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A Code-Based Comparison of Seismic Performance of Regular and Plan-Irregular RC Buildings using NBC 105:2020 and IS 1893:2016

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Abstract

Nepal's location in an active seismic zone, along with escalating emphasis on architectural aesthetics and land scarcity, has led to increasing plan-irregular buildings that complicate seismic design and compromise structural safety. This study compares the seismic performance of regular and plan-irregular reinforced concrete (RC) buildings designed per IS 1893:2016 and NBC 105:2020 codes, addressing the gap in cross-code, multi-height analyses. For this purpose, one square regular building (RM) and 6 alternative L-shaped irregular buildings (IRM1-IRM6) with 3, 6, 9, and 12 story configurations designed under both codes were analyzed using response spectrum methods in ETABS to evaluate seismic parameters like base shear, drift ratio, displacement, time period, torsion ratio, story stiffness and shear. The findings revealed that NBC-compliant buildings had shorter time periods (up to 40% shorter) but higher base shear (1.75 – 6 times IS), displacement, drift ratio, torsion ratio, story shear, and stiffness than IS-compliant buildings, reflecting stricter seismic demands under NBC that may result in more robust yet cost-intensive designs. Regular models displayed lower base shear (up to 74% reduction) and stiffness, with higher time periods, displacements, and torsional irregularity (TIR > 1.2), indicating increased seismic vulnerability due to asymmetry and stress concentrations. These findings inform resilient seismic design for Nepal's urban landscape.

Keywords: *Irregular Buildings, NBC, Torsional Irregularity, Response Spectrum Analysis, Earthquake*

1. Introduction

An earthquake is a sudden release of stored elastic energy in the Earth's crust, resulting in ground shaking and vibrations due to the propagation of seismic waves. Nepal lies in one such tectonically active zone, the Himalayan seismic belt, formed by the ongoing collision between the Indian Plate and the Eurasian Plate (Chaulagain et al., 2018). Analysis of historical seismic records indicates that Nepal generally experiences two major earthquakes, with magnitudes between 7.5 and 8.0. As nearly seven decades have passed since the major 1934 Bihar–Nepal earthquake before the catastrophic 2015 Gorkha earthquake (Mw 7.8), there are growing concerns that the region may face another large-magnitude quake in the near future (Bhagat et al., 2018; Dutta et al., 2015; Endo & Hanazato, 2021; Gautam et al., 2015; Gautam & Chaulagain, 2016; Varum et al., 2018). Existing research on seismic performance predominantly employs numerical methods like finite element modeling in ETABS, focusing on reinforced concrete (RC) frames under NBC 105 and IS 1893 provisions (Bohara, 2022, 2023, 2025; Bohara, Joshi, et al., 2025). Studies comparing regular and irregular structures reveal that irregularities amplify torsional effects, stress concentrations, and deformation demands, increasing vulnerability (Khanal & Chaulagain, 2020). For instance, (Paudel et al., 2024) analyzed multi-story RC frames with vertical and horizontal irregularities using ETABS, finding that regular buildings exhibit higher stiffness than vertically irregular ones. Comparative code-based studies highlight disparities between NBC and IS. (Sapkota et al., 2024) assessed low-rise RC buildings in Nepal using multiple codes, including NBC 105:2020 and IS 1893:2016, via response spectrum analysis. NBC-compliant designs yielded shorter fundamental periods (average 40% less than IS) but higher base shear, displacements, and drifts, reflecting stricter seismic demands. Irregular models showed increased periods and drifts, with NBC underestimating finite element-derived periods less than IS (0.4% vs. 91.7% error for 3-story regular). Torsional and irregularity effects are further explored in (Bohara et al., 2022; Khanal & Chaulagain, 2020) , who simulated L-shaped frames, noting up to 9.5% period increases in high-rises due to torsional flexibility, with irregular models exceeding TIR thresholds (>1.2). Khadka (2020) analyzed asymmetric RC structures, observing 3.3-fold base shear differences between regular and highly irregular models, recommending dynamic analysis for mitigation.

This study aims to compare the seismic performance of regular and plan-irregular reinforced concrete (RC) buildings designed per IS 1893:2016 and NBC 105:2020, addressing the increasing prevalence of irregular structures in Nepal's rapidly urbanizing landscape due to architectural demands and land scarcity. The specific objectives are to: (1) conduct seismic analyses using equivalent static, response spectrum, nonlinear pushover, and time history methods for one regular (RM) and six L-shaped irregular (IRM1–IRM6) building models across 3, 6, 9, and 12 stories; (2) quantitatively compare key seismic parameters, including base shear, story displacement, drift ratio, fundamental time period, torsional irregularity ratio, and story stiffness, between regular and irregular configurations under both codes; and (3) evaluate how plan irregularities and code-specific provisions influence overall seismic resilience. By highlighting the heightened seismic vulnerability of irregular buildings, particularly due to torsional effects and stress concentrations, this study provides critical insights for improving earthquake-resistant design. With over 70% of new constructions in Kathmandu featuring irregular plans, these findings inform safer structural practices and policy recommendations, enhancing safety and stability in Nepal's tectonically active Himalayan region.

