Comparative Analysis of an Apartment Building using Seismic Codes NBC 105:1994 and NBC 105:2020 (A Case Study)

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ABSTRACT

The present study undertakes a comparative analytical examination of seismic analysis standards in Nepal, focusing on NBC 105:1994 and the updated NBC 105:2020, encompassing both the Ultimate Limit State (ULS) and Serviceability Limit State (SLS). Employing a regular Reinforced Concrete (RC) apartment building in Pokhara as a case study, the geometric and sectional configurations of structural elements are intentionally kept consistent for comparison. The analysis involves creating a 3D model using ETABS version 19, encompassing linear static, Equivalent Static (ES), and linear dynamic Response Spectrum (RS) analyses, followed by nonlinear static (pushover) analysis. The results highlight substantial differences between the two codes. Base shear from NBC 105:2020 is notably higher, being 28.59% ULS and 22.74% SLS greater than NBC 105:1994. The scale factor for combined response design values is significantly lower in both X and Y directions for NBC 105:2020. Story shear is extended by 33% ES and 37% RS with NBC 105:2020 compared to NBC 105:1994. Maximum design displacement and Inter-Story Drift (ISD) are markedly higher with NBC 105:2020, indicating its more severe seismic parameters. This study emphasized the enhanced seismic resilience provided by NBC 105:2020, particularly evident in increased base shear, reduced design scale factors, and higher values for story shear, displacement, and ISD. These findings contribute valuable insights into the seismic design improvements introduced in Nepal's seismic codes after the Gorkha Earthquake in 2015.

Keywords-Response Spectrum (RC) building; linear analysis; Ultimate Limit State (ULS); Serviceability Limit State (SLS); Equivalent Static (ES); Response Spectrum (RS); Inter-Story Drift (ISD)

I. INTRODUCTION

Nepal is located in a seismically active region due to the subduction of the Indian plate under the Eurasian plate with a subduction rate of approximately 25-40 cm/year [1-4], causing apparent seismic risks for buildings. Approximately 17% of the world's largest earthquakes have occurred in the region [5], ranking it as the 11th most earthquake-prone country in terms of seismic vulnerability [6]. Strain energy accumulates due to the tectonic movement potentially leading to earthquakes with magnitudes greater than M_w 8 [7]. Nepal has experienced many great earthquakes including those of Kathmandu (1934), Bajhag (1966, 1980), Udayapur (1988), while the impact of the 2015 Gorkha earthquake has been thoroughly documented [8-10]. Approximately 800,000 houses were damaged, the majority of which was destroyed and 250,000 were partially damaged, resulting in 8,790 deaths and 22,300 injuries. Out of 75 districts, 31 were identified as the most affected ones, with

14 being severely impacted [11]. The damage was largely seen in residential structures in rural, mountainous areas, with over 96% of them being load-bearing structures [12]. Authors in [13] conducted ambient vibration measurements in medium to high-rise buildings. Given the seismic vulnerability of structures, seismic and design analyses have become integral to the structural design process, emphasizing the need for resilient infrastructure in earthquake-prone regions. Following the significant Udayapur earthquake in 1988, Nepal implemented its seismic code, NBC 105:1994, later updated to NBC105:2020. The code, influenced by Indian construction practices and technology, draws heavily from Indian standard codes. Authors in [14] highlight the popularity and widespread use of Indian standards as a design code in Nepal, reflecting shared practices in the construction industry.

In response to the seismic impact of the Gorkha earthquake, Nepal revised its seismic code from NBC 105:1994 to NBC 105:2020. While the former commonly employed soil type II, medium soil, for design, the latter introduced a refined classification system with four soil types, (Types A to D). These classifications consider cohesive soil characteristics, undrained shear strength, and SPT values. Researchers have examined NBC 105:2020, comparing it with IS 1893:2016, contributing to a comprehensive understanding of its seismic design improvements. Authors in [15] assessed NBC 105:2019 (draft) using three regular low-rise Finite Element Models (FEMs). Their findings revealed superior performance, but with the caveat that the former did not meet performance requirements for spans exceeding 4.5 m [16]. This study aims to compare the outcomes of ES and RS analyses between NBC 105:1994 and NBC 105:2020 for an apartment building in Pokhara. Utilizing a three-dimensional FEM, the analysis assumes soil type II for NBC 105:1994 and soil type B for NBC 105:2020, based on the corresponding soil investigation reports.

