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Adapting IS 1893 (2023) for the Nepalese Seismic Context: Evaluating Base Shear Coefficients

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ABSTRACT- This study investigates the applicability of draft IS 1893:2023 for the seismic design of RC buildings in Nepal, focusing on the base shear coefficients for 'Zone VI' bordering Nepal on three sides. Key changes in the code are highlighted that control the design base shear coefficient. One of them is the shift from Deterministic Seismic Hazard Assessment (DSHA) to Probabilistic Earthquake Hazard Assessment (PEHA), which has significantly increased the seismic zone factor. Other changes include updated site classifications, the introduction of serviceability checks, reformed acceleration response spectra, and the provision of minimum design horizontal base shear. The base shear coefficients were obtained using IS 1893:2023 for zone VI for different variations of site categories, structural systems, and importance classes. The obtained coefficients from the code were then compared with the existing NBC 105:2020 and IS 1893:2016 under the fundamental periods. Overall, the base shear coefficients from the IS 1893:2023 (SD) code were found to be the highest in all scenarios followed by the NBC 105:2020 (ULS). Significant margins in the coefficients were seen between these two for the RC SMRF buildings. However, for the dual systems - RC shear wall & RC SMRF buildings, narrow margins were seen. The study reveals implementing IS 1893:2023 in Nepal (Zone VI) would notably increase the base shear, resulting in a potentially more earthquake-resistant design, but also higher construction costs.

KEYWORDS- IS 1893:2023, NBC 105:2020, Seismic codes, Base shear coefficients, Comparative study, RC buildings

I. INTRODUCTION

Nepal is highly susceptible to seismic vulnerability characterized by its location at the convergence of the Indian and Eurasian plates. Nepal has a notorious history of devastating earthquakes such as the earthquakes of 1255, 1408, 1505, 1833, 1934, and 2015. Among these, 1934 (M_w 8.4) and 2015 (M_w 7.8) earthquakes were particularly destructive, each causing over 8,500 deaths and extensive economic losses [1] [2]. The recent earthquake that occurred in Jajarkot on 3rd November 2023 (M_w 5.7) resulted in the loss of 154 lives and damage of 26,557 houses [3]. In a country like Nepal, where seismic activity is frequent, robust seismic codes are crucial. The development of building codes in Nepal began after the 1988 Udayapur earthquake giving birth to the NBC 105:1994. However, NBC 205:1994 was preferred in construction as it followed the mandatory rules of thumb and was comparatively easier to use. The IS 1893:2002 was also very popular in Nepal for the design of structures and was employed more than the NBC 105:1994. Several researchers pointed out various drawbacks of NBC 105:1994 [4] [5] [6] [7]. The Gorkha earthquake in 2015 drew considerable attention from researchers worldwide and led to numerous research in the field of structural and earthquake engineering in Nepal. In 2016, a sixth revision of the Indian code was published and in 2020, the Nepalese seismic code was revised following the Gorkha earthquake. These two codes; IS 1893:2016 and NBC 105:2020 are predominantly used while designing structures in Nepal [8] [9]. Comparative studies show that the Nepalese seismic code is on a more conservative side than the Indian seismic code [6] [10] [11] [12] [13] [14].

In April 2023, the Bureau of Indian Standards (BIS) released a draft version of the seventh revision of IS 1893 (hereafter referred to as IS 1893:2023) [15] [16]. The final version which is yet to be published, will closely resemble the draft code with a few minor changes [17] [18]. One of the major changes in the IS 1893:2023 is that the new seismic zoning map of India is based on the Probabilistic Earthquake Hazard Assessment (PEHA) which previously was based on the Deterministic Seismic Hazard Assessment (DSHA). The values of the zone factor (Z) for different zones are determined based on the various return periods, T_{RP} (years). The current IS 1893:2016 has four seismic zones whereas the IS 1893:2023 has five seismic zones as shown in Figure A2 and A3 of Appendix section. A new zone VI is introduced in this revision which borders Nepal on three sides. Some other important changes are the introduction of serviceability checks, site classifications based on average shear wave velocities, changes in the values of response reduction factors, and so on.

II. AIMS AND SCOPE

Conventionally, when calculating the base shear using IS 1893:2016 for structures situated in Nepal, only the corresponding value of zone V is considered. This value is generally chosen instead of zone IV to be on the more conservative side since Nepal is prone to frequent earthquakes. On the other hand, while employing the NBC 105:2020, different seismic zones are provided which makes it more accurate for base shear calculations within the country. According to the seismic zoning map provided in the IS 1893:2023 code, zone VI borders the three sides of Nepal.

The purpose of this study is to employ the IS 1893:2023 for calculating base shear coefficients for RC buildings in the context of Nepal. To find the base shear coefficients, factors associated with it need to be assessed as well. These factors are site classifications, design acceleration response spectra, importance factor, seismic zone factor, and response reduction factor. Thus, in this study, the base shear coefficient and factors affecting it are evaluated and compared with the existing Indian and Nepalese codes. All possible variations of base shear coefficients are included in this study. As this study is focused on RC buildings, only Part 1 and Part 2 of IS 1893:2023 are considered.

III. SITE CLASSIFICATION

The local subsoil significantly influences ground motion and, consequently, the design response spectrum [19]. Building codes typically account for this effect by categorizing soil strata into simplified site classes and assigning corresponding soil amplification factors [20]. NBC 105:2020 classifies sites into four subsoil categories (A-D) based on representative undrained shear strength (S_u) and Standard Penetration Test (SPT) N values. In contrast, the IS 1893:2023 divides sites into five categories (A-E) using average shear wave velocity (V_s) as the basis. This is also one of the key updates in the seventh revision of IS 1893. However, the draft code does not specify the nomenclature of these site classes, nor does it provide correlations between shear wave velocity, SPT values, and undrained shear strength. To address this, a comparison of the shear wave velocity values in the IS 1893:2023 with those in ASCE 7-16 has been made [21]. These are shown in Table 1 to Table 3.

Table 1: Correlation of site classes of IS 1893:2023 with ASCE 7-16 based on shear wave velocity

Site class	V_s (ASCE 7-16)	V_s (IS 1893:2023)	N value (ASCE 7-16)	S_u (ASCE 7-16)
A (Hard rock)	>1524	>1500	-	-
B (Rock)	762-1524	760-1500	-	-
C (Dense soil/Soft rock)	366-762	360-760	>50	>95.8
D (Stiff soil)	183-366	180-360	15-50	48-95.8
E (Soft clay soil)	<183	<180	<15	<48

Table 2: Correlation of site classes of NBC 105:2020 and IS 1893:2016 based on N-values

N value	NBC 105:2020	IS 1893:2016
>30	A (Stiff/Hard soil)	A (Rock/Hard soil)
10-30	B (Medium soil)	B (Medium/Stiff soil)
4-10	C (Soft soil)	C (Soft soils)
<4	D (Very soft soil)	

Table 3: Correlation of site classes of NBC 105:2020 and ASCE 7-16 based on S_u

Site class (ASCE 7-16)	S_u (ASCE 7-16)	S_u (NBC 105:2020)
A (Hard rock)	-	
B (Rock)	-	
C (Dense soil/Soft rock)	>95.8	>100 (Site A)
D (Stiff soil)	48-95.8	50-100 (Site B)
E (Soft clay soil)	<48	12.5-50 (Site C)
		<12.5 (Site D)

The above tabular descriptions of site classes are represented in graphical forms which are illustrated in Figure 1 to Figure 3

