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Comparative Seismic Performance Evaluation of RC Dual System Buildings Under NBC 105:2020 and IS 1893:2016 Across Varying Heights

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Abstract

This paper presents a comparative seismic performance evaluation of reinforced concrete (RC) dual system buildings, comprising shear walls and moment-resisting frames, of varying heights (4, 8, and 16 storeys) analyzed under NBC 105:2020 and IS 1893 (Part I):2016. Key seismic performance indices base shear, lateral storey displacement, inter-storey drift, and fundamental time period are systematically compared using the Response Spectrum Method. NBC 105:2020 yields significantly higher seismic demands, with base shear ratios of approximately 1.6, 3.0, and 5.2 times that of IS 1893:2016 for 4-, 8-, and 16-storey buildings, respectively. These differences arise from NBC 105:2020's probabilistic seismic hazard framework, higher spectral accelerations, and the combined application of ductility and overstrength factors in place of a single response reduction factor. The study highlights the conservative nature of NBC 105:2020 and its implications for structural design economy and safety in seismically active regions like Nepal.

Keywords: Seismic Performance, Response Spectrum Method, Base Shear, Lateral Storey Displacement, Inter-Storey Drift, Fundamental Time Period

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1. Introduction

Urban expansion in seismically active regions such as Nepal and India have led to increased construction of buildings of varying heights, making seismic safety a paramount concern. Building codes provide mandatory guidelines to enhance structural safety and mitigate economic losses due to earthquake events. In Nepal, seismic design provisions were first introduced following historical earthquake events, and have evolved through successive revisions incorporating updated seismic research and improved design methodologies. The latest revision, NBC 105:2020, issued in the aftermath of the 2015 Gorkha Earthquake, incorporates probabilistic seismic hazard analysis (PSHA), stricter zoning parameters, updated soil amplification factors, and enhanced provisions covering a broad range of structural heights [1]. In India, IS 1893 (Part I):2016 serves as the primary standard for earthquake-resistant design [2].

Despite the geographical proximity of Nepal and India and their shared tectonic environment, significant differences exist in the design philosophies of the two codes. NBC 105:2020 adopts PSHA, which accounts for uncertainties in earthquake magnitude, frequency, and source location, leading to stricter seismic demands, higher base shear, and more rigorous drift control requirements. IS 1893:2016, by contrast, follows a deterministic seismic hazard approach, which generally results in lower seismic demand estimates [3, 4, 5, 6, 7, 8]. A critical distinction lies in the force-reduction framework: NBC 105:2020 uses separate ductility factors (μ) and overstrength factors (Ω) at both ultimate limit state (ULS) and serviceability limit state (SLS), whereas IS 1893:2016 employs a single response reduction factor (R). This difference significantly influences the computed seismic base shear, particularly for taller buildings with longer fundamental periods.

Prior research has consistently documented the conservative nature of NBC 105:2020 relative to IS 1893:2016. Aryal and Bhatta [5] reported that base shear under NBC 105:2020 was 47.06% higher than IS 1893:2016, resulting in increased displacements, drifts, and a 5.48% rise in structural cost. Shakya and Kharel [6] compared NBC 105:1994, NBC 105:2020, and IS 1893:2016, finding maximum seismic responses under NBC 105:2020 attributable to the updated seismic hazard index. Karki and Bista [11] demonstrated up to 60% higher base shear in mid-rise RC buildings under NBC 105:2020, while Maharjan and Dahal [12] noted

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larger drift demands under NBC necessitating stricter detailing practices. Pandey and Singh [13] found that the NBC design spectrum produces higher spectral accelerations at shorter periods, increasing demands on low- and mid-rise buildings. Differences in site classification and soil amplification factors between the two codes can also produce divergent seismic responses for identical building types and site conditions [14]. Furthermore, Shrestha et al. [15] highlighted that differences between analytical methods become increasingly significant with building height, particularly for dual-system structures. These findings collectively establish the practical implications of NBC 105:2020’s probabilistic approach and its relatively conservative seismic demands compared to IS 1893:2016.

Despite these documented differences, a gap remains in the literature regarding RC dual system buildings comprising shear walls combined with moment-resisting frames which are widely used in practice in both Nepal and India, but have received limited attention in comparative code-based seismic studies. To address this gap, the present study performs a comparative evaluation of key seismic performance parameters base shear, maximum lateral storey displacement, inter-storey drift, and fundamental time period for 4-, 8-, and 16-storey RC dual system buildings, representing low-, mid-, and high-rise structures, analyzed under both NBC 105:2020 and IS 1893 (Part I):2016. In addition to quantifying these performance parameters, the study specifically analyzes how the differences in seismic demand between the two codes vary with building height, thereby highlighting practical implications for structural design in seismically active regions.