2. Materials and Methods

2.1 Building Model Description

A total of 56 analytical models were analyzed and designed in ETABS software in compliance with both the Indian Standards (IS 1893:2016) (IS 1893, 2016) and the Nepal National Building Code (NBC 105:2020) (105:2020, 1994) for the study, equally divided between the Indian Standards (IS) and the NBC, with 28 models in each code category. The buildings were classified into three height categories based on story numbers: low-rise (3-story), mid-rise (6 and 9-story), and high-rise (12-story) as shown in tables 1, 2 and figures 1 and 2. For each height category, one square regular-plan and six L-shaped irregular-plan RC building configurations were modeled, resulting in seven models per rise category for each code. This classification and modeling framework enabled to assess the seismic performance variations across codal provisions and building configurations. The building structural dimensions are tabulated below:

Table 1: Structural Dimension

Component	Specification
No. of Stories	3, 6, 9, 12
No. of Bays X*Y	8x8
Spacing	6m
Slab Thickness	120 mm
Height of each floor	3.5 m

Table 2: Beam and Column Dimensions Designed by using Seismic Code

Building Story No.	**Floors**	**Beam Dimensions (mm x mm)**		**Column Dimension (mm x mm)**	
		IS Model	NBC Model	IS Model	NBC Model
3 Story Model	1 to 3	300 x 475	500 x 600	475 x 475	675 x 675
6 Story Model	1 to 3	350 x 500	675 x 775	600 x 600	800 x 800
	3 to 6	325 x 475	600 x 700	500 x 500	675 x 675
9 Story Model	1 to 3	350 x 600	750 x 975	750 x 750	1025 x 1025
	3 to 6	350 x 550	700 x 925	600 x 600	850 x 850
	6 to 9	350 x 500	550 x 700	450 x 450	625 x 625
12 Story Model	1 to 3	400 x 600	825 x 975	900 x900	1200 x 1200
	3 to 6	375 x 575	775 x 900	800 x 800	950 x 950
	6 to 9	350 x550	675 x 800	750 x750	800 x 800
	9 to 12	325 x 525	575 x 700	700 x700	700 x 700