II. MATERIALS AND METHODS

A newly under-construction apartment building from central Pokhara was considered in this study. Each tower in the building consists of three building units separated by a seismic joint. Building unit A was chosen for the current study, while a typical floor plan is portrayed in Figure 1. ES and RS analyses were conducted deploying the FEM utilized in [17] to evaluate the code-based analysis of the case study building. Authors in [18] considered a 7-story building utilizing a precast column, whereas an onsite cast frame structure was included in this study. The building has a basement, ground floor, and eight-storys (B+G+8). The building comprises a 230 mm thick infill masonry wall throughout which weight is considered during structure modeling and analysis. The building has dimensions of 16.57 m and 14.95 m along the X and Y directions, respectively, with a typical floor height of 3.45 m. Similar structural components, construction technology, and workmanship involving the non-structural components are found in almost all apartment buildings as highlighted in [9, 19].

(a)

(b)

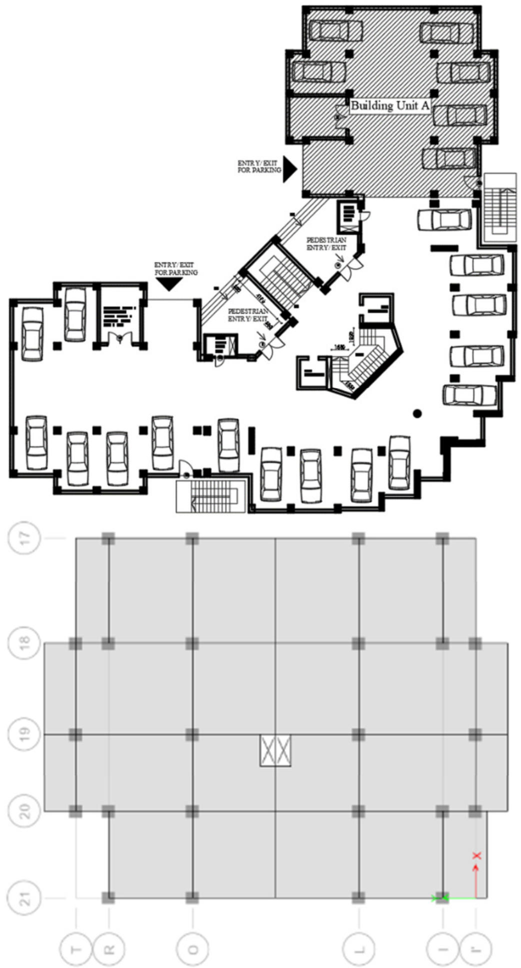

Fig. 1. Ground floor plan of the case study building: (a) typical plan layout, (b) grid layout of hatch portion in the analytical model.

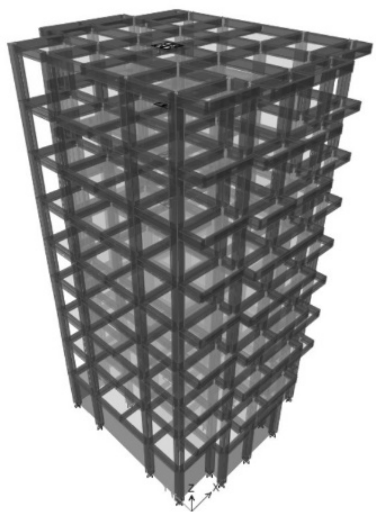

Fig. 2. FEM of the building.

The building under investigation is situated in soil type B and medium soil type according to NBC105:2020 and NBC105:1994, respectively. The identification of soil type relied on the geotechnical report conducted before the construction of the case study building. Concrete grades of M25 (beam, slab), M35 (column, RC wall), and Fe-500 reinforcement were employed in the construction. Shear resistance for RC T-beam has been investigated in [20] Regarding the FEM, the geometrical dimensions of the columns (500 mm × 500 mm), beams (300 mm × 500 mm), floor slabs (125 mm), and stair slabs (150 mm) were consistent with those of the actual construction. Column layout is displayed in Figure 3 and Table I.

