Seismic Performance Assessment of Retrofitted Reinforced Concrete Buildings Using Pushover Analysis

Lakshmi Devi Nalamothu
Independent Researcher
India

ABSTRACT

This study investigates the seismic performance of retrofitted reinforced concrete (RC) buildings through nonlinear static pushover analysis. The objective is to evaluate the effectiveness of various retrofit techniques in improving the seismic capacity and ductility of existing RC structures, which are often vulnerable to seismic hazards due to inadequate original design or deterioration over time. The research incorporates different retrofitting schemes such as steel jacketing, FRP (Fiber Reinforced Polymer) wrapping, and shear wall addition. Using pushover analysis, capacity curves are developed for both the original and retrofitted structures, enabling comparison of base shear, displacement capacity, and performance levels. The findings demonstrate significant enhancement in strength and deformation capacity post-retrofit, affirming pushover analysis as a reliable tool for seismic performance evaluation in retrofit design. The study also discusses the practical implications for engineering design and seismic rehabilitation strategies.

KEYWORDS Seismic performance, Reinforced concrete, Retrofitting, Pushover analysis, Structural capacity, Ductility, Fiber reinforced polymer.

INTRODUCTION

Reinforced concrete (RC) buildings constitute a substantial portion of the built environment worldwide, especially in seismically active regions. However, many existing RC structures were designed under outdated codes or without adequate consideration for seismic forces, rendering them vulnerable to earthquake damage. The increasing urbanization and demand for safety in existing infrastructure necessitate the evaluation and upgrading of such structures to meet current seismic performance standards.

Seismic retrofitting aims to improve the strength, stiffness, and ductility of existing buildings to withstand seismic events with reduced damage. Various retrofit techniques have been developed and widely adopted, including steel jacketing of columns, FRP wrapping, addition of shear walls, and base isolation.

Each technique targets specific structural weaknesses and offers differing levels of performance enhancement.