2. Methodology

The study was conducted on three reinforced concrete dual system buildings of 4, 8, and 16 storeys (plus one basement level), each comprising shear walls and moment-resisting frames for lateral load resistance. Structural element dimensions were scaled with building height to reflect realistic design practice. Key geometric and material properties are summarized in Table 1. All buildings were modeled as three-dimensional structures and analyzed using the Response Spectrum Method

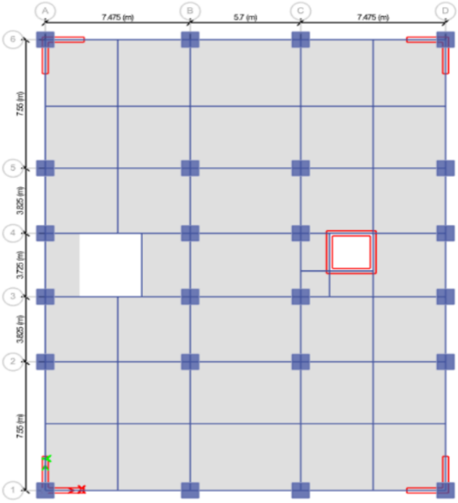

Figure 1. Typical plan view of the building models.

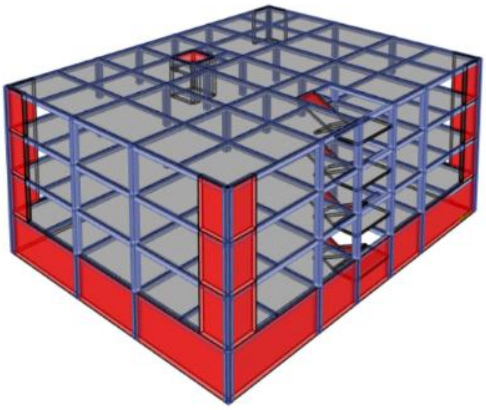

Figure 2. 3D view of 4-storey building model.

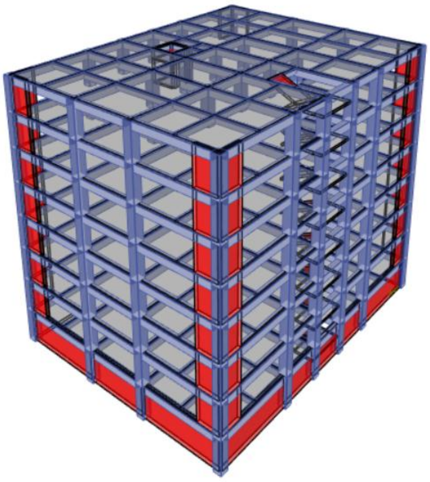

Figure 3. 3D view of 8-storey building model.

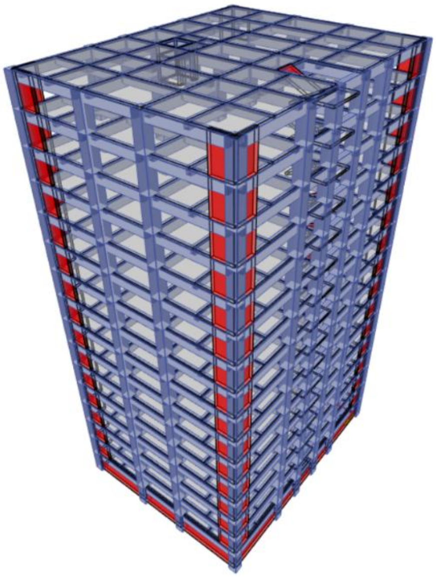

Figure 4. 3D view of 16-storey building model

Table 1. Structural member dimensions and concrete grades for varying building heights.

Building Height	Concrete Grade	Slab Thick.	Waist Slab Thick.	Secondary Beam	Main Beam	Column
4-Storey	M25	125 mm	150 mm	150×225 mm	230×300 mm	350×350 mm
8-Storey	M30	150 mm	200 mm	300×450 mm	450×600 mm	700×700 mm
16-Storey	M35	175 mm	225 mm	450×550 mm	500×800 mm	900×900 mm

2.1. Research Workflow

The research followed a systematic workflow:

- Selection of representative building heights (4, 8, and 16 storeys); 3D models shown in Figures 2–4, typical plan view in Figure 1, and key dimensions and material properties in Table 1.
- Development of three-dimensional structural models in ETABS v21.0.0.
- Assignment of material properties, section dimensions, boundary conditions (fixed base), and rigid diaphragm constraints at each floor level.
- Application of 5×5 mesh to shell elements for improved accuracy.
- Definition of loads and mass source (dead load and a code-specified fraction of live load).
- Implementation of response spectrum functions: built-in IS 1893:2016 spectrum and user-defined NBC 105:2020 spectrum.
- Assignment of load combinations in accordance with both codes (see Table 2).
- Modal analysis to determine natural periods and mode shapes, followed by Response Spectrum Analysis using the Complete Quadratic Combination (CQC) method.

