

APPLICATION OF M-FACTOR IN SEISMIC ASSESSMENT OF AN EXISTING MRT BUILDING AS PER NBC 105:2020 AND ASCE 41-17

Menaka Phagu^{1*}, Sajan Rai², Anup Shrestha²

¹ PG Department of Earthquake Engineering, Khwopa Engineering College
Purbanchal University, Nepal

² Miyamoto International Nepal, Lalitpur, Nepal

Abstract

This study presents a comparative evaluation of seismic performance assessment methodologies for a Reinforced Concrete (RC) moment-resisting frame building originally designed using Mandatory Rules of Thumb (MRT) as per NBC 205:1994. The building is re-evaluated under the current prescriptive design framework of NBC 105:2020 and the advanced Performance-Based Design (PBD) methodology specified in ASCE 41-17, with particular emphasis on the role of the modification factor (m-factor) in seismic capacity evaluation. The objective is to examine the applicability, limitations, and effectiveness of conventional code-based design versus modern performance-oriented approaches in the context of existing buildings in seismically active regions.

ASCE 41-17 provides a comprehensive and flexible framework grounded in nonlinear analysis and component-level performance objectives, enabling tailored seismic demand assessments under varying hazard scenarios. The study reveals significant discrepancies in structural performance, material utilization, safety margins, and retrofit implications between the two methodologies. The research advocates for the integration of performance-based assessment techniques, such as those in ASCE 41-17, to more accurately characterize seismic vulnerabilities and inform effective retrofit strategies. The findings support a shift toward more detailed and context-specific evaluation methods to enhance resilience and guide post-disaster reconstruction planning.

Keywords: Performance based design; Seismic assessment; Reinforced concrete; Retrofit; Nonlinear

1. Introduction

In 1994, Nepal published its first building code as Nepal Building Code, NBC205:1994(NBC205:1994, 1994). Later the code was revised for better seismic performance of the building and published as a final draft NBC205:2012(NBC205:2012, 2012). The structures built in accordance with this code observed severe damage during the 2015 Gorkha Earthquake (Bhusal et al., 2024). A report showed of a total 604,930 buildings were fully or partially damaged (NDRRIP, 2015). After devastating earthquake - the Gorkha Earthquake of magnitude 7.8 (Goda et al., 2015), the head-storming loss of lives in the building led the Nepal government to amend the strong seismic resilience building code known as NBC

105:2020 (Pokhrel et al., 2026). Many reinforced concrete (RC) buildings constructed before the adoption of modern seismic design provisions often lack adequate ductility and energy dissipation capacity (Poudel et al., 2025). In the context of performance-based seismic evaluation, the modification factor (m-factor) plays a crucial role in representing the inelastic deformation capacity of structural components. By appropriately assigning m-factors, the non-linear behaviour of elements can be approximated within linear analysis frameworks, thus enabling a rational and simplified estimation of structural performance under seismic loading (Sulthan et al., 2023)

The Nepal Building Code (NBC105:2020, 2020) provides guidelines for seismic analysis and design of buildings, incorporating capacity design principles and response modification factors consistent with the ductility and detailing level of structural systems. However, its application to existing structures remains challenging

*Corresponding author: Menaka Phagu
Khwopa Engineering College, Bhaktapur, Nepal
Email: civil.er.menaka@gmail.com
<https://doi.org/10.3126/jsce.v13i1.89580>

(Shrestha et al., 2021, Pradhan et al., 2022). In parallel, ASCE (ASCE/SEI41-17, 2017), recognized for seismic evaluation and retrofit of existing buildings offers a comprehensive framework for performance-based assessment through nonlinear and linear procedures. The standard defines Basic Safety Earthquake (BSE) hazard levels of Existing Building Level 1 (BSE-1E) and Existing Building Level 2 (BSE-2E), which are associated with target performance objectives of Life Safety and Collapse Prevention, respectively. This standard introduces m-factor allowing to represent the expected nonlinear performance of elements within linear static or dynamic analysis. The m-factor is a component-level force modification factor used in linear seismic analysis to represent the estimated inelastic deformation capability of individual structural components. Instead of explicitly modelling the nonlinear behaviour, ASCE/SEI41-17 (2017) allows to reduce elastic demands using the m-factor. It serves a similar purpose to the response modification factor R in force-based design, but they apply at the component level rather than the global system level, allowing more nuanced evaluation of existing buildings with potentially inconsistent detailing. The m-factors values for linear analysis are given through Chapter 10-15 of ASCE 41-17(ASCE/SEI41-17, 2017) depending on material and component type. Principally, the m-factor values mostly depend on factors like failure modes (ductile flexure, $m > 1$ and brittle shear, $m = 1$), detailing and confinement, and performance objectives (different m-factors for IO, LS, CP).