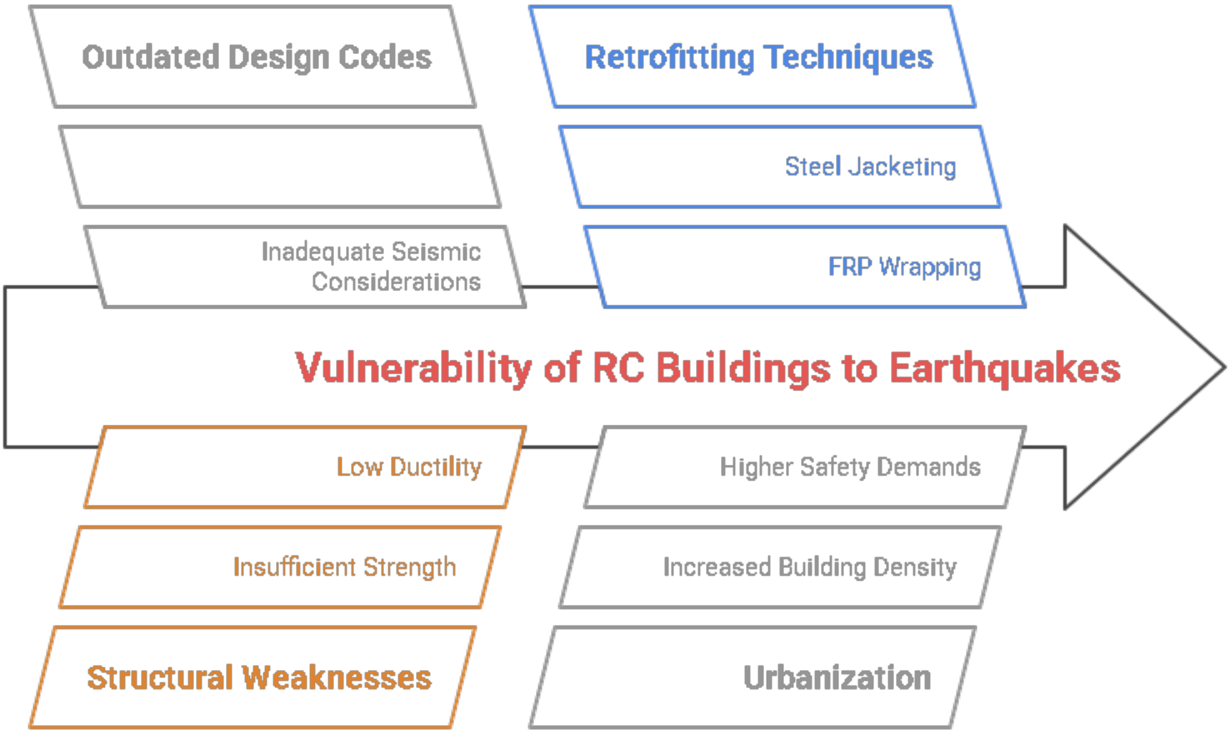

Fig: Enhancing Seismic Resistance of RC Buildings

Pushover analysis, a nonlinear static procedure, has gained prominence as a practical and computationally efficient method for assessing the seismic performance of structures. It simulates the progressive lateral displacement of a building under gradually increasing lateral loads until a target displacement or collapse mechanism is reached. The resulting capacity curve provides insights into the strength, ductility, and failure modes of the structure.

This manuscript presents a comprehensive seismic performance assessment of retrofitted RC buildings using pushover analysis. It evaluates the effectiveness of selected retrofit techniques and provides a comparative study of original versus retrofitted building performance. The analysis and findings are aligned with seismic engineering practices and code requirements prevalent until 2021.

LITERATURE REVIEW

Several studies have explored the seismic assessment and retrofitting of RC buildings employing pushover analysis.

Pushover Analysis Methodology: Chopra (2011) elaborates on the fundamentals of pushover analysis as a reliable approach for performance-based seismic design. The method captures nonlinear behavior and identifies weak points in the structure, offering a balance between detailed nonlinear dynamic analysis and simpler linear procedures.

Retrofitting Techniques and Effectiveness: Fibers reinforced polymers (FRP) have gained traction due to their high strength-to-weight ratio and ease of installation. Triantafillou and Antonopoulos (2000) demonstrated significant improvement in shear capacity and ductility of RC columns wrapped with CFRP (carbon fiber reinforced polymer). Similarly, steel jacketing, as documented by Park and Paulay (1975), has proven effective in increasing confinement and flexural strength of columns.

Seismic Assessment of Retrofitted Structures: Mwafy and Elnashai (2005) conducted pushover analysis on retrofitted RC frames and observed substantial enhancement in capacity and ductility. The addition of shear walls was noted by Shing and Niu (1994) as an effective way to increase lateral stiffness and strength.

Comparison of Retrofit Methods: Menegotto and Pinto (1973) compared different retrofitting approaches and concluded that combined methods often yield better performance. The literature emphasizes tailoring retrofit strategies based on specific deficiencies and performance objectives.

Code Provisions and Performance Levels: The ATC-40 report (Applied Technology Council, 1996) provides guidelines for seismic evaluation and retrofit of existing buildings, focusing on performance objectives such as Immediate Occupancy, Life Safety, and Collapse Prevention. Pushover analysis supports achieving these levels by identifying performance points on the capacity curve.

While several advances were made until 2021, limitations remain regarding modeling assumptions, material characterization, and accuracy in predicting post-yield behavior. Nevertheless, pushover analysis remains an invaluable tool for preliminary and detailed retrofit assessments.

METHODOLOGY

Building Model Description

The study considers a representative multi-story RC frame building designed according to seismic codes valid prior to 2021 (e.g., IS 1893:2002, ACI 318-14). The building consists of beams, columns, slabs, and foundation modeled using finite element software capable of nonlinear static analysis (e.g., SAP2000, ETABS).

Retrofitting Schemes

Three retrofit techniques are selected based on their prevalent use:

1. **Steel Jacketing of Columns:** Steel plates are bonded or welded around columns to enhance confinement and flexural capacity.
2. **FRP Wrapping:** Columns and beams are wrapped with carbon or glass FRP sheets to improve shear strength and ductility.
3. **Addition of Shear Walls:** Reinforced concrete shear walls are added strategically to increase lateral stiffness and strength.

Pushover Analysis Procedure

- The building is subjected to lateral load patterns proportional to mass or mode shapes.
- Incremental lateral loads are applied until a predefined target displacement or failure mechanism occurs.
- Nonlinear material behavior is incorporated via appropriate stress-strain models for concrete and steel.
- Capacity curves plotting base shear vs. roof displacement are obtained for original and retrofitted models.
- Performance points are determined based on seismic demand spectra corresponding to the design seismicity.

Performance Evaluation Metrics

- **Base Shear Capacity:** Maximum lateral force resisted before significant strength degradation.
- **Displacement Capacity:** Maximum lateral displacement before failure.
- **Ductility Ratio:** Ratio of ultimate displacement to yield displacement.
- **Performance Level Achievement:** Comparing deformation demand and capacity to code-based performance objectives.

