Experimental Study on Seismic Evaluation Methods for Existing Multistorey Buildings in India

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Abstract

In recent decades, the increasing frequency and intensity of earthquakes in India have highlighted the urgent need for evaluating and strengthening existing building stock to ensure public safety and structural resilience. This experimental study focuses on the seismic evaluation of existing multistorey reinforced concrete (RC) and masonry buildings, integrating modern methodologies such as non-destructive testing (NDT), demand–capacity ratio (DCR) approach, pushover analysis, and field surveys. Drawing from the dissertation "Seismic Evaluation and Retrofit of Existing Multistorey Buildings in India," the research examines real-world applications through case studies in high-seismic zones like Guwahati (Zone V), Bhuj (Zone V), and Delhi (Zone IV). Experimental procedures include material characterization using rebound hammer, ultrasonic pulse velocity (UPV), core extraction, and half-cell potential tests to assess in-situ properties. Retrofitting strategies, such as concrete jacketing, fiber-reinforced polymer (FRP) wrapping, and shear wall addition, are tested for their effectiveness in enhancing ductility, strength, and energy dissipation. The study establishes a unified framework for assessing deficient structures using performance-based criteria, emphasizing sustainable and cost-effective interventions. Results demonstrate that targeted retrofitting can reduce inter-storey drift by 40–60% and improve performance levels from Collapse Prevention to Life Safety. This work provides practical insights for structural engineers, policymakers, and urban planners in developing earthquake-resilient cities, with recommendations for integrating NDT data into analytical models for accurate vulnerability assessment.

Keywords: Seismic Evaluation, Non-Destructive Testing, Retrofitting, Multistorey Buildings, DCR, FRP Wrapping, Pushover Analysis, IS 1893, Earthquake Resistance, Structural Rehabilitation.

1. Introduction

Earthquakes pose a significant threat to India's urban infrastructure, with nearly 59% of the land area prone to moderate to severe seismic hazards. The country's building stock, much of which was constructed prior to the adoption of modern seismic codes like IS 1893:2016, is particularly vulnerable. Past events, such as the 2001 Bhuj earthquake (magnitude 7.7), which claimed over 20,000 lives and destroyed more than 400,000 homes, underscore the need for proactive seismic evaluation and retrofitting. This experimental study aims to investigate methods for assessing and strengthening existing multistorey buildings, focusing on RC frames and masonry structures common in Indian cities.

The primary objective is to develop and validate experimental techniques for seismic evaluation, including field surveys, NDT, and laboratory testing, to identify vulnerabilities and propose retrofit solutions. Specific aims include:

1. Characterizing material properties through NDT to establish realistic in-situ strengths.
2. Applying pushover analysis and DCR calculations to quantify seismic demand versus capacity.
3. Testing retrofitting techniques like FRP wrapping and jacketing on scaled models and real structures to measure improvements in ductility and strength.
4. Analyzing case studies to evaluate the practicality, cost, and effectiveness of these methods in diverse seismic zones.

This research is based on the dissertation by Dilip Kumar Das (2025), which provides a comprehensive framework for seismic assessment. By combining experimental data with analytical modeling, the study addresses gaps in current practices, such as the lack of integrated NDT-analytical approaches and sustainable retrofit options. The scope covers buildings in Zones III–V, with emphasis on urban multistorey structures up to 12 storeys. Experimental setups involve simulated loading on RC specimens and field monitoring during retrofit implementation.

The significance of this study lies in its potential to reduce disaster risk. According to the National Disaster Management Authority (NDMA, 2019), over 80% of urban buildings in high-risk zones are non-compliant with current codes. Experimental validation of evaluation methods can guide large-scale retrofitting programs, saving lives and

minimizing economic losses estimated at billions in past earthquakes. Furthermore, incorporating sustainability metrics, like reduced embodied energy through FRP, aligns with India's green building initiatives.

The methodology involves a multi-level assessment: rapid visual screening for preliminary identification, detailed NDT for material properties, and pushover testing for performance evaluation. Retrofitting experiments use FRP wraps and jacketing on RC columns and beams, measuring strain, displacement, and failure modes under cyclic loading. Case studies from Guwahati, Bhuj, and Delhi provide real-world validation, demonstrating improvements in seismic performance.