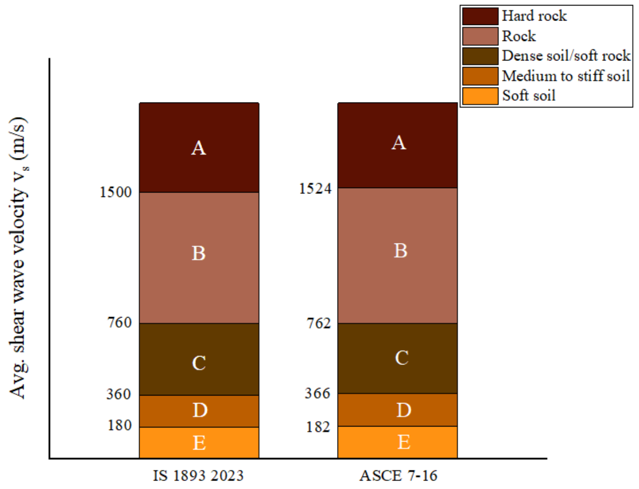


Figure 1: Comparison of site classes between IS 1893:2023 and ASCE 7-16 based on average shear wave velocities

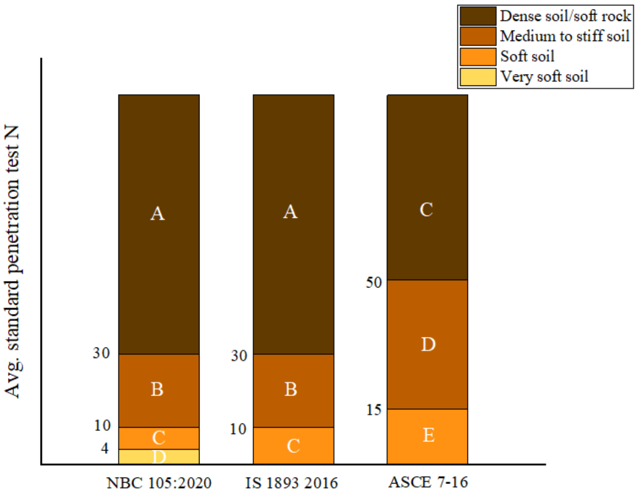


Figure 2: Comparison of site classes between NBC 105:2020, IS 1893:2016, and ASCE 7-16 based on N values

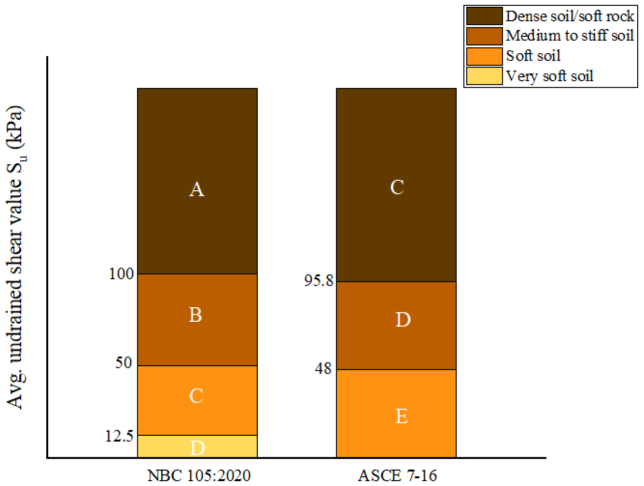


Figure 3: Comparison of site classes between NBC 105:2020 and ASCE 7-16 based on S_u

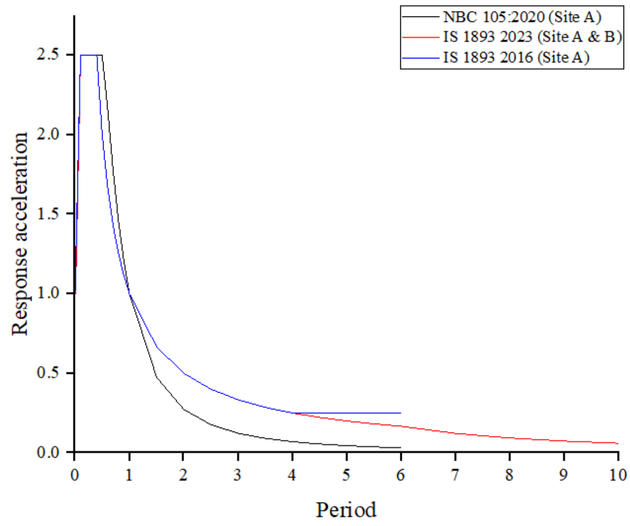
From Table 1 to Table 3, the equivalency of site classes can be interpreted. It is seen that site class A of NBC 105:2020 and IS 1893:2016 is equivalent to the site A, B, and C classes of IS 1893:2023. Similarly, site classes B and C of NBC 105:2020 and IS 1893:2016 are equivalent to the site D and E classes of IS 1893:2023 respectively. However, these correlations are not clearly defined in the IS 1893:2023. This interpretation is based on the site classification data of ASCE 7-16. The response spectrum of site E in IS 1893:2023 is not defined instead site-specific hazard assessment is suggested by the code. Therefore, the comparison of site E in IS 1893:2023 with site C in NBC 105:2020 and IS 1893:2016 is not possible. Hence, the site classes of IS 1893:2023 are assumed to be equivalent to NBC 105:2020 and IS 1893:2016 as shown in Table 4.

Table 4: Equivalent site classes among NBC 105:2020, IS 1893:2016 and IS 1893:2023 used in the study

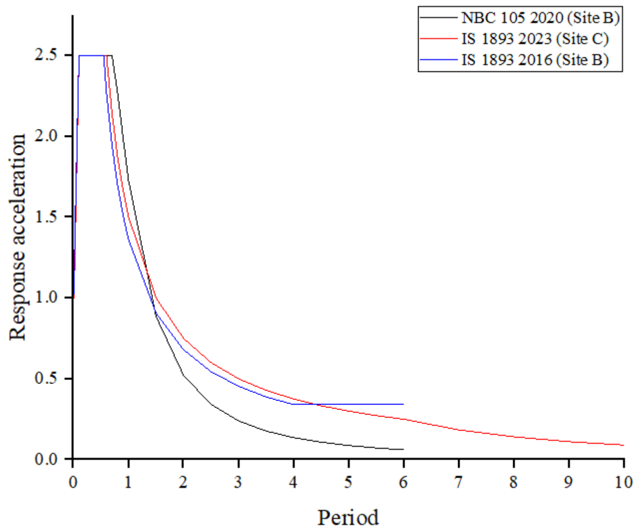
NBC 105:2020	IS 1893:2016 equivalent site class	IS 1893:2023 equivalent site class
A (Stiff/Hard soil sites)	A	A, B
B (Medium soil sites)	B	C
C (Soft soil sites) D (Very soft soil sites)	C	D

IV. DESIGN ACCELERATION RESPONSE SPECTRA

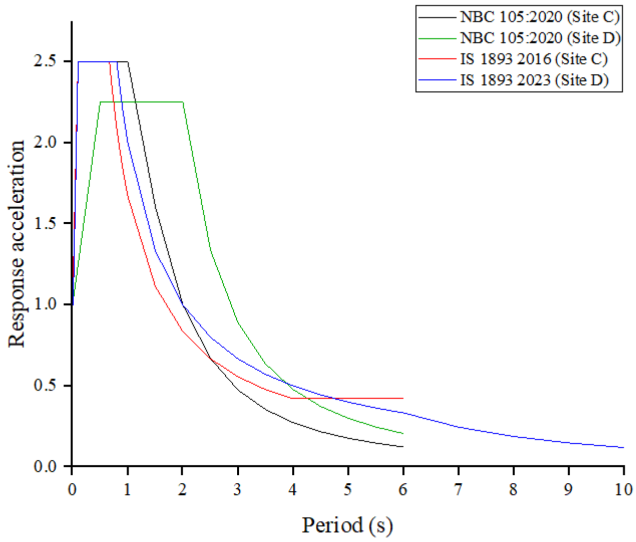
The design acceleration response spectrum is termed as the spectral shape factor (C_hT) in the NBC 105:2020. Four distinct response spectra are provided for four site classes in the Nepalese code. Similarly, for four site classes, three response spectrum graphs are provided in the IS 1893:2023 code. For site classes A and B in the IS 1893:2023 code, an identical response spectrum is made. For site class E, site-specific hazard assessment is required. A damping ratio of 5% is conventionally employed in building design codes. Comparisons of the response spectra for equivalent site classes are shown in Figure 4.