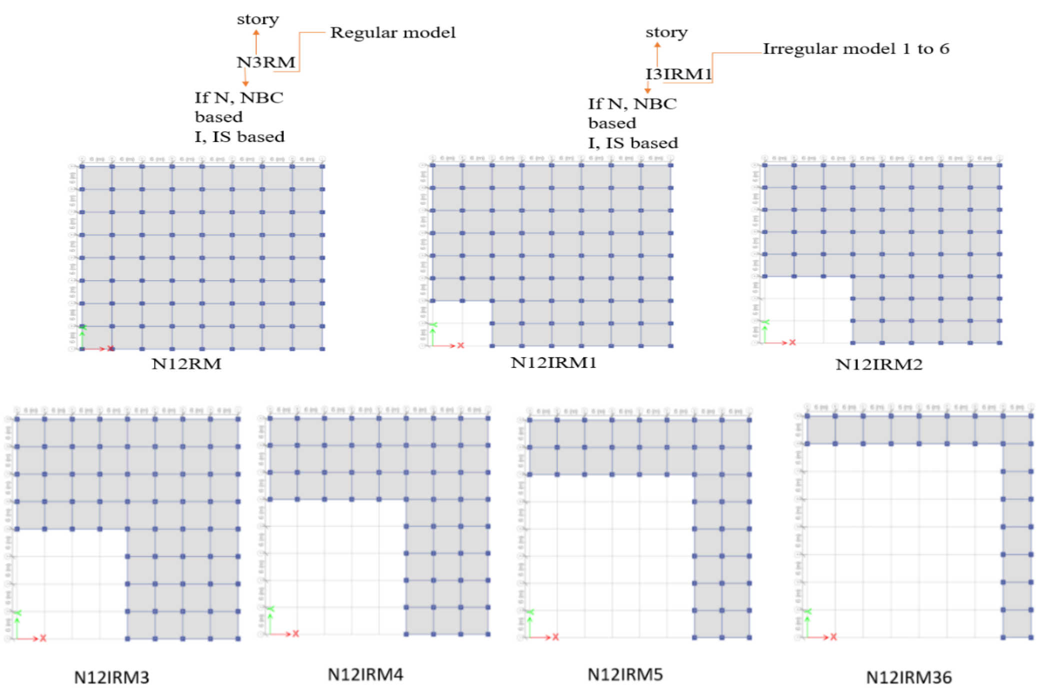

Figure 1: Models with their Naming

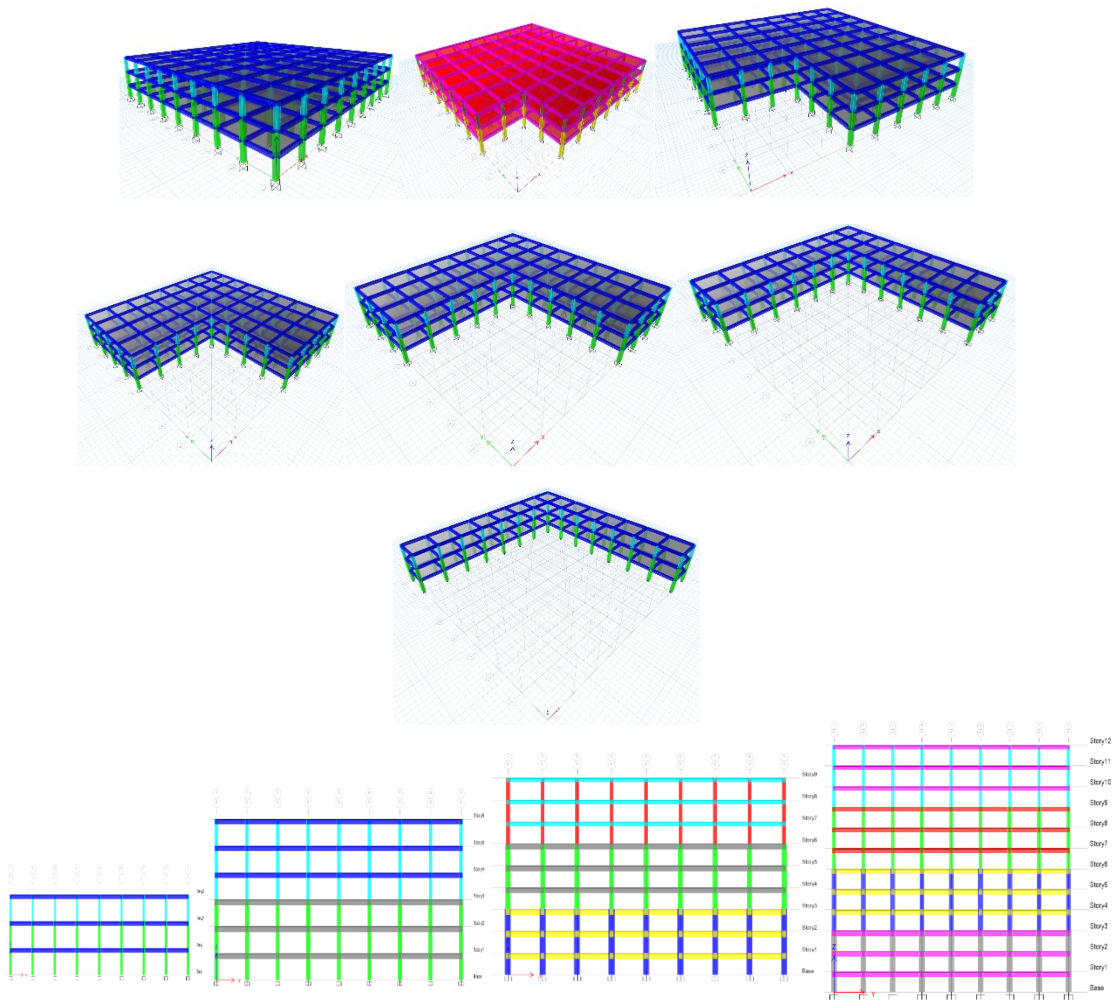

Figure 2: Regular and L shape building plan and elevation

2.1.1. Codal Provision for Structural Configurations

Structural irregularities, as described by NBC 105:2020 and IS 1893:2016, have a major impact on seismic performance and are divided into vertical and plan irregularities. Plan irregularities involve torsional irregularity, characterized by maximum story displacement being more than 1.5 times the minimum (as defined by both codes), and re-entrant corners, where projections exceed 15% of the plan dimension (NBC) or 20% (IS). Diaphragm discontinuity occurs due to cutouts or changes in stiffness greater than 50% (both codes), and out-of-plane offsets take place when vertical elements are misaligned. The stricter thresholds outlined by NBC (e.g., stiffness and mass) indicate the greater seismic demands in Nepal when compared to IS, highlighting the need for a resilient design to lessen torsional impacts and ensure structures can withstand earthquakes.

2.1.2. Response Spectrum Analysis

Response Spectrum Analysis (RSA) is a dynamic evaluation technique utilized to assess the seismic resilience of structures by calculating their maximum responses to ground motions induced by earthquakes, as outlined by seismic codes such as NBC 105:2020 and IS 1893:2016. RSA uses modal analysis to determine a structure's natural periods and mode shapes, which are then employed to derive spectral accelerations from a code-defined design response spectrum, reflecting the anticipated intensity of ground motion for a specific site and seismic zone. These spectral accelerations are statistically combined using approaches like the Square Root of the Sum of Squares (SRSS) or Complete Quadratic Combination (CQC) to ensure contributions from multiple modes, including higher-mode influences, are adequately addressed for a thorough evaluation of structural response. In this analysis, RSA was performed using ETABS software to evaluate both regular and L-shaped irregular reinforced concrete (RC) building models consisting of 3, 6, 9, and 12 stories, designed according to NBC 105:2020 and IS 1893:2016, with results compared for parameters such as base shear, story displacement, drift, and torsional irregularity.

