International Journal on Engineering Technology (InJET)

www.kec.edu.np/journal
Volume 1, issue no. 1, Nov 2023, Page 27-36
Received Date: June 29, 2023
Accepted Date: Sept 28, 2023
ISSN: 3021-940X (print)

Comparative Seismic Analysis, Design, and Cost Estimation of a Residential Building

Mahesh Pokhrel[1*], Ujjwal Adhikari[2], Suvechha Dhakal[3], Aashish Dhakal[4], Sachita Ghimire[5], Anup Shrestha[6]

[1]*Department of Civil Engineering, Sagarmatha Engineering College, Sanepa, Lalitpur, Nepal, 075bce026.mahesh@sagarmatha.edu.np*
[2]*Department of Civil Engineering, Sagarmatha Engineering College, Sanepa, Lalitpur, Nepal, 075bce048.ujjwal@sagarmatha.edu.np*
[3]*Department of Civil Engineering, Sagarmatha Engineering College, Sanepa, Lalitpur, Nepal, 075bce046.suvechha@sagarmatha.edu.np*
[4]*Department of Civil Engineering, Sagarmatha Engineering College, Sanepa, Lalitpur, Nepal, 075bce004.aashish@sagarmatha.edu.np*
[5]*Department of Civil Engineering, Sagarmatha Engineering College, Sanepa, Lalitpur, Nepal, 075bce039.sachita@sagarmatha.edu.np*
[6]*Department of Built Environment, Aalto University, Espoo, Finland, anup.shrestha@sagarmatha.edu.np*

Abstract

The updated National Building Code (NBC 105:2020) for professionally engineered buildings provides guidelines for analyzing and designing earthquake-resistant buildings. Though it has been three years since the update of the NBC, the Indian standard code, IS 1893:2016, still seems to be prevalent; however, it has not been updated after 2016. Therefore, comparing the seismic behavior of buildings analyzed and designed by these two prevailing methods in Nepal is essential. This study aims to compare the seismic parameters, design results, and the total cost of the buildings for NBC and IS for a three-story with a staircase-cover residential building. The response Spectrum Method was used to analyze and compare the response parameters like base shear, story drift, and story displacement. The seismic response parameters are more significant; however, the total cost is not significantly greater (i.e., only 5.5% approx.) for NBC, though the base shear was relatively higher than IS. Thus, this study helps understand the structural performance and emphasizes the use of NBC in all parts of Nepal.

1. Introduction

Nepal experiences frequent seismic activities due to its location in a seismic-prone zone, where the Indian and Eurasian plates collide, resulting in continental collisions (Rajesh, et al., 2021). The territories of Nepal lie at a high seismic zone due to the subduction of the two plates at the rate of 40cm/year (Prateek & Vashudev, 2019). Constructing seismically resistant structures is crucial to reduce the potential for casualties and property damage. Thus, it is necessary to consider the impact of earthquake loads during the analysis and design of the structure. Nowadays, researchers and professionals use various analysis software like ETABS and SAP to integrate the effects of the earthquake loads to examine the behavior of structures.

Earthquake loads are provided according to the codal provisions in different countries based on the diverse earthquakes observed due to the variations in topography and geological conditions (Devendra & Shakshi, 2022). Different seismic codes based on the respective countries are the National Building Code (NBC) of Nepal (NBC, 2020), the Indian Standard (IS) of India (IS 1893(Part 1), 2016), the Eurocode of Europe, the Japanese Seismic Design Code of Japan, the Northern Cyprus Seismic Code (NCSC)of Cyprus, American Standard Codes of America, etc. In the context of Nepal, NBC 105:1994 was a governing code up to 2020 for the design of seismic-resistant buildings. After the devasting earthquake of 2015, shortcomings and insufficiencies within the 1994 NBC 105 were exposed. This highlighted the necessity for extensive research, advancements in seismic technology, and a deeper understanding of seismic benefits (NBC, 2020). A draft of new updated code was proposed as NBC 105:2019, and finally, NBC 105:2020 was implemented. Before the revised National Building Code, the Indian Standard was more prevalent in Nepal for seismic-resistant design. However, after the update of NBC105:2020, some metropolitan cities use NBC, whereas many other municipalities still use IS 1893:2016. Given that the

**Corresponding Author*

Indian Standard Code hasn't been updated since 2016 and the National Building Code (NBC) was revised in 2020, it becomes essential to compare and contrast the provisions of these codes when applying them to seismic analysis and structural design in Nepal. The findings from the various studies (Dhurba , et al., 2022) (Devendra & Shakshi, 2022) (Jagat, et al., 2021) indicate that the emphasis has primarily been on seismic parameter comparison rather than on cost comparison. This paper aims to compare earthquake parameters and costs associated with RCC structural members of a three-and-a-half-story residential building by using both NBC 105:2020 and IS 1893:2016 codes for analysis and design. Various researchers and professionals have employed analysis software such as ETABS and SAP to assess the behavior of structures under earthquake loads. ETABS has been chosen for its advanced algorithms and efficiency in computational time and memory. In response to the irregular land availability and the limitations in terms of land size in Kathmandu, an irregular building plan for the study has been formulated. Since this type of building could be built in Kathmandu, the research aims to assess the notable differences that may arise from adopting and implementing the recently developed NBC (National Building Code) alongside the IS (Indian Standard) code. The result can be used as a baseline for designers to analyze and design according to NBC and compare the costs related to the design using both codes. Also, this can be used by decision-makers in municipalities to decide on the suitability of the codes in practice.