(i) Hard soil



(ii) Medium soil



(iii) Soft soil

Figure 4: Comparison of acceleration response spectra for i) Hard soil ii) Medium soil iii) Soft soil according to NBC 105:2020, IS 1893:2023, and IS 1893:2016

V. IMPORTANCE FACTOR

Based on the intended use, occupancy, and potential level of failure, an importance level is assigned to a structure. This helps in adjusting the magnitude of design loads that are applied to the structure so that they can withstand severe conditions. According to the Nepalese code, there are three importance classes classified as I, II, and III with factors 1,1.25, and 1.50 respectively. These are based on the structure type, for instance, low-rise residential buildings fall under I, school buildings fall under II and critical structures such as hospitals fall under III class. Similarly, the IS 1893:2023 code has classified structures into five categories based on the relative severity of the consequences in the event of failure of structures. These five categories are normal structures, important structures, critical and lifeline structures, special structures, and nuclear power plant structures. Each type of structure is further divided into specific sub-categories (referred to as Set 1, Set 2, Set 3, and Set 4). These sub-categories help in classifying the structures into one of the five broader categories. The importance factor assigned to the normal structures, important structures, critical and lifeline structures, and special structures is 1.0 (with an exception for some particular normal structures whose factor is to be taken 1.15). This uniform importance factor for all building types is justified by the differences in the return period assigned to these structures. For example, the return period (T_{RP}) of strength design for a normal structure is 475 years whereas for important structures the TRP is 975 years. Depending on these T_{RP}, the zone factor also varies. For nuclear power plant structures, the importance factor is to be specified by the Atomic Energy Regulatory Board (AERB), Government of India. A summary of these details is shown in Table 5.

Table 5: Importance factor for various structures according to IS 1893:2023

Category of structures	Return period		Importance factor, I
	Strength design	Serviceability check	
Normal structures	475	73	1.0 & 1.15
Important structures	975	225	1.0
Critical and lifeline structures	2475	475	1.0
Special structures	4995	975	1.0
Nuclear power plants	To be specified by the appropriate statutory authority		

VI. SEISMIC ZONE FACTOR

Nepal is divided into various seismic regions as per the national seismic code with zone factor (Z) ranging from 0.25 to 0.40. This value can be obtained from the contour map shown in Figure A1 of Appendix section. Some specific locations of Nepal have been listed with their corresponding Z value in Table 4 and 5 of NBC 105:2020. This shows variations in the zone factor from region to region within Nepal. The values of Z were determined by PSHA. The value of Z represents the PGA for a 475-year return period. On the other hand, the seismic hazard mapping in IS 1893:2016 was based on DSHA. However, the draft IS 1893 code is based on PSHA which is named Probabilistic Earthquake Hazard Assessment (PEHA). This change is one of the key changes in the 7th revision. The seismic hazard map is based on the PGA values expected at the ground surface conducted by PSHA corresponding to a return period of 2475 years. A new seismic zone is introduced in this revision i.e. 'Zone VI' for the most severe zone where seismic intensity is maximum. Two different values of zone factors are introduced for strength design and serviceability checks which indicates that the Indian code is stepping towards performance-based design [17]. From the seismic zoning map, it can be seen that the three sides of India bordering Nepal are Zone VI. Therefore, in this study, the corresponding values of PGA of Zone VI are taken for Nepal for all return periods. The Z values assigned to zone VI for different return periods according to the IS 1893:2023 are shown in Table 6.

Table 6: Zone factors (Z) assigned to zone VI in IS 1893:2023 for different return periods

Return periods (T_{RP}) in years	Zone factor (Z) assigned to zone VI
73	0.3000
225	0.3750
475	0.5000
975	0.6000
2475	0.7500
4975	0.9375
9975	1.1250

VII. RESPONSE REDUCTION FACTOR

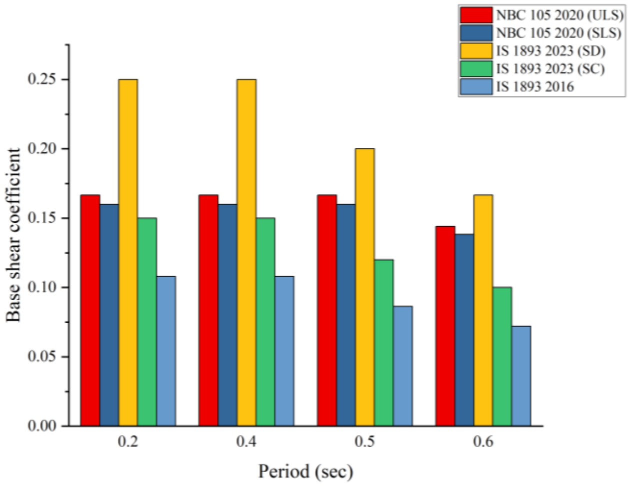
To account for the structure's inelastic behavior, the Response Reduction Factor (R) is introduced while calculating the lateral forces. According to the Applied Technology Council, R is the product of ductility (R_μ), overstrength (Ω), and redundancy factor (R_r) [22]. The NBC 105:2020 has a combination of overstrength factor (Ω_U for ULS and Ω_S for SLS) and ductility factor (R_μ for ULS and R_S SLS) to design a structure so that they are economical as well as have adequate strength. In the IS 1893:2023 code, the previous response reduction factors have been modified and renamed as 'Elastic Force Reduction Factors'. A comparison of the response reduction factor is shown in Table 7.

Table 7: Comparison of response reduction factors provided in NBC 105:2020, IS 1893:2023, and IS 1893:2016

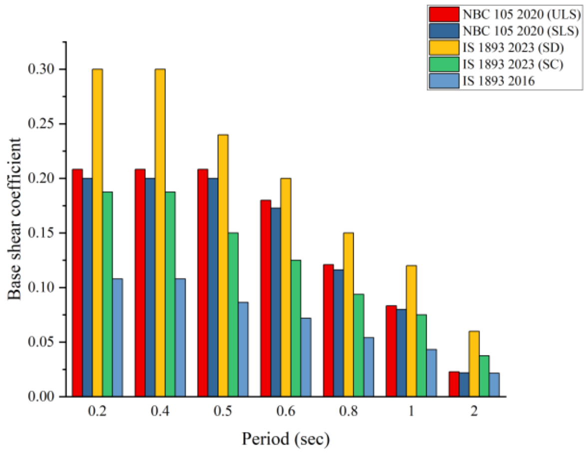
RC structural systems	IS 1893 2016	IS 1893 2023	NBC 105:2020	
	R	R	R_μ / R_s	Ω_U/Ω_S
RC buildings SMRF	5.0	5.0	4.0 / 1.0	1.50/ 1.25
Dual systems - Buildings with RC SSWs-NBE & RC SMRF	5.0	5.5	3.5 / 1.0	1.40/ 1.20
Dual systems - Buildings with RC SSWs-BE & RC SMRF		6.0		