The design response spectra employed in this research, illustrated in Figure 10 (IS 1893:2016) and Figure 11 (NBC 105:2020), were created based on site-specific factors, including seismic zone factor (Z), soil classification, and importance factor. Initially, the structural model in ETABS underwent modal analysis to ascertain natural periods and mode shapes, followed by applying the corresponding code-based response spectra to calculate peak accelerations for each mode. The spectra vary due to NBC's elevated zone factor and more stringent spectral shape tailored to Nepal's Himalayan seismic conditions in comparison to IS, leading to higher seismic demands for designs that comply with NBC. Modal responses were aggregated using the CQC method to represent dynamic interactions effectively, especially for irregular models demonstrating torsional impacts. The analysis output offered vital insights into story shear, displacement, and drift, underscoring the heightened susceptibility of irregular structures resulting from asymmetry, as well as the conservative stance of NBC 105:2020 compared to IS 1893:2016 regarding seismic force estimation.

3. Results and Discussion

3.1. Fundamental Time Period

The fundamental time period, as a critical seismic design parameter, represents the duration required for a structure to complete one full cycle of vibration in its primary mode (Bohara, 2021; Ganaie et al., 2021). It is calculated to characterize the dynamic response of buildings and to ensure structures can safely dissipate seismic energy through controlled oscillation. The results demonstrate that NBC 105:2020's stiffer design assumptions yield shorter fundamental time periods (avg. 40% shorter than IS 1893:2016), increasing seismic force demands in NBC-based models (Bohara et al., 2022). While both codes underestimate finite element-derived periods, IS 1893:2016 exhibits larger errors (91.7% vs. NBC's 0.4% for 3-storey RM), suggesting its empirical formula is less reliable for irregular structures. Irregularity reduced periods in low-rises (−5.0% for IS 3-storey) but increased them in high-rises (+9.5% for NBC 12-storey), confirming that torsional flexibility dominates in taller buildings, as shown in Figure 3.