TABLE I. COLUMN DESIGN TABLE

Basement					
Grid	**20**	**21**	**19**	**18**	**17**
T	C1	-	C1	C1	-
R	C2	C2	-	C2	C2
O	C3	C1	C3	C3	C1
L	C1	C1	C1	C3	C1
I	C2	C2	-	C2	C2
I'	C1	-	C2	C1	-
Ground to 2nd Floor					
Grid	**20**	**21**	**19**	**18**	**17**
T	C2	-	C1	C2	-
R	C2	C2	-	C2	C2
O	C3	C1	C3	C3	C1
L	C1	C1	C1	C3	C1
I	C2	C2	-	C2	C2
I'	C2	-	C2	C2	-
3rd Floor					
Grid	**20**	**21**	**19**	**18**	**17**
T	C2	-	C1	C2	-
R	C2	C2	-	C2	C2
O	C1	C2	C1	C1	C2
L	C1	C2	C1	C1	C2
I	C2	C2	-	C2	C2
I'	C2	-	C2	C2	-
4th Floor					
Grid	**20**	**21**	**19**	**18**	**17**
T	C2	-	C2	C2	-
R	C2	C2	-	C2	C2
O	C1	C2	C1	C1	C2
L	C1	C2	C1	C1	C2
I	C2	C2	-	C2	C2
I'	C2	-	C2	C2	-
5th to 6th Floor					
Grid	**20**	**21**	**19**	**18**	**17**
T	C2	-	C2	C2	-
R	C2	C2	-	C2	C2
O	C2	C2	C2	C2	C2
L	C2	C2	C2	C2	C2
I	C2	C2	-	C2	C2
I'	C2	-	C2	C2	-
7th Floor					
Grid	**20**	**21**	**19**	**18**	**17**
T	C4	-	C4	C4	-
R	C4	C4	-	C4	C4
O	C4	C4	C4	C4	C4
L	C4	C4	C4	C4	C4
I	C4	C4	-	C4	C4
I'	C4	-	C4	C4	-

Seismic parameters from NBC 105:1994, [21] and NBC105:2020 were considered for the finite element analysis, as evidenced in Tables II and III. A damping factor of 5% was adopted, in line with the suggestions from [21, 22]. NBC 105:2020 defines the crack section for the beam, column, and wall as 0.35EI, 0.7EI, and 0.5EI for flexural stiffness, respectively, and 0.4EA for shear stiffness in all components whereas, the crack section is not explained in the initial version of the code. Hence the particular section is not taken into account for the analysis using NBC105:1994. The seismic weight of the building under investigation constitutes 25% of the live load up to 3kN/m^2, 50% above 3kN/m^2 according to NBC 105:1994.

TABLE II. SEISMIC PARAMETERS (NBC 105:1994)

Parameter	**NBC 105:1994**	
Seismic zone factor	Z	1
Importance factor	I	1.5
Structure performance factor	K	1
Building height (m)	H	27.5
Building period (s)	$T1 = 0.06\ H^{0.75}$	0.720
Soil type	Medium type	
Basic seismic coefficient	C	0.047
Horizontal seismic coefficient	Cd=CZIK	0.071

TABLE III. SEISMIC PARAMETERS (NBC 105:2020)

Parameter	**NBC 105:2020**	
Seismic zone factor	Z	0.3
Importance factor	I	1.25
Building height (m)	H	27.5
Ductility factor	Rμ	4
Over strength factor (ULS)	Ωμ	1.5
Over strength factor (SLS)	Ωs	1.25
Building period (s)	$T = 0.075\ H^{0.75}$	0.900
Amplified period (s)	T1 =1.25*T	1.125
Soil type	Type B	
Spectral shape factor :	Ch(T)	1.443
Elastic site spectra (ULS):	C(T)	0.541125
Elastic site spectra (SLS):	Cs(T)=0.2*C(T)	0.108225
Horizontal seismic coefficient (ULS)	Cd=C(T)/Rμ Ωμ	0.0901875
Horizontal seismic coefficient (SLS)	Cd = Cs(T)/Ωs	0.08658