Evaluating how the selection of m-factors influences the predicted seismic demand and performance level of existing structures is critical for developing reliable assessment methodologies compatible with both international and national code frameworks. This paper aims to investigate the application and influence of m-factor in the seismic assessment of an existing MRT building by conducting linear and non-linear analysis following the provisions of NBC105:2020 (2020) and ASCE/SEI41-17 (2017). The study compares the resulting performance parameter at local and global level. The outcomes are expected to contribute to a better understanding of performance-based evaluation approaches for existing MRT buildings in Nepal, supporting more consistent and realistic assessment practices in line with current seismic design philosophy

2. Methodology

The study (Figure 1) commenced with an extensive review of force-based seismic design principle as provisioned in NBC(NBC105:2020, 2020) and performance-based seismic design approaches as outlined in ASCE41-17(ASCE/SEI41-17, 2017), focusing on modelling requirements, performance objectives, and acceptance criteria, particularly

for buildings designed under earlier standards such as NBC205:1994(ASCE/SEI41-17, 2017) and NBC205:2012(NBC205:2012, 2012). An existing reinforced concrete moment-resisting frame building, originally designed following the Mandatory Rules of Thumb, was selected as the case study to represent typical pre-modern design practices in Nepal.

According to ASCE/SEI41-17 (2017), with risk category II, the building was evaluated under Basic Safety Earthquake Levels BSE-1E and BSE-2E seismic hazards, corresponding to Life safety (LS) and collapse prevention (CP) performance levels respectively. A Tier-3 evaluation framework was adopted to perform a detailed component-level assessment. Following the structural analyses, member demand-to-capacity ratios were computed manually using the modification factor (m-factor) as prescribed in ASCE/SEI41-17 (2017) to account inelastic deformation capacity and ductility of structural components to adjust member strength parameters, thereby enabling comparison between elastic analysis results with expected inelastic performance.

Likewise, the building was also analysed and designed using the provisions of recent Nepal Building Code NBC 105:2020. The study building's zone factor is taken as $Z = 0.35$, with ductility factor $R = 4$ and overstrength factor $\Omega = 1.5$ at Ultimate limit State (ULS). The importance factor is considered 1.0 for residential building. The ETABS 22.4.0 program facilitates building analysis in each case. The material properties, section definitions, and gravity load specifications were assigned in accordance with NBC 205:1994, while the seismic load combinations and hazard levels were assigned in accordance with the requirements of NBC 105:2020 and ASCE 41-17. The plan configuration and 3D model of the building are presented in Figure 2 and Figure 3 respectively.

3. Results

The building was analysed under three assessment approaches: NBC 105:2020, ASCE 41-17 BSE-1E, and ASCE41-17 BSE-2E. Under NBC105:2020, the building exhibits inter-storey drift in the range of 0.019-0.023, indicating a stiff global response. These drift values are within the limit as 0.025 for ultimate limit state, suggesting minimal expected structural damage under code-level design earthquake forces. Under ASCE41-17, the drift demand significantly increases as shown in Table 1. The ASCE 41-17 result indicate the building will undergo inelastic deformation, consistent with Life Safety (BSE-1E) and Collapse Prevention (BSE-2E) performance levels. Similarly, Table 1, showing deflection result indicating the building experience higher deformation demands, indicating significant participation of inelastic action at BSE-1E and BSE-2E levels.