2. Literature Review

2.1. Indian Standard Code (IS):

IS 1893:2016 is an Indian standard code used in India and South Asia for designing structures to resist seismic forces (IS 1893(Part 1), 2016). It employs Deterministic Hazard Analysis and divides India into four seismic zones. The seismic force is calculated using Equivalent Static and Dynamic Analysis methods. The design horizontal seismic coefficient (A_h) is determined based on the building's height, seismic zone, soil conditions, importance factor, and response reduction factor. Soil is classified into three types in IS 1893:2016, i.e., Hard, Medium, and soft soil. The seismic load is calculated by considering the dead load and a percentage of the live load based on its magnitude. The design seismic base shear is obtained by multiplying the design horizontal seismic coefficient with the seismic weight of the building. The code covers various structural systems, providing guidelines for their design and detailing to withstand earthquake forces.

The primary objective of structural design is to ensure that the structure can reliably endure all anticipated loads and meet serviceability criteria, such as deflection and crack limitations, throughout its intended lifespan. The predefined level at which safety and serviceability requirements are considered acceptable and structural failure is avoided is referred to as a "limit state." The aim of the design is to achieve acceptable probabilistic so that the structure will not become unfit for its intended use; that is, it will not reach a limit state.

2.2. Nepal Building Code (NBC):

NBC 105:2020, a revision of NBC 105:1994 prompted by the 2015 earthquake, adopts a Probabilistic Seismic Hazard approach (NBC, 2020). It introduced a Seismic Hazard Map of Nepal based on probabilistic methods and revised the Peak Ground Acceleration (PGA) values for selected cities and municipalities in Nepal. The code categorizes subsoil into four types (A, B, C, D). Also, the structure must endure design seismic forces without failure, maintaining its integrity, stability, and load-bearing capacity. It should also withstand more probable seismic forces without damage that limits its use. Designing for the ultimate limit state ensures an acceptable risk of structural collapse. This is met when the entire structure remains stable against overturning and sliding, fulfilling its load-bearing function. In the context of designing for serviceability conditions, damage limitation states mark the point at which the structure no longer meets service requirements due to damage. This indicates the force level within the structure below which it can still function as intended without requiring repairs. It addresses the ultimate limit state and serviceability limit state for calculating the horizontal base shear coefficient, ductility factor, and other parameters. The code emphasizes ductile detailing for all structural elements. It incorporates seismic zone, importance factor, spectral shape factor, and elastic site spectra to calculate the horizontal base shear coefficient. The base shear is determined by multiplying the horizontal base shear coefficient with the seismic weight. The horizontal design spectrum for the modal response spectrum method differs for the ultimate limit state and the serviceability limit state.

Dynamic analysis is preferred because it offers a more accurate assessment of seismic forces and responses than static analysis. Unlike static analysis, which assumes uniform forces, dynamic analysis accounts for the time-varying nature of ground motion. It's widely adopted in building codes like the NBC and IS, allowing engineers to customize seismic analysis based on site-specific characteristics. Dynamic analysis also considers various vibration modes, which are crucial as structures can behave differently in different modes. Dynamic analysis enhances safety and resilience by addressing various earthquake scenarios, enabling engineers to design buildings that can withstand seismic forces and protect occupants.

The Dynamic analysis includes two methods: response spectrum and time history. The response spectrum method is commonly employed, utilizing the design acceleration spectrum, which consists of the natural modes of oscillation and the number of modes that need to be considered. Also, a combination of the model effects, such as story drift, story shear, displacement, and moment, shall be carried out using an established method, such as the Square Root of the Sum of the Squares (SRSS) or the Complete Quadratic Combination (CQC) method or any other generally accepted combination methods.

Several researchers have studied various Reinforced Concrete by comparing two different codes. Jagat K. Shrestha, Nirajan Paudel, Bishal Koirala, Binod R. Giri, and Aadarsha Lamichhane compared various parameters for two and four-story with masonry infill walls for IS 1893: 2002, IS 1893: 2016, NBC 105: 1994 and NBC 105: 2020 (Jagat, et al., 2021). Also, R. Resatoglu and M. K. A. Hamed compared Eurocode 8 and NCSC 2015 for a four-story RC building in Nicosia, Northern Cyprus (R. & M. K . A., 2019). Devendra Shah and Shakshi Chalotra modeled a nine-story regular RC building (Devendra & Shakshi, 2022). Several research studies have been conducted to compare the different parameters of the analysis, like story drift, story displacement, lateral forces, and time period (Devendra & Shakshi, 2022) (Jagat, et al., 2021) (R. & M. K . A., 2019). Devendra Shah and Shakshi Chalotra have compared the overturning moment for NBC105:2020 and IS1893:2002 (Devendra & Shakshi, 2022). Similarly, R. Resatoglu and M. K. A. Hamed compared bending moment and column axial force for earthquake load for Eurocode 8 and NCSC 2015(Northern Cyprus Seismic Code) (R. & M. K . A., 2019). ETABS and SAP were this research's most commonly used software (Jagat, et al., 2021) (R. & M. K . A., 2019).

