Строительная механика инженерных конструкций и сооружений
Structural Mechanics of Engineering Constructions and Buildings

2025. 21(3). 270–280

ISSN 1815-5235 (Print), 2587-8700 (Online)
HTTP://JOURNALS.RUDN.RU/STRUCTURAL-MECHANICS

DOI: 10.22363/1815-5235-2025-21-3-270-280
EDN: UMRKLR

Research article / Научная статья

Seismic Vulnerability of Non-Code-Compliant and Code-Compliant RC Buildings

Birendra K. Bohara✉, **Sangam Jagari**, **Nirmal M. Joshi**

Far Western University, *Kanchanpur, Nepal*
✉ bbohara2@gmail.com

Received: February 28, 2025.
Revised: May 15, 2025.
Accepted: May 25, 2025

Abstract. This study investigates the seismic vulnerability of non-code-compliant reinforced concrete (RC) buildings compared to code-based structures. The research uses linear elastic and nonlinear pushover analyses (NPA) to evaluate critical seismic performance parameters such as natural periods, mass participation, base shear, capacity curve, ductility ratio, overstrength factor, collapse mechanics, and nonlinear hysteretic damping (NHD). Structures designed following standards like NBC 205 (old), RUD 205 new, and Indian standard IS 1893 are analyzed against non-code-compliant building samples (NES1–NES6) to highlight performance gaps. The findings reveal that code-compliant buildings demonstrate significantly higher seismic resistance, greater flexibility, effective earthquake energy dissipation, higher ductility, overstrength factor, and base shear capacity. Non-code-compliant buildings often exhibit soft-story failure, with initial damage observed in the columns, highlighting their vulnerability during seismic events. Meanwhile, code-compliant RC buildings (RUD) designed with seismic principles demonstrate better seismic performance, adhering to the “strong column, weak beam” philosophy and superior strength-to-capacity ratios, higher overstrength factors, and enhanced ductility ratios, highlighting their resilience under seismic loads. The results conclude that addressing the code provisions ensures earthquake-resistant buildings with warranted ductile behavior for structural systems, enabling the achievement of the intended collapse mechanism.

Keywords: nonlinear pushover analysis, overstrength factor, NBC

Conflicts of interest. The authors declare that there is no conflict of interest.

Authors’ contribution: *Bohara B.K.* — conceptualization, methodology, data collection, field survey support, modeling and analysis, result interpretation, text writing, supervision; *Jagari S.* — literature review, data tabulation, modeling, text writing and review; *Joshi N.M.* — field documentation, drafting figures and tables, referencing, result interpretation, text review

For citation: Bohara B.K., Jagari S., Joshi N.M. Seismic vulnerability of non-code-compliant and code-compliant RC buildings. *Structural Mechanics of Engineering Constructions and Buildings.* 2025;21(3):270–280. http://doi.org/10.22363/1815-5235-2025-21-3-270-280

Birendra K. Bohara, Assistant Professor, Far Western University, Kanchanpur, Nepal; ORCID: 0000-0002-4654-3428; e-mail: bbohara2@gmail.com
Sangam Jagari, UG, School of Engineering, Far Western University, Kanchanpur, Nepal; ORCID: 0009-0001-8595-4940; e-mail: jagarisangam111@gmail.com
Nirmal M. Joshi, UG, School of Engineering, FWU, Kanchanpur, Nepal; ORCID: 0009-0005-0358-8924; e-mail: Joshinirmalmani123@gmail.com

Сейсмическая уязвимость железобетонных зданий, соответствующих и не соответствующих строительным нормам и правилам

Б.К. Бохара✉**, С. Джагари, Н.М. Джоши**

Дальневосточный университет, *Канчанпур, Непал*
✉ bbohara2@gmail.com

Поступила в редакцию: 28 февраля 2025 г.
Доработана: 15 мая 2025 г.
Принята к публикации: 25 мая 2025 г.

Аннотация. Исследована сейсмическая уязвимость железобетонных зданий, не соответствующих требованиям строительных норм и правил в сравнении с сооружениями, построенными с их соблюдением. Для оценки критических сейсмических характеристик, таких как собственный период колебаний, коэффициент участия масс, поперечная сила в основании, спектр несущей способности, коэффициент пластичности, коэффициент сверхпрочности, механика разрушения и нелинейное гистерезисное демпфирование, использован линейный упругий и нелинейный статический расчет. Сооружения, спроектированные в соответствии с непальскими сводами правил NBC 205 (старый) и RUD 205 (новый), а также индийским сводом правил IS 1893, были проанализированы относительно образцов зданий (NES1-NES6), не соответствующих строительным нормам, с целью выявить различие в характеристиках. Полученные результаты показывают, что здания, соответствующие строительным нормам, демонстрируют значительно более высокую сейсмостойкость, гибкость, эффективное рассеивание энергии землетрясения, высокую пластичность, коэффициент сверхпрочности и предел поперечной силы у основания. В зданиях, не соответствующих строительным нормам, часто наблюдается разрушение гибкого этажа, при этом первоначальные повреждения наблюдаются в колоннах, что подчеркивает их уязвимость во время сейсмической активности. Вместе с тем железобетонные здания, спроектированные по RUD с учетом сейсмических принципов, демонстрируют лучшие сейсмические характеристики, придерживаясь концепции «прочная колонна, слабая балка», а также превосходное соотношение прочности и сейсмостойкости, более высокие коэффициенты сверхпрочности и пластичности, что подчеркивает их сейсмоустойчивость. Результаты показывают, что соблюдение положений строительных норм и правил обеспечивает сейсмостойкость зданий с гарантированной пластичностью несущей конструкции, что позволяет реализовать расчетный механизм разрушения.