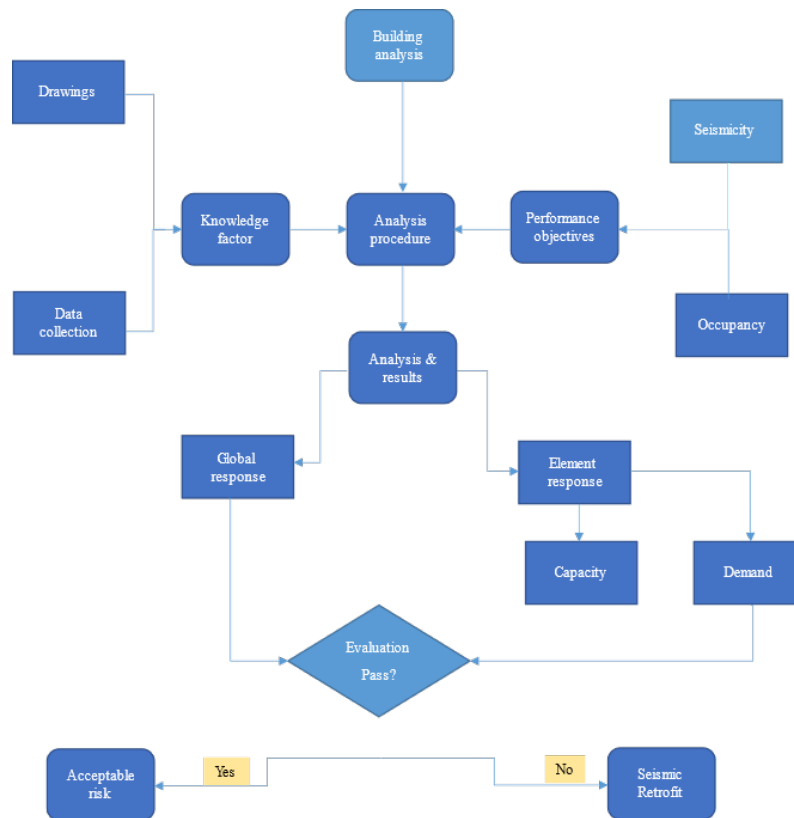


Figure 1. Tier 3 evaluation methodology as prescribed by ASCE 41-17

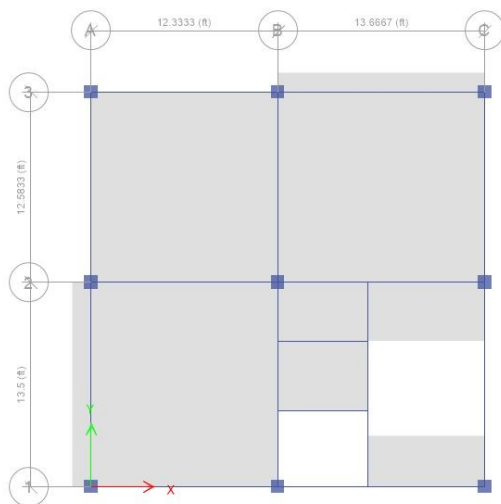


Figure 2. Plan view of MRT building model

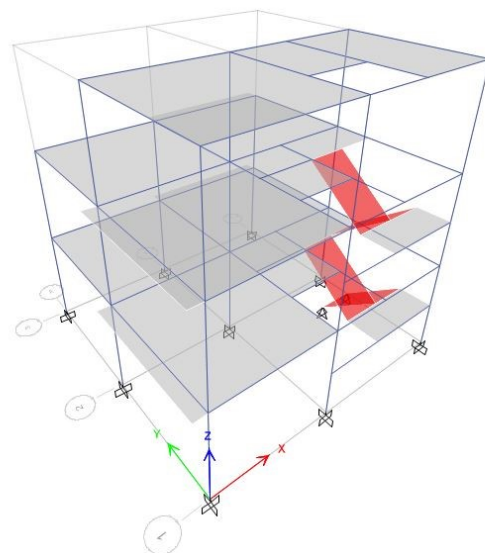


Figure 3. 3D view of MRT building model

The building component was further analysed to know its performance level. The Demand Capacity ratio (DCR) of beam and column for flexure and shear is computed. NBC105:2020 consistently produced the highest flexural DCR, with several beam exceeding acceptable limits. While ASCE41-17 (BSE-1E) resulted in moderate