Concerning NBC 105:2020, 60% of the live load is considered for storage and the other 30%. A three-dimensional FEM was prepared as illustrated in Figure 2 using ETABS V 19 for statistic and dynamic analyses as per NBC105:1994 and NBC105:2020. ULS analysis was performed using NBC105:1994, whereas both ULS and SLS were carried out utilizing NBC105:2020. The RS curve suggested by the Nepal's standard seismic code is depicted in Figures 3 and 4. The initial scale factor for RS analysis was employed to determine the design displacement and ISD. In [23], the load-deflection relationship reinforcing beam with GFRP bars was presented. For this study, iron rebars are considered. Self-weight and imposed load were adopted as per NBC102:1994 and NBC103:1994, respectively, which is recommended by Indian standard IS 875 [24, 25]. Since the structural element reinforcement is designed as per NBC 105:2020, pushover analysis was carried out on reinforcement demand by NBC 105:2020 to determine the capacity and performance of the building. Hinges are defined as ASCE 41-17 for the mathematical module implemented in ETABS software. Pushover analysis is performed for Maximum Considered Earthquake (MCE). The stress-strain relationship utilized in the analysis is defined as per Indian Standard [3]. The material properties used are: Modulus of Elasticity of Steel, Es = 20000 N/mm^2,Modulus of Elasticity of Concrete, Ec = 25000 N/mm^2 for M25, and 29580.4 N/mm^2 for M35, and Yield stress for steel, fy = 500 MPa.

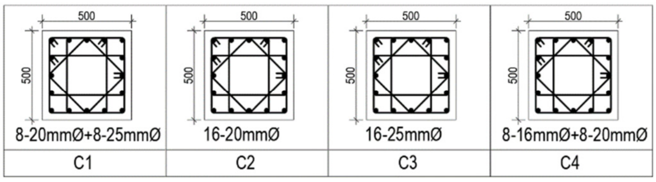

Fig. 3. Column design used in the model.

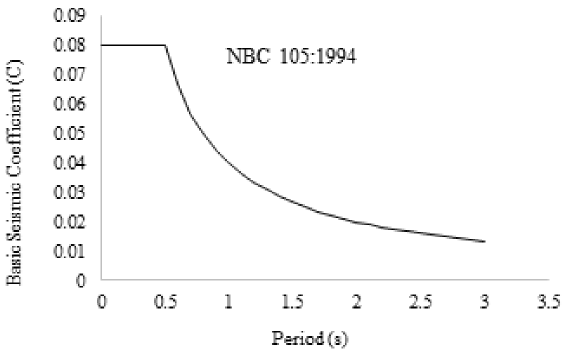

Fig. 4. Basic RS for soil type II (NBC 105:1994).

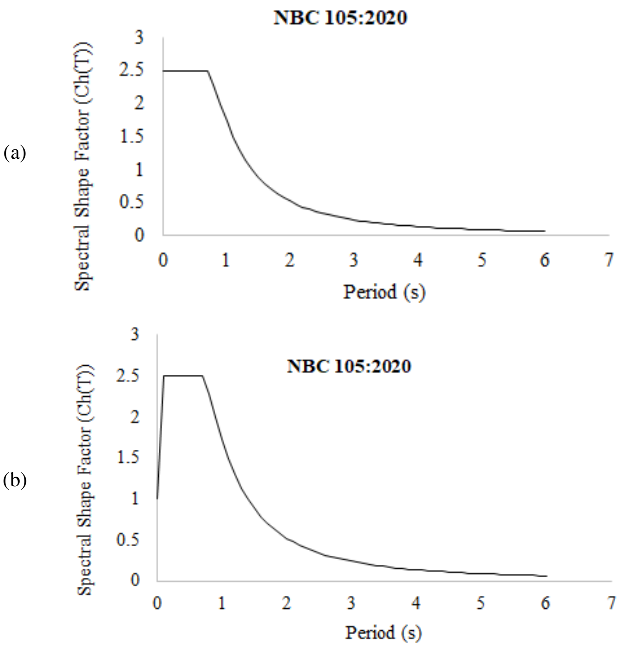

Fig. 5. Seismic shape factor (model RS method) for soil type B (NBC 105:2020): (a) Static, (b) dynamic.