Ключевые слова: нелинейный статический метод, коэффициент сверхпрочности, строительные нормы Непала

Заявление о конфликте интересов. Авторы заявляют об отсутствии конфликта интересов.

Вклад авторов: *Бохара Б.К.* — концептуализация, методология, сбор данных, полевые исследования, моделирование и расчет, интерпретация результатов, написание текста, руководство; *Джагари С.* — обзор литературы, сведение данных в таблицы, моделирование, написание и редактирование текста; *Джоши Н.М.* — полевая документация, составление рисунков и таблиц, ссылки, интерпретация результатов, редактирование текста.

Для цитирования: *Bohara B.K., Jagari S., Joshi N.M.* Seismic vulnerability of non-code-compliant and code-compliant RC buildings // Строительная механика инженерных конструкций и сооружений. 2025. Т. 21. № 3. С. 270–280. http://doi.org/10.22363/1815-5235-2025-21-3-270-280

1. Introduction

Nepal is situated in one of the most seismically active regions in the world, lying along the boundary of the Indo and Eurasian tectonic plates [1]. This geographical setting has exposed the country to frequent and severe earthquakes, necessitating a critical evaluation of building practices to mitigate seismic risks in the structure. The many past earthquakes in 1934 (M_w 8.1), 1980 (M_w 6.5), 1988 (M_w 6.5), 2011 (M_w 6.9), 2015 (M_w 7.8), and 2023 (M_w 5.7) have resulted in a great number of casualties and extensive damage to structures [2–4]. Recent earthquakes Gorkha (2015) and Jajarkot earthquakes (2023) highlighted the vulnerability of many existing structures, particularly non-code-compliant reinforced concrete (RC) buildings, which suffered significant damage and loss of life [5].

Бохара Бирендра Кумар, доцент, Дальневосточный университет, Канчанпур, Непал; ORCID: 0000-0002-4654-3428;e-mail: bbohara2@gmail.com

Джагари Сангам, студент, инженерная школа, Дальневосточный университет, Канчанпур, Непал; ORCID: 0009-0001-8595-4940; e-mail: jagarisangam111@gmail.com

Джоши Нирмал М., студент, инженерная школа, Дальневосточный университет, Канчанпур, Непал; ORCID: 0009-0005-0358-8924; e-mail: Joshinirmalmani123@gmail.com

Non-code-compliant RC buildings, typically constructed without adhering to established design codes, constitute a significant portion of the built environment in Nepal. These structures often lack adequate reinforcement detailing and proper column and beam sizes [6; 7]. It was also observed that structural irregularities, such as vertical and plan irregularities, are commonly present [8–10]. Issues like the presence of short columns, which are highly vulnerable to shear failure, and soft-story configurations, where the ground floor is weaker or more flexible than the upper floors, further exacerbate their vulnerability [11–13]. These deficiencies collectively make non-code-compliant buildings highly susceptible to significant damage or collapse during even moderate seismic events, underscoring the urgent need for improved design practices.

In contrast, code-based RC buildings designed according to national and international seismic standards, such as the Nepal National Building Code (NBC), and Indian Standards (IS 1893), demonstrate significantly higher resistance to seismic forces. However, the comparative performance of these two categories under various seismic loading conditions remains insufficiently explored, particularly in remote and hilly regions, a high seismic risk area in Far-Western Nepal. Previous research has established that non-code-compliant buildings are particularly susceptible to moderate seismic events, with shorter structures showing heightened vulnerability. Studies such as Pokharel et al. (2020) [14] have highlighted the critical need for retrofitting and the enforcement of seismic design codes to reduce earthquake-related damage. It further evaluates current building practices and the sufficiency of existing guidelines, and proposes measures for improving the resilience of structures to mitigate future earthquake risks.

Before the Gorkha earthquake, Nepal's residential buildings, based on NBC 205:1994, lacked seismic considerations, making them highly vulnerable. Enforced in 2005, NBC 205:1994 regulated up to three-story buildings, but inadequate column and beam sizes persisted. The updated NBC 205:2024 introduced Ready-to-Use Detailing (RUD) guidelines, mandating a minimum column size of 320 × 320 mm and improved reinforcement for low-rise RC buildings, enhancing seismic resilience. Prior to RUD, NBC 205:2070 (2010) specified a minimum column size of 300 × 300 mm for rooms up to 4.5 m × 3.0 m, aligning with NBC standards. In Nepal, Indian Standards (IS) are widely followed, particularly IS 1893-2016 for seismic analysis in high-risk zones and IS 13920:1993 for ductile detailing. Dead/live loads follow IS 875, with load combinations per IS 456-2000.