2.2. Software and Modelling Setup

All modelling and analysis were conducted in ETABS Version 21.0.0, which supports frame and shell elements, modal analysis, and response spectrum analysis. The built-in IS 1893:2016 spectrum was used directly, while the NBC 105:2020 spectrum was defined manually using the user-defined spectrum feature.

2.2.1. Material Properties

Concrete material properties used in the models are listed in Table 1. For each building height, concrete grade was selected to reflect realistic design practice: M25 for 4-storey, M30 for 8-storey, and M35 for 16-storey buildings. Concrete unit weight was taken as 25 kN/m³, Poisson's ratio as 0.2, and modulus of elasticity was computed from the respective concrete grade as per standard code provisions. Steel reinforcement was assumed as Fe500 with a yield strength of 500 MPa, consistent with standard practice in Nepal and India. These material properties were uniformly applied across all models to ensure consistency.

2.2.2. Structural Elements

Beams and columns were modeled as frame elements; slabs and shear walls were modeled as shell elements. The seismic mass was derived from dead load plus an appropriate fraction of live load as specified by each code.

2.3. Boundary Conditions and Constraints

Fixed base conditions were applied at the foundation level, restraining all six degrees of freedom. Rigid diaphragm constraints were assigned at each floor level to simulate in-plane stiffness and ensure realistic lateral load distribution.

2.4. Damping Assumption

A uniform damping ratio of 5% was adopted for all modes in both IS 1893:2016 and NBC 105:2020 analyses, consistent with the recommendations of both codes for reinforced concrete structures.

2.5. Loads and Mass Source

Dead, live, and superimposed dead loads were applied according to standard code provisions. The seismic mass was defined as dead load plus 25% of live load for floors, and 100% of dead load for the roof, consistent with both codes' requirements.

2.6. Response Spectrum Functions

Two response spectrum functions were employed: (i) IS 1893:2016 — the built-in ETABS spectrum with code-specified parameters for Zone V, Soil Type III; and (ii) NBC 105:2020 — a user-defined spectrum constructed manually in accordance with code provisions for Kathmandu (Seismic Zone Factor Z = 0.35, Soil Type D). The NBC 105:2020 spectrum accounts for ductility and overstrength factors at both ULS and SLS levels, as described in Section 2.8.

2.7. Load Combinations

Load combinations were formulated in accordance with the provisions of each code. The NBC 105:2020 load combinations reflect separate SLS and ULS requirements, while IS 1893:2016 combinations follow the provisions of IS 456:2000 with seismic load factors. The complete set of load combinations used in the analysis is presented in Table 2.

Table 2. Seismic load combinations used for analysis under NBC 105:2020 and IS 1893:2016.

NBC 105:2020	**IS 1893 (Part 1):2016**
1.0DL + 1.0LL + 1.0EQX (SLS)	1.2DL + 1.2LL + 1.2RSX
1.0DL + 1.0LL + 1.0EQY (SLS)	1.2DL + 1.2LL + 1.2RSY
1.0DL + 1.0LL + 1.0EQX (ULS)	1.5DL + 1.5LL
1.0DL + 1.0LL + 1.0EQY (ULS)	1.5DL + 1.5RSX
1.2DL + 1.2LL + 1.2EQX (SLS)	1.5DL + 1.5RSY
1.2DL + 1.2LL + 1.2EQY (SLS)	0.9DL + 1.5RSX
1.2DL + 1.2LL + 1.2EQX (ULS)	0.9DL + 1.5RSY
1.2DL + 1.2LL + 1.2EQY (ULS)	

2.8. Seismic Design Parameters

The seismic analysis parameters for all models, assuming a site in Kathmandu, are summarized in Table 3. A key distinction between the two codes is that IS 1893:2016 employs a single response reduction factor (R = 5.0) for dual systems, whereas NBC 105:2020 uses separate ductility factor (μ = 3.5) and overstrength factors (Ωu = 1.4 at ULS; Ωs = 1.2 at SLS). This approach in NBC 105:2020 produces higher effective seismic forces, particularly for taller buildings, as it does not permit the same level of force reduction allowed under IS 1893:2016.