III. RESULTS AND DISCUSSION

The seismic weight of the building under investigation was 23820.41 kN and 23967.71 kN, derived from NBC105:1994 and NBC105:2020, respectively. The base shear identified from the analysis is shown in Figure 6. Based on the analysis result, it is determined that the base shear from NBC 105:2020 had 28.59% ULS and 22.7% SLS more than that determined from NBC 105:1994 for the ES analysis. On the other hand, for the RS analysis considering NBC 105:2020, the base shear was determined to have 27.56% more ULS and 21.75% more SLS. Scale factors obtained for the RS analysis were 2.57 and 2.751 from NBC 105:1994 and 1.12 and 1.175 from NBC 105:2020 in X and Y-directions, respectively.

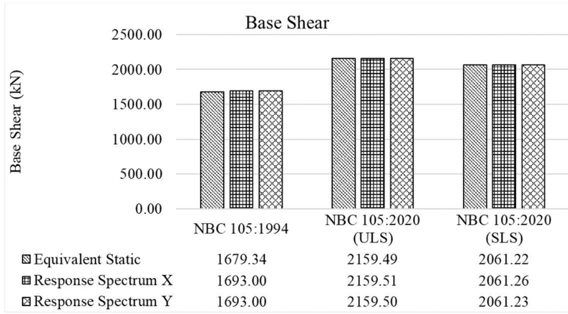

Fig. 6. Base shear as per Nepal Standard NBC 105.

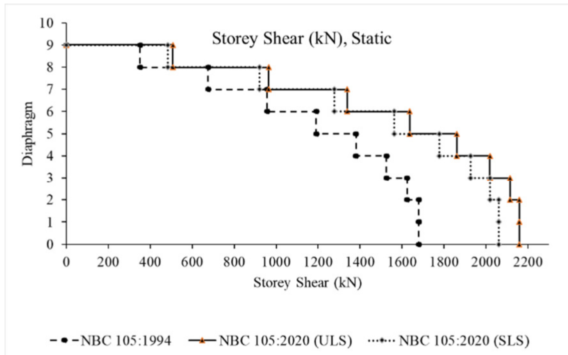

Fig. 7. Story shear from ES analysis using NBC 105:1994 and NBC 105:2020.

Figures 7 and 8 display the story shear acquired from the analysis. The story shear obtained from NBC105:2020 was extended by 33% (ES, ULS), 27% (ES, SLS), 37% (RS, ULS), and 31% (RS, SLS) more than that obtained from NBC105:1994.

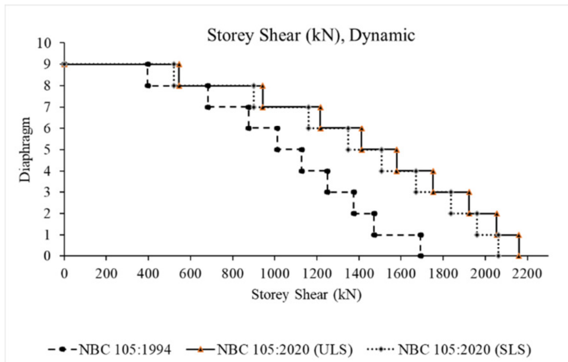

Fig. 8. Story shear from RS analysis using NBC 105:1994 and NBC 105:2020.

The story displacement, depicted in Figures 9 and 10, indicates that the displacement due to SLS aligns more closely with NBC105:1994 than the ULS analysis using NBC105:2020 does. In the X-direction, story design displacements from NBC 105:2020 were found to be 5.39 times (ES) and 11.36 times (RS) more, while in the Y-direction, they were 5.39 times (ES) and 10.9 times (RS more than those obtained from NBC105:1994.

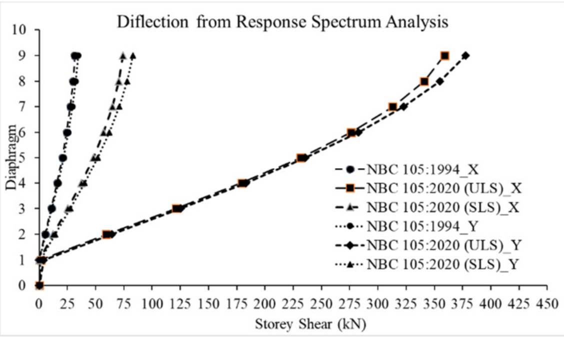

Fig. 9. Diaphragm displacement from ES analysis.