Acceptance ratio (AR) which is calculated by dividing DCR by m-factor, with members falling within controlled deformation acceptance due to application of m-factors and BSE-2E showed lower AR, reflecting lower seismic hazard levels associated with the collapse prevention

Table 1. Comparison of drift and deflection of MRT building

Loading Case	Drift	Deflection (mm)
NBC105:2020		
EQx, ultimate	0.019	32.004
EQy, ultimate	0.023	38.628
ASCE/SEI 41-17		
BSE-1Ex	0.064	111.842
BSE-2Ex	0.095	167.757
BSE-1Ey	0.091	159.516
BSE-2Ey	0.136	224.264

objective. The plotted chart in Figure 4 clearly illustrate that NBC105:2020 places significantly higher flexural demand with $DCR \leq 2$ and Figure 5 shows Shear demand with $DCR \leq 3$, while both ASCE41-17 performance levels permit deformation based acceptance when actual DCR is divided by m- factor. For BSE-1E beam flexural $AR < 1$ (refer Figure 6) and shear $AR \leq 0.5$ (See Figure 7) and for BSE-2E, beam flexural $AR < 0.6$ (See Figure 8) and shear $AR < 0.5$ (See Figure 9).

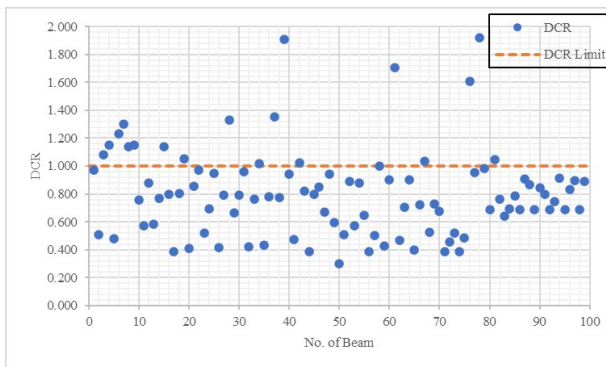


Figure 4. DCR beam flexure (NBC105:2020)

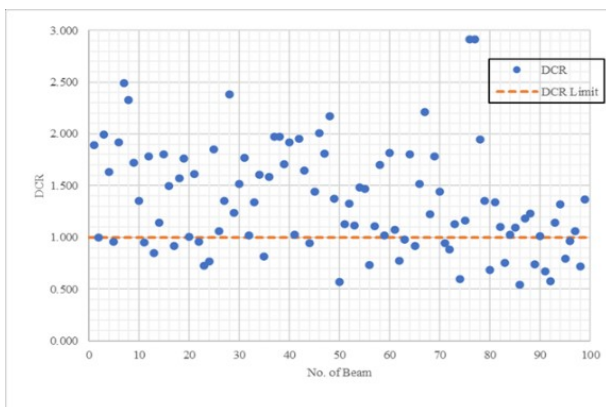


Figure 5. DCR beam shear (NBC105:2020)

Likewise, Column flexural and Shear DCR were calculated following the same comparison procedure. Under NBC105:2020, Column Flexure DCR limit of 2.5

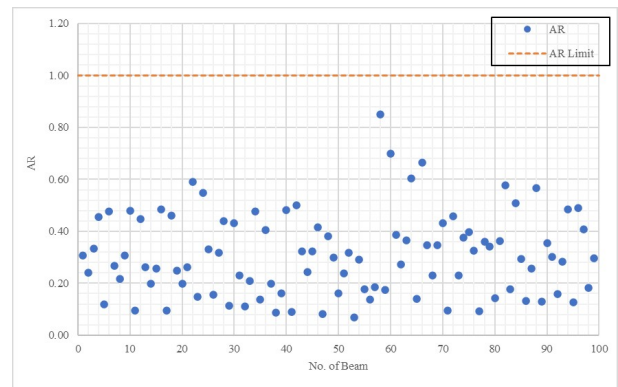


Figure 6. AR beam flexure (ASCE41-17, BSE-1E)

