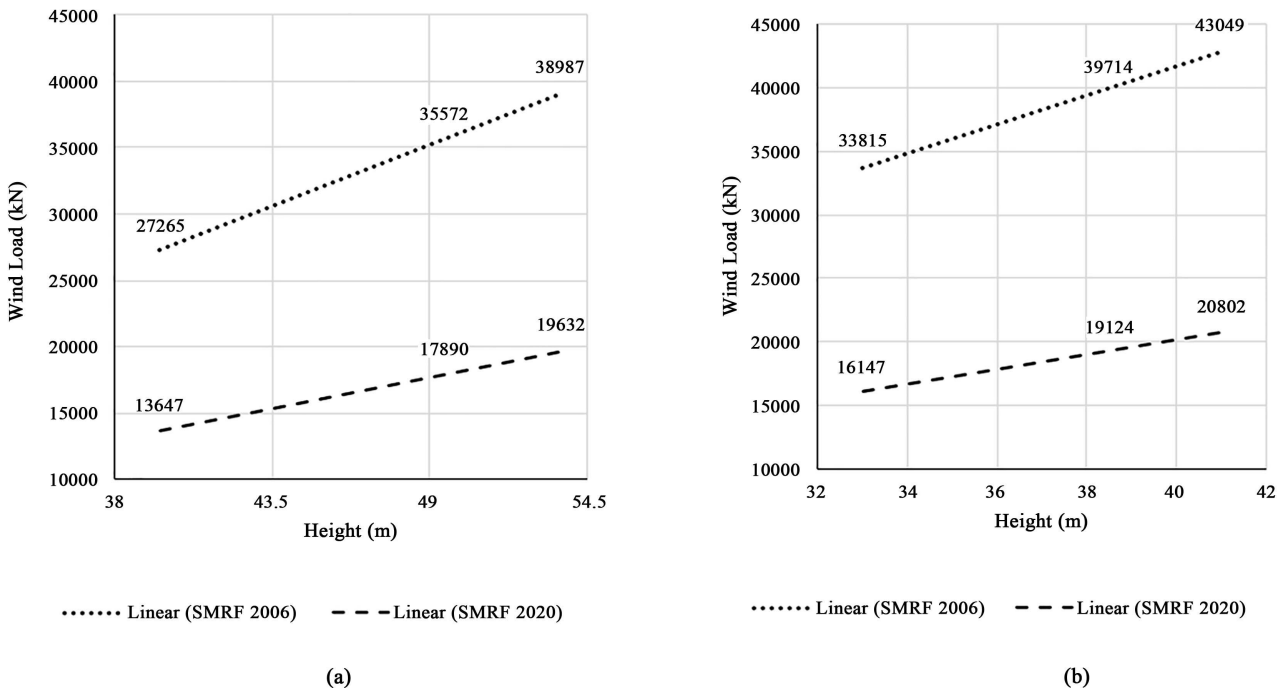


Figure 5. Comparison of wind load variation for (a) building 1 and (b) building 2.

From Figures 5-8 wind load values are depicted for BNBC 2006 and BNBC 2020. Though basic wind speed is increased in the later code but most of the wind load values for BNBC 2006 are greater than the values for BNBC 2020. From Figure 5 it is seen that wind load values are almost halved in the later code

