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A COMPARATIVE STUDY OF MIDDLE RISE APARTMENT BUILDING WITH DIFFERENT SEISMIC CODES

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Abstract

This study presents a seismic analysis of a reinforced concrete (RCC) apartment building, evaluated against various seismic codes to ensure structural safety in earthquake-prone regions. The analysis employs a finite element approach and considers different seismic parameters, including torsion, drift, displacement, and base shear. The building was modelled in ETABS, maintaining consistent horizontal and vertical configurations. Seismic analysis was conducted using the Linear Equivalent Static Method and the Linear Dynamic Response Spectrum Method. The Nepal National Building Code (NBC) - 105:1994 and 105:2020, as well as Indian Standards (IS) - 1893:2002 and 1893:2016, were utilized for designing the building structure. As compared to IS codes, NBC 105:2020 codes give higher results in base shear by 43.48%, considering the ULS method and by 37.66%, considering the SLS method for the same building used in the analysis. Nepalese code considers higher accidental eccentricity (10%) than Indian code (5%), which can result in higher torsional forces in NBC 105 designs.

Keywords: Response Spectrum, Drift, Tectonic Plate, Seismic Codes, Base Shear

1. Introduction

Earthquakes are defined as a vibration of the earth's surface that occurs after a release of energy in the earth's crust. Most earthquakes are small but are not readily felt. More significant and violent earthquakes occur in a release of energy as the plates slide past or collide with one another (Patriat and Achache, 1984). In seismically active areas, earthquakes are the main threat to civil infrastructure development. Nepal is located in a seismically active region due to its location in the subduction of the Indian plate under the Eurasian plate with an approximate subduction rate of 25-40 cm/year. Such an area is prone to weak to moderate ground shaking, causing the failure of major Civil Infrastructures like buildings, bridges, towers, roads, etc. Here, in Nepal, the damage was largely seen in residential structures in rural, mountainous areas, with over 96% of them being load-bearing structures (Adhikari and D'Ayala, 2020; Malla *et al.,* 2024).

The behaviour of a structure during an earthquake depends on the distribution of stiffness, mass, plan, strength and many other irregularities in both the vertical and horizontal direction of the structure (Ghimire and Chaulagain, 2024). Buildings with simple geometry, uniformly distributed mass, and stiffness in plan and elevation are less vulnerable compared to structures with irregular configurations (Kostinakis and Athanatopoulou, 2020). The G+5 story with consistent configuration is modelled in ETABS version 19.2. Beams and columns in moment frames are proportioned and detailed in such a manner that they must resist flexural, axial, and shearing actions that result in a building sway through multiple displacement cycles during strong earthquake ground shaking (Landingin *et al.,* 2013; Dhanvijay *et al.,* 2015; Hampshire *et al.,* 2018; Patil *et al.,* 2021).

The Nepal National Building Code (NBC) was established following the devastating earthquake in 1988, revealing significant weaknesses in Nepal's construction practices. It was officially implemented in 1994, with the primary goal of improving building safety, particularly regarding seismic resistance. The codes are periodically revised to incorporate advancements in engineering practices and lessons learned from past disasters, including the 2015 Gorkha earthquake, with the most recent update occurring in 2020. Similarly, IS 1893 is a foundational code in Indian earthquake engineering, providing guidelines for designing structures to withstand seismic forces. Since its first publication in 1962, it has been revised several times, with significant updates in 1984, 2002, and the latest in 2016, reflecting advancements in understanding earthquake dynamics and structural behaviour (IS 1893 Part 1: 2002; IS 1893 Part 1: 2020).

Story drift

It is the relative displacement between the floors above or below the storey under consideration (Adhikari and Poudel, 2023). These limits vary depending on the building's occupancy and function. Residential buildings typically have stricter limits. In contrast, Industrial structures may allow more flexibility. The story drift will be controlled through different mediums like shear walls, braced frames, or moment-resisting frames or incorporating Damping Systems like base isolators or tuned mass dampers, ensuring symmetry in mass and stiffness to reduce torsional effects. Understanding and controlling story drift is fundamental for ensuring structures' safety, functionality, and resilience in dynamic conditions.

Displacement

Displacement refers to moving a point or a structure from its original position due to applied forces, such as loads, thermal effects, or seismic activity. Determination of the story displacement is an important indicator of the building's ability to withstand seismic forces. It provides important information for the design of lateral load-resisting elements as well as the overall lateral stability of the building (Sapkota *et al.,* 2013).

Torsion

Torsion is generally the twisting or rotation effect produced by the forces that cause the unequal movement of the floor within the same level. The major source of torsion is eccentricity, and initial attempts should be made to minimize the eccentricity in the building. Eccentricity in the building can be minimized by Maintaining symmetry in buildings, avoiding changes in the direction of forces within a frame, not allowing the intersection of the cantilever section, and designing the structural members to withstand torsional forces/moments as per standard codes. (Ghimire and Chaulagain, 2021).

Nepal and India are in active seismic zones, where earthquakes pose significant risks to life and property. Comparing these two codes is crucial to ensure that structures in both countries are designed to withstand seismic forces effectively. Both nations have experienced devastating earthquakes, such as the Gorkha Earthquake in 2015 and the Bhuj Earthquake in 2001. By examining each code, both countries can adopt best practices and learn from each other's seismic experiences. Understanding the differences and strengths of each code can help enhance their seismic regulations, aligning them with global best practices while addressing local needs (Suliman and Lu, 2024; M. Afifi and R. Ahmed).

The aim of comparing Nepal's national building seismic codes and India's seismic codes (IS 1893) is to evaluate their similarities, differences, and overall effectiveness. The primary objective is to analyze the underlying design principles, including load assumptions, response spectrum analysis, ductility requirements, and base shear calculations. Additionally, the comparison will assess the seismic zoning maps, zone factors (Z), and ground motion parameters, such as soil types and response spectra used in both codes.
This study does have limitations; specifically, it does not create an infill model, but it does consider the weight of the wall in the analysis. The study emphasizes the importance of the evolution of seismic codes in earthquake-prone regions, yet it only compares the latest two revised editions of Indian and Nepalese codes. Furthermore, only one model is used to achieve the study's objectives.