Despite numerous studies on the seismic vulnerability of RC buildings in Nepal, most have primarily focused on basic structural parameters such as inter-story drift, base shear, and displacement, overturning moment under seismic loading, often using simplified linear analysis techniques. However, there remains a significant research gap in the comprehensive evaluation of advanced seismic performance indicators, particularly failure (collapse) patterns, ductility factors ($R\mu$), overstrength (Rs), and nonlinear hysteretic behaviour, especially for non-code-compliant structures prevalent in hilly regions (Darchula) of Nepal. These critical aspects, which provide deeper insights into actual structural behaviour under lateral loads, have received limited attention in the national context. This study addresses that gap by employing both linear and NPA to investigate these underexplored parameters, offering a more detailed understanding of the seismic performance and vulnerabilities of non-code-compliant versus code-compliant RC buildings. By identifying the key weaknesses of non-code-compliant RC buildings and demonstrating the benefits of code-compliant designs, this study aims to contribute to the development of effective seismic risk reduction strategies.

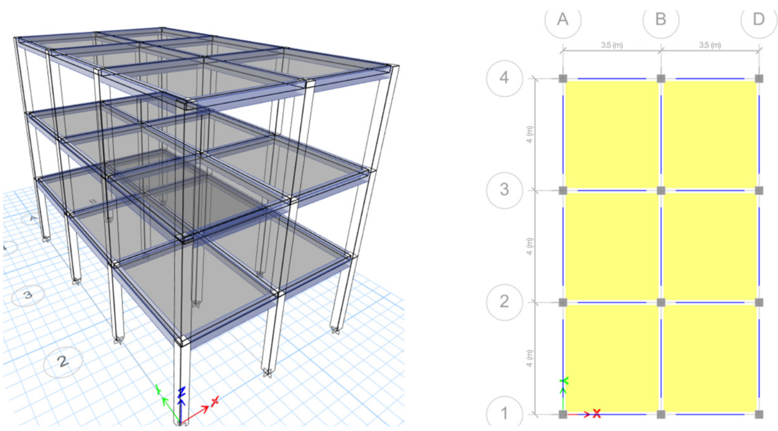
2. Method

Field surveys were conducted in the Darchula District, a high-risk seismic zone in Far-Western Nepal. A total of six non-code-compliant RC buildings (NES1 to NES6) were selected using sampling, based on their typicality, accessibility, and representation of common construction practices and structural aspects in the region (Figure 1). Structural characteristics such as story height, bay length, beam-column dimensions, beam-column joint, reinforcement details, and visible defects were documented using direct measurements, videos, photographs, and site sketches. Data reliability was ensured through repeated site visits and verification against interviews with local masons, house owners and municipal engineers. Common issues include unreinforced masonry, irregular layouts, poor beam-column joints, poor column construction, size of columns and beams, columns in sloping terrain, insufficient amount of reinforcement and the absence of seismic reinforcements like steel ties. Many buildings have undersized columns (230 mm × 230 mm) with less than 0.8% rebar, and beams of similar dimensions, using 10–12 mm bars instead of the required 12–16 mm, often paired with 6mm stirrups spaced too widely (≥ 150 mm). Additionally, improper column casting, insufficient cover, and the use of untested locally made blocks increase structural risks in hillsides. These deficiencies highlight the urgent need for code compliance, quality materials, proper detailing, and sustainable urban planning to mitigate risks and enhance structural safety in earthquake-prone areas.

Figure 1. Non-code-compliant RC buildings observed in Darchula and Hillside
Source: photo by B.K. Bohara [16]

Three code-compliant models were developed: one based on the NBC 205 (old), one with the updated NBC 205:2024 RUD guidelines, and one designed according to IS 1893 and IS 13920 standards. These were designed to match the overall plan dimensions of non-engineered structure (NES) buildings to allow fair performance comparison under identical loading and seismic conditions.

The study focuses on three-story RC buildings (commonly observed maximum buildings are three story), which are common in the Far Western side of Nepal. For structure modelling, material, load and seismic properties were assumed as shown in Table 1 and three-dimensional and plan views shown in Figure 2. Based on observation, nine RC building models were selected for analysis. Models NES1 to NES6: representing non-code-compliant (NE) ordinary moment-resisting frames (OMRF) commonly found in hillside Nepal as shown in Table 2. NBC 205 old and NBC 205 (2014) new and IS models: representing code-based special moment-resisting frames (SMRF) designed according to the NBC, RUD and IS, respectively as shown in Table 2.



a *b*

Figure 2. Proposed model: *a* — 3D view; *b* — Plan

S o u r c e: made by B.K. Bohara

Table 1

Material properties, loads and seismic parameters used in each nine models

Material properties			
Grade of	Concrete	M20	For all models
	Steel	415 Mpa	For all models
Modulus of Elasticity of	Concrete	22.36 Gpa	For all models
	Steel	200 Gpa	For all models
Loads			
Live load on floor level		3 kN/m^2	For all models
Live load on roof level		1.5 kN/m^2	For all models
Finishing in roof load		1 kN/m^2	For all models
Weight of the wall on each floor		11.2kN/m	For all models
Weight of the parapet wall in the roof		4kN/m	For all models
Seismic factor			
Seismic zone according to the Indian standard		V	For all models
Zone factor according to the Indian standard (Z)		0.36	For all models
Importance factor for all models (I)		1	For all models
Type of soil (assumed)		II	For all models
Response reduction factor R (SMRF)		5	Models NBC, RUD and IS
Response reduction factor R (OMRF)		3	for models NES1 to NES6