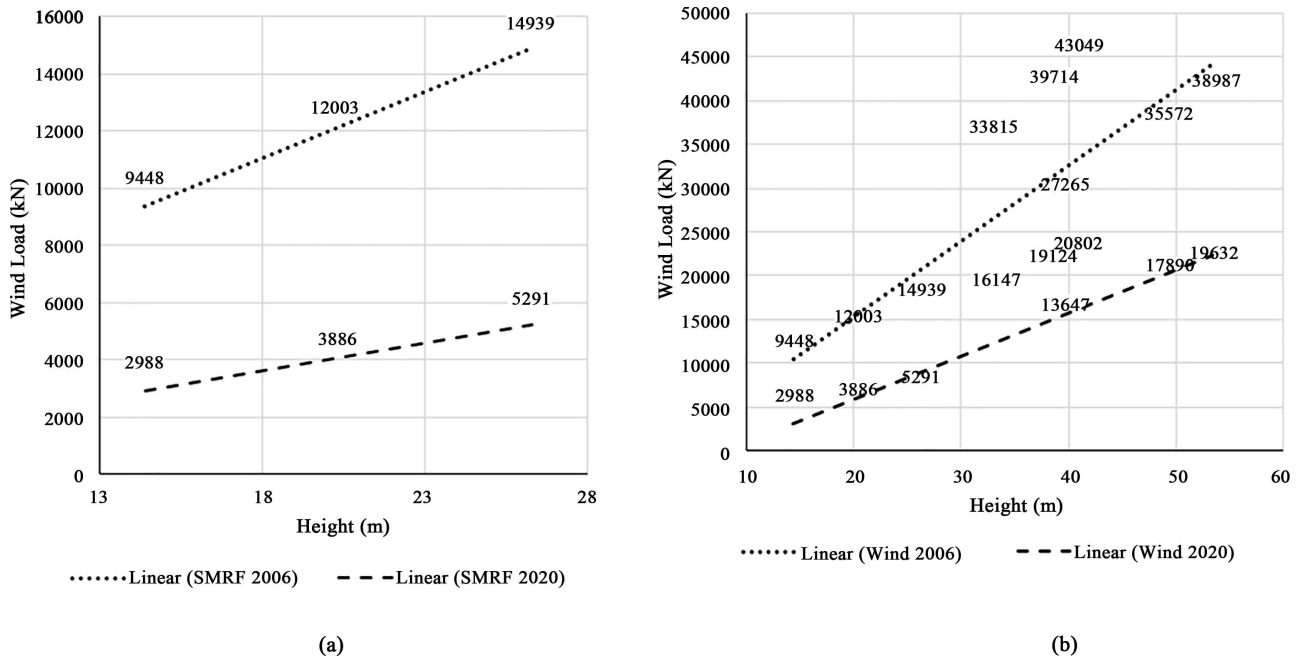


Figure 6. Comparison of wind load variation for (a) building 3 and (b) all the buildings.