Table 3. Key seismic design parameters for buildings located in Kathmandu.

Seismic Parameter	**NBC 105:2020**	**IS 1893 (Part 1):2016**
Seismic Zone Factor (Z)	0.35	Zone V, Z = 0.36
Soil Type	D (Very Soft Soil)	Type III (Soft Soil)
Importance Factor (I)	1.25	1.25
Response Reduction Factor (R)	—	5.0
Ductility Factor (μ)	3.5	—
Overstrength Factor (ULS, Ωu)	1.4	—
Overstrength Factor (SLS, Ωs)	1.2	—
Damping Ratio	5%	5%
Analysis Method	Response Spectrum (CQC)	Response Spectrum (CQC)

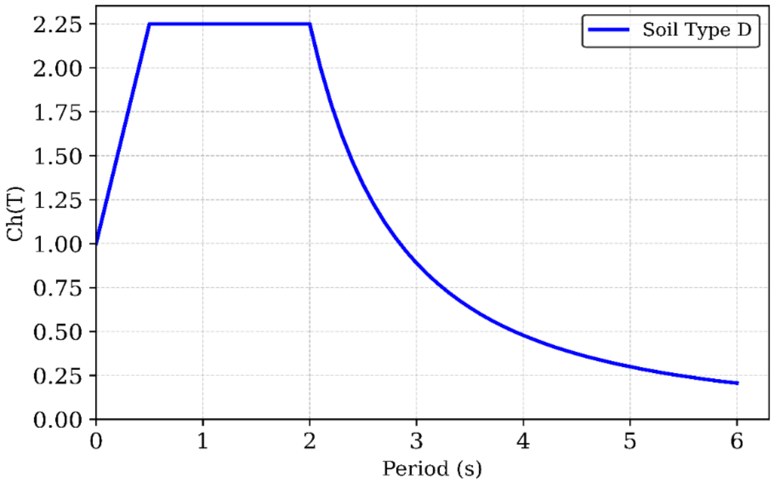

Figure 5. Response spectrum curve as per NBC 105:2020 for Soil Type D.

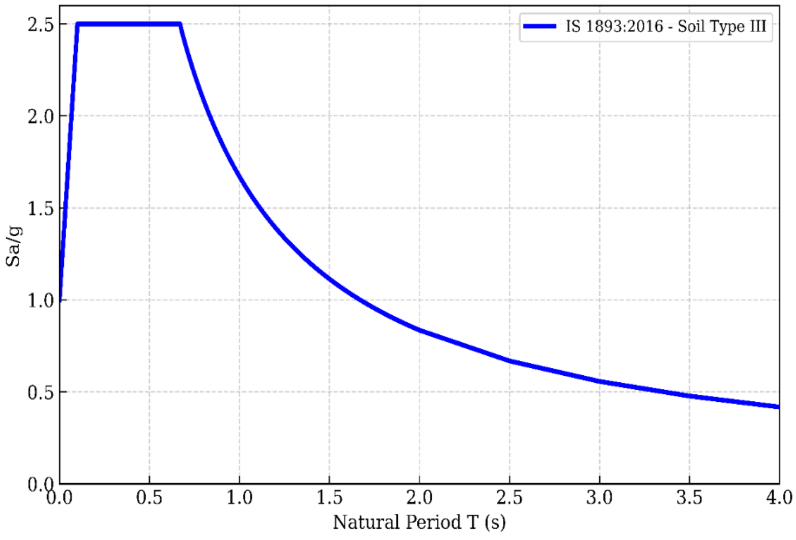

Figure 6. Response spectrum curve as per IS 1893 (Part 1):2016 for Soil Type III.

Figures 5 and 6 present the design response spectra for NBC 105:2020 (Soil Type D) and IS 1893:2016 (Soil Type III), respectively. Both spectra rise sharply at low natural periods, plateau for mid-range periods, and decline at longer periods corresponding to taller structures. The NBC 105:2020 spectrum exhibits a higher and more extended plateau, with a slower decline at longer periods, resulting in greater seismic demands particularly for buildings with longer fundamental periods (i.e., taller structures). The selection of Soil Type D for NBC 105:2020 and Soil Type III for IS 1893:2016 is appropriate, as both represent soft soil conditions commonly found in the Kathmandu Valley. Both soil categories exhibit low shear wave velocities and high amplification potential, thereby representing critical (conservative) foundation conditions for seismic demand evaluation.

2.9. Structural Analysis

Modal analysis was first performed to extract natural periods, mode shapes, and modal mass participation ratios. Sufficient modes were included to ensure at least 90% mass participation in each principal direction. Response Spectrum Analysis was then conducted using the CQC modal combination method, which appropriately accounts for modal coupling and is suitable for three-dimensional irregular structures.