Nepal Building Code (NBC) - 105:1994 and 105:2020, along with Indian Standard (IS) - 1893:2002 and 1893:2016, are utilized for designing building structures, while seismic parameters will be assessed based on these standards.
According to NBC 105:2020 Load Combinations for Parallel Systems are:

$1.2DL + 1.5LL$ (1)

$DL + \lambda LL \pm E$ Where, $\lambda = 0.6$ for storage facilities= 0.3 for other usage (2)

Also, from NBC 105:2020 Load Combinations for Non- Parallel Systems are:

$1.2DL + 1.5LL$ (3)

$DL + \lambda LL + (Ex \pm 0.3Ey)$

$DL + \lambda LL + (0.3Ex \pm Ey)$ (4)

Where, $\lambda = 0.6$ for storage facilities = 0.3 for other usage

As per IS 1893: 2016 the structure should be designed for the given load combinations

$\pm EL_X \pm 0.3\ EL_Y\}]$ and (5)

$\pm 0.3EL_X \pm EL_Y\}]$ (6)

where X and Y are two orthogonal horizontal plan directions. Thus, EL in the load combinations given above shall be replaced by ($EL_X \pm 0.3\ EL_Y$) or ($EL_Y \pm 0.3\ EL_X$). Hence, the sets of load combinations to be considered shall be as given below:

$1.2[DL+IL\pm[\{\ EL_X \pm 0.3\ EL_Y\}]$ and (7)

$1.2[DL+IL\pm[\{\ EL_Y \pm 0.3\ EL_X\}]$; (8)

$1.5[DL\pm[\{\ EL_X \pm 0.3\ EL_Y\}]$ and (9)

$1.5[DL\pm[\{\ EL_Y \pm 0.3\ EL_X\}]$; (10)

$0.9[DL\pm 1.5[\{EL_X \pm 0.3\ EL_Y\}]$ and (11)

$0.9[DL\pm 1.5[\{EL_Y \pm 0.3\ EL_X\}]$ (12)

2. Materials and Methodology

2.1 Building configuration

The model used for comparison is the same for all seismic codes, and the salient features of the building are described below in tabular form.

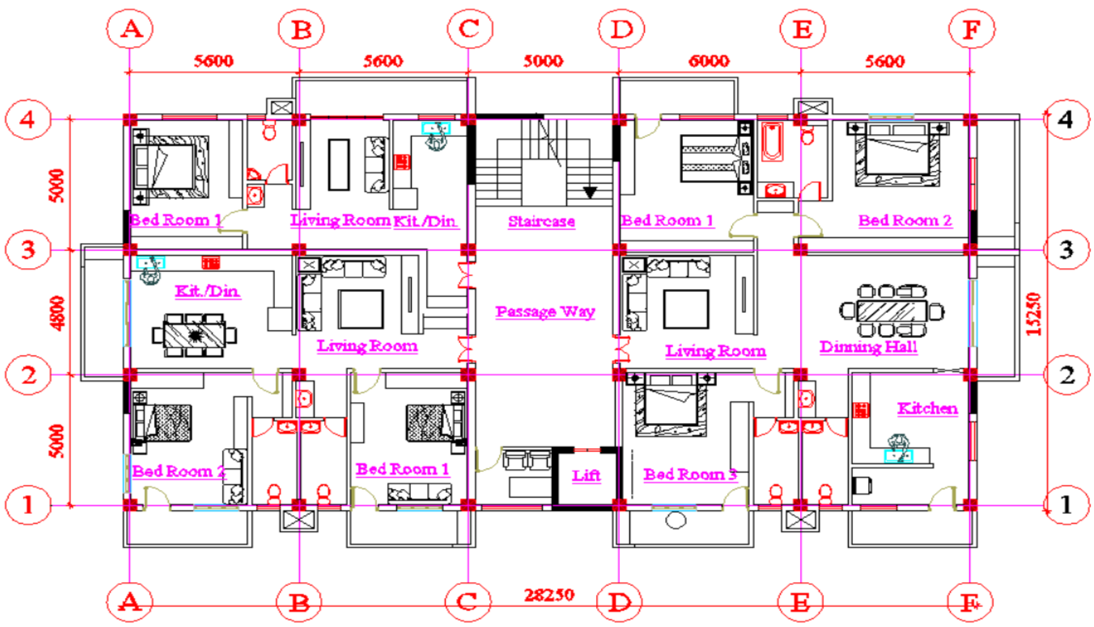


Figure 1: Architectural Drawing of Ground Floor.

Table 1: Description of Building (NBC 206:2015, Architectural Design Requirements).

Parameters	**Details**
Types of Building	Apartment Building
Category of Building	Mid-Rise Building
Structural System	RCC Frame Structures; SMRF
Number of Story	6 (G + 5 + Staircase Cover)
No. of Bays in X Direction	5 nos. of Bays
No. of Bays in Y Direction	3 nos. of Bays
Plint Area	430.8125 Sq m
Floor Height	3.05 m
Size of Building	Length = 28500 mm, Breadth = 15250 mm
Grade of Concrete	M25 for Beam, Column and Slab
Grade of Steel	Fe 500
Type of Slab	Two - way Slab
Type of Beam	Rectangular main Beam
Type of Column	Rectangular Column
Type of Foundation	Mat Foundation
Type of Stair-case	3^{rd} Quarter Landing Type
Method of Analysis	Static and Dynamic

2.2 Material

Table 2: Parameters used for the design of models (IS 456:2000, Indian Standard Code of Practice for Plain and Reinforced Cement Concrete).

Description	Section/Constant	Units
Parameters	Data	Unit
Column size	500X500	mm X mm
Main Beam size	300X500	mm X mm
Secondary Beam size	250X400	mm X mm
Slab thickness	125	Mm
Shear wall	200	Mm
Specific weight of concrete	25	KN/m^3
Unit weight of Brick	19.2	KN/m^3
Modulus of elasticity of concrete	25000	MPa

2.3 Modelling of Buildings

Modelling is done using ETABS 2000 Vs. 19.1, using the finite element model of a building. Modelling is done as per the architectural drawing, and the changes are made later as per the structural requirements. Special attention is given while modelling the building in ETABS as a very small and unnecessary section may cause the failure of the whole structure which is undesirable.