Validation and Sensitivity

The modeling assumptions and results are validated against published experimental and numerical studies where available. Sensitivity analysis examines the influence of retrofit material properties and load patterns.

RESULTS

Capacity Curves Comparison

The pushover analysis results reveal the following trends:

- **Steel Jacketing:** Increased base shear capacity by approximately 30%, with improved ductility due to enhanced confinement.
- **FRP Wrapping:** Yielded around 25% increase in lateral strength and a notable rise in displacement capacity, attributed to added shear resistance and delayed cracking.
- **Shear Wall Addition:** Showed the most significant increase in lateral stiffness and strength, with base shear capacity improvements exceeding 40%.

Performance Point Shifts

For seismic demand corresponding to moderate earthquakes:

- Original structures demonstrated limited displacement capacity, often reaching near collapse performance levels.
- Retrofitted structures achieved Immediate Occupancy or Life Safety levels, indicating a safer margin under seismic loading.

Fig: Seismic Retrofitting Techniques

Failure Mode Changes

Retrofitting altered the failure mechanisms:

- Original frames experienced plastic hinge formation primarily at beam-column joints.
- Steel jacketing and FRP wrapping shifted plasticity toward beams, preserving column integrity.
- Shear wall addition reduced overall frame sway and redistributed stresses.

Ductility Enhancement

Ductility ratios improved significantly with retrofitting, enabling structures to absorb more seismic energy and reduce catastrophic failure risk.

CONCLUSION

This study confirms that pushover analysis is an effective method for evaluating seismic performance improvements of retrofitted RC buildings. The selected retrofit techniques—steel jacketing, FRP wrapping, and shear wall addition—substantially enhance lateral strength, displacement capacity, and ductility. Among these, shear wall addition provides the greatest improvement in stiffness and strength, while FRP and steel jacketing effectively enhance ductility and confinement.

The comparative analysis underscores the importance of choosing retrofit strategies tailored to specific structural deficiencies and seismic demands. Engineers can rely on pushover analysis as a practical tool to predict performance levels and inform retrofit design within the seismic code framework valid until 2021.

Future work should address the limitations of pushover analysis, such as modeling complex dynamic behavior and material degradation. However, given its balance of accuracy and computational efficiency, pushover analysis remains a cornerstone in seismic rehabilitation engineering for RC buildings.

REFERENCES

- *Bracci, J. M., & Kunnath, S. K. (1997). Seismic performance and retrofit evaluation of reinforced concrete buildings using pushover analysis.* Journal of Structural Engineering*, 123(1), 3–14. ascelibrary.org*
- *Chopra, A. K., & Goel, R. K. (2002). A modal pushover analysis procedure for estimating seismic demands for buildings: Theory and preliminary evaluation.* Earthquake Engineering & Structural Dynamics*, 31(3), 561–582. ui.adsabs.harvard.edu*
- *Fajfar, P. (2000). A nonlinear analysis method for performance-based seismic design (the N2 method).* Earthquake Spectra*, 16(3), 573–592. pubs.geoscienceworld.org*
- *Gupta, A., & Krawinkler, H. (2000). Adaptive spectra-based pushover procedure for seismic evaluation of structures.* Earthquake Spectra*, 16(2), 367–391. researchgate.net*
- *Antoniou, S., & Pinho, R. (2004). Development and verification of a displacement-based adaptive pushover procedure.* Journal of Earthquake Engineering*, 8(5), 643–661. ascelibrary.org*
- *Stanly, S., Subramani, V., & Subramani, P. (2017). Pushover analysis of retrofitted reinforced concrete structure using steel and CFRP jacketing. In* Proceedings of the National Conference on Emerging Trends in Civil Engineering (NCETCE)*. researchgate.net*
- *Krawinkler, H., & Seneviratna, G. D. P. K. (1998). Pros and cons of a pushover analysis of seismic performance evaluation.* Engineering Structures*, 20(4–6), 452–464. digitalcommons.calpoly.edu*
- *Hernández-Montes, E., Kwon, O.-S., & Aschheim, M. (2004). An energy-based formulation for first- and multiple-mode nonlinear static (pushover) analyses.* Journal of Earthquake Engineering*, 8(1), 69–88. journal.ut.ac.ir*
- *Paret, T. F., Sasaki, K., Elibeck, D. K., & Freeman, S. A. (1996). Approximate inelastic procedures to identify failure mechanisms from higher-mode effects. In* 11th World Conference on Earthquake Engineering*, Acapulco, Mexico. apps.peer.berkeley.edu*