3. Results and Discussion

Significant and consistent differences in seismic response were observed between buildings analyzed under NBC 105:2020 and IS 1893:2016, with the disparity becoming increasingly pronounced with building height. The results in the X- and Y-directions exhibited similar trends, confirming the consistency of findings across both principal directions. A summary of all key response parameters is presented in Table 4.

Table 4. Seismic response comparison under IS 1893:2016 and NBC 105:2020.

Building Height	Code	Base Shear (kN)	Max. Lateral Disp. X (mm)	Max. Lateral Disp. Y (mm)	Max. Inter-Storey Drift X (%)	Max. Inter-Storey Drift Y (%)
4-Storey	IS 1893	2,002	5.5	6.25	0.071	0.081
	NBC 105	3,252	10	11	0.13	0.15
8-Storey	IS 1893	5,504	31	30	0.17	0.168
	NBC 105	16,406	75	68	0.41	0.38
16-Storey	IS 1893	7,697	54	48	0.16	0.146
	NBC 105	40,388	250	208	0.76	0.63

Note: The 16-storey NBC 105:2020 lateral displacement in the X-direction was corrected to 250 mm (previously reported as 25 mm, which was a typographical error inconsistent with the observed trend and Y-direction value of 208 mm).

The percentage difference between the NBC and IS results for each parameter was calculated as:

$$\text{Percentage Difference (\%)} = [(\text{NBC} - \text{IS}) / \text{IS}] \times 100 \qquad \text{(Equation 1)}$$

where IS and NBC denote the values computed under IS 1893:2016 and NBC 105:2020 provisions, respectively. These percentage differences for base shear, maximum lateral storey displacement, maximum inter-storey drift, and fundamental time period across all three building heights in the X-direction are presented in Figure 7.

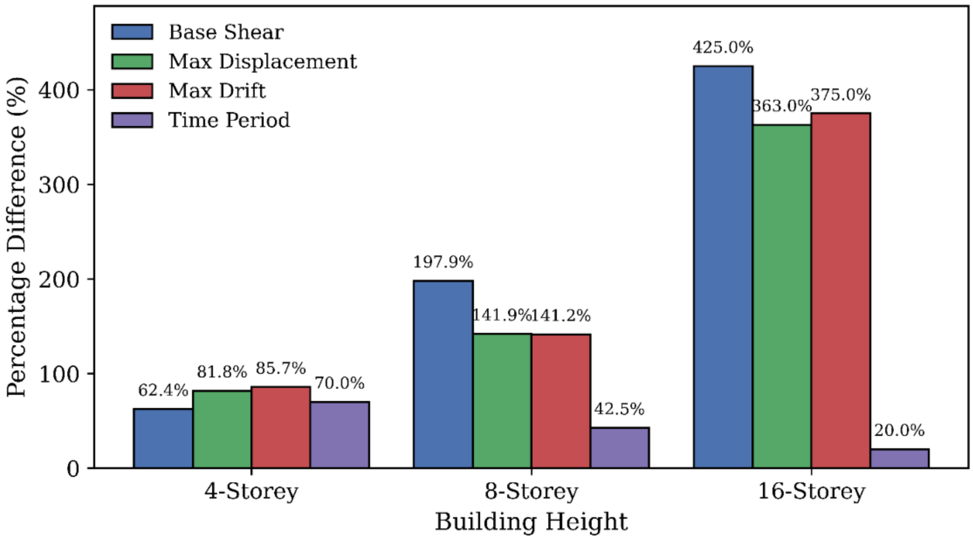

Figure 7. Percentage differences between NBC 105:2020 and IS 1893:2016 results for different structural parameters across building heights (X-direction).