Comparison of various parameters between IS 1893:2016 and NBC 105:2020:

Table 1: Codal Provisions for IS code and NBC code

S.N.	Parameters	IS 1893:2016	NBC105:2020
1	Time Period	$T_a = 0.075H^{3/4}$ For RC MRF buildings without masonry infills	$T = K_t H^{3/4}$ where,` K_t=0.075 for the moment resisting concrete frame
2	Displacement	0.04*story height	$\frac{0.025H}{R_\mu}$ where, R_μ is the ductility factor
3	Story Drift	0.04*story height	$\frac{0.025H}{R_\mu}$ where, R_μ is the ductility factor
4	Horizontal Seismic Coefficient	$A_h = \frac{S_a}{g} * \frac{I}{R} * \frac{Z}{2}$ Where, $\frac{S_a}{g}$= design acceleration coefficient	$C_d(T) = \frac{C(T)}{R_\mu * \Omega_u}$ Where, $C(T) = C_h(T)ZI$ $C_h(T)$=Spectral Shape Factor
5	Base Shear	$V_B = A_h * W$	$V = C_d(T) * W$
6	Lateral Force Distribution	$Q_i = \frac{W_i h_i^2}{\Sigma W_i h_i^2} * V_B$	$Q_i = \frac{W_i h_i^k}{\Sigma W_i h_i^k} * V$ Where, k=1 for a time period≤ 0.5 k=2 for a time period≥ 2.5 It is obtained from linear interpolation for the period between 0.5 to 2.5.
7	Load Combination	1) $1.2[DL+LL \pm (EL_x \pm 0.3EL_y)]$ 2) $1.2[DL+LL \pm (0.3EL_x \pm EL_y)]$ 3) $1.5[DL+LL \pm (EL_x \pm 0.3EL_y)]$ 4) $1.5[DL+LL \pm (0.3EL_x \pm EL_y)]$	1) $1.2DL + 1.5LL$ 2) $DL + \lambda LL \pm (E_x \pm 0.3E_y)$ 3) $DL + \lambda LL \pm (0.3E_x \pm E_y)$ where, λ=0.6 for storage facilities λ=0.3 for other usage

5) 0.9[DL+LL$\pm(EL_x \pm 0.3EL_y)$]
6) 0.9[DL+LL$\pm(0.3EL_x \pm EL_y)$]

3. Methodology

For the study, three and a half story residential building without masonry infill was chosen for analysis as this type of building typology has been extensively adopted for the urban regions of Nepal. The building was analyzed and designed, and a comparison was made between two seismic design codes: IS 1893:2016 and NBC 105:2020. Since dynamic analysis accounts for the time-varying nature of ground motion, it has been applied to analyze the building. Since the design acceleration spectrum was used to calculate force, the response spectrum method was performed. The research primarily focuses on differences in parameters and cost variations for a sole building with the same frame size.

The preliminary design was performed to determine the approximate size of various structural members. It included load assessment and structural idealization. Two models were prepared in ETABS, one for IS 1893:2016 and the other for NBC 105:2020, respectively, as shown in Figure 2. Both models had identical sectional properties. Column and beam elements were represented as line elements, whereas floor slabs were modeled as shell elements. All the joints in the frame were assumed to be rigid, and the frames were interconnected using a rigid diaphragm in the horizontal plane. The seismic resistance of the prepared model was checked. If the structure was seismically resistant, design and detailing, estimation, and costing were performed; otherwise, the size of the structural members or material properties were changed. At last, a comparison of various seismic parameters and estimated cost of structural members was performed. Figure 1, presented below, illustrates the methodology employed in our research.