S o u r c e: made by B.K. Bohara

Table 2

Columns, reinforcement and beam size of each model

Models	Size of column	Reinforcement used in the column	The tie bar used in the column	Size of Beam
NBC	300×300	4-12d+4-16d	8 dia	250×300
RUD	350×350	8-20d	8 dia	250×380
		8-16d	8 dia	250×355
IS	300×300	8-16d	8 dia	250×300
NES1	300×300	4-12d	6 dia	230×250
NES2	300×300	4-16d	6 dia	230×250
NES3	300×300	6-12d	6 dia	230×250
NES4	230×230	4-12d	6 dia	230×230
NES5	230×230	6-12d	6 dia	230×250
NES6	250×230	4-16d	6 dia	230×250

S o u r c e: made by B.K. Bohara

ETABS v22 was used to create 3D models for each of the nine buildings. Structural elements were modeled using frame elements (beams and columns) and shell elements (slabs). Diaphragm constraints were assigned at each floor level. NPA used default hinge properties for concrete frames. Both X and Y directions were considered, with lateral loads applied as per code-based equivalent static procedure for linear analysis and as distributed lateral forces for pushover analysis. Key seismic parameters assessed include the fundamental time period, base shear, capacity curves, overstrength factor, and collapse mechanisms. These analyses provided a comprehensive comparison of the seismic behavior of non-code-compliant and code-compliant RC building models.

3. Results and Discussion

3.1. Dynamic characteristics

Figures 3, 4, and Table 3 present a comparison of seismic parameters for RC models (NES1–NES6) against designs that comply with codes (NBC, RUD, IS 1893). A linear elastic analysis shows the seismic forces based on IS 1893 (2016), which are affected by the time period, mode shapes, and base shear. The fundamental periods vary from 0.602 to 1.144 seconds, with more flexible non-code-compliant models (such as NES4) surpassing code-compliant models (which range from 0.75 to 0.79 seconds). The mass participation ratios are high (0.88–0.90), consistent with IS 1893 standards. The base shear in NES1–NES3 is greater, reflecting differences in stiffness and mass. Nonetheless, a NPA is essential to evaluate inelastic behavior, capacity curves, and potential collapse mechanisms to thoroughly assess seismic resilience.

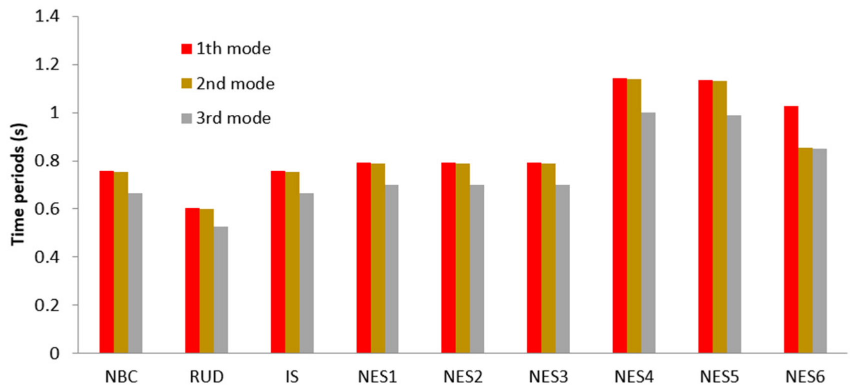


Figure 3. Time periods of the building models
Source: compiled by N.M Joshi

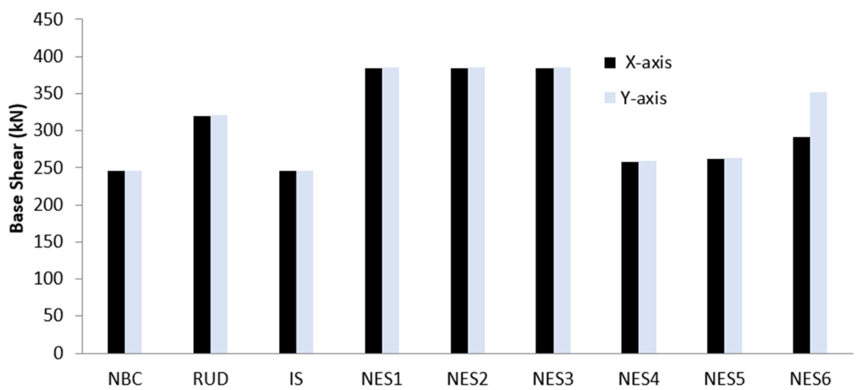


Figure 4. Base shear of the building models
Source: compiled by N.M. Joshi

Table 3

Mass participation

Mode	NBC	RUD	IS	NES1	NES2	NES3	NES4	NES5	NES6
	Mass Participation Ratio (Models)								
1th mode	0.8873	0.8784	0.8873	0.8794	0.8794	0.8794	0.9014	0.9031	0.8984
2nd mode	0.8881	0.8792	0.8881	0.8805	0.8805	0.8805	0.9023	0.9038	0.8874

S o u r c e: compiled by N.M. Joshi

3.2. Pushover Curve and Maximum Deflection

Figure 5 presents the results of NPA for the studied building models under x and y directional loading. The capacity strength of the RUD and IS models surpasses that of the NBC model, while non-code-compliant buildings demonstrate significantly lower strength, highlighting their vulnerability compared to code-compliant structures. The pushover curves indicate that the RUD model has the highest base shear capacity and exhibits significant stiffness and ductility, followed by the IS model with a peak around 1000 kN, suggesting a strong and resilient structure. The NBC model demonstrates moderate strength, aligning with code-based design principles, while NES3 performs slightly lower. The NES1, NES2, NES4, NES5, and NES6 models exhibit significantly lower strength and displacement capacities, indicating weaker, more vulnerable structures. The steeper and higher curves correspond to well-designed, code-compliant buildings, while the flatter, shorter curves highlight the fragility of non-code-compliant or poorly reinforced structures [17; 18]. Figure 6 shows how each scenario affects the building's displacement, providing insights into the structural behavior and potential vulnerabilities under seismic conditions. This information is crucial for evaluating the effectiveness of different design approaches and ensuring the safety and resilience of the structure.