3.2. Torsional Irregularity

It is commonly assessed using the torsional irregularity ratio (TIR) the ratio of maximum peripheral inter-story drift (including accidental eccentricity) to the average drift at the same level. In the 12-storey IRM6 configuration, NBC produced a maximum TIR of 1.250 compared to 1.160 under IS reflecting a 7.8% increase and greater sensitivity to plan asymmetry (Bohara, Kunwar, et al., 2025). Both codes exceeded the critical threshold (TIR > 1.2) in highly irregular models, suggesting elevated torsional vulnerability. Regular models (RM) demonstrated uniformly lower TIR values (≤ 1.106) (see Figure 4) in both codes, confirming that plan symmetry effectively reduces torsional amplification. IS-based irregular models exhibited comparatively lower TIR values than NBC, indicating potential underestimation of torsional demands, which could compromise seismic performance in asymmetric configurations (Bohara, Kunwar, et al., 2025). These results highlight that while NBC's stricter torsional provisions may lead to stiffer and more costly designs, they provide better control over rotational response critical for the seismic safety of irregular buildings (Herrera & Soberón, 2008; Jereen et al., 2017).

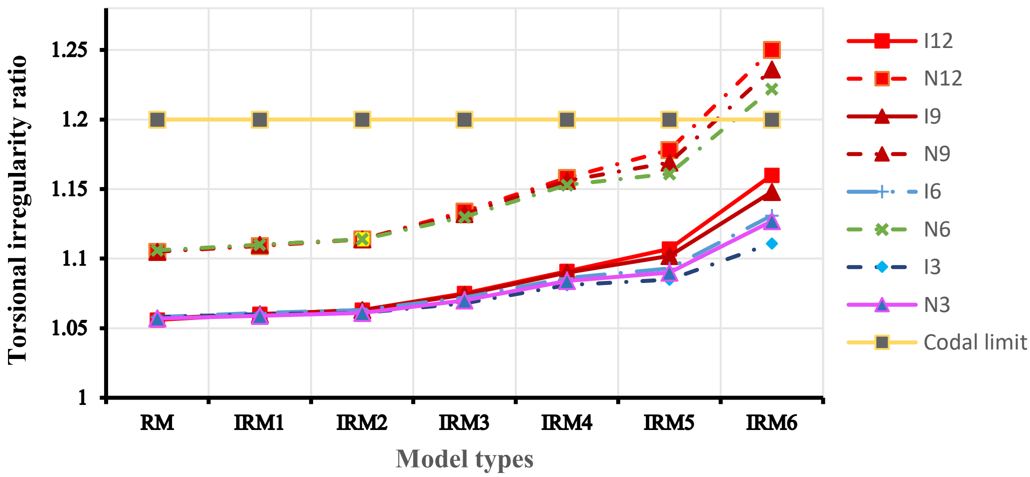

Figure 3: Maximum torsional irregularity ratio

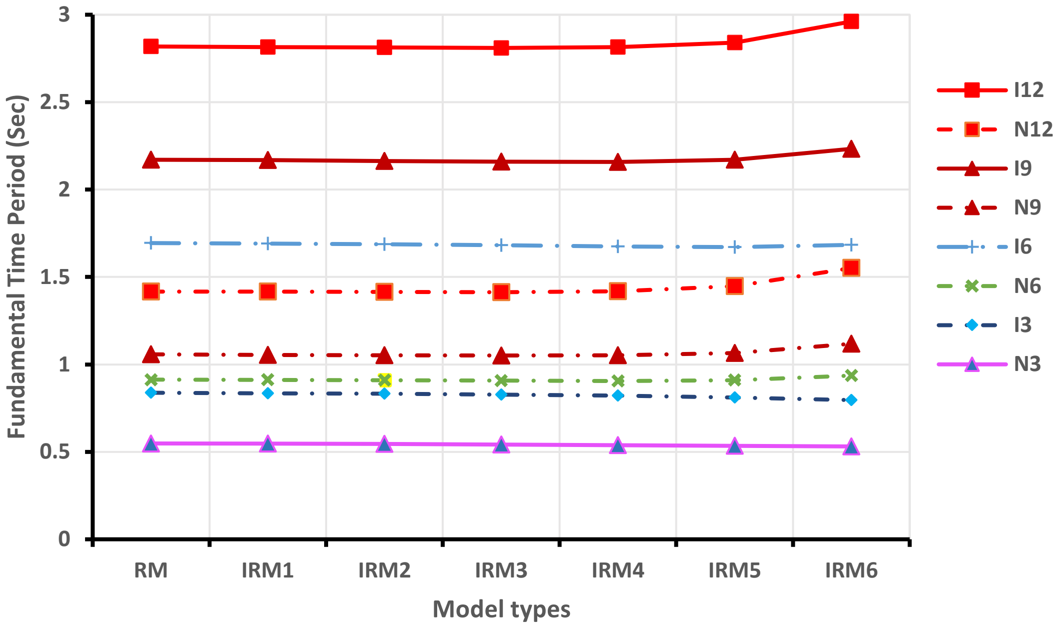

Figure 4: Fundamental Time period

3.3. Storey Shear

Story shear refers to the total lateral force acting on a building at a particular story level due to seismic excitation. It is a key parameter for understanding how lateral forces are distributed along the building height. Typically, larger story shear values are observed at lower stories due to the accumulation of forces from upper levels. Analyzing this distribution helps assess the structure's lateral load-resisting capacity and seismic design adequacy. The analysis shows that models designed using NBC 105:2020 produce higher story shear than those designed with IS 1893-1:2016. The average shear ratio (NBC/IS) is 3.74 for 3-story, 5.22 for 6-story, 5.56 for 9-story, and 4.58 for 12-story buildings, as shown in Figure 5. The largest difference is seen in the 9-story model, with a peak ratio of 6.73, showing that mid-rise buildings are more affected by the stricter seismic rules in NBC. This is due to NBC's higher design base shear requirements based on regional seismic hazards. Even the 6-story model shows a significant increase (5.22 times), proving that NBC leads to much higher seismic forces even in shorter mid-rise buildings (Bohara, Jagari, et al., 2025; Bohara & Saha, 2022). Moreover, regular models (RM) consistently exhibited higher story shear than irregular models (IRM1–IRM6). This trend indicates that structural irregularity lowers the efficiency of shear distribution, making irregular structures more vulnerable to seismic effects due to discontinuities in stiffness and load paths.