3.1. Base Shear

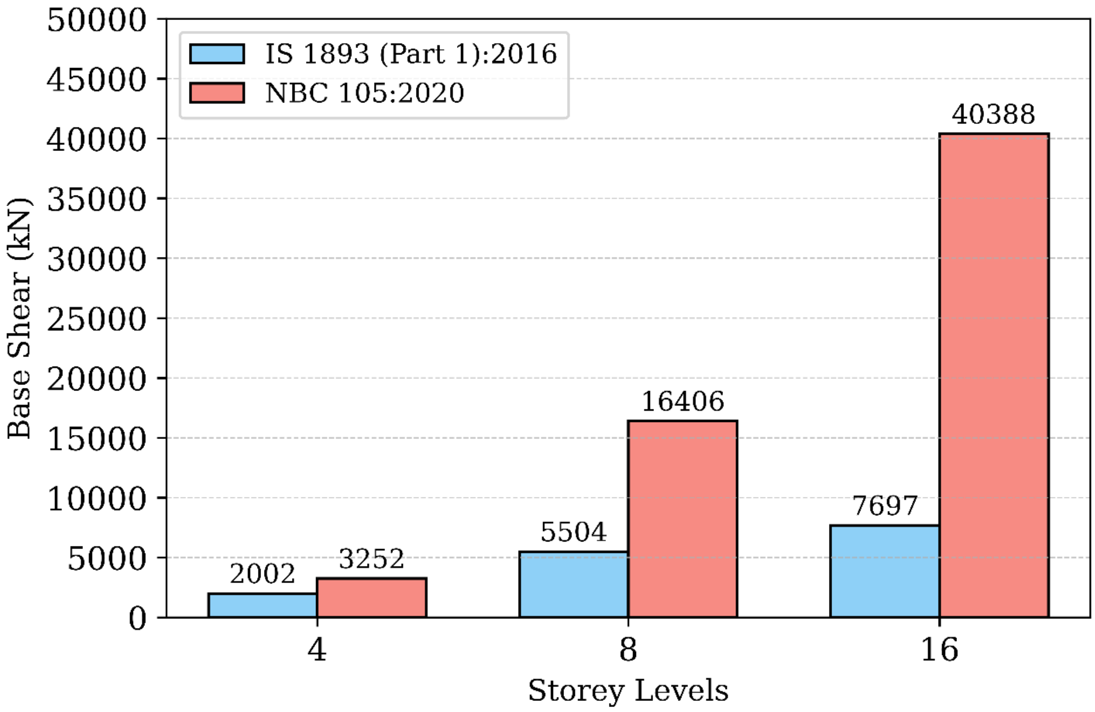

Figure 8. Base shear variation with storey levels: NBC 105:2020 vs IS 1893 (Part I):2016.

NBC 105:2020 consistently yields higher base shear than IS 1893:2016, and the ratio increases markedly with building height:

- 4-Storey: 3,252 kN (NBC) / 2,002 kN (IS) = 1.62 times
- 8-Storey: 16,406 kN (NBC) / 5,504 kN (IS) = 2.98 times
- 16-Storey: 40,388 kN (NBC) / 7,697 kN (IS) = 5.24 times

This height-dependent divergence in base shear is illustrated in Figure 8. The growing disparity arises from NBC 105:2020's higher spectral accelerations at longer natural periods, its use of separate ductility and overstrength factors (which do not permit the same degree of force reduction as the single R-factor in IS 1893:2016), and its more conservative seismic zoning provisions for the Kathmandu Valley. As buildings become taller, their fundamental periods increase and fall into the portion of the NBC spectrum that remains elevated relative to the IS spectrum, amplifying the base shear ratio between the two codes.

3.2. Maximum Lateral Storey Displacement

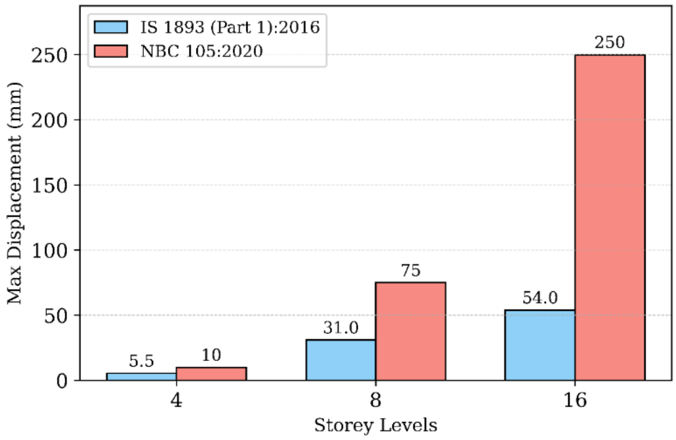

Figure 9. Max Lateral Displacement Variation with Storey Levels (X-direction

Maximum lateral storey displacement under NBC 105:2020 is substantially higher than under IS 1893:2016 across all building heights, as a direct consequence of the higher base shear demands. The NBC-to-IS displacement ratio increases with building height:

- 4-Storey: approximately 1.8 times higher under NBC 105:2020.
- 8-Storey: approximately 2.3–2.4 times higher under NBC 105:2020.
- 16-Storey: approximately 4.3–4.6 times higher under NBC 105:2020.

As shown in Figure 9, maximum lateral storey displacement increases sharply with building height under NBC 105:2020, while the increase under IS 1893:2016 is comparatively moderate. This trend underscores the importance of adopting more robust lateral load-resisting systems when designing tall buildings in compliance with NBC 105:2020, particularly to satisfy serviceability displacement limits.