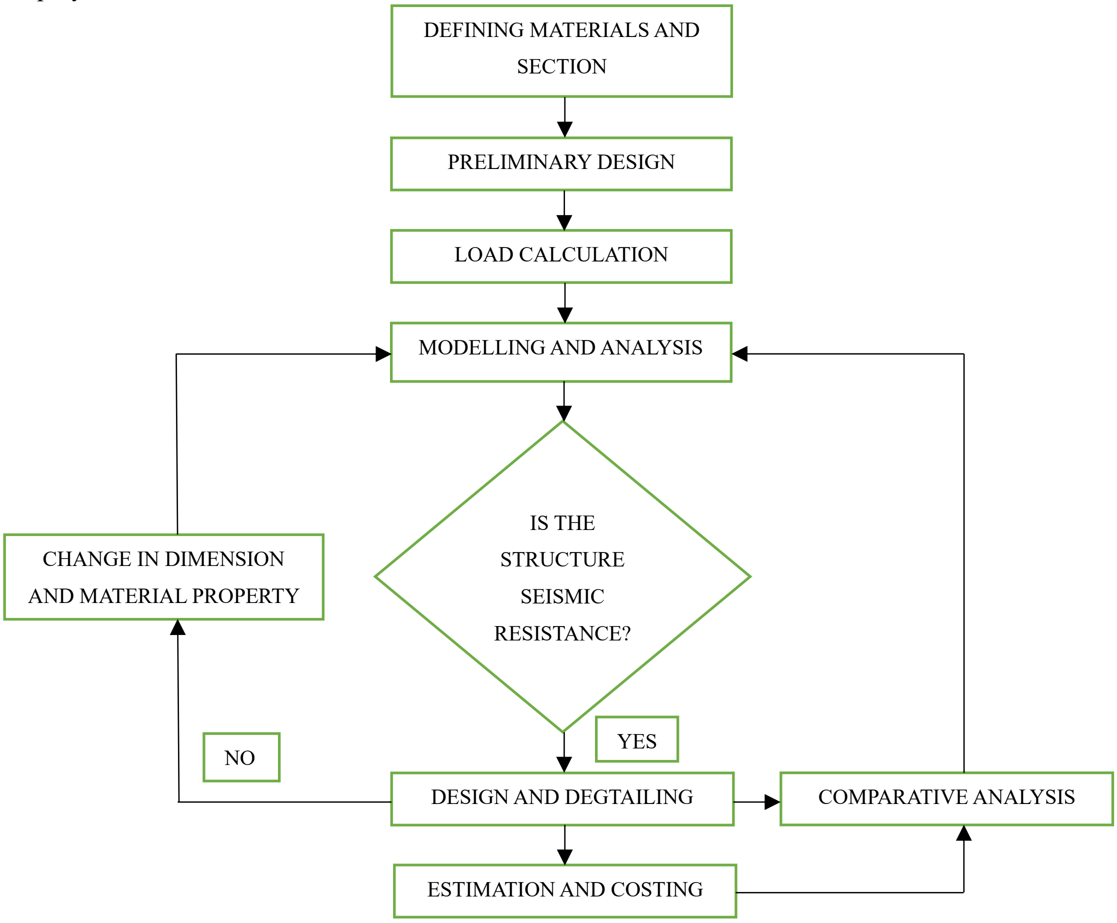

Figure 1: Methodological adopted for study

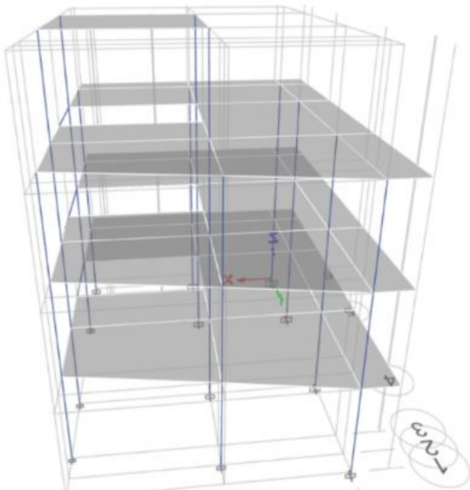

Figure 2: 3D Model of the building

Table 2: General Description of Building

S.N.	Parameters	General Description
1	Types of building	Residential Building
2	Plinth Area	82.014m^2
3	No. of story	4
4	Floor Height	2.8448m
5	Size of Beam	14"*12"
6	Size of Column	14"*14"
7	Depth of Slab	140mm
8	Type of Staircase	Dog legged
9	Type of Footing	Isolated
10	Depth of foundation	5ft
11	Support Condition	Fixed
12	Width of wall	9"
13	Width of the partition wall	4"

Table 3: Characteristic Strength of Materials

S.N.	Parameter	General Description
1	Concrete type	M25
2	Grade of Steel	Fe500
3	Compressive Strength of Concrete	25KN/m^3
4	Compressive Strength of Brick	19.4KN/m^3
5	Bearing Capacity of soil	150KN/m^3

So, the zonal factors and soil type for buildings assumed to be located in Kathmandu Valley are adopted from respective building codes.

Table 4: Site Parameters

S.N.	Parameters	IS 1893:2016	NBC 105:2020
1	Seismic Zone	V (0.36)	Kathmandu (0.35)
2	Soil type	III (Soft soil)	D (Very Soft soil)
3	Importance factor	1	1
4	Response reduction factor	5(SMRF)	-
5	Response spectrum coefficient /spectral shape factor	2.5	2.25
6	Elastic site spectra	-	0.7875
7	Ductility factor (ULS)	-	4
8	Overstrength factor (ULS)	-	1.5

The various loads were applied to the frame structure. IS 875 (Part 1) was used for calculating dead loads, and IS 875 (Part 2) was utilized for calculating live loads. Load combinations were used by referring to respective seismic codes. For load combinations, refer to Table 1.