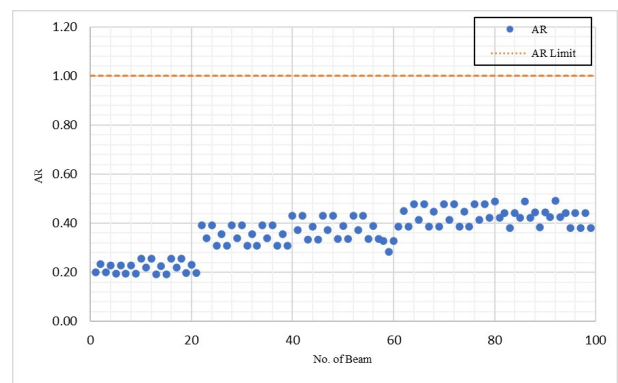


Figure 7. AR beam shear (ASCE41-17, BSE-1E)

as shown in Figure 9, suggesting potential deficiency and shear $DCR < 1$ in Figure 10, indicating force-controlled deficiency. Similarly, under ASCE41-17, the permissible flexural AR increases up to 4 (Figure 11) and shear AR up to 3 (Figure 12) on BSE-1E and Column flexure $AR \leq 4.5$ (Figure 13) and Shear $AR \leq 3.5$ (Figure 14). This shows column reached higher flexural and shear demand capacity ratio showing unfavourable for seismic response, as column forming plastic hinge before beam.

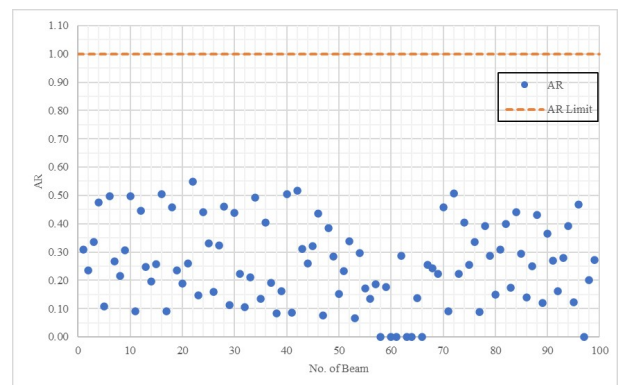


Figure 8. AR beam flexure (ASCE41-17, BSE-2E)

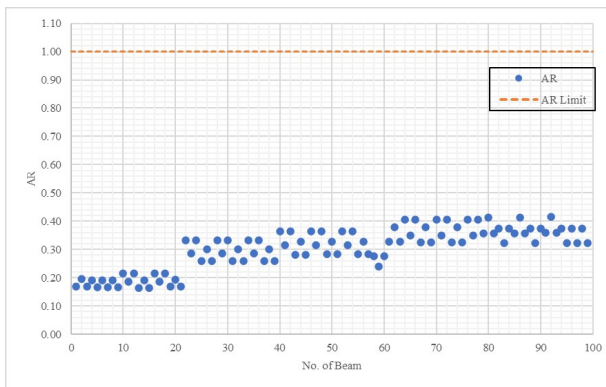


Figure 9. AR beam shear (ASCE41-17, BSE-2E)

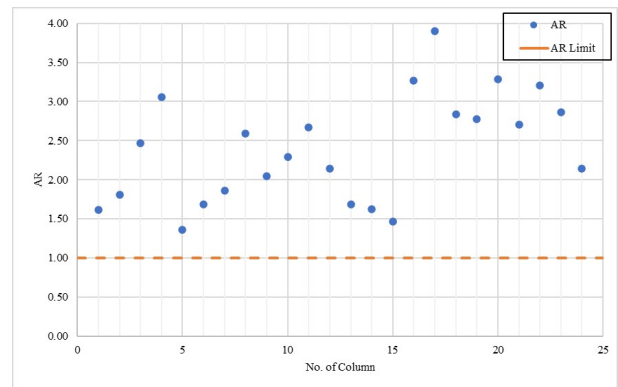


Figure 12. AR column flexure (ASCE41-17, BSE-1E)

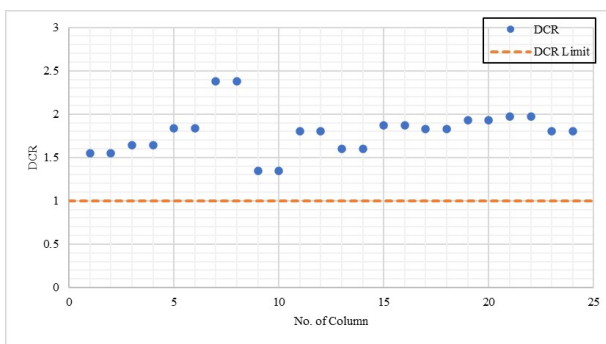


Figure 10. DCR column flexure (NBC105:2020)