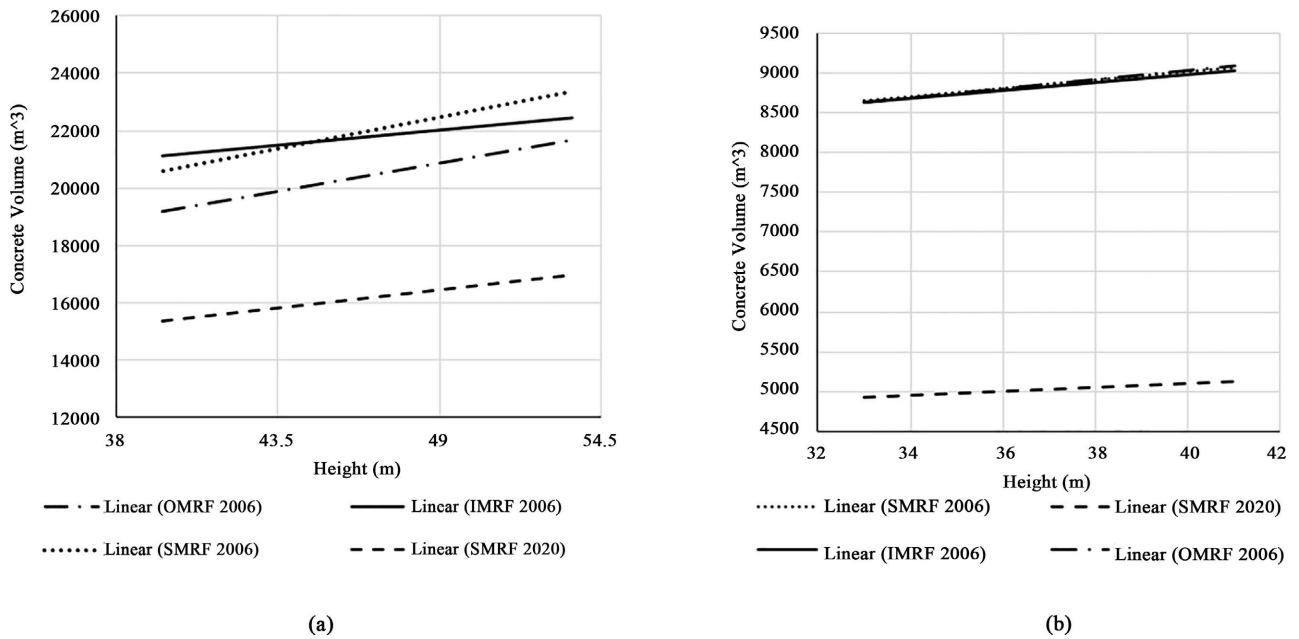


Figure 7. Comparison of wind load variation for (a) building 1 and (b) building 2.

for flat roof RC frame structure. The main causes are the gust coefficient (G) value, which has significantly dropped and is now between half and three-fourths of the BNBC 2006 [33] [36]-[38]. Additionally, the internal pressure effects during the design wind pressure calculation are lowering the building’s overall wind pressure [39]-[41]. In the case of building 3 (Figure 6), the wind load values are one-third to one-fourth of the wind load values of BNBC 2006. The key reason here is the increased variation of gust response factors G_h with the gust coefficient

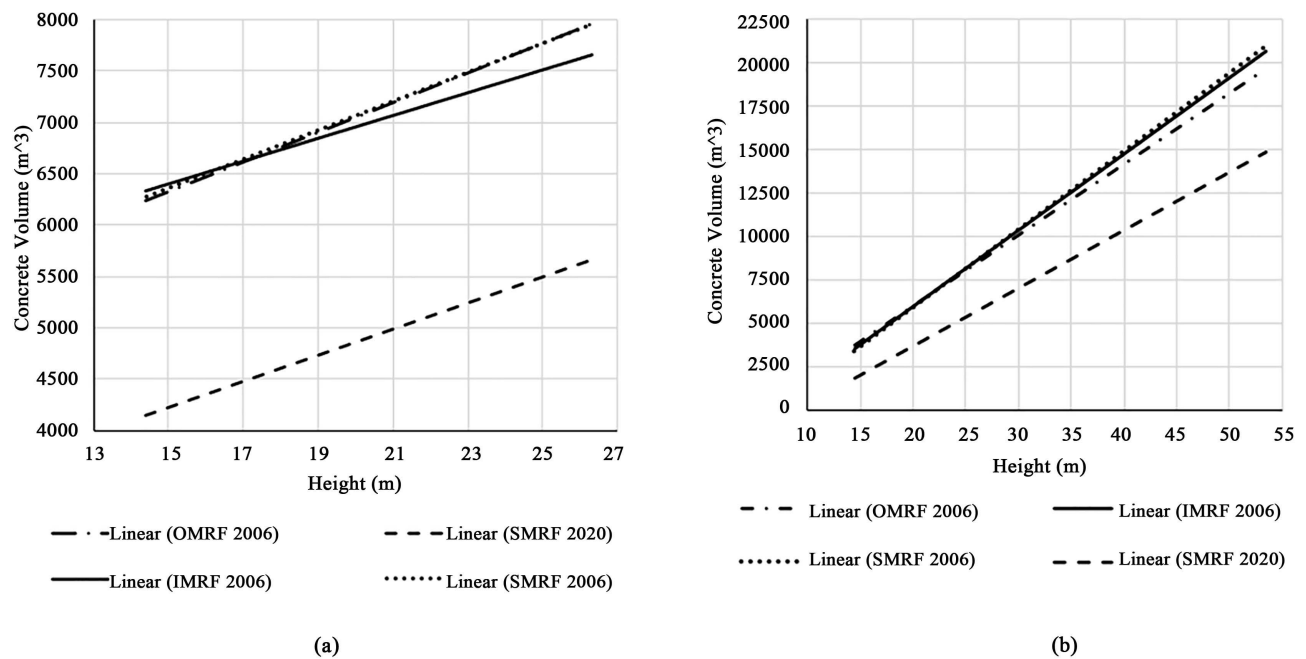


Figure 8. Comparison of concrete volume for (a) building 3 and (b) all the buildings.