VIII. DESIGN BASE SHEAR COEFFICIENT

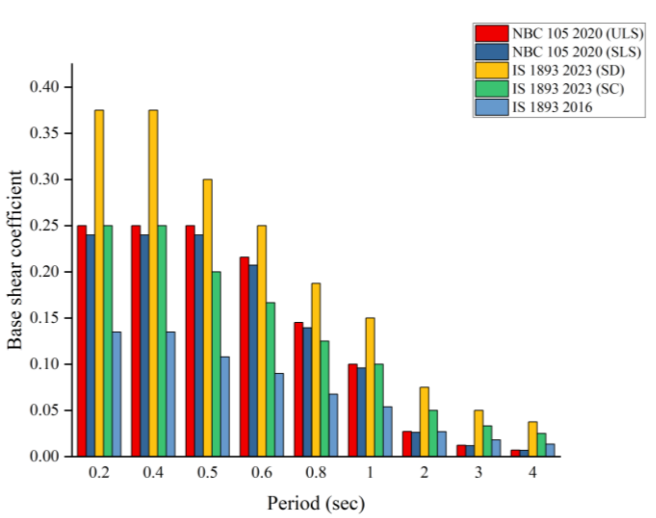
A combined contribution of all the above-mentioned parameters accounts for the design base shear of structures in the Nepalese and Indian seismic codes. The base shear coefficients are calculated according to the provisions of NBC 105:2020, IS 1893:2023, and IS 1893:2016 and compared with variations of sites, importance factors, and structural systems. Three sites are taken for the study i.e. hard soil, medium soil, and soft soil. Similarly, three importance classes i.e. class 1, 2, and 3 (normal, important, and critical structures respectively) are taken with corresponding importance factors from the codes. Three RC structural systems are considered. They are RC Special Moment Resisting Frame (RC-SMRF) structures, dual systems-RC Special Structural Walls with Non-Boundary Elements (RC SSWs NBE & RC SMRF), and dual systems-RC Special Structural Walls with Boundary Elements (RC SSWs BE & RC SMRF). While calculating the base shear coefficients using IS 1893:2023 for Nepal, only zone VI is considered since only zone VI borders Nepal on three sides. The values obtained from these calculations are then compared with the values of the base shear coefficient obtained from NBC 105:2020 and IS 1893: 2016 at maximum PGA values (i.e. Z=0.36 for Indian code and Z=0.40 for Nepalese code. For the Nepalese code, both Ultimate Limit State (ULS) and Serviceability Limit State (SLS) were considered. Similarly, for the draft Indian code, both Strength Design (SD) and Serviceability Check (SC) were considered. Also, the period is limited to 0.6s for normal structures, 2s for important structures, and 4s for critical structures. These are shown in Figure 5-7.