3.3. Maximum Inter-Storey Drift

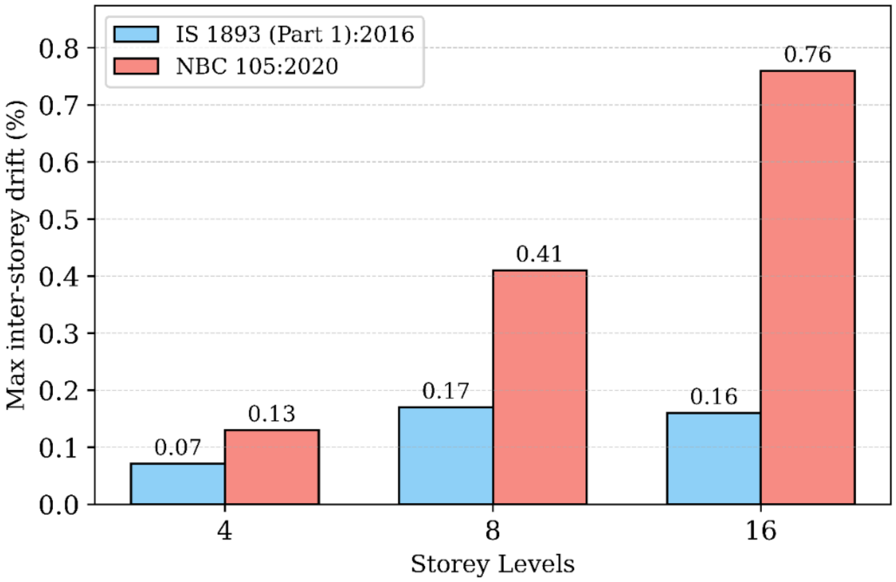

Figure 10. Maximum inter-storey drift variation with storey levels: NBC 105:2020 vs IS 1893 (Part I):2016 (X-direction).

Inter-storey drift is a critical parameter for evaluating potential damage to both structural and non-structural components. NBC 105:2020 produces significantly higher inter-storey drifts than IS 1893:2016 across all building heights, with the difference becoming more pronounced for taller structures:

- 4-Storey: 0.13% (NBC) vs 0.071% (IS) = 1.83 times
- 8-Storey: 0.41% (NBC) vs 0.17% (IS) = 2.41 times
- 16-Storey: 0.76% (NBC) vs 0.16% (IS) = 4.75 times

As illustrated in Figure 10, these elevated inter-storey drift values under NBC 105:2020 are a direct consequence of the higher prescribed spectral accelerations and base shear, especially for buildings with longer fundamental periods. All drift values remain within the permissible limits of the respective codes (1.0% for NBC 105:2020 at ULS; 0.4% for IS 1893:2016 at SLS), confirming code compliance; however, the results highlight that structures designed under NBC 105:2020 must be detailed more carefully to manage non-structural damage at higher drift levels.

3.4. Fundamental Time Period

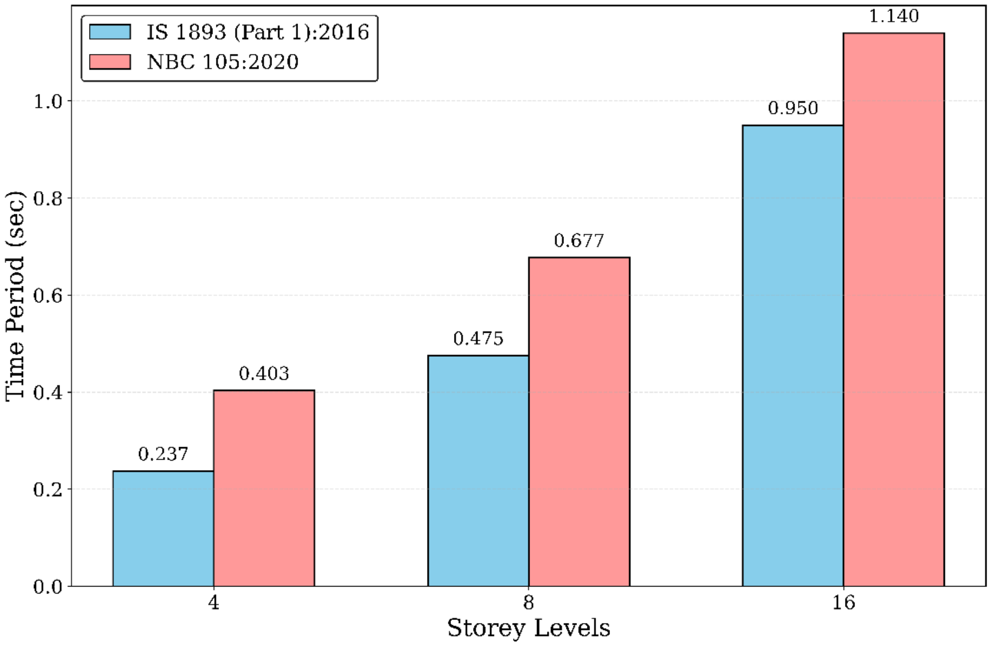

Figure 11. Fundamental time period variation with storey levels: NBC 105:2020 vs IS 1893 (Part I):2016.