Table 5: Various loading and their standards

S.N.	Loads	Load applied
1	Dead load wall	According to the opening on the wall
2	Live load on the floor	2 KN/m²
3	partition wall load	Varies according to slab area
4	Floor finish	1 KN/m²
5	Roof live load	1.5 KN/m²
6	Balcony load	3 KN/m²
7	Water tank load	3 KN/m²
8	Earthquake load	adopted as per the code

The analysis of the building was performed using both the Equivalent lateral force (static) method and the response spectrum (dynamic) method. IS 456:2000, IS 13920:2016, and NBC 105:2020 were used for designing structural members, including beam, column, slab, staircase, and footing. The arrangement of rebars was prepared in AutoCAD for various structural members, and the quantity of reinforcement required and the amount of concrete for structural members were estimated for each model.

The rate analysis of the proposed building was done using the Kathmandu District rate 2079, and the total cost was estimated for structural members using two codes. Finally, the various earthquake parameters, along with estimated costs, were compared for each code.

4. Results

4.1. Analysis

The response of the building is analyzed using both linear static and linear dynamic approaches for the different codal provisions. The response parameters under comparison were seismic weight, base shear, maximum displacement, and inter-story drift. Additionally, the total rebar quantity and overall cost estimate of the structural members were compared.

From the results obtained from the ETABS, in the modal mass participation ratio, mode one and mode two consistently exhibits translations, whereas mode 3 exhibit rotation that corresponds to the codal provision for each code. However, the eccentricity in NBC 105:2020 and IS 1893:2016 was more significant than the permissible 5%.

The time period for both models is 0.66 sec, almost similar to the natural time period. The similarity in both codes was due to RC buildings with no masonry infill time period solely depends on the height of the building for both codes. Similarly, the time period on seismic analysis of the modal lies between 10-20% of the difference between consecutive modes.

Based on seismic activity, base shear estimates the maximum expected lateral force on the structure's base. Similarly, the lateral force acts horizontally in the building on each floor due to an earthquake. It is calculated for both NBC and IS. Figure 3 and Figure 4 represent seismic loads and base shear values from NBC 105:2020 and IS 1893:2016. It shows that NBC 105:2020 has more seismic weight and base shear than NBC 105:2020.

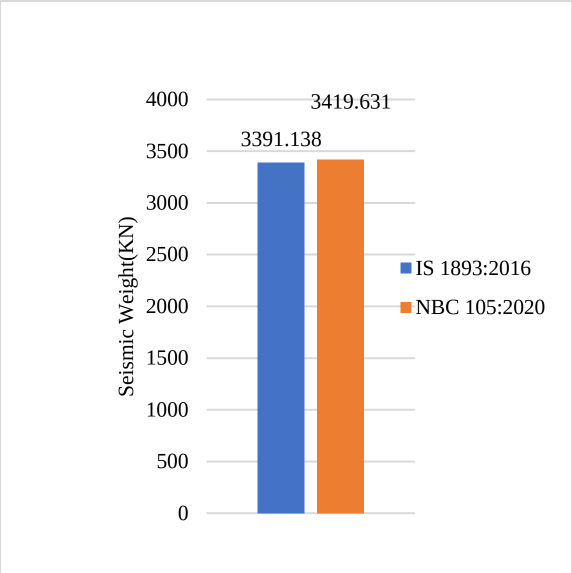

Figure 3: Seismic Weight Comparison

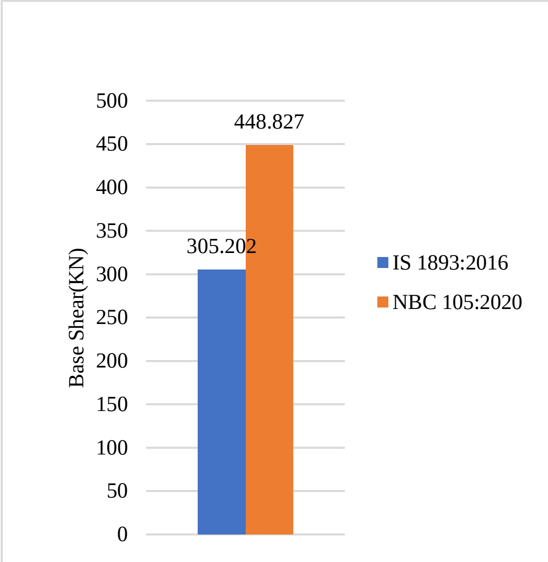

Figure 4: Base Shear Comparison

Story displacement is the displacement of a story relative to the base of a structure. It is obtained for each story of the structure. The maximum story displacement occurred in NBC when the earthquake load was applied in the X direction of the building (Figure 5).

Story drift is the displacement of one story relative to the other, obtained for each story of structure. The maximum story drift was maximum in NBC for story 2 when the earthquake load was applied in X direction of the building (Figure 6).