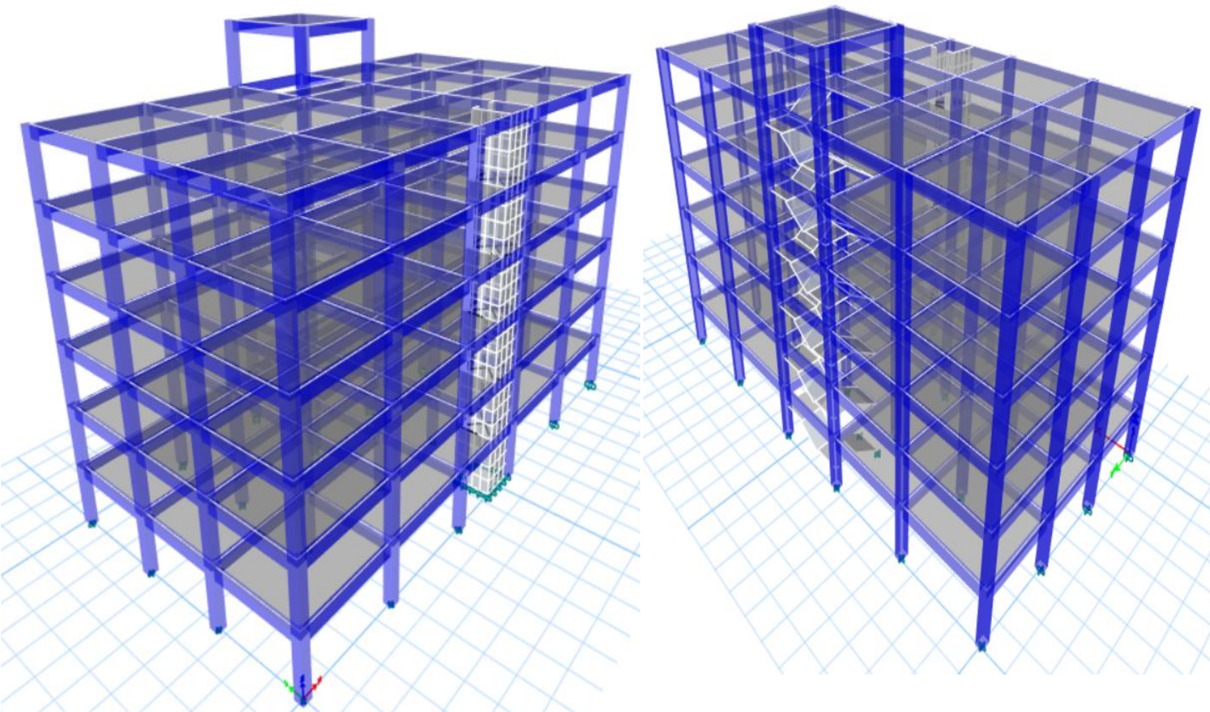


Figure 2: Different sides Extrude view of building from ETABS.

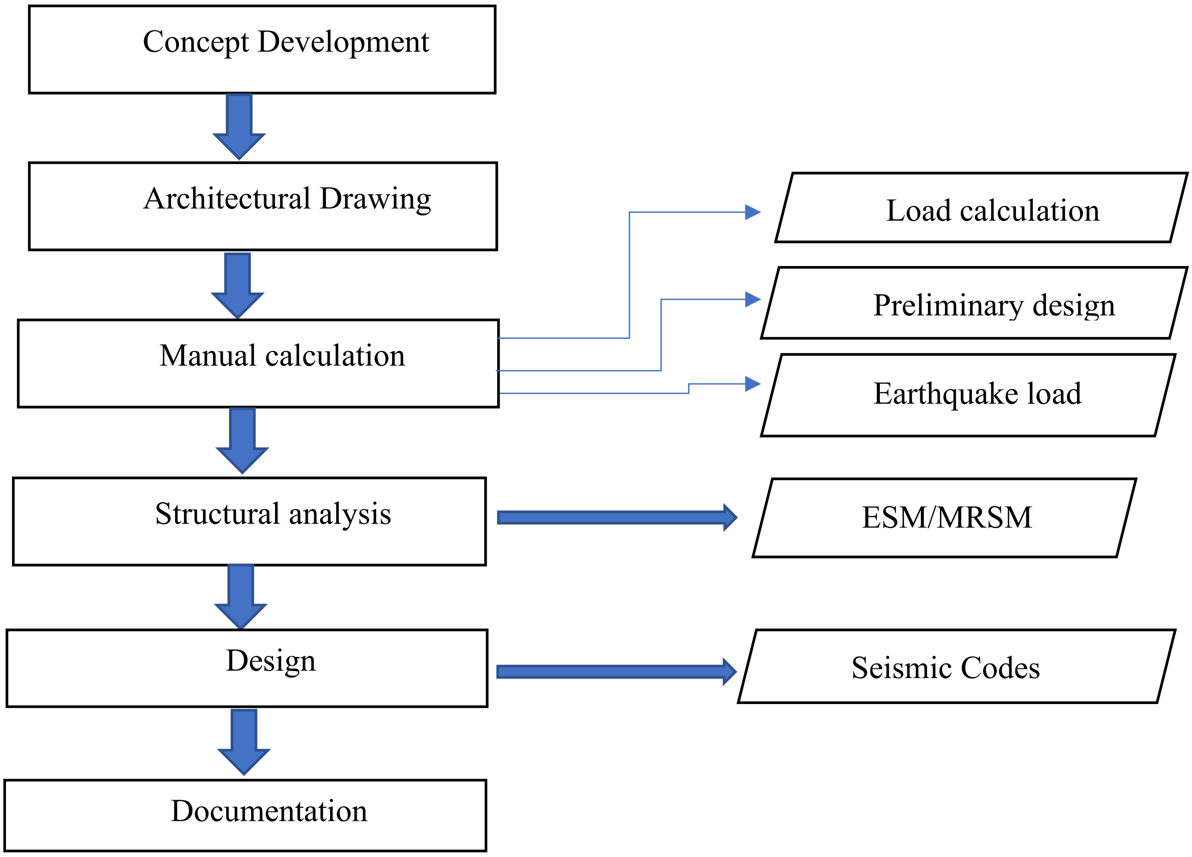


Figure 3: Methodology flowchart.

2.4 Seismic coefficient calculation:

The base shear is the total horizontal seismic force that acts at the base of a structure during an earthquake. According to IS 1893:2016 (Part 1), the base shear coefficient is determined based on various factors such as the seismic zone, importance of the structure, and the structural system's response.

The base shear is calculated using the formula:

$$V_B = Ah.W \tag{13}$$

where, V_B = Total base shear (in KN)

Ah = Horizontal seismic coefficient

W= Seismic weight of the structure (in KN)

$$Ah = \frac{Z.I.Sa}{2.R.g} \tag{14}$$

Z = Zone Factor

I = Importance Factor

R = Response Reduction Factor

Sa/g = Average Response Acceleration

g = Acceleration due to gravity

From NBC 105:2020, The base shear coefficient will be determined separately for ultimate limit state and serviceability limit state from the figure 4.

Cd(T1) = (C(T1))/((Rμ)(Ωu)) (15)

Cd(T1) = (Cs(T1))/Ωs (16)

Where, Cd(T1) = Elastic Site Spectra for Ultimate Limit State

Cs (T1)) = Elastic Site Spectra for Serviceability Limit State

Rμ= Ductility Factor

Ωu = Over strength Factor for Ultimate Limit State

Ωs = Over strength Factor for Serviceability Limit State

The horizontal seismic base shear at the base of the structure in the direction is calculated as:

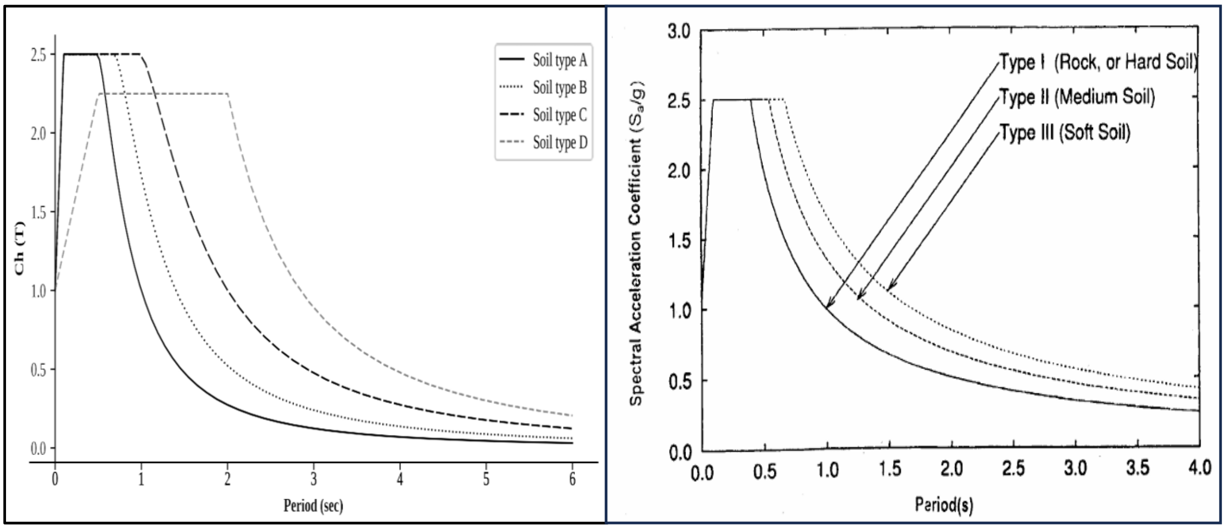
V =Cd(T1).W (17)

Where, Cd(T1) = Horizontal base shear coefficient

The Elastic site spectra for horizontal loading shall be as given by

C (T) =Ch(T) Z I (18)

where, Ch(T) = Spectral Shape factor



(a) (b)

Figure 4: (a) Spectral Shape Factor, Ch(T) for Modal Response Spectrum Method (NBC 105:2020), (b) Response Spectra for MRSM (IS 1893:2016)

The Vertical Distribution of Seismic Forces induced at each level 'i' shall be calculated as:

$$F_i = \frac{W_i h_i^k}{\sum_i^n W_i h_i^k} \times V$$

where Wi = seismic weight of the structure assigned to level 'i';

hi= height (m) from the base to level 'i';

n= total number of floors/levels

V= horizontal seismic base shear calculated as per 6.2

k= an exponent related to the structural period

The horizontal design spectrum for the modal response spectrum method is also different for ultimate limit state and for serviceability limit state. A separate section on structural irregularity has been added. This code includes checking the inter-story drift for both ultimate limit state and serviceability limit state as 0.025 and 0.006. Response spectrum method is performed as the combination of modal effects (such as story shear, moment, drift, displacements (Gwaccha, *et al.,* 2015; Banjara *et al.,* 2015).

Table 3: According to IS 875 (Part 1): 1987, Indian Standard Code of Practice for Design Loads.

Parameters	**Dead Load**	**Units**
Full Brick thick External wall Without Opening	13.46	KN/m
Full Brick thick External wall 25% Opening	10.10	KN/m
Half brick thick External wall Without Opening	8.95	KN/m
Half brick thick External wall With Opening	6.72	KN/m
Full brick, 1.2 m high parapet wall	6.18	KN/m
Dead load of Floor finish for Roof	0.75	KN/m^2
Dead load of Floor finish with Granite	1.55	KN/m^2
Dead load of Floor finish with Tile	1.35	KN/m^2

Table 4: As per IS 875 (Part 2): 1987, Indian Standard Code of Practice for Design Loads.

Parameters	**Dead Load**	**Units**
Balcony, staircase, lobby	4	KN/m^2
Kitchen, conference hall	3	KN/m^2
Office room with separate storage	2.5	KN/m^2
Toilet, bathroom	2	KN/m^2
Roof accessible	1.5	KN/m^2
Roof not accessible	0.75	KN/m^2

3. Results and Discussion

A study is performed in apartment RC Building through different edition of National Building Code (NBC) from Nepal, and Indian Standard Code (IS) from India i.e. previously existing and revised standards with consideration of several design compliances. NBC 105:1994 was revised to NBC 105:2020 and also IS 1893:2002 to IS 1893:2016 which are used in current analysis. The Results are interpreted in terms of base shear, displacement, torsion, drift, lateral forces.

The seismic weight of the building under investigation is 34353.03 KN, 36281.08 KN, 36281.08 KN 34353.03 KN and 34353.03 KN derived from NBC105:1994 and NBC105:2020 (SLS), NBC 105:2020 (ULS), IS 1893:2002, IS 1893:2016 respectively. The value is same for IS 1893:2016, IS 1893:2002 and NBC 105:1994 because there is the provision to take the live load reduction factor of 0.25 (for LL<3KN/m^2) and 0.5 (for LL>3KN/m^2). Also, the value is identical for NBC 105:2000 (ULS) and NBC 105:2000 (SLS) because LL reduction factor is taken as 0.3 (for LL<3KN/m^2) and 0.6 (for LL>3KN/m^2).

Obviously, it is sure from the former case that its value shall be less than the latter case. And hence, the obtained values of seismic weight also justify the condition. Base shear identified from the analysis is shown in figure 5 along X direction and in figure 6 along Y direction. Based on the analysis, NBC 105:2020 (ULS) demonstrates higher spectral acceleration values for Type B - Medium Soil Sites compared to other investigated codes, resulting in a 45.75% increase in base shear compared to NBC 105:1994, indicating varying seismic loading criteria between revisions.

Base Shear comparison bar chart is illustrated:

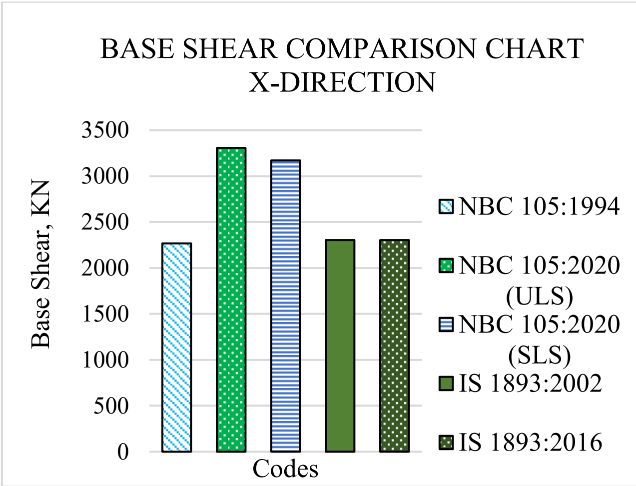


Table 5: Base Shear along X- Direction due to ESM/MRSM

Codes	Value
NBC 105:1994	2261 KN
NBC105:2020 (ULS)	3298 KN
NBC105:2020 (SLS)	3171 KN
IS 1893:2002	2297 KN
IS 1893:2016	2303 KN

Figure 5: Base Shear in EQX Direction from ESM/RSM.