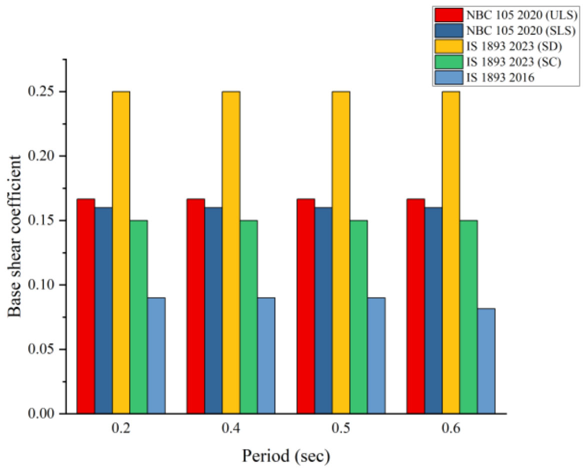
(i) Hard soil-Importance class 1



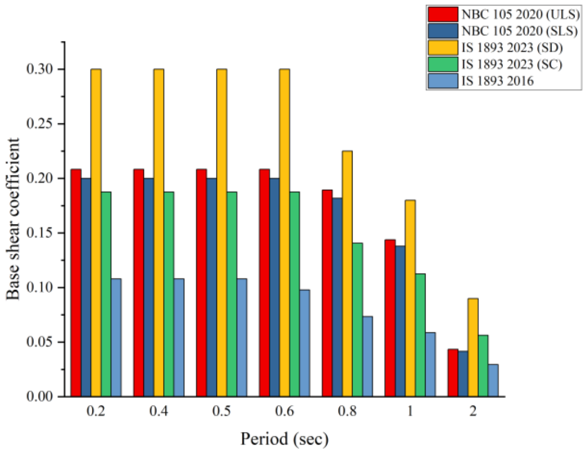
(ii) Hard soil-Importance class 2



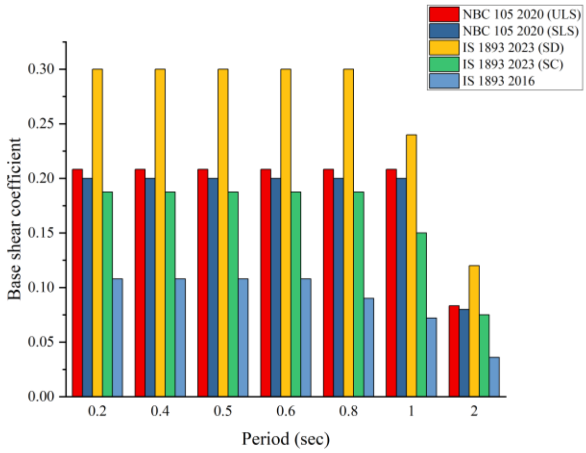
(iii) Hard soil-Importance class 3



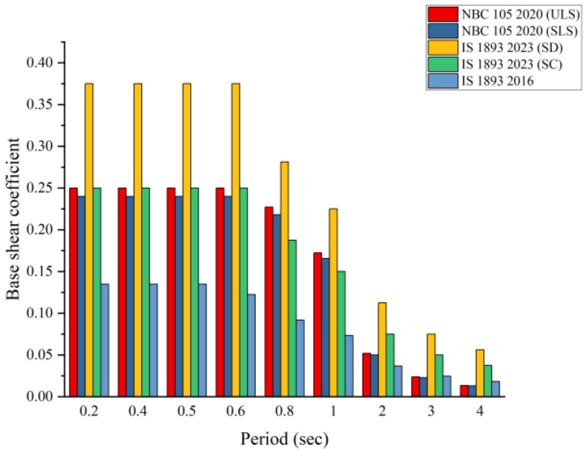
(iv) Medium soil-Importance class 1



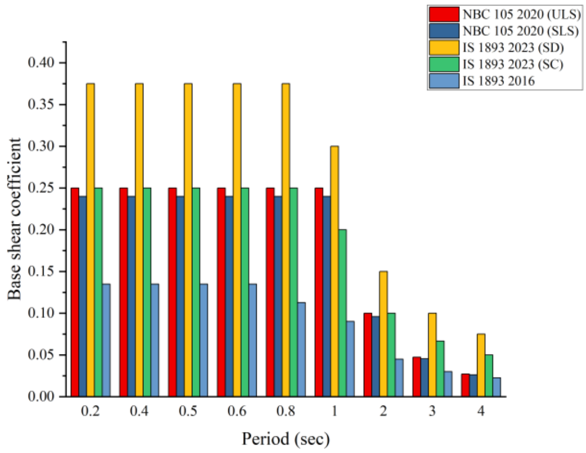
(v) Medium soil-Importance class 2



(viii) Soft soil-Importance class 2



(vi) Medium soil-Importance class 3



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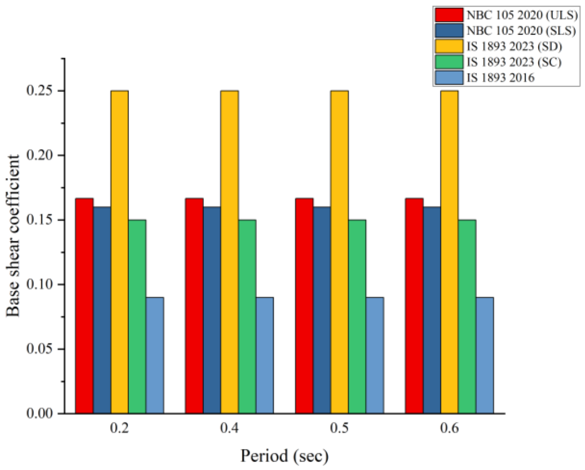
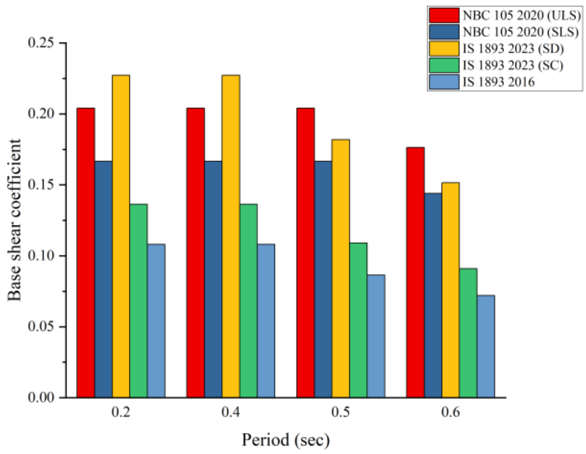


(vii) Soft soil-Importance class 1

Figure 5 Comparison of design base shear coefficients of NBC 105:2020, IS 1893:2023, and IS 1893:2016 for RC SMRF structures



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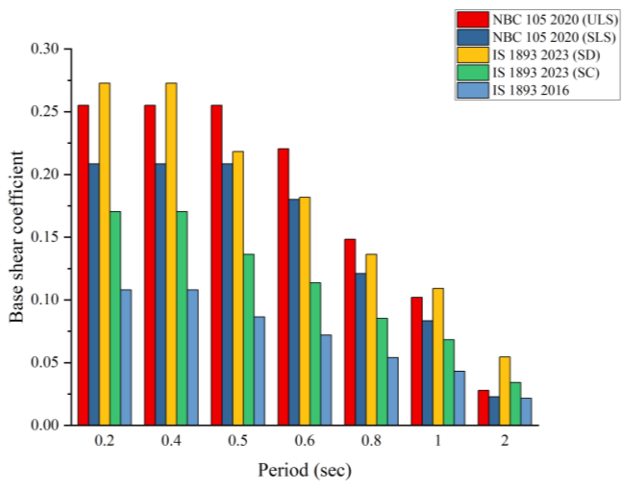

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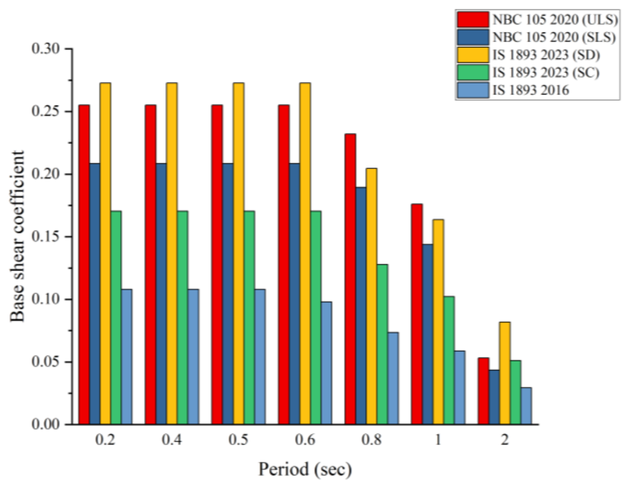
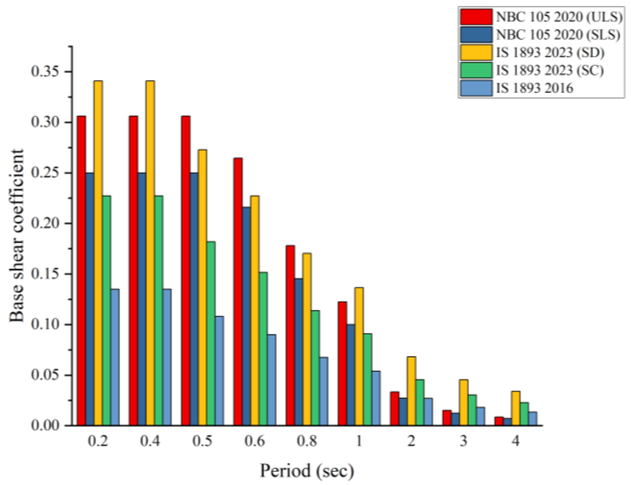


(v) Medium soil-Importance class 2



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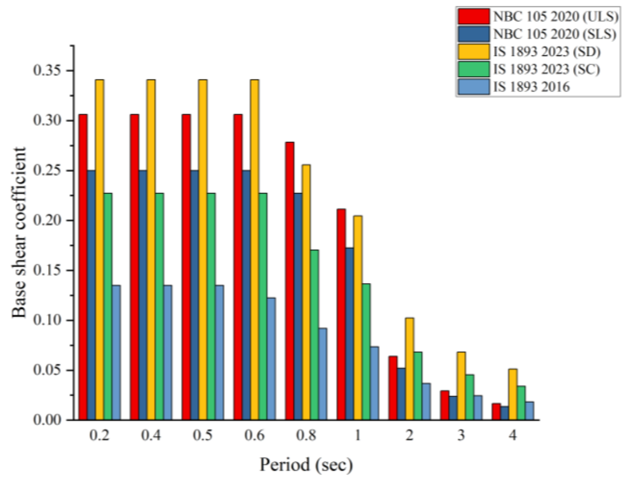

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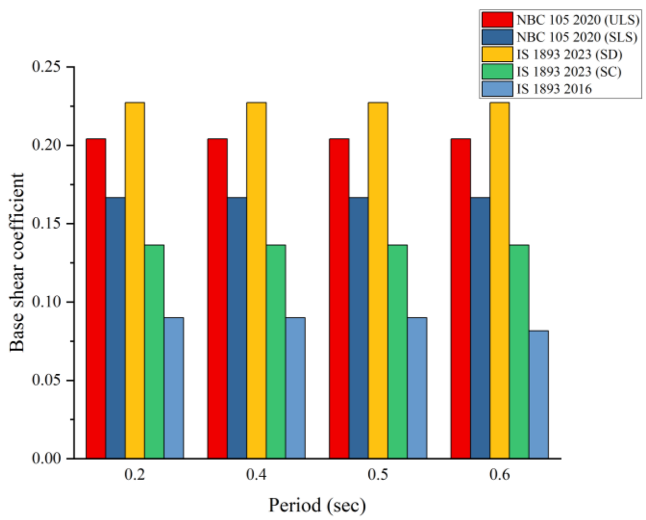