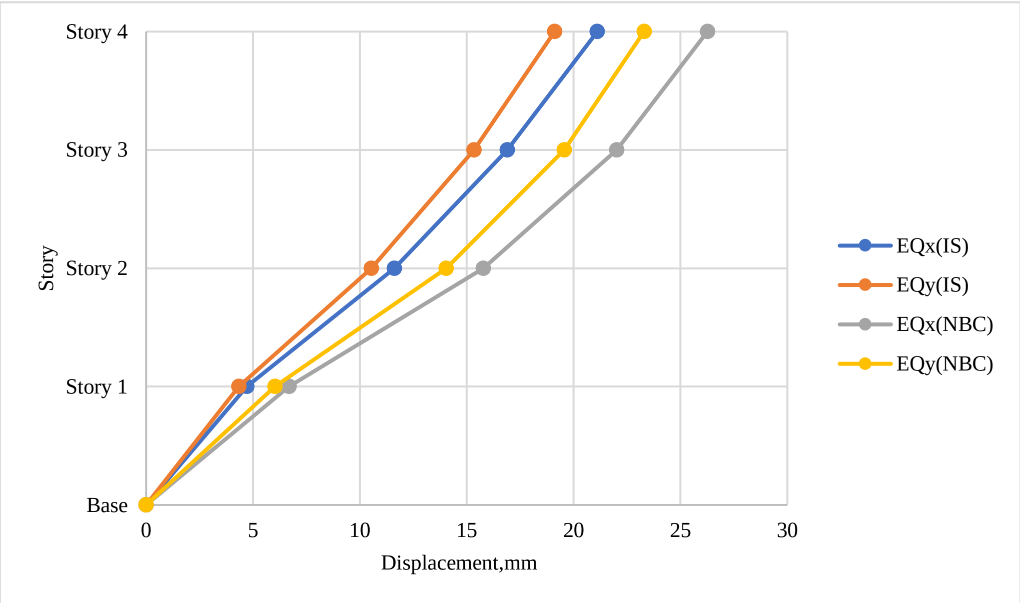

Figure 5: Story Displacement Comparison

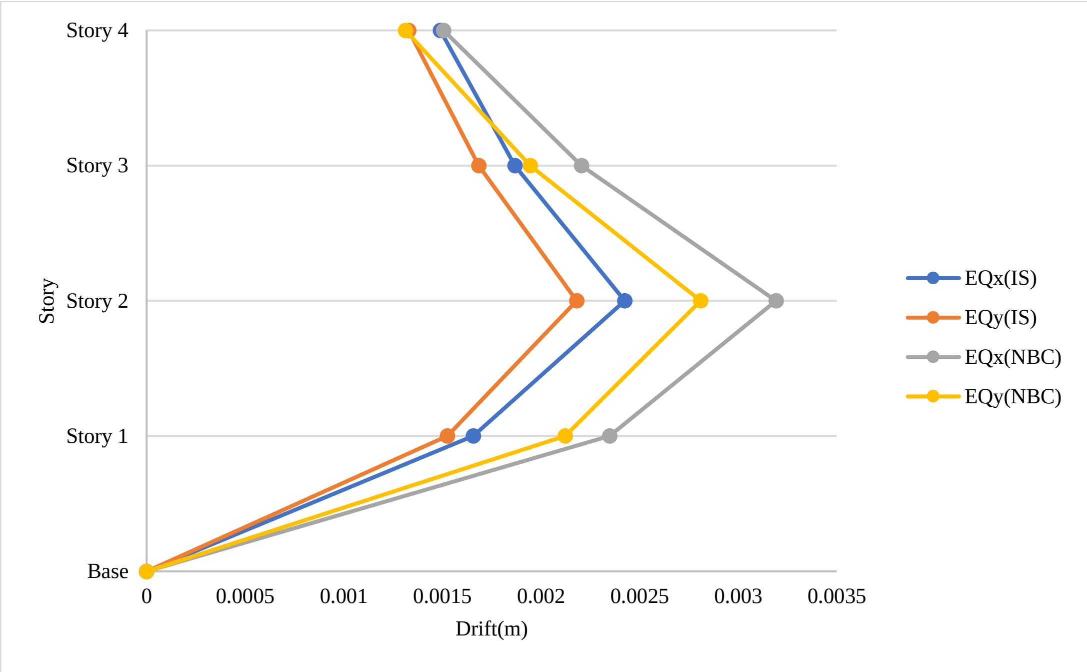

Figure 6: Story Drift Comparison

4.2. Comparison Results

The estimated amount of rebar considering wastage is determined for all the structural members. For the same frame size except for footing following rebar amount, the total estimated cost is determined for each code as shown below.