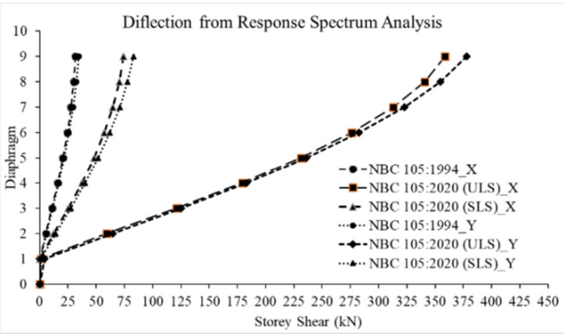

Fig. 10. Diaphragm displacement from RS analysis.

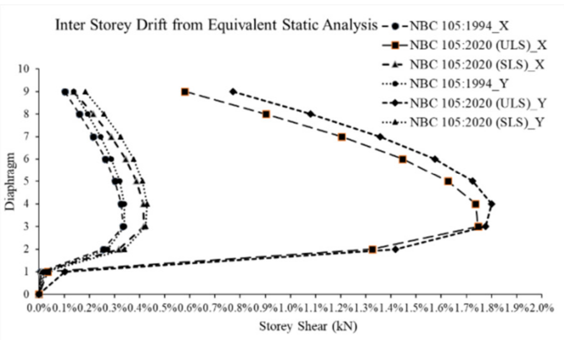

Fig. 11. ISD for ES analysis.

The allowable percentage for ISD as per NBC105:1994 is 0.4% and as per NBC105:2020 is 2.5% (ULS) and 0.6% (SLS). ISD is determined as the ratio of the inter-story design deflection to the corresponding story height. Figures 11 and 12 display that ISD from NBC105:1994 is close to the ISD from NBC105:2020 (SLS). ISD derived from ES analysis using NBC105:2020 was 5.24 (ULS) and 1.25 (SLS) along the X-direction, and 5.31 (ULS), 1.27 (SLS) along the Y-direction, times more than that attained from NBC 105:1994 . In contrast, according to the RS analysis, ISD using NBC105:2020 was 6.18 (ULS), 1.48 (SLS) along the X-direction and 5.69 (ULS), 1.37 (SLS) along the Y-direction, times more than that acquired from NBC 105:1994.

The maximum base shear obtained from NBC 105:1994 is 1693.002 kN, while NBC 105:2020 yields a higher value of 2159.51 kN, as observed in Figure 6. Analysis indicates six hinges at the IO-LS level with a base force of 8261.1 kN, as detailed in Table IV (showing only a portion of the analysis). The building's capacity for MCE is determined to be 11335.54 kN, as illustrated in Figure 13, showcasing its resilience and performance under seismic forces.

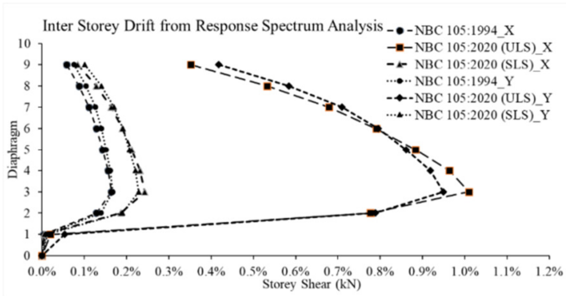

Fig. 12. ISD for RS analysis.

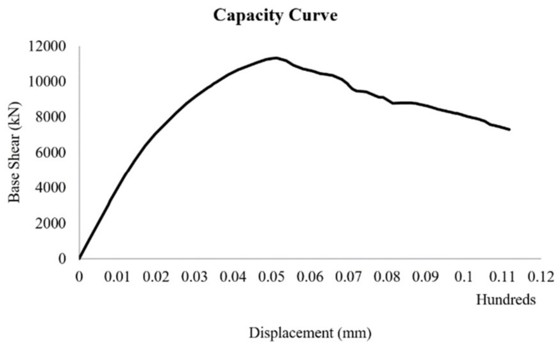

Fig. 13. Capacity curve.