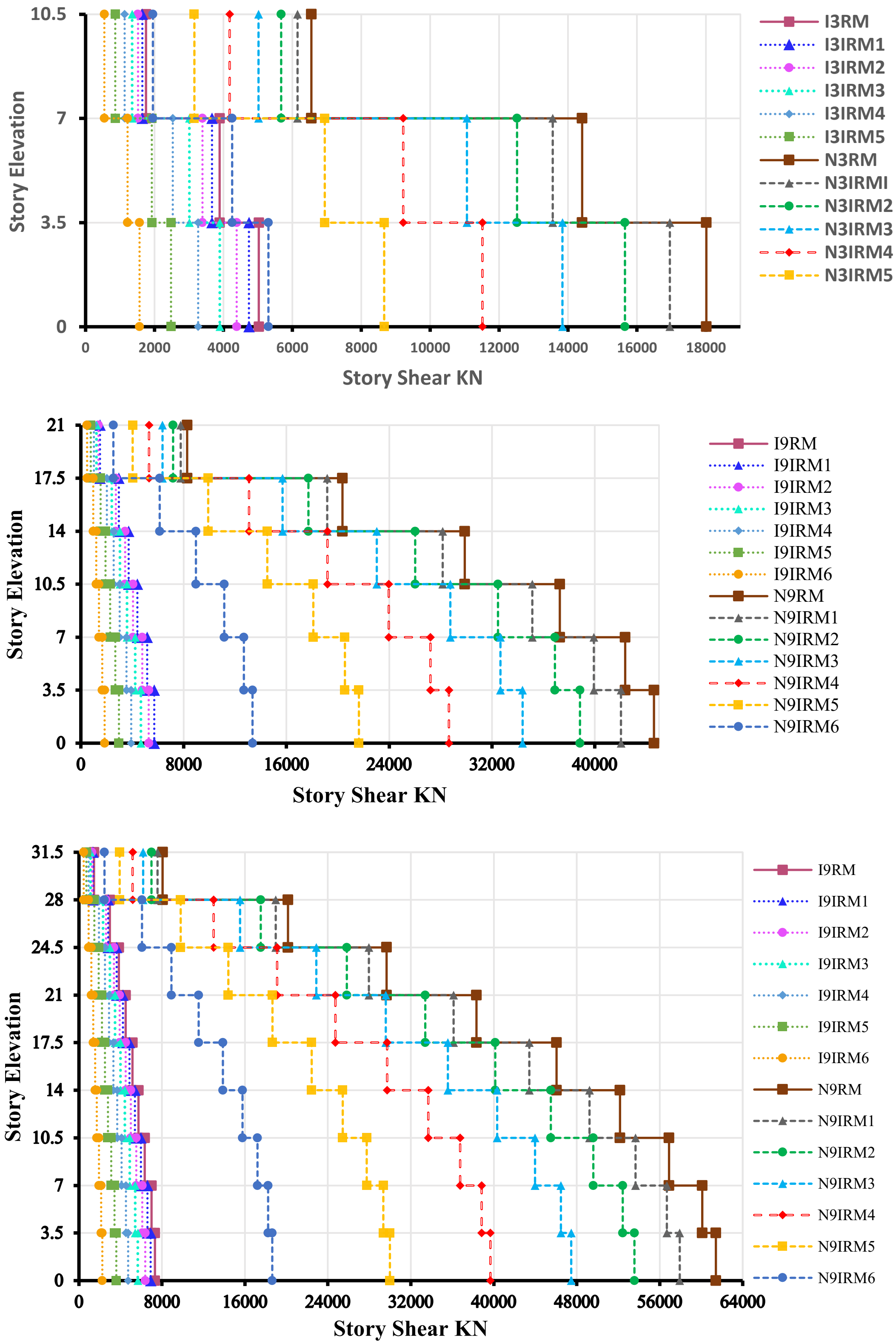

Figure 5a: Story Shear

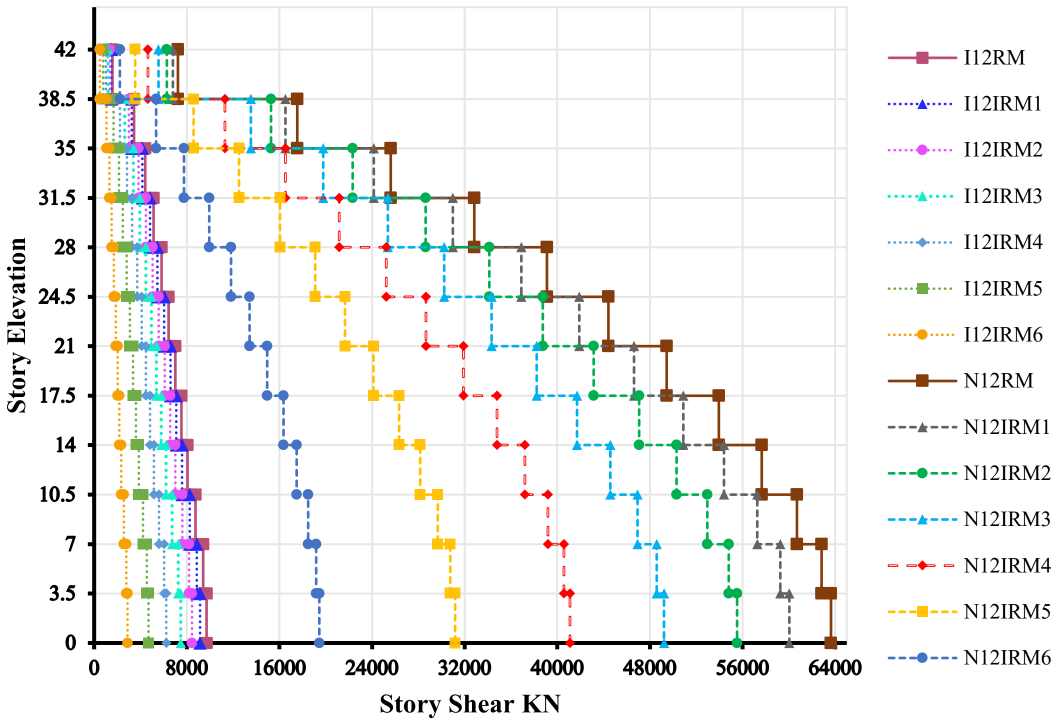

Figure 5b: Story Shear

3.4 Base Shear

Base shear, as the seismic design parameter, stands for the total lateral force at the base of a structure resulting from ground motion in an earthquake. It is calculated to determine the seismic forces that the structure must withstand and to guarantee that structures are stable and safe when subjected to seismic loads. Thus, base shear calculation is an essential phase in the design and analysis of the seismic resistance of a building (Birendra Kumar Bohara, 2021). The comparative base shear ratios (NBC/IS) between buildings designed using the NBC and the IS tend to increase for low-rise and mid-rise buildings (the observed average base shear ratios(NBC/IS) were: 3.6 for 3-story, 7.5 for 6-story and 8.7 for 9-story) (see Figure 6), indicating higher shear demand in NBC-designed buildings in comparison to that of IS-designed buildings up to 9-story buildings. With a further increase in the number of stories beyond 9 stories, i.e., high-rise buildings, the base shear ratio (NBC/IS) begins to decrease (the average base shear ratio NBC/IS being 6.8 for 12-story buildings). This trend indicates that as building height increases, particularly in high-rise buildings, the difference in base shear demand between the two codes reduces, and both begin to converge toward similar base shear values.