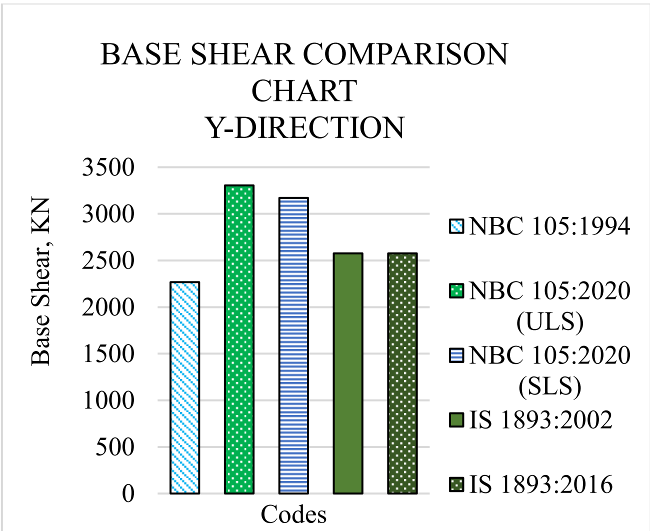


Table 6: Base Shear along Y- Direction due to ESM/MRSM

Codes	Value
NBC 105:1994	2267 KN
NBC 105:2020 (ULS)	3305 KN
NBC 105:2020 (SLS)	3185 KN
IS 1893:2002	2568 KN
IS 1893:2016	2576 KN

Figure 6: Base Shear in EQY Direction from ESM/RSM.

The Base shear in revised codes is increased by 45.75% of NBC codes and remains almost equal in IS codes. As compared to IS codes, NBC 105:2020 codes give more Base shear by 43.48%, considering the ULS method and by 37.66%, considering the SLS method for the same building used in the analysis.

The story Drift ratio is presented in the line graph:
The inter-story drift should be within the limit of different codes, as in Table 7.

Table 7: Comparing Elastic drift limits from different codes

Codes	Inter story drift limit	Clause no.
NBC 105:2020 (ULS)	0.024 = 2.4%	5.6.3
NBC 105:2020 (SLS)	0.006 = 0.6%	5.6.3
NBC 105:1994	0.010 = 1%	9.3, 12.6.2
IS 1893:2016	0.004 = 0.4%	7.11.1.1
IS 1893:2002	0.004 = 0.4%	7.11.1