TABLE IV. HINGE FORMATION IN NONLINEAR STATIC ANALYSIS

Step	Monitored displacement	Base force	A-IO	IO-LS	LS-CP	>CP	Total
	mm	kN					
0	0	0	1389	0	0	0	1389
1	25.176	1033.699	1389	0	0	0	1389
2	50.351	2059.075	1389	0	0	0	1389
3	75.527	3048.445	1389	0	0	0	1389
4	81.000	3258.706	1389	0	0	0	1389
5	119.170	4690.635	1389	0	0	0	1389
6	144.519	5573.899	1389	0	0	0	1389
7	171.275	6373.495	1389	0	0	0	1389
8	197.614	7038.584	1389	0	0	0	1389
9	222.826	7622.341	1389	0	0	0	1389
10	252.926	8261.106	1383	6	0	0	1389
11	279.816	8768.074	1373	16	0	0	1389
12	305.232	9209.993	1365	24	0	0	1389
13	334.491	9655.880	1363	24	2	0	1389

Figure 14, generated through ETABS using the FEMA440 EL plot type, visually depicts the structural design as per NBC 105:2020. The pushover analysis demand curve obtained using NBC 105:1994 indicates significantly lower values compared to those when employing NBC 105:2020, highlighting the enhanced seismic resilience of the building under the updated code. In both cases, the building remains within IO-LS, emphasizing its improved earthquake performance and reinforcing the importance of adopting contemporary seismic design standards.

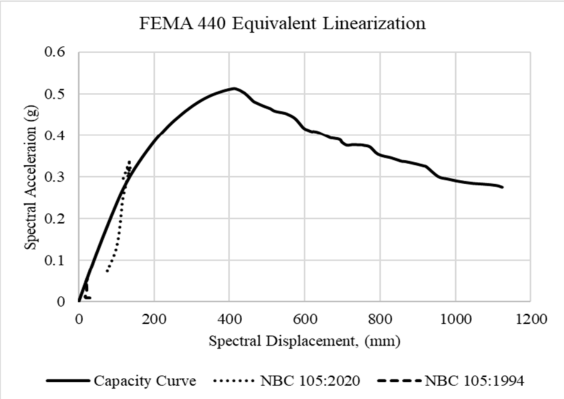

Fig. 14. Pushover curve.

IV. CONCLUSION

In this study, NBC 105:194 was compared with NBC 105:2020 through a case study and it was determined that NBC 105:2020 is more resilient. The analysis of the case study built the conclusion that the seismic parameters of NBC105:2020 are more enhanced than those of NBC105:1994. The following results were drawn:

- Base shear from NBC 105:2020 was determined to be 28.59% ULS and 1.28 times more than NBC 105:1994 from Equivalent Static (ES) and Response Spectrum (RS) analyses, respectively.
- Story shear of NBC 105:2020 exceeded by 33% (ES) and 37% (RS), the one acquired from NBC105:1994.
- Maximum displacement using NBC105:2020 was determined to be 5.39 (ES) and 11.36 (RS) times more along the X-direction and 5.39 (ES) and 10.9 (RS) times more along the Y-direction, than when utilizing NBC105:1994.
- Maximum Inter-Story Drift (ISD) using NBC105:2020 was 5.24 along the X-direction and 5.31 along the Y-direction times more from the ES analysis and 6.18 along the X-direction and 5.69 along the Y-direction times more from the RS analysis than when deploying NBC105:1994.
- The building is in IO-LS according to the capacity curve and demand curve for the pushover analysis using NBC 105:1994, which is much less than NBC 105:2020, i.e. the building is much more resilient to earthquakes using NBC 105:2020.

The limitation of this study is that the infill model was not created but the weight of the wall was considered in the analysis. The study emphasizes the importance of seismic code evolution in earthquake-prone regions. The findings demonstrate improved seismic performance of the building due to the revision of the Nepal code from NBC 105:1994 to NBC 105:2020. This has global implications, hilighting the continual need for updated and enhanced seismic standards to ensure the resilience of structures in earthquake-prone areas worldwide.

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