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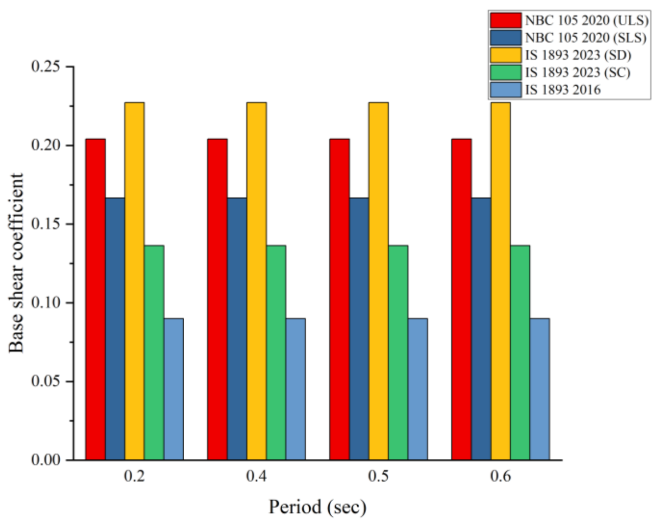
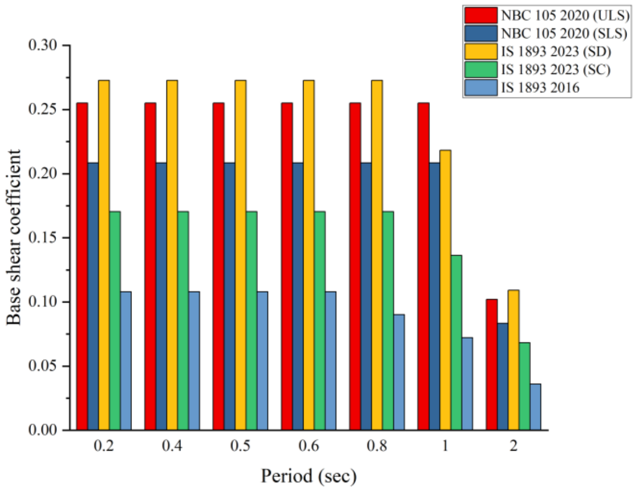


(vii) Soft soil-Importance class 1



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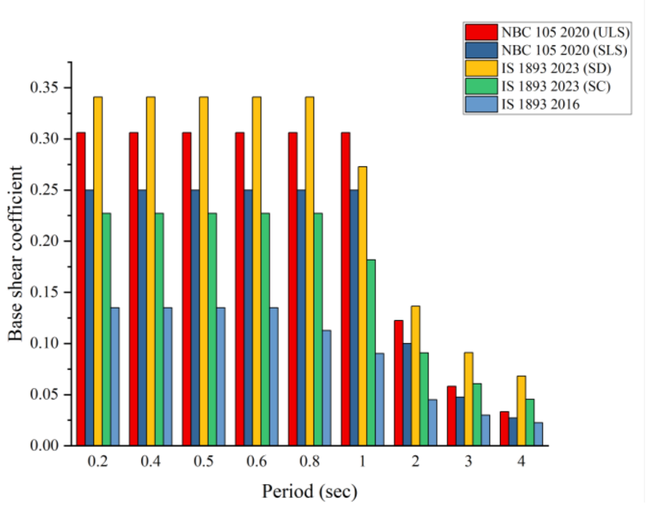
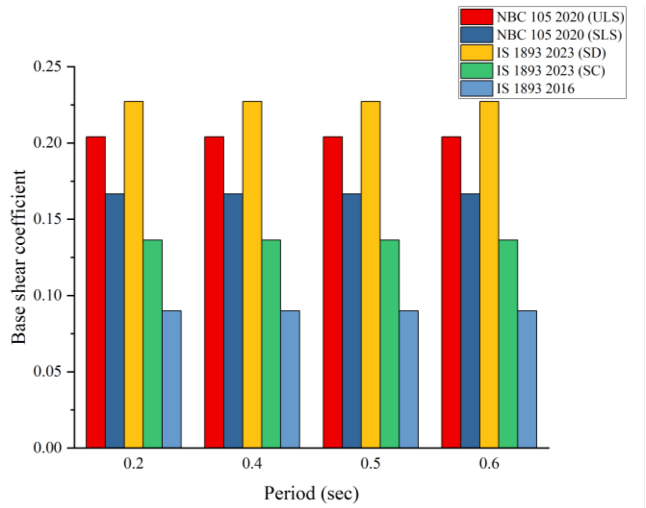


(ix) Soft soil-Importance class 3

Figure 6 Comparison of design base shear coefficients of NBC 105:2020, IS 1893:2023, and IS 1893:2016 for dual systems – buildings with RC SSWs-NBE and RC SMRF



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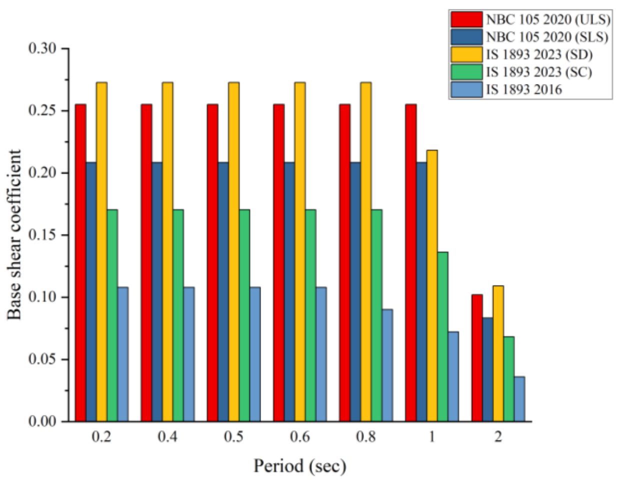

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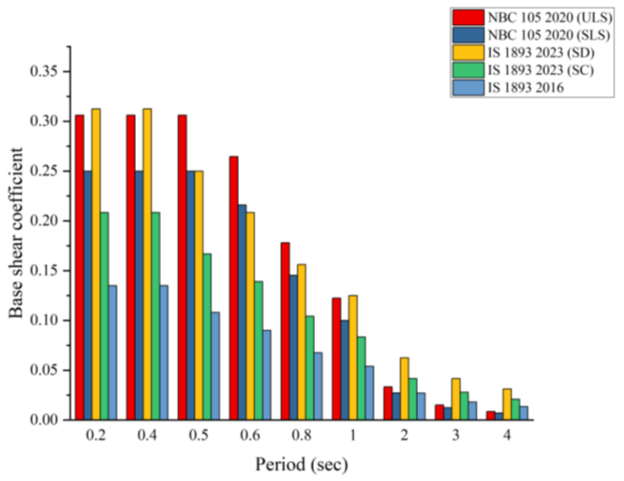

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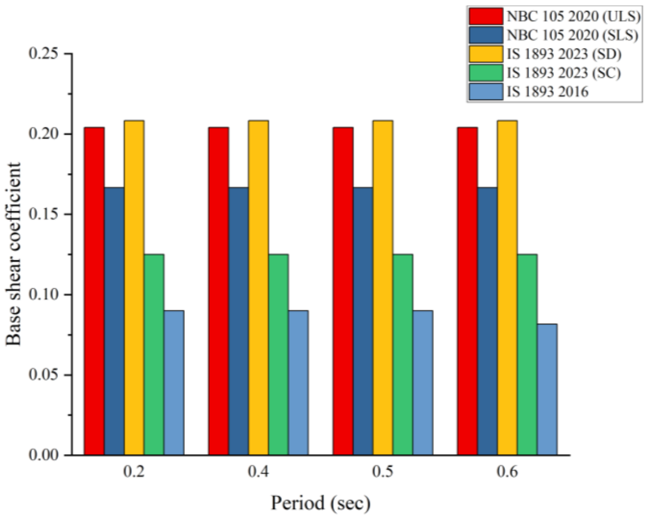