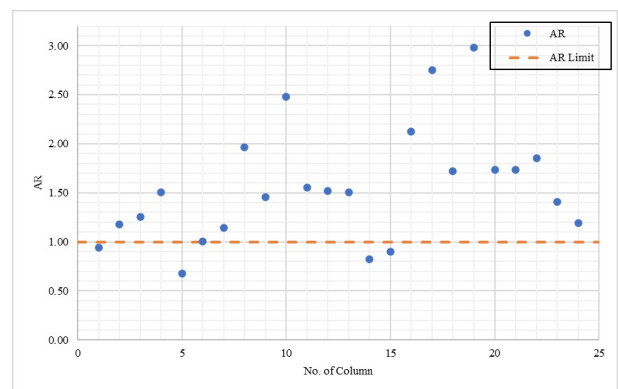


Figure 13. AR column shear (ASCE41-17, BSE-1E)

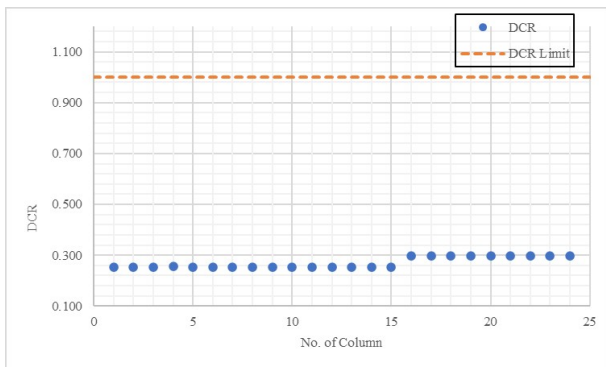


Figure 11. DCR column shear (NBC105:2020)

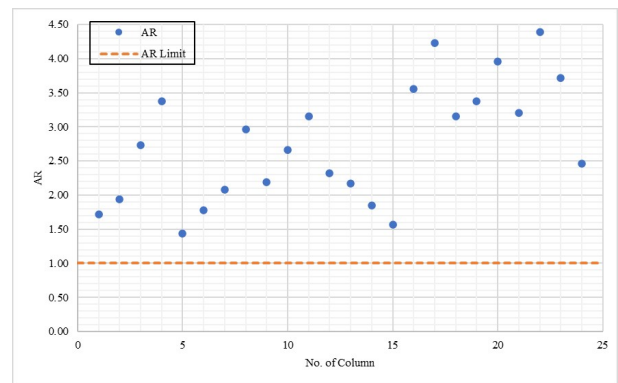


Figure 14. AR column flexure (ASCE41-17, BSE-2E)

4. Conclusion

This study evaluated the seismic performance of an existing MRT building using NBC105:2020 and ASCE41-17 under both BSE-1E and BSE-2E hazard levels. NBC105:2020 model satisfied the code criteria of drift and displacement limit, while ASCE41-17 model exhibited exceeding deflection for both performance level and for BSE-2E exceeding drift limit, reflecting higher inelastic demand allowed within ASCE41-17 methodology.

The component level performance evaluation further highlighted fundamental behavioural differences. Beam

flexural and shear AR were consistently lower in ASCE 41-17 than comparing to DCR in NBC105:2020 due to the application of m-factors, which increase allowable deformation capacity for existing members. In contrast, column flexural and shear AR were higher under ASCE41-17, indicating that columns are attracting larger inelastic demands relative to beams. This result in a weak column and strong beam mechanism, which is undesirable for seismic performance and suggest potential vulnerability to story-level instability during severe ground shaking.