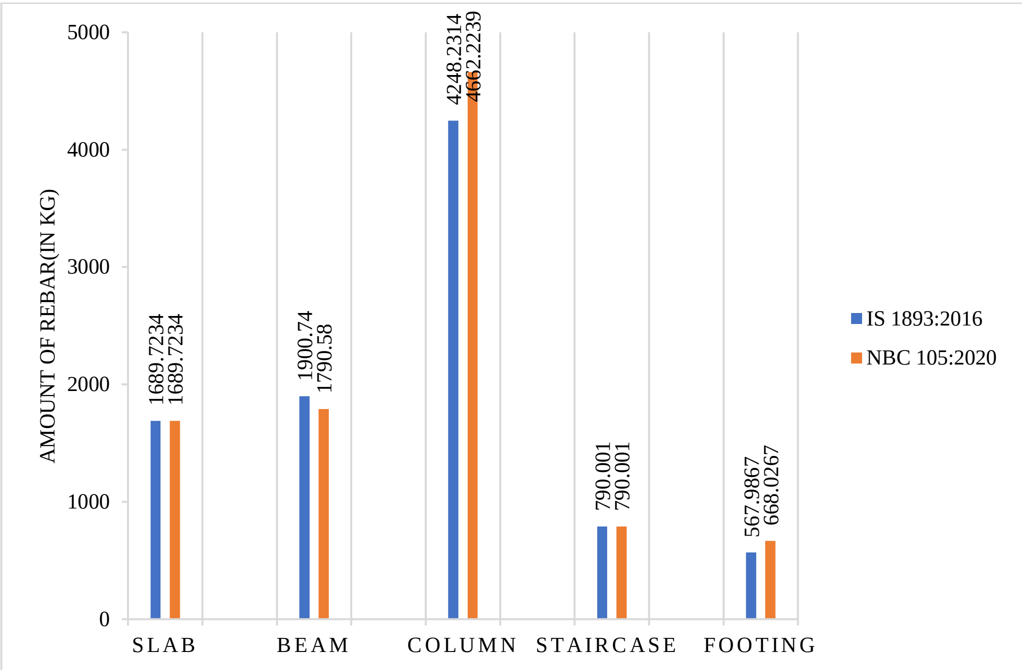

Figure 7:Rebar Amount Comparison

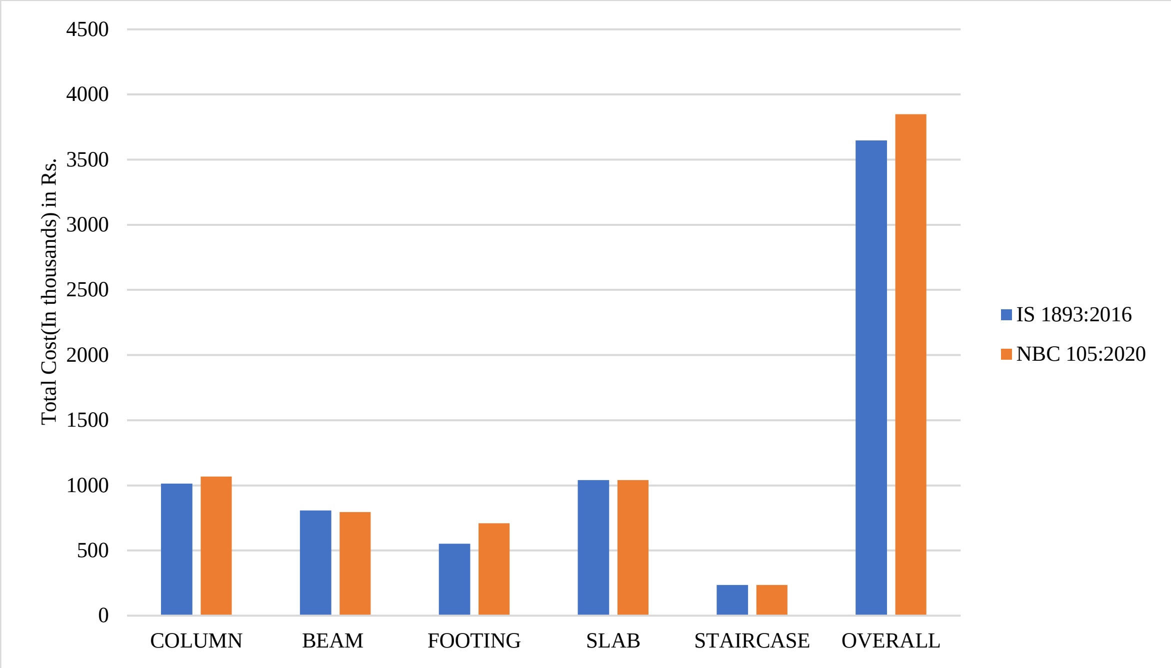

Figure 8: Overall Cost Comparison

The total Rebar quantity for design by IS code is 9196.68 Kg, and by NBC code is 9600.55 Kg for structural members of the building. The total cost of the frame structure of the building design by IS code is Rs3648393, and by NBC code is Rs3848388.