The fundamental time period is higher under NBC 105:2020 compared to IS 1893:2016, and the difference reduces with building height:

- 4-Storey: 0.403 s (NBC) vs 0.237 s (IS) = 1.70 times
- 8-Storey: 0.677 s (NBC) vs 0.475 s (IS) = 1.43 times
- 16-Storey: 1.14 s (NBC) vs 0.95 s (IS) = 1.20 times

The longer fundamental time periods under NBC 105:2020 reflect greater building flexibility under the higher seismic forces imposed by the code. As shown in Figure 11, the convergence of time periods at higher building heights suggests that both codes produce similar dynamic characteristics for tall buildings, even though the spectral demands remain substantially different. The discrepancy in time periods at lower building heights indicates that the two codes' empirical period formulae produce differing estimates for short structures, with NBC 105:2020 yielding longer periods that place these buildings in a less favorable portion of the response spectrum.

Collectively, the results demonstrate that NBC 105:2020 imposes substantially higher seismic demands than IS 1893:2016 across all parameters and building heights, with the difference increasing consistently with building height. This height-dependent amplification is primarily driven by NBC 105:2020's more conservative seismic hazard model, its higher spectral amplifications at longer natural periods, and its force-reduction framework, which distributes seismic demand across ULS and SLS levels rather than applying a single blanket reduction factor. For practitioners, this implies that mid- and high-rise RC dual system buildings in Nepal designed under NBC 105:2020 will require larger structural member sizes, stronger lateral load-resisting systems, and more stringent detailing to satisfy code-prescribed performance objectives compared to buildings designed under IS 1893:2016.

4. Novelty and Limitations

4.1. Novelty

- This study focuses on RC dual system buildings (shear wall + moment-resisting frame), which are widely used in practice but have received limited attention in comparative code-based seismic analyses.
- It systematically quantifies the height-dependent variation in seismic response differences between NBC 105:2020 and IS 1893:2016, demonstrating that code-induced divergences increase significantly with building height.
- Multiple seismic performance parameters base shear, maximum lateral storey displacement, inter-storey drift, and fundamental time period are evaluated simultaneously, providing a holistic assessment of code-specific effects on structural performance.

4.2. Limitations

- The analysis assumes linear elastic structural behavior and idealized fixed boundary conditions, which may not fully capture the nonlinear response observed during strong earthquakes.
- Soil-structure interaction effects and nonlinear material behavior were not considered, which may influence real seismic response.
- The study is limited to three building heights and a single site (Kathmandu); findings may not be directly applicable to other building configurations, soil conditions, or seismic regions.

5. Conclusion

This study presents a systematic comparative evaluation of the seismic performance of RC dual system buildings of varying heights under NBC 105:2020 and IS 1893 (Part I):2016. The key findings are:

- NBC 105:2020 is consistently more conservative than IS 1893:2016, with the disparity growing substantially with building height. The base shear ratio (NBC/IS) increases from approximately 1.6 for 4-storey buildings to approximately 3.0 for 8-storey and approximately 5.2 for 16-storey buildings.
- The higher base shear prescribed by NBC 105:2020 results in substantially larger lateral storey displacements and inter-storey drifts, particularly for taller structures, necessitating stronger lateral load-resisting systems and more rigorous detailing.
- The differences in seismic demand arise from NBC 105:2020's probabilistic seismic hazard framework, its higher spectral amplifications at longer natural periods, and its force-reduction methodology that applies separate ductility and overstrength factors rather than a single response reduction factor.
- The choice of seismic design code significantly influences structural design decisions, material quantities, and construction costs particularly for mid- and high-rise buildings in seismically active regions like Nepal.

From a practical perspective, the more stringent seismic demands of NBC 105:2020 provide improved safety margins against collapse during strong earthquakes. However, they also entail higher construction costs and material consumption, requiring engineers to carefully balance safety objectives with economic constraints. These findings offer quantitative guidance for practicing engineers and policymakers in Nepal and similar seismically active regions where both codes may be applicable.

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