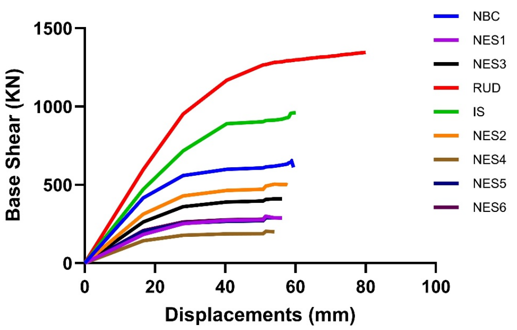


Figure 5. Capacity curves for proposed models
S o u r c e: compiled by N.M. Joshi

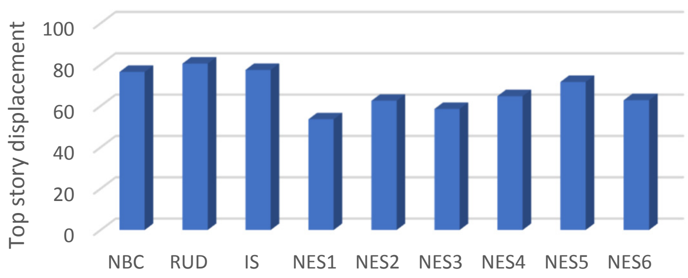
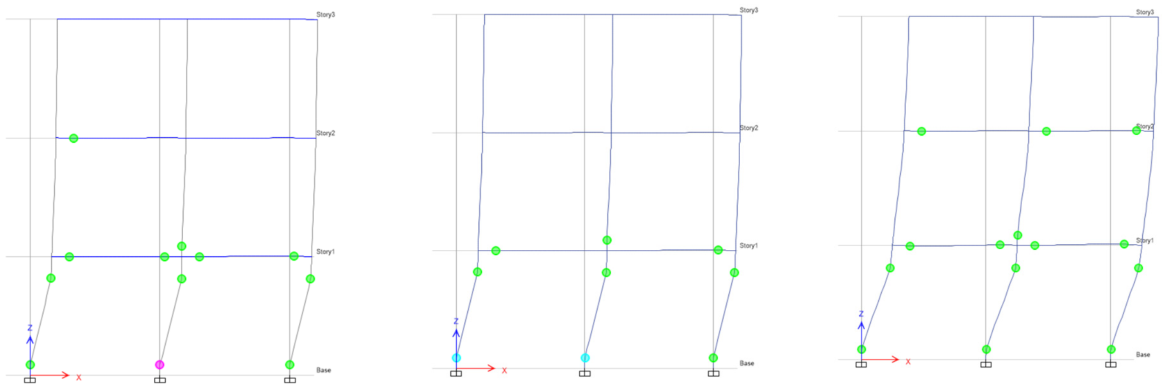


Figure 6. Maximum top story displacement from pushover analysis
S o u r c e: compiled by N.M. Joshi

3.3. Yielding Mapping

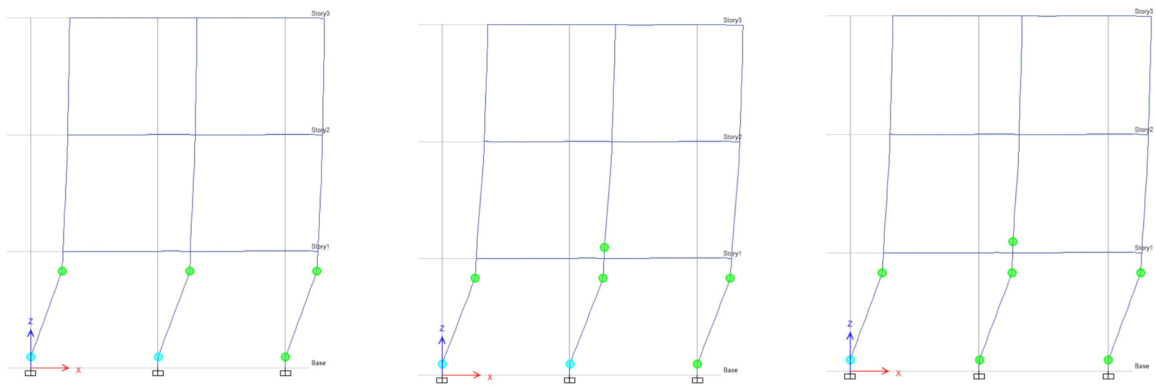
Yielding mapping refers to the process of identifying the sequence and locations of initial yielding in structural elements and failure mechanisms, emphasizing crucial areas during a NPA [19; 20]. In the analyzed models, code-compliant structures (RUD, NBC, IS) experience yielding (Figure 7) at higher load thresholds, predominantly in secondary elements, whereas non-code-compliant buildings (NES1–NES6) show earlier yielding in primary components, indicating a reduced safety margin as shown in Figure 8. Yielding mappings at different load increments evaluate the nonlinear response and alignment with the strong column-weak beam principle. Overstrength factors, resulting from the redundancies in materials and geometries, play a significant role in influencing nonlinear behavior. Mappings along the *X*-direction depict the progression of yielding, highlighting the initial yielding in beams before columns. Variations in certain models point to vulnerabilities such as inadequate detailing or non-adherence to seismic regulations, particularly in non-code-compliant structures, underscoring the necessity for enhanced reinforcement measures.