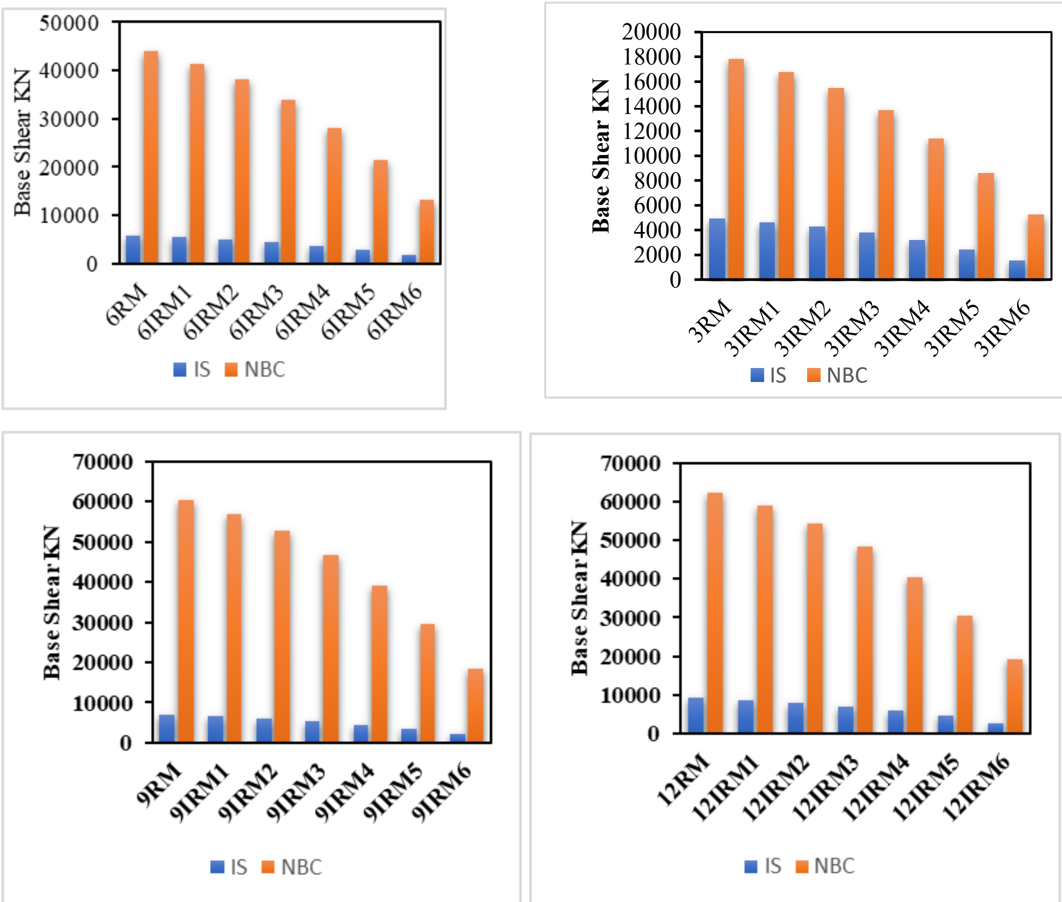

Figure 6: Base Shear

3.5 Story Displacement

Story displacement is the measure of the lateral movement of a story with respect to the base of the building due to lateral loads like an earthquake. It reflects the overall sway profile of the building structure. Large story displacement indicates more flexibility of the structure, whereas smaller displacement indicates greater stiffness of the structure. Thus, plotting the story displacement of a building structure gives an idea about the structural behavior of the building during the earthquake. The graphical representation of the story displacement for various story models under RSAx (Response Spectrum Analysis X) can be seen in the figure above, which illustrates that with an increase in height of the structure, story displacement also increases (Bohara et al., 2021). The buildings designed using NBC codes exhibited greater displacement values than those designed using IS codes, which is consistent with results reported in. For low-rise and mid-rise buildings (3-story, 6-story and 9-story), the variation of story displacement between the NBC-designed buildings and IS-designed buildings increases, and for high-rise buildings, i.e., 12-story buildings, the variation tends to decrease, suggesting that seismic design provisions in NBC and IS codes become increasingly aligned for high-rise buildings (See Figure 7). Among the analyzed models, the regular models exhibited lower story displacement than irregular structural models, indicating improved stiffness distribution and more efficient seismic force resistance due to uniform geometry and mass distribution, which is consistent with the results drawn in existing literature. The story displacement increases progressively from model RM to IRM6, with a minimum value observed in RM models and a maximum value in IRM6 in the all different story buildings designed using IS and NBC codes, indicating that the irregular buildings are more susceptible to seismic damage than regular buildings.