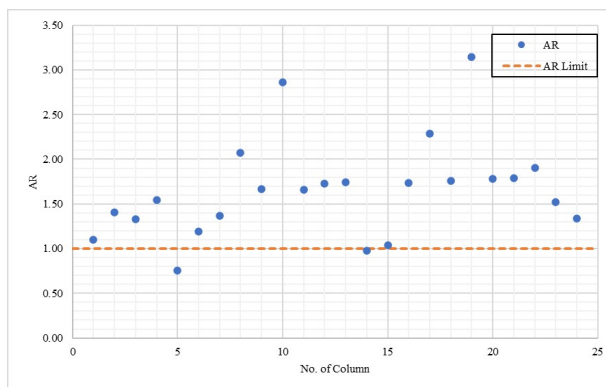


Figure 15. AR column shear (ASCE41-17, BSE-2E)

Although ASCE41-17 provides a more realistic deformation-based assessment for existing structures, the observed deflection exceeds the limit and the weak column response indicate further detailed evaluation is necessary. In particular, non-linear analysis such as push over analysis as mentioned in Tier-3 procedure in ASCE41-17 should be conducted to capture inelastic behaviour, identify hinge formation patterns, and confirm the buildings global and component level performance more accurately. These findings underline the importance of selecting appropriate assessment methodology and incorporating nonlinear procedures when evaluating existing buildings under modern performance based seismic standards.

Authors' Contribution

Main Author conceptualized the study, conducted the analysis, and wrote the manuscript. Second Author contributed to the analysis and interpretation of the results. Third Author reviewed the results, provided critical feedback, and revised the manuscript. All authors read and approved the final version of the paper.

References

- ASCE/SEI41-17. (2017). *Seismic evaluation and retrofit of existing buildings* (ASCE/SEI 41-17). American Society of Civil Engineers.
- Bhusal, B., Pradhananga, A., Paudel, S., & Najam, F. A. (2024). Evaluating and strengthening low-rise reinforced concrete buildings constructed in nepal. *Structures*, 63, 106388.
- Goda, K., Kiyota, T., Pokhrel, R. M., Chiaro, G., Katagiri, T., Sharma, K., & Wilkinson, S. (2015). The 2015 gorkha nepal earthquake: Insights from earthquake damage survey. *Frontiers in Built Environment*, 1, 153814.
- NBC105:2020. (2020). *Nepal national building code: Nbc 105, seismic design of buildings in nepal*.

Department of Urban Development; Building Construction.

- NBC205:1994. (1994). *Nepal national building code: Nbc 205, mandatory rules of thumb reinforced concrete buildings without masonry infill*. Department of Urban Development; Building Construction.
- NBC205:2012. (2012). *Nepal national building code: Nbc 205, ready to use guideline for detailing of low rise reinforced concrete buildings without masonry infill*. Department of Urban Development; Building Construction.
- NDRRIP. (2015). Nepal earthquake 2015.
- Pokhrel, R. M., De Risi, R., De Luca, F., Gilder, C. E., Werner, M. J., Maskey, P. N., Sextos, A., & Vardanega, P. J. (2026). Revisions to the nepalese building code (nbc 105: 2020): New seismic hazard provisions. *Natural Hazards Review*, 27(1), 06025002.
- Poudel, J., Khatiwada, P., & Adhikari, S. (2025). Seismic performance evaluation of low-rise reinforced concrete framed buildings with ready-to-use guidelines (rud-nbc 205: 2024) in nepal. *CivilEng*, 6(3), 50.
- Pradhan, S., Li, Y., & Sanada, Y. (2022). Seismic performance evaluation and risk assessment of typical reinforced concrete frame buildings with masonry infill and conventional vertical extension in nepal. *Bulletin of Earthquake Engineering*, 20(2), 853–884.
- Shrestha, J. K., Paudel, N., Koirala, B., Giri, B. R., & Lamichhane, A. (2021). Impact of revised code nbc105 on assessment and design of low rise reinforced concrete buildings in nepal. *Journal of the Institute of Engineering*, 16(1), 1–5.
- Sulthan, F., Rusli, M., Seki, M., et al. (2023). Seismic evaluation of existing building structure using united states (asce 41-17) and japanese (jbdpa) standard: Case study office building in indonesia. *E3S Web of Conferences*, 429, 05001.

This work is licensed under a [Creative Commons](https://creativecommons.org/licenses/by-nc-nd/4.0/) "Attribution-NonCommercial-NoDerivatives 4.0 International" license.