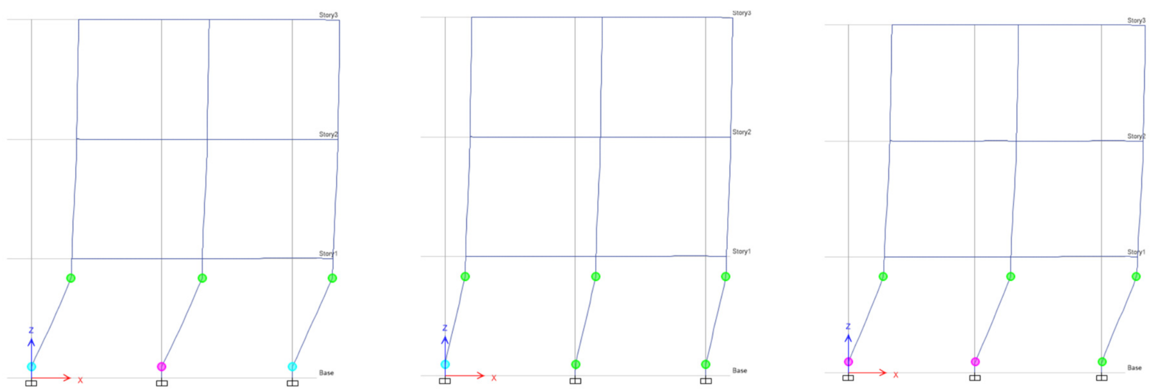
a *b* *c*

Figure 7. Failure mapping for code-based models:
a — IS; *b* — NBC; *c* — RUD

S o u r c e: compiled by B.K. Bohara



a *b* *c*



d *e* *f*

Figure 8. Failure mapping for non-code-compliant building models:
a — NES1; *b* — NES2; *c* — NES3; *d* — NES4; *e* — NES5; *f* — NES6

S o u r c e: compiled by B.K. Bohara

3.4. Modification Factors: Rμ and Rs

Rμ indicates a structure's ability to endure considerable deformation past its elastic limit without facing a sudden failure in strength. It quantifies the relationship between the strength needed to maintain a structure in an elastic state (VE) and its peak strength (Vu) [21; 22]. It reflects how well a structure can dissipate energy through plastic deformations during seismic events. The *Rs* denotes the extra strength present in a structure beyond the anticipated seismic requirements, acting as an essential safety buffer in structural engineering. It is characterized as the ratio of the peak strength (*Vu*) to the design strength (*V*des), reflecting the reserve capacity that results from elements like material overperformance, adherence to minimum detailing standards, redundancy in load distribution, and real-world construction practices [21–23]. Analysing the *Rs* factor is crucial in seismic assessments, as it measures a structure's capacity to endure forces that exceed those outlined by design standards, thus ensuring stability during extreme occurrences. This aspect is especially significant when contrasting buildings that comply with codes against those that do not, as it reveals differences in their resilience and guides efforts to enhance seismic safety. Figure 9 depicts the relationships between ductility ratios and overstrength factors, showcasing the distinctions between compliant and non-compliant buildings. Structures that meet code requirements demonstrate greater ductility ratios, which means they can experience considerable deformations without failing, effectively absorbing seismic energy. In comparison, buildings that do not comply with codes present reduced ductility and overstrength, rendering them more fragile and susceptible to seismic pressures. This indicates that non-compliant structures often lack the essential reinforcements, proper detailing, and quality materials needed to ensure resilience against seismic activity, resulting in an increased risk of early failure during earthquakes. The results highlight the necessity for better construction methods and strict adherence to seismic design standards, particularly in high-risk areas such as Darchula, where such non-compliant structures are common.

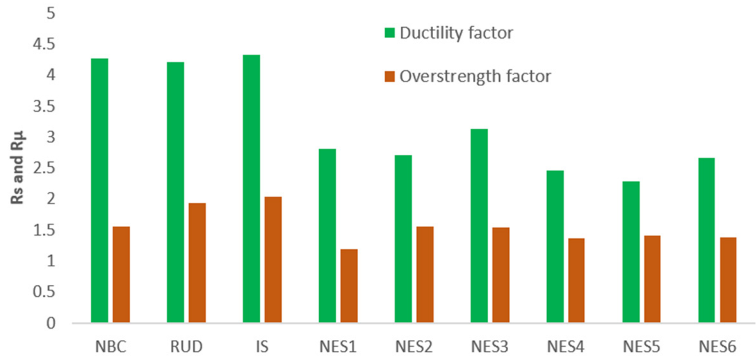


Figure 9. Overstrength factor and ductility ratio
S o u r c e: compiled by B.K. Bohara

3.5. Nonlinear Hysteretic Damping

Figure 10 presents NHD [24] data for both code-compliant and non-code-compliant buildings, highlighting a significant disparity in their seismic performance. Code-compliant buildings, represented by NBC, RUD, and IS curves, exhibit superior damping capacity, with steady and higher increases in damping values, particularly the RUD curve, which reaches the maximum (40 kNm). In contrast, non-code-compliant buildings, represented by NES1 to NES6, show lower and inconsistent damping performance, with several curves plateauing at early stages, indicating limited energy dissipation capacity. This contrast underscores the critical importance of code-compliant design standards in enhancing the seismic resilience of buildings, as non-code-compliant structures demonstrate significantly lower hysteretic damping, making them more vulnerable to seismic forces.