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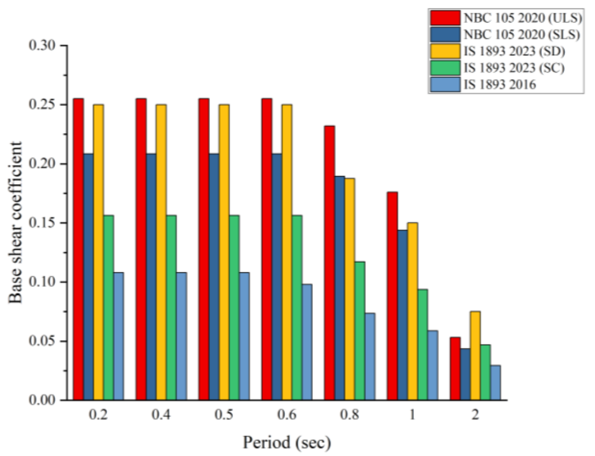
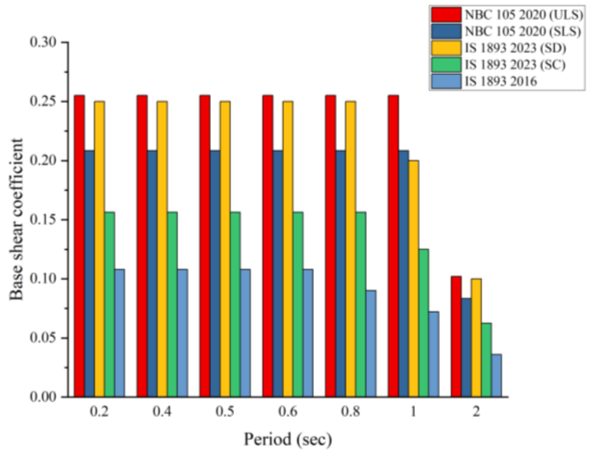
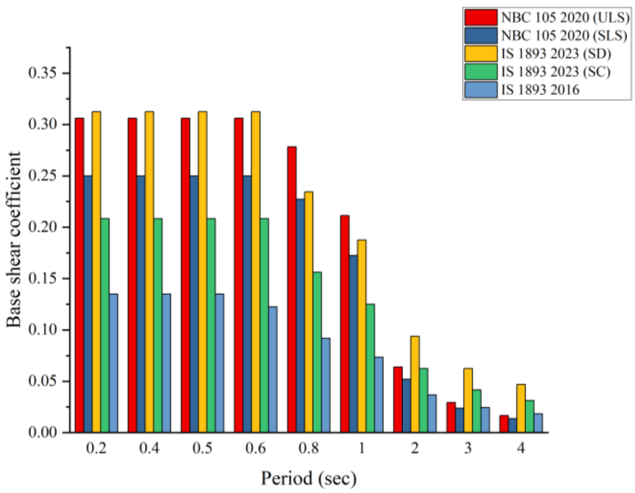


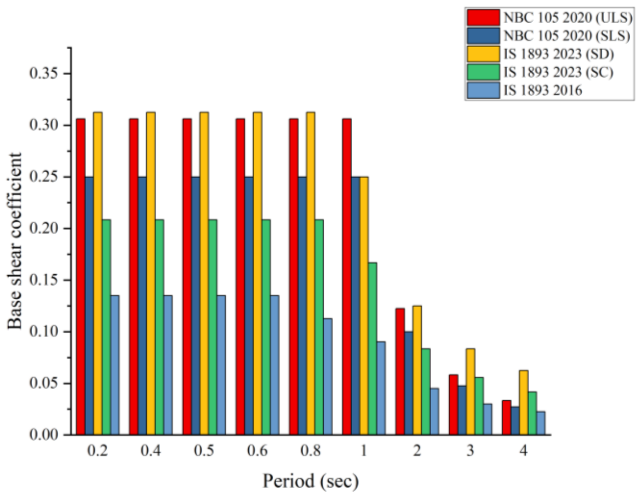
(v) Medium soil - Importance class 2



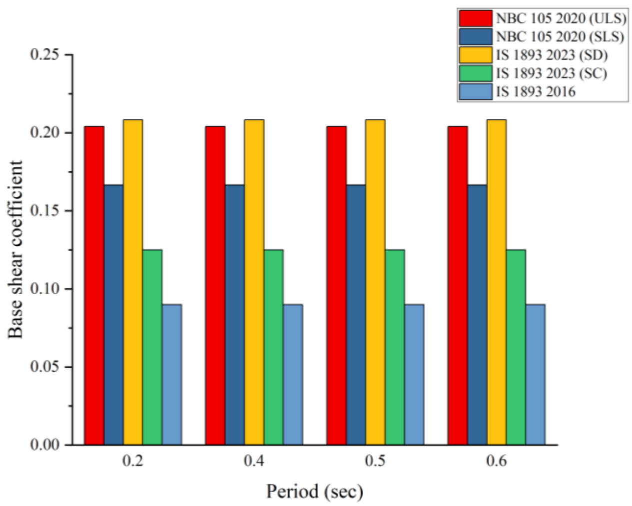
(viii) Soft soil-Importance class 2



(vi) Medium soil - Importance class 3



(ix) Soft soil - Importance class 3



(vii) Soft soil-Importance class 1

Figure 7 Comparison of design base shear coefficients of NBC 105:2020, IS 1893:2023, and IS 1893:2016 for dual systems – buildings with RC SSWs-BE and RC SMRF

IX. CONCLUSIONS

In the study, parameters controlling the base shear coefficient as provided in the Nepalese code, current Indian code, and draft Indian code have been described thoroughly and compared. Following this, base shear coefficients were obtained from the IS 1893:2023 for strength design and serviceability check and then compared with NBC 105:2020 and IS 1893:2016. Corresponding values of zone factors were taken from the Indian codes for the seismic context of Nepal whereas only the maximum value of zone factor was taken from the Nepalese code for calculations. Multiple variations in site classes, importance classes, and structural systems were made to get a broader range of results and exploration of extremes. The following conclusions are drawn from the study:

- One of the major changes in the IS 1893:2023 is the incorporation of the new seismic hazard map which is based on the Probabilistic Earthquake Hazard Assessment (PEHA). This has led to a significant increment in the zone factors of overall regions. Previously, while adopting the IS 1893:2016 for the seismic design of buildings in Nepal, zone V was considered and therefore zone factor was 0.36. This value was the Maximum Considered Earthquake (MCE) value for seismic design. For the Design Basis Earthquake (DBE), this value was multiplied by a factor of 0.5. However, in the IS 1893:2023, there is no clarification regarding whether the zone factor is considered MCE or DBE. Considering this, new zone factors will significantly increase the base shear for buildings in Nepal.