5. Discussion

The analysis results obtained from two different codes show a variation when compared. The variation in seismic weight is due to variation in the live load factor in the two codes. According to the IS code, for a live load greater or equal to $3KN/m^{2,}$ ^{the} live load factor is 0.25; for greater than $3KN/m^{2,}$ ^{the} live load factor is 0.5. For the NBC code, the live load coefficient is 0.6 for storage and 0.3 for other purposes. Similarly, the live load factor is 0 for roof live. The base shear obtained from the NBC code is 47.06 % greater than the IS code. The variation in base shear is due to the difference in live load factors set by two codes, zone factors, seismic weight, and different parameters like response spectrum coefficient, ductility factor, and over-strength factor set by two codes. The maximum displacement value in NBC 105:2020 is 24.39% greater than IS 1893:2016. Similarly, the value of maximum story drift is 31.63% greater in NBC 105:2020 compared to IS 1893:2016. The variation is due to the higher lateral force on NBC 105:2020 than on IS 1893:2016. The base shear, maximum story drift, and maximum displacement were more significant for NBC 105:2020 than IS 1893:2016. Similar results were obtained by Devendra Shah and Shakshi Chalotra (Devendra & Shakshi, 2022) and by Jagat K. Shrestha (Jagat, et al., 2021).

From estimating and costing, the rebar amount in NBC 105:2020 is 4.39% greater than that of IS 1893:2016, primarily because the various loads and bending moments were obtained higher for the NBC code than the IS code. Similarly, the total cost of the frame structure in NBC 105:2020 was 5.48% greater than that of IS 1893:2016. This is due to the higher demand for reinforcement for NBC code than that for IS code.

The study found that the NBC exhibits greater values for maximum displacement, drift, seismic weight, base shear, and lateral force than the IS for a residential building with three and a half stories. When constructing a frame structure of the same size, the NBC design necessitates more reinforcement than the IS design for the frame structure. Additionally, the overall structural design requirements outlined in the NBC result in slightly higher costs than those specified in the IS.

6. Conclusion

After the devasting Earthquake of 2072, Nepal updated its seismic code to NBC 105:2020. With the objective of designing a structure that is resistant to seismic activity, a seismic analysis was conducted for a residential building. A study assumes a typical plan of a three-and-a-half-story residential building in Kathmandu Valley.

Considering the relevancy of two codes, the Indian Standard (IS) and the National Building Code (NBC), in Nepal, a seismic analysis was performed by maintaining identical dimensions of the structural members, leading to variations in response and parameters. Based on the seismic analysis result, the structural members' design and detailing were done, altering the reinforcement quantity and arrangement. This affected the total amount of rebar needed, which spontaneously resulted in varied total costs for the frame members of the building. From the analysis data, the seismic parameters like story drift, displacement, and base shear are more significant in the NBC model than in the IS model, and the NBC model requires slightly more cost than the IS model. The outcome obtained reflects that a designer in Nepal should prefer NBC due to its recent updates and relevancy, although it shows a slight difference in the total cost of the building. Furthermore, it will provide guidelines for the NBC designer on the research related to the comparative analysis of IS and NBC code.

This research is limited to a typical plan of a three-and-a-half-story residential building having the identical size of the structural members. Changing the dimensions of structural elements might yield seismic analysis and cost outcomes that differ from the findings presented in this research. Hence, further research considering different plans, sectional sizes, and building types, which might give a better understanding of the seismic parameters and the cost of the building, is recommended.

7. Acknowledgement

We want to extend our heartfelt thanks to our college, "Sagarmatha Engineering College" for the arrangement and support for working on the research. We are particularly indebted to Er. Sudeep Lamsal, the Head of the Civil Department, for his initiation, encouragement, suggestions, and comments regarding the research and for leading us toward completing the research work.

8. References

Devendra, S. & Shakshi, C., 2022. Comparative Study of RC Frame Building with NBC 105:2020. *International Journal of Innovative Research in Engineering & Management (IJIREM),* Volume 9, pp. 68-73.

Dhurba , A., Sushil, A. & Deepak, T., 2022. A Comparative Study on Seismic Analysis of National Building Code of Nepal, India, Bangladesh and China. *Open Access Library Journal,* Volume 9.

IS 1893(Part 1), 2016. Criteria for Earthquake Resisrtant Design of structure. *Bureau of Indian Standards.*

Jagat, K. S., Nirajan , P., Bishal, K. & Aadarsha, L., 2021. Impact of Revised Code NBC105 on Assessment and Design of Low Rise Reinforced Concrete Buildings in Nepal. *Journal of the Institute of Engineering,* Volume 16.

NBC, 2020. Nepal National Building Code NBC 105:2020. *Seismic Design of Buildings in Nepal.*

Prateek , R. P. & Vashudev, M. V., 2019. COMPARATIVE ANALYSIS OF NBC 105:1994 AND IS 1893:2016 SEISMIC. *International Research Journal of Engineering and Technology (IRJET),* Volume 06.

R., R. & M. K . A., H., 2019. Comparative Study of different Seismic Codes for Reinforced Concrete Buildings in Northern Cyprus using Static and Dynamic Methods. *Journal of Engineering Science and Technology,* Volume 14, pp. 1314 - 1329.

Rajesh, B., Deepak, T., Tek, B. K. & Sailesh, A., 2021. *Seismic Behaviour of Buildings as per NBC 105:1994, NBC 105:2020 and IS 1893:2016.* s.l., Proceedings of 10th IOE Graduate Conference.