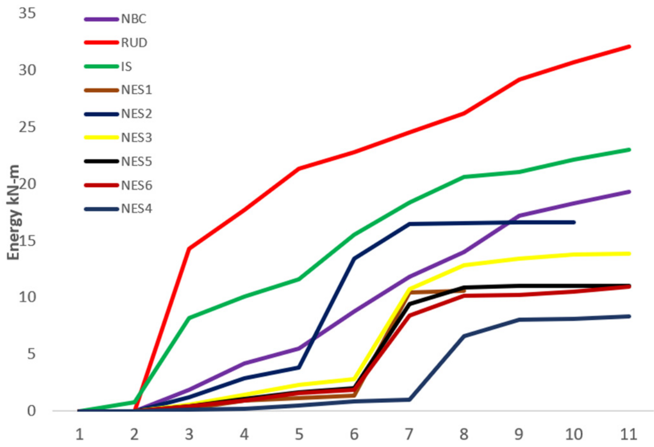


Figure 10. NHD for the proposed model

Source: compiled by B.K. Bohara

4. Conclusion

This study evaluates the seismic vulnerability of code-compliant and non-code-compliant RC buildings using NPA, yielding mapping and seismic response modification factors. The following key scientific findings were obtained from the study:

1. The fundamental time periods of non-code-compliant structures, especially NES4, are greater than those predicted by code-based models, suggesting increased flexibility and possible susceptibility to seismic forces. The increased base shear values seen in NES1–NES3 underscore the effects of structural irregularities and loss of stiffness.

2. NPA reveals that code-compliant buildings (especially RUD and IS models) exhibit higher base shear capacity, ductility, and overstrength factors, ensuring better seismic performance. Code-compliant buildings consistently demonstrate superior performance across all seismic parameters. In particular, the RUD model exhibits the highest base shear capacity, ductility, overstrength factor, and NHD capacity, reflecting robust energy dissipation and structural redundancy.

3. Yield mapping analysis indicates that columns in non-compliant buildings experience premature failure, while code-compliant models demonstrate the expected “strong column–weak beam” behavior.

4. NHD analysis further supports these findings, showing higher damping capacity in code-compliant models, particularly RUD (40 kNm), while non-code-compliant structures exhibit inconsistent damping, reducing seismic energy absorption.

5. The study confirms that updated NBC 205:2024 RUD provides improved seismic resilience in RC buildings.

6. The broader implication of these findings is the need for regulatory intervention in seismic-prone regions Darchula, Nepal. Local governments, engineers, and builders must collaborate to ensure stricter enforcement of building codes, capacity-building for local masons, and the promotion of affordable, earthquake-resistant technologies suitable for hillside terrains.

References

1. Chaulagain H., Gautam D., Rodrigues H. Revisiting major historical earthquakes in Nepal: Overview of 1833, 1934, 1980, 1988, 2011, and 2015 seismic events. *Impacts and Insights of the Gorkha Earthquake*. 2018:1–17. https://doi.org/10.1016/B978-0-12-812808-4.00001-8

2. Mishra A.K. Structural Features for Earthquake-Resistant Load-Bearing Residential Buildings in Nepal. *Journal of Advanced Research in Geo Sciences & Remote Sensing*. 2019;6(1):1–16. https://doi.org/10.24321/2455.3190.201901

3. Adhikari R.K., D’Ayala D. 2015 Nepal earthquake: seismic performance and post-earthquake reconstruction of stone in mud mortar masonry buildings. *Bulletin of Earthquake Engineering*. 2020;18(8):3863–3896. https://doi.org/10.1007/S10518-020-00834-Y EDN: LXVUEU

4. Poudel H.R., Chaulagain H. The Jajarkot Earthquake: Revealed the Vulnerability of Load Bearing Structures in Western Nepal. *Himalayan Journal of Applied Science and Engineering.* 2024;5(1):1–22. https://doi.org/10.3126/hijase.v5i1.68334 EDN: JXSHQX

5. Gautam D., Chaulagain H. Structural performance and associated lessons to be learned from world earthquakes in Nepal after 25 April 2015 (MW 7.8) Gorkha earthquake. *Engineering Failure Analysis.* 2016;68:222–243. https://doi.org/10.1016/j.engfailanal.2016.06.002

6. Tremblay R., Bruneau M., Nakashima M., Prion H.G.L., Filiatrault M., DeVall R. Seismic design of steel buildings: lessons from the 1995 Hyogoken Nanbu earthquake. *Canadian Journal of Civil Engineering.* 1993;23(3):727–756. https://doi.org/10.1139/l96-885