- A new approach towards the classification of site categories is seen in the IS 1893:2023 which is based on the average shear wave velocity. Four site classes were taken for base shear coefficient calculation and comparisons were made with the equivalent site classes from the current Nepalese and Indian codes. It was found that no clear correlations of site classifications between present IS and previous IS codes were made. Therefore, based on the assumption shown in Table 5, further analyses were done.
- Three design response acceleration spectra were drawn on three different equivalent site classifications. From spectra, it was found the responses from the IS 1893:2023 were lower than the from the NBC 105:2020 for shorter periods and vice versa for all site categories. However, the responses from IS 1893:2023 were higher than the IS 1893:2016 for medium soil and soft soil site categories but identical responses for hard soil site categories. In addition, the response spectra have been defined up to 10s in the draft code.
- Three importance classes, three structural systems, and three site classifications were taken for the study. Overall, the base shear coefficients from the IS 1893:2023 (Strength Design) are the maximum in all scenarios followed by the NBC 105:2020. For RC SMRF buildings, significant margins between IS 1893:2023 (SD) and NBC 105:2020 (ULS) can be seen in the base shear coefficients, particularly in the lower range of periods (45% - 50%). The ranges of base shear coefficients from IS 1893:2023 and NBC 105:2020 (ULS and SLS) are in similar ranges whereas the base shear coefficients from IS 1893:2016 are the lowest among all. For dual systems, the differences in base shear coefficients from IS 1893:2023 and NBC 105:2020 are 10%-15% only. From the comparative base shear coefficient graphs (Figure no. 5-7), it is evident that the coefficients from the IS 1893:2023 (strength design) are the highest among all for zone VI. Thus, adopting IS 1893:2023 in Nepal (Zone VI) would significantly increase the base shear, leading to a potentially more seismically resistant design but also higher construction costs.

APPENDIX

A. Base shear coefficient calculation formulae

The expressions adopted by the NBC 105:2020, IS 1893:2023, and IS 1893:2016 are shown in Table A-1.

Table A-1 Formulae for calculating base shear coefficients

1.	NBC 105:2020 (ULS)	$C_d(T_1)$	=	$\frac{C(T_1)}{(R_\mu)(\Omega_u)}$
2.	NBC 105:2020 (SLS)	$C_d(T_1)$	=	$\frac{0.2C_h(T)ZI}{\Omega_s}$
3.	IS 1893:2023 (SD)	$A_{HD}(T)$	=	$\frac{A_{NH}(T)ZI}{R}$
4.	IS 1893:2023 (SC)	$A_{HD}(T)$	=	$\frac{A_{NH}(T)ZI}{R}$
5.	IS 1893:2016	A_h	=	$\frac{ZIS_a}{2Rg}$

Expression for minimum horizontal base shear according to IS 1893:2023:

$$V_{BD,\,H,\,min} = 0.625 * \frac{ZI}{R}$$

B. Seismic hazard maps of Nepal and India

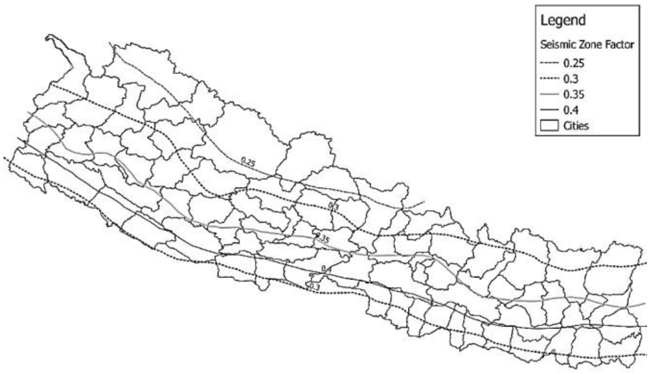


Figure A1: Seismic zoning map of Nepal according to NBC 105:2020

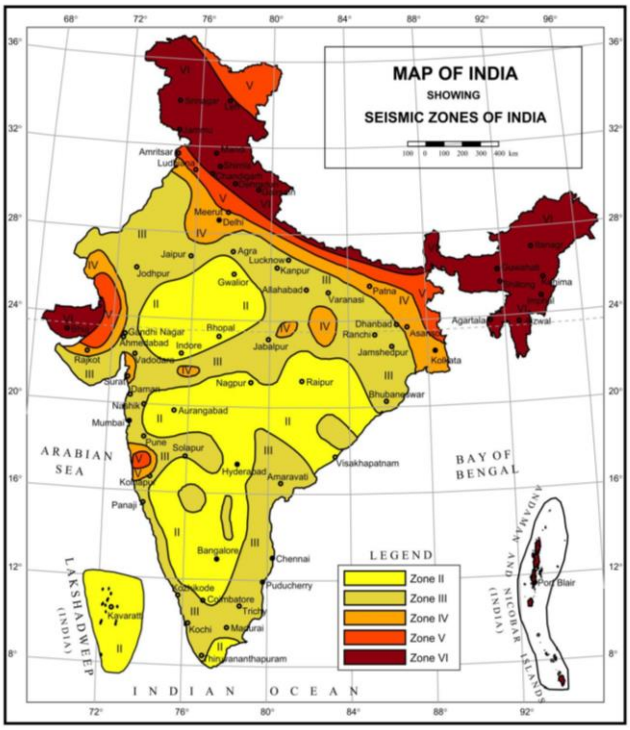


Figure A2: Seismic zoning map of India according to IS 1893:2023

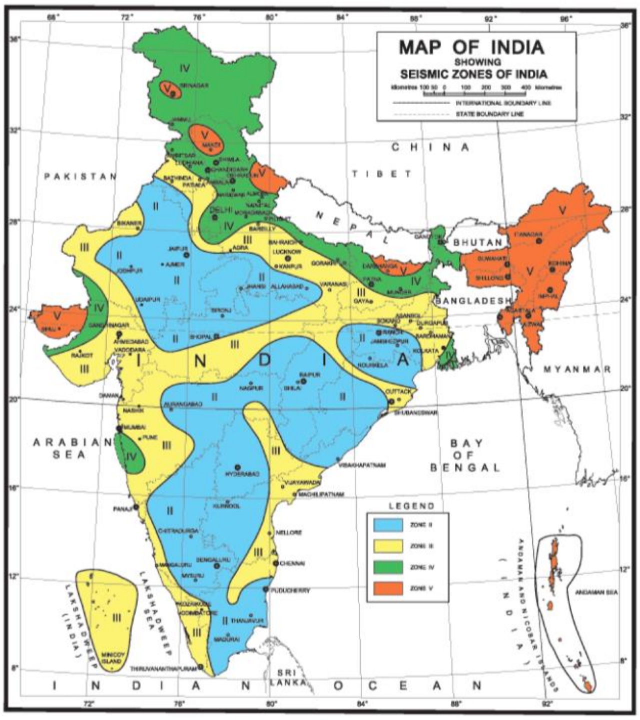


Figure A3: Seismic zoning map of India according to IS 1893:2016

ABBREVATIONS

DBE	=	Design Basis Earthquake
DSHA	=	Deterministic Seismic Hazard Assessment
I	=	Importance Factor
IS	=	Indian Standard
MCE	=	Maximum Considered Earthquake
NBC	=	Nepal Building Code
PEHA	=	Probabilistic Earthquake Hazard Assessment
PGA	=	Peak Ground Acceleration
PSHA	=	Probabilistic Seismic Hazard Assessment
R	=	Response Reduction Factor
SC	=	Serviceability Check
SD	=	Strength Design
SLS	=	Serviceability Limit State
SMRF	=	Special Moment Resisting Frame
SPT	=	Standard Penetration Test
SSW	=	Special Structural Wall
S_u	=	Undrained shear strength
TRP	=	Return Period
ULS	=	Ultimate Limit State
V_S	=	Shear wave velocity
Z	=	Zone Factor

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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