G in the lower height regions. In **Figure 6**, the base shear values for all the buildings for the wind load application are depicted to get a comprehensive picture of shear force variation at different heights of the buildings for the two codes.

BNBC 2020 follows ASCE-7-05 wind load provisions which are based on 3s gust wind speed while the previous version used fastest-mile wind speed as the basis of basic wind speed [33]. The 3 s gust speed is generally 150 percent hourly wind speed of fastest-mile wind speed which is averaged in a period of 3 seconds while the fastest-mile wind speed is averaged over 30 to 60 seconds. In the later code the wind load factor has increased from 1.3 to 1.6. Therefore, loads derived from the wind speed map multiplied by the wind load factor represent the “ultimate load,” which is estimated to have a 500-year return period [42] [43]. Other major changes include introduction of topographic factor K_{zt} and directionality factor K_d . Another major change is the inclusion of internal pressure for the main wind-force resisting system (MWFRS) for all types of structures based on enclosure classification [44] [45]. Buildings are classified into enclosed, partially enclosed, and open depending upon amount and nature of openings in walls and in roofs [46]-[48].

In **Figure 7** and **Figure 8**, volume comparisons of concrete are depicted for BNBC 2006 and BNBC 2020. Most of the concrete volume values for BNBC 2020 are lower than the values for BNBC 2006. Several factors are contributing here to the volume variations e.g., load combinations, load factors, design reduction factors etc. [49]. All these things have changed and thus contribute a lot in the final analysis and results. From the combined volume comparisons of all the buildings we can see that there is a significant variation in the overall concrete volume values between the codes.

In BNBC 2006 most of the components of building 1 are governed by the seismic force that's why there are variations in concrete volume for different framing conditions. But in the case of building 2 and 3 almost all the components are governed by the wind forces and for that there are very minimal levels of concrete volume variations among different framing conditions.

Concrete volume has become lower in the updated code because the buildings are in a high wind zone and low seismic area [31]. In the later code wind force is reduced while seismic force is increased. But here the wind is the key factor of determining the design force of the structural elements and for that total concrete volume of the structures are significantly reduced.

4. Conclusions

Numerous research are taking place all over the world and with the help of the research findings analysis and design equations and methods are updating continuously and so are the necessity of code update is required for all the nations [50]-[52]. But for the end user, it is the cost that is the key concern of whatever changes take place [50] [52]-[54]. In this research, analysis of three buildings is done by two codes and finally, cost comparisons are shown from the output results. Based on the results presented in this paper, the major findings can be summarized as follows:

- 3-s gust wind speed is used in the updated code. Though this speed is more than the previous wind speed used in the earlier code, the overall wind load effect is reduced in the later code. And if a member or most of the members of a structure are governed by the wind load combinations then overall economy can be achieved by the updated code.
- Maximum considered earthquake (MCE) with a return period of 2475 years is used in the later code. Two-thirds of MCE is taken as the design basis seismic force calculation and from these it is seen that seismic force is significantly increased in the later code and thus contributing more to governing member design.
- From the output results it is seen that the BNBC 2020 code is more cost-effective than the BNBC 2006 code in case of a high wind zone and a low seismic zone.
- The overall impact can't be explained by analyzing it in one area only. For this, buildings with different geometry, different heights, and different framing conditions should be analyzed in different areas of the country with different soil profiles. From that analysis the overall picture can be depicted, and overall observations can be made.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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