7. Dutta S.C., Mukhopadhyay P.S., Saha R., Nayak S. 2011 Sikkim earthquake at eastern himalayas: Lessons learnt from performance of structures. *Soil Dynamics and Earthquake Engineering*. 2015;75:121–129. https://doi.org/10.1016/j.soildyn.2015.03.020

8. Khanal B., Chaulagain H. Seismic elastic performance of L-shaped building frames through plan irregularities. *Structures*. 2020;27:22–36. https://doi.org/10.1016/j.istruc.2020.05.017 EDN: CZBTQC

9. Jereen A.T., Anand S., Issac B.M. Seismic evaluation of buildings with plan irregularity. *Applied Mechanics and Materials*. 2017;857:225–230. https://doi.org/10.4028/www.scientific.net/amm.857.225

10. Bohara B.K., Ganaie K.H., Saha P. Effect of position of steel bracing in *L*-shape reinforced concrete buildings under lateral loading. *Research on Engineering Structures & Material*. 2022;8(1):155–177. Available from: https://jresm.org/wp-content/uploads/resm2021.295st0519.pdf (accessed: 12.01.2025)

11. Varum H., Dumaru R., Furtado A., Barbosa A.R., Gautam D., Rodrigues H. Seismic performance of buildings in Nepal after the Gorkha earthquake. *Impacts and Insights of the Gorkha Earthquake*. 2018;47–63. https://doi.org/10.1016/B978-0-12-812808-4.00003-1

12. Gautam D., Bhetwal H., Rodrigues K.K., Neupane P., Sanada Y. Observed damage patterns on buildings during 2015 Gorkha (Nepal) Earthquake. *Proceedings of the 14th International Symposium on New Technologies for Urban Safety of Mega Cities in Asia*. 2015;10:29–31. Available from: https://scholar.google.com/scholar?oi=bibs&cluster=10419973631905408764&btnI=1&hl=en (accessed: 12.01.2025)

13. Duwadi S., Pradhan P.M. Retrofitting design of Kathmandu university staff QUARTER BLOCK 32 'A' after Gorkha earthquake 2015. *International Conference on Earthquake Engineering and Post Disaster Reconstruction Planning,* 24-26 April 2016, Bhaktapur, Nepal, 2016. ISSN 2505 – 0737

14. Pokharel A.R., Joshi B.R. Impact of variation orders on construction project cost: A case study of land pooling project at Kathmandu of Ichangu Narayan, Nepal. *Saudi Journal of Engineering and Technology*. 2020;05(05):203–230. https://doi.org/10.36348/sjet.2020.v05i05.003 EDN: HEVMHP

15. Ahmad N., Shahzad A., Ali Q., Rizwan M., Khan A.N. Seismic fragility functions for code compliant and non-compliant RC SMRF structures in Pakistan. *Bulletin of Earthquake Engineering.* 2018;16. https://doi.org/10.1007/s10518-018-0377-x EDN: HBSGHN

16. Bohara B.K. Study of Common Construction Practices and Structural Defects in RC Buildings in Darchula District Far-Western Nepal. *Far Western Review*. 2023;1(2):117–137. https://doi.org/10.3126/fwr.v1i2.62137 EDN: WOGKER

17. Mushina W., Alewi H., Mushina J. The effect of vertical aspect ratio of RC Structures on the Performance Levels using Pushover Analysis. *Disaster Advances*. 2023;16(7):42–49. https://doi.org/10.25303/1607da042049 EDN: VVTNMF

18. Chapagain K., Chaulagain H. Seismic Fragility Analysis of Existing Old Newari Brick Masonry Building in Pokhara Valley. *Structural Mechanics of Engineering Constructions and Buildings*. 2024;20(2):120–133. https://doi.org/10.22363/1815-5235-2024-20-2-120-133 EDN: JNAYFF

19. Mwafy A.M., Elnashai A.S. Static pushover versus dynamic collapse analysis of RC buildings. *Engineering Structures*. 2001;23(5):407–424. https://doi.org/10.1016/S0141-0296(00)00068-7

20. Ghaffarzadeh H., Maheri M.R. Mechanical compression release device in steel bracing system for retrofitting RC frames. *Earthquake Engineering and Engineering Vibration*. 2006;5:151–158. https://doi.org/10.1007/s11803-006-0626-x

21. Bohara B.K. Ductility, *R*μ, and overstrength factors for *V* braced reinforced concrete buildings. *International Journal of Structural and Construction Engineering*. 2022;16(3):101–105. Available from: https://scholar.google.com/citations?user=7rXbhFAAAAAJ&hl=en (accessed: 12.01.2025)

22. Tamboli K., Amin J.A. Evaluation of response reduction factor and ductility factorfor RC braced frame. *Journal of Materials and Engineering Structures.* 2015;2(3):120–129. Available from: https://core.ac.uk/download/pdf/143976571.pdf (accessed: 12.01.2025)

23. Tapia-Hernandez E., Garcia-Carrera S. Inelastic response of ductile eccentrically braced frames. *Journal of Building Engineering*. 2019;26:100903. https://doi.org/10.1016/j.jobe.2019.100903

24. Design R., With O.F.R., Energy H., Devices D., Soft I.N. *Resilient Design of Rc-Buildings with Hysteretic Energy*. 2020. Available from: https://scholar.google.com/scholar?oi=bibs&cluster=10884261233381155935&btnI=1&hl=en (accessed: 12.01.2025)