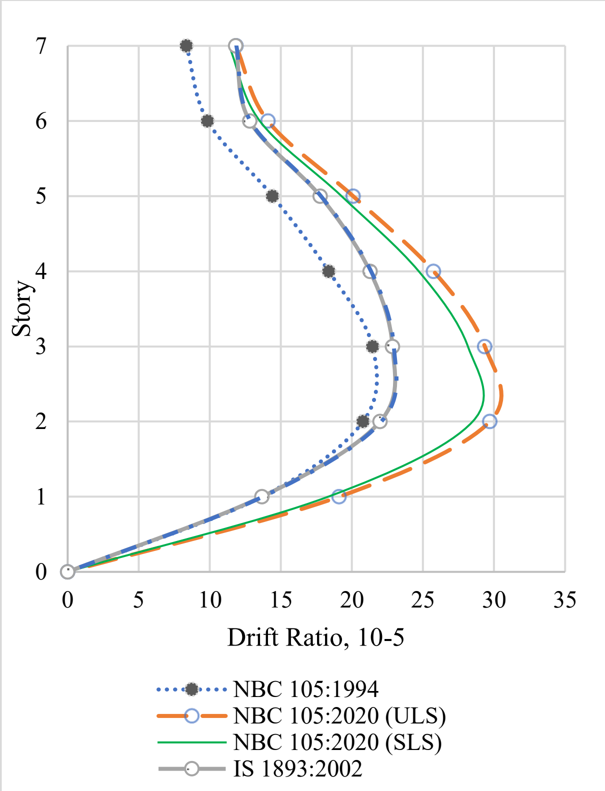


Figure 7: Inter Story Drift in X- Direction from ESM

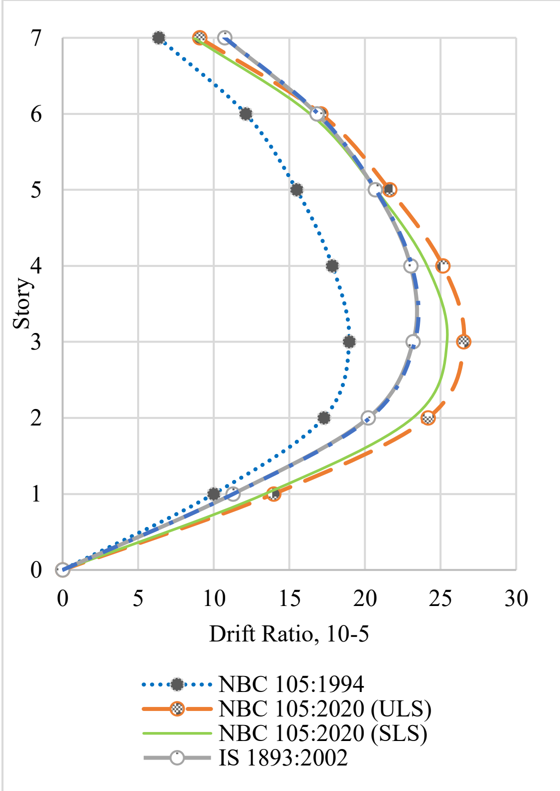


Figure 8: Inter Story Drift in Y- Direction from ESM

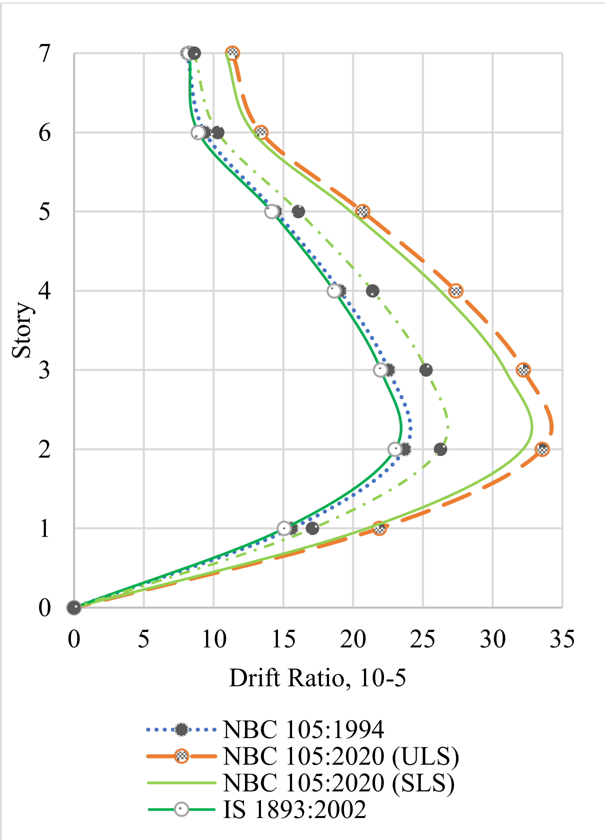


Figure 9: Inter Story Drift in X- Direction from MRSM

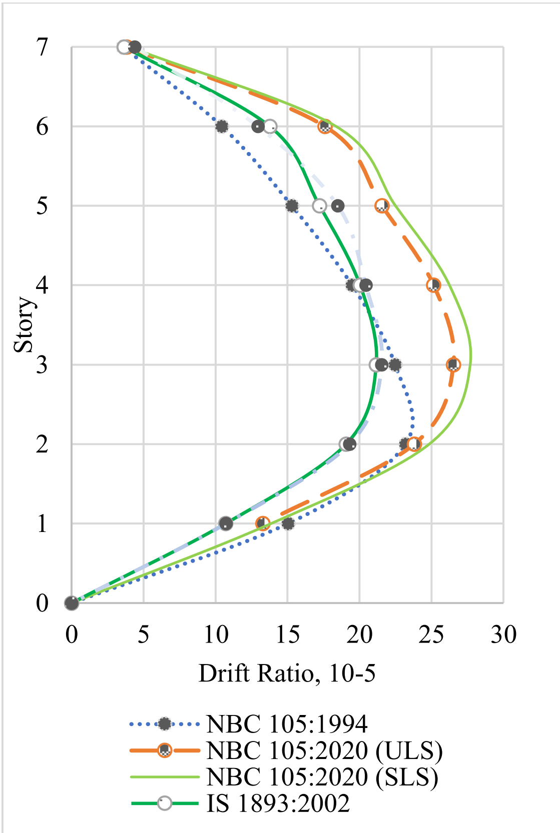


Figure 10: Inter Story Drift in Y- Direction from MRSM

The allowable value of the drift ratio is shown in table 2. The ISD ratio value calculated by analyzing this model is found within the value described in table 2. Figures 7,8,9 and 10 show the ISD ratio in the X and Y-direction using the ESM and MRSM, respectively.

The ISD ratio calculated by using NBC 105:2020 (ULS) gives the largest value. However, in Y-direction using MRSM, NBC 105:2020 (SLS) gives the maximum value. Both the IS codes give almost the exact value of the ISD ratio. NBC 105:1994 give the smallest value of the ISD ratio using ESM in both X and Y directions. However, using the MRSM, IS 1893:2002 gave the smallest value.

Displacement is demonstrated in line graph:

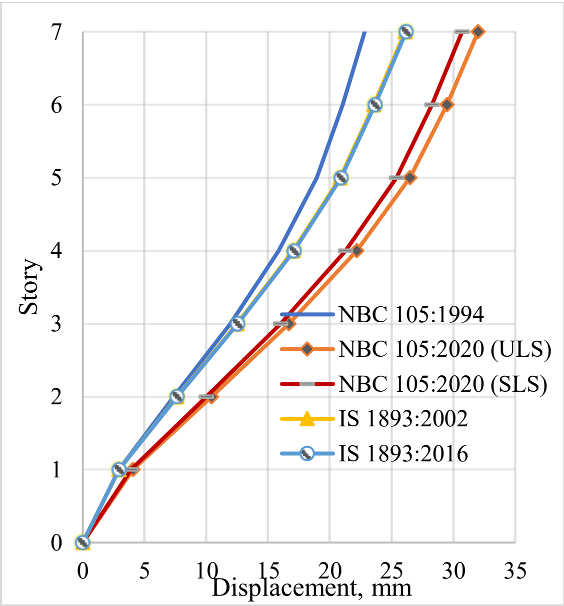


Figure 11: Displacement in X-Direction from ESM

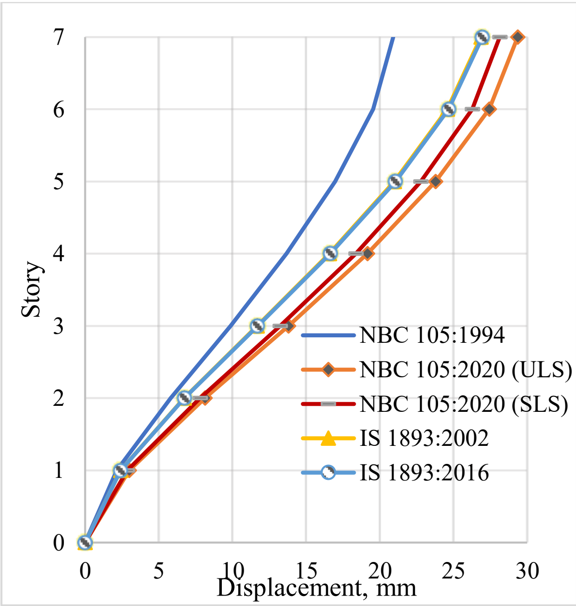


Figure 12: Displacement in Y-Direction from ESM

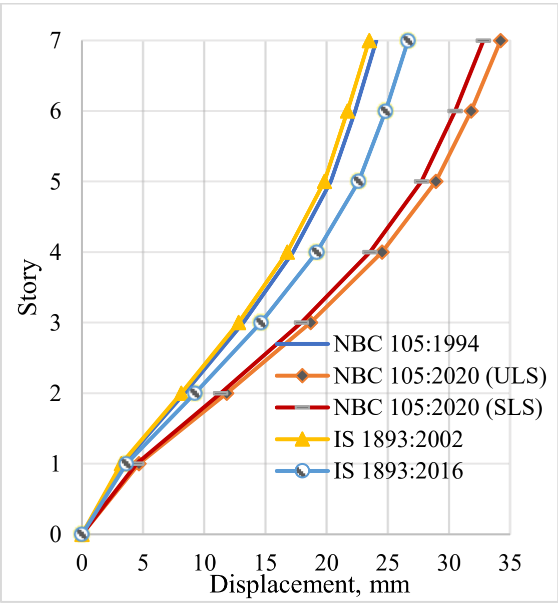


Figure 13: Displacement in X-Direction from MRSM

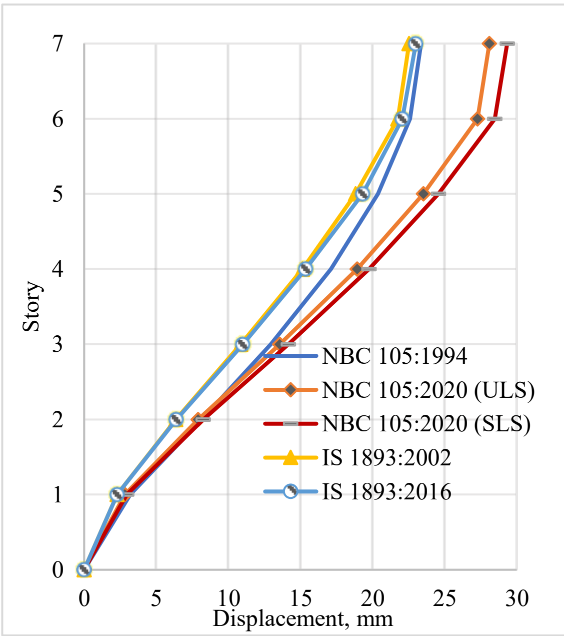


Figure 14: Displacement in X-Direction from MRSM

The story displacement, depicted in Figures 11,12,13 and 14 indicates that the displacement using both the IS code aligns more closely with each other. In contrast, NBC105:1994 gives less displacement than the SLS and ULS analysis using NBC105:2020. In the equivalent static method along X-direction, story design displacements from NBC 105:2020 ULS found to be 31.98mm, which is the maximum value followed by NBC 105:2020 SLS (30.685mm), IS 1893:2016 (26.164mm), IS 1893:2002 (26.065mm) and NBC 105:1994 (22.806mm) respectively.
In the Y direction also, the maximum displacement on the 7th floor is more in 105:2020 ULS (29.357mm). secondly, it is from 105:2020 SLS with 28.136mm then IS 1893:2016 gives a displacement of 26.958mm, which is slightly more than IS 1893:2002, i.e. 26.958mm. Also, we know NBC105:1994 gives less displacement of the Top floor with 20.91mm.
The deflection from MRSM was found to be more than ESM. In X direction, the displacement from NBC 105:1994 is 5.5% more in MRSM; from NBC 105:2020, the deflection at the top floor is almost 7% more in MRSM through both ULS and SLS. While it is almost the same in Indian Codes.

The distribution of Lateral forces is given in the line graph:

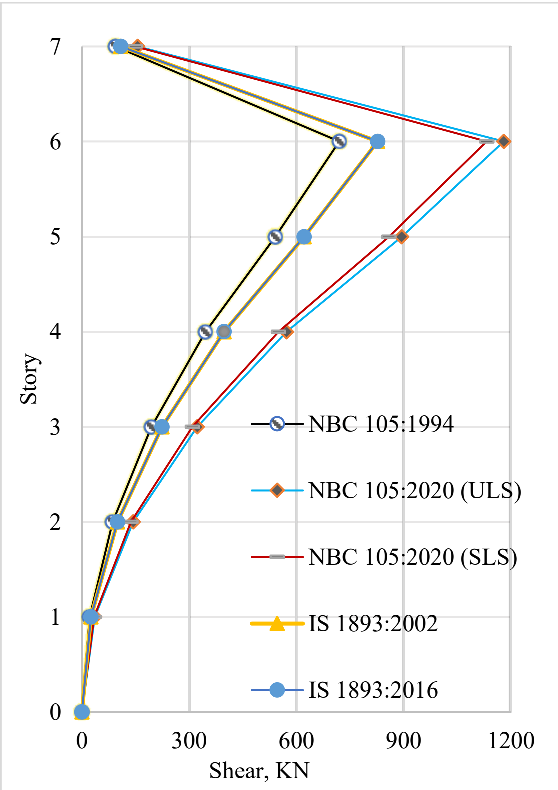


Figure 15: Lateral force distribution in X-Direction from ESM/MRSM

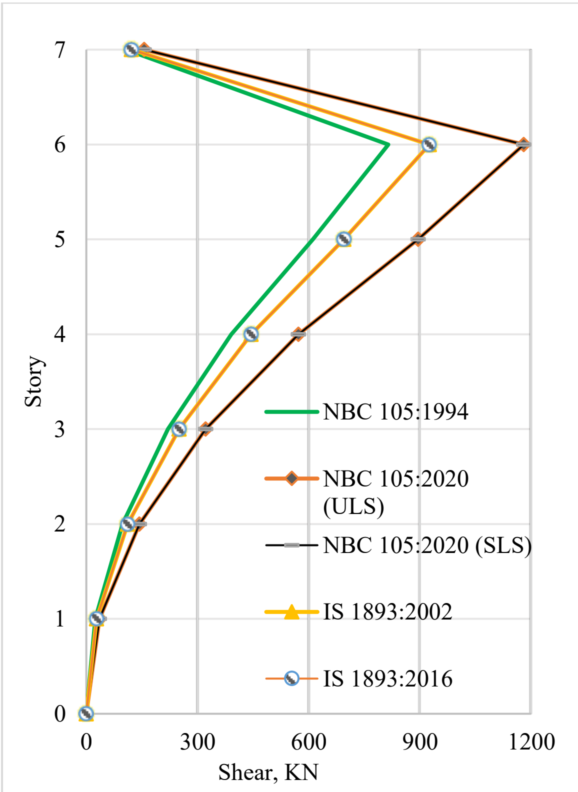


Figure 16: Lateral force distribution in Y-Direction from ESM/MRSM

Lateral force at each floor is distributed proportionally to the seismic weight and height of each floor. While the fundamental approach to distributing lateral forces along the height and in plan is similar in both codes, however, differences in seismic coefficients and zone factors in NBC 105 often result in higher forces for Nepal.
The lateral force in X-direction for IS 1893:2002 and IS 1893:2016 is only 2% more than NBC 105:1994 through ESM and MRSM, while for NBC 105:2020 ULS, it is 44.96% greater, followed by NBC 105:2020 SLS with a result of 39.06% more.

Also, if we measure lateral force in the Y-direction for IS 1893:2002 and IS 1893:2016, the result is 14.15% more than NBC 105:1994 through ESM and MRSM, while for NBC 105:2020 ULS and SLS, it is 44.96% greater.

Torsion is compared in the Bar graph:

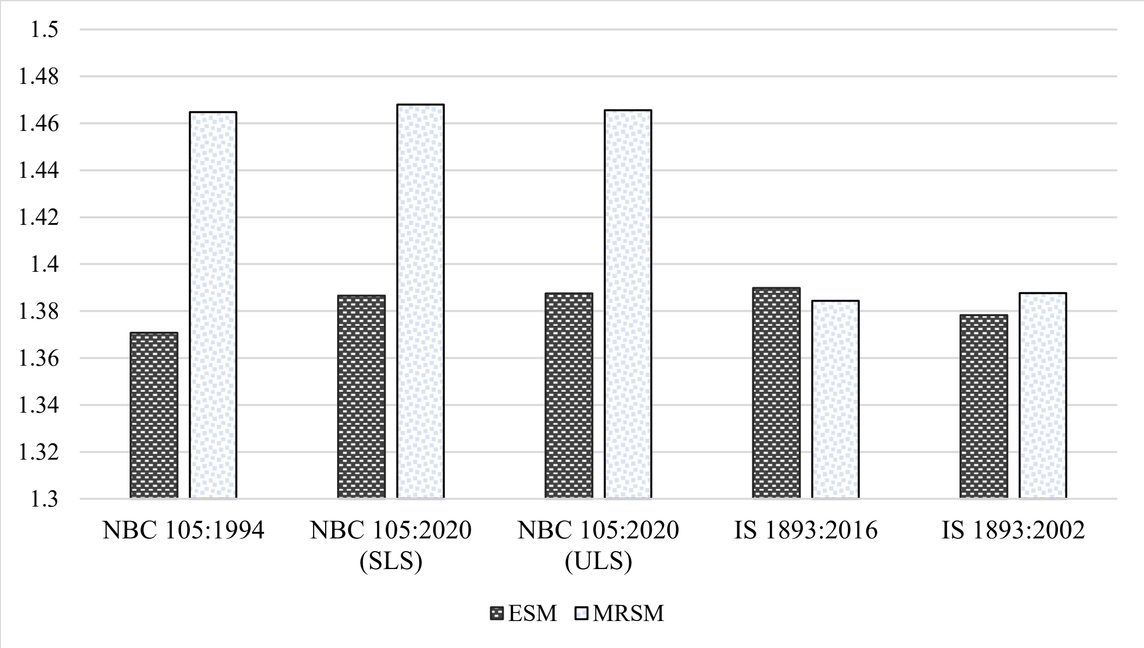


Figure 17: Maximum torsion in EQX Direction from ESM/MRSM

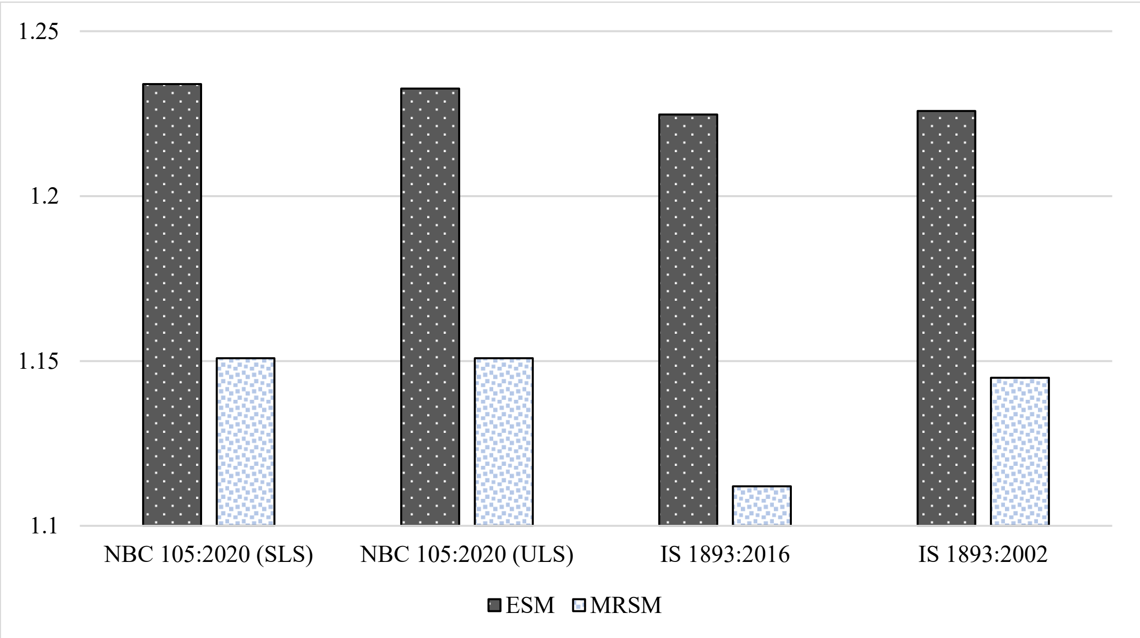


Figure 18: Minimum torsion in EQY Direction from RSM/MRSM.

Both countries have their own seismic design codes influenced by their respective seismic risks and geotechnical conditions. Nepalese code considers higher accidental eccentricity (10%) compared to Indian code (5%), which can result in higher torsional forces in NBC 105 designs. Buildings designed using NBC 105 typically experience higher torsional moments due to larger base shear values driven by higher seismic zone factors. Accidental eccentricity is also explicitly included to address irregularities in mass distribution.

Beam-Column Percentage

The percentage of average reinforcement is compared in Beam and Columns for similar conditions from different seismic codes. The average of all columns and beams is calculated through an Excel sheet and mentioned in table 8.

Table 8: Beam and column average longitudinal reinforcement calculations.

Codes	NBC 105:1994		NBC 105:2020		IS 1893:2002		IS 1893:2016	
	ESM	MRSM	ESM	MRSM	ESM	MRSM	ESM	MRSM
Beam %	0.32	0.3	0.35	0.3	0.27	0.27	0.273	0.276
Column%	0.32	0.3	0.35	0.3	0.27	0.27	0.273	0.276
Allowable	Max	Min	Max	Min	Max	Min	Max	Min
Beam %	2.5	0.215	2.5	0.215	2.5	0.215	2.5	0.215
Column %	6	0.8	4	1	6	0.8	6	0.8

After completion of the structural analysis, the design of the building is carried out in accordance with the design code recommended by the relevant codes. The NBC and IS codes suggest the use of IS 456:2000, Table 4 presents the average longitudinal reinforcement percentage results for columns and beams. The NBC 105:2020 codes result in a higher reinforcement percentage, averaging around 1.28%. The IS 1893:2016 code results in an average reinforcement of 1.18%, which is the second highest.

4. Conclusions

- The analysis indicates that NBC 105:2020 (ULS) results in a 45.75% increase in base shear compared to NBC 105:1994, highlighting the differences in seismic loading criteria between the revisions.
- When compared to IS codes, the NBC 105:2020 codes show an increase in base shear by 43.48% under the ULS method and by 37.66% under the SLS method for the same building used in the analysis.
- The deflection found using the Modified Response Spectrum Method (MRSM) was greater than that obtained with the Equivalent Static Method (ESM). In the X direction, the displacement from NBC 105:1994 is 5.5% greater in the MRSM, while NBC 105:2020 shows a top-floor deflection that is almost 7% higher in the MRSM under both ULS and SLS conditions.
- The lateral force in the X direction for IS 1893:2002 and IS 1893:2016 is only 2% greater than that of NBC 105:1994 when using ESM and MRSM. However, for NBC 105:2020 under the ULS method, the lateral force is 44.96% higher, followed by a 39.06% increase under the SLS method.
- Overall, NBC 105:2020, along with IS 1893:2016, generally requires a higher percentage of longitudinal rebar than IS1893:2002, while NBC 105:1994 indicates the lowest requirement.
- The ISD ratio calculated using NBC 105:2020 (ULS) yields the largest value. However, in the Y-direction, the MRSM method shows that NBC 105:2020 (SLS) provides the maximum value. Both IS codes produce almost identical values for the ISD ratio.

- The Nepalese code accounts for a higher accidental eccentricity of 10%, compared to 5% in the Indian code. This difference can lead to increased torsional forces in the designs of NBC 105.
- Beam-column joints frequently do not meet the required B/C ratio criteria, necessitating adjustments to the section, size, or reinforcement.

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