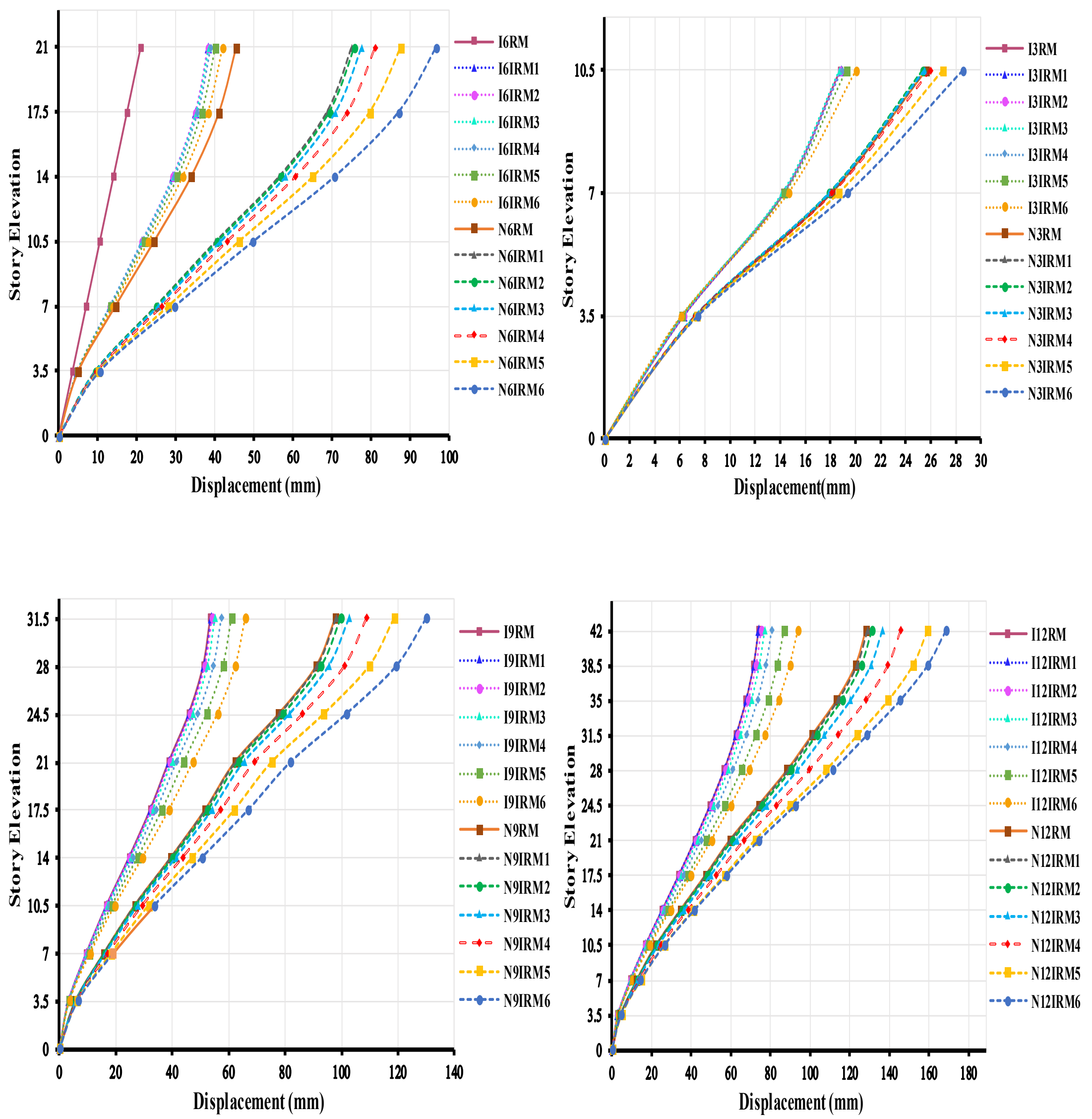

Figure 7: Story Displacement

3.6 Story Drift

Inter-story drift (ISD) ratio, also known as story drift ratio, is the ratio of the relative displacement between two adjacent stories to the story height. IS 1893:2016 and NBC 105:2020 impose limits on inter-story drift ratios to ensure structural safety and serviceability. The inter-story drift ratio limit specified by Clause 7.11.1.1, IS 1893:2016, is 0.004(0.4%) while Clause 5.6.3, NBC 105:2020, allows up to 0.025(2.5%) for Ultimate limit state (ULS) and 0.006(0.6%) for Serviceability limit state (SLS) as shown in Figure 8. These limits control lateral deformation to ensure structural and non-structural safety in seismic design. The graphical representation of the inter-story drift ratio indicates that the NBC-compliant buildings exhibited higher inter-story drift ratio values than IS Code-compliant buildings, which is consistent with. The inter-story drift ratios of IS Code-compliant buildings remained within the permissible limits of the IS Code, while NBC-designed buildings satisfied the drift criteria defined by the NBC code in all models for all the different story buildings.

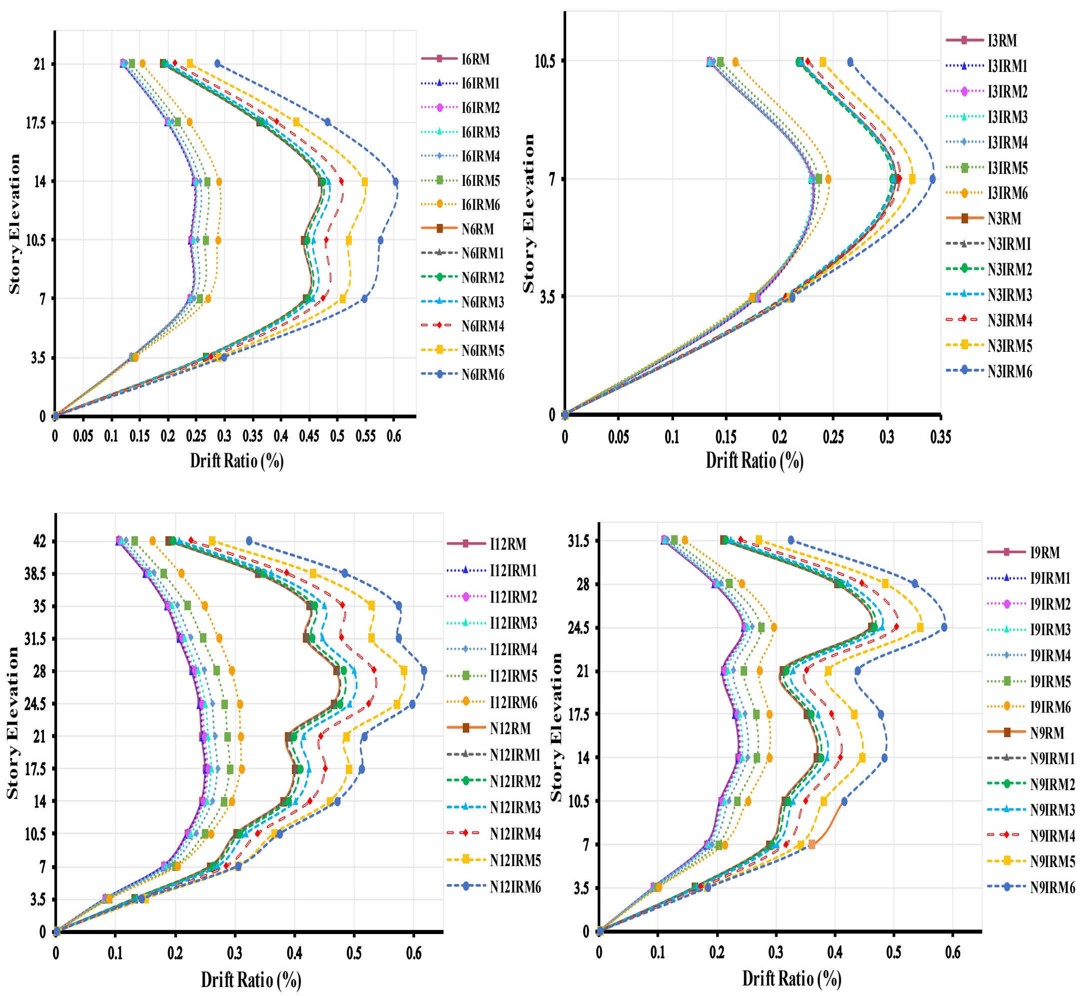

Figure 8: Drift Ratio

4. Conclusion

From the response spectrum analysis it was found that, the values of the story displacement, torsional irregularity ratio and drift ratio, increased with increase in planar irregularity (i.e I6RM to I6IRM6 and N6RM to N6IRM6). But values of the time period, base shear, story stiffness and story shear, decreased with increase in planar irregularity. This indicates that the irregular models have higher seismic vulnerability as compared to regular models, which was due to increase in torsion and discontinuous load path in irregular models, demanding careful dynamic analysis and additional strengthening measures. However the overall comparison between NBC and IS models showed the higher values for the NBC models than IS models that might be due to difference in codal provisions, response reduction factor, seismic zone coefficient, soil type and importance factor. This indicates the conservative design of structure using NBC than IS code. From the study, irregular models were found to be more seismically vulnerable than irregular models. So, irregularity in structure should be avoided as afar as possible. Otherwise, more careful analysis of irregular models should be performed as well as sufficient strengthening measures should be adopted.

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