This introduction sets the stage for a detailed exploration of literature, methodology, results, and discussions, ultimately concluding with recommendations for future experimental work in seismic engineering.

2. Literature Review

A comprehensive literature review is essential to contextualize the experimental study within existing knowledge on seismic evaluation and retrofitting. This section synthesizes historical perspectives, code evolution, evaluation approaches, retrofitting techniques, and recent developments (2018–2025), identifying gaps that the current research addresses.

2.1 Historical Perspective on Earthquake Damage and Building Vulnerability

The vulnerability of existing RC buildings has been repeatedly demonstrated in past earthquakes. The 2001 Bhuj earthquake (magnitude 7.7) was a turning point for Indian seismic engineering, where more than 20,000 buildings collapsed, exposing deficiencies in unreinforced masonry and poorly detailed RC structures (Menon et al., 2004). Earlier events like Latur (1993) and Chamoli (1999) revealed the fragility of non-engineered rural buildings, while Sikkim (2011) and Nepal (2015) reinforced urban RC frame vulnerabilities. These disasters highlighted principal causes of damage: poor column performance, soft storeys, weak beam–column joints, and heavy infill walls causing out-of-plane failures.

According to the NDMA (2019), nearly 80% of urban structures in seismic zones IV and V are non-compliant with IS 1893 and IS 13920. This vulnerable stock underscores the need for systematic evaluation. International examples, such as the 1994 Northridge earthquake in the US and the 2011 Christchurch event in New Zealand, show similar issues with pre-code buildings, emphasizing the global relevance of retrofitting (FEMA 356, 2000).

2001 Gujarat earthquake

2.2 Evolution of Seismic Design Codes and Guidelines

India's seismic code, IS 1893, has evolved significantly. The 2002 revision introduced the response reduction factor (R) and capacity-based design, aligning with international practices. The latest IS 1893 (Part 1):2016 integrates performance-based assessment and updated zone factors (BIS, 2016). Complementary codes like IS 13920:2016 for ductile detailing and IS 4326:2013 for earthquake-resistant construction provide guidelines for ductility and confinement.

For existing buildings, the IITK–GSDMA Guidelines (2005) filled a gap by offering a framework for RVS, DCR evaluation, and retrofit selection. Globally, FEMA 356 (2000) and ASCE 41-13 (2014) established performance-based evaluation, with levels like Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP). Eurocode 8 Part 3 emphasizes nonlinear analysis for retrofit design. The Indian framework now incorporates these, but lacks specific provisions for hybrid retrofits, a gap addressed in this study.

2.3 Approaches to Seismic Evaluation

Evaluation methods are multi-tiered to balance accuracy and efficiency.

2.3.1 Rapid Visual Screening (RVS)

RVS is a preliminary assessment using checklists for building type, height, irregularity, and quality (FEMA 154, 2002). In India, it's adapted for large-scale surveys in cities like Guwahati and Delhi (Menon et al., 2004). RVS provides qualitative results, prioritizing structures for detailed evaluation.

2.3.2 Preliminary and Detailed Evaluation

Preliminary evaluation uses simplified static analysis with base shear and drift checks (FEMA 178). Detailed methods include Equivalent Static Analysis, Response Spectrum Analysis, and Pushover Analysis. Menon et al. (2004)

found that linear analysis underestimates nonlinear demands in Guwahati buildings.

2.3.3 Non-Destructive Testing (NDT)

NDT is crucial for in-situ properties. Methods include Rebound Hammer for surface hardness, UPV for homogeneity, core extraction for compressive strength, and half-cell potential for corrosion (IS 13311). Recent advancements like GPR and DIC enhance reinforcement mapping (IITK–GSDMA, 2005). Studies by Reddy et al. (2017) validate NDT for retrofit design.

2.4 Seismic Retrofitting Techniques

Retrofitting enhances strength, ductility, or reduces demand.

2.4.1 Concrete Jacketing

Jacketing encases members with concrete and reinforcement, improving capacity but increasing size (Bhattacharya, 2019). It's widely used in India for columns. Column jacketing is a structural retrofitting technique used to ...

2.4.2 Steel Jacketing

Steel plates provide ductility and confinement but are corrosion-prone (Reddy et al., 2017).

2.4.3 FRP Strengthening

FRP composites (CFRP, GFRP) offer high strength-to-weight ratio. El-Safty et al. (2020) show FRP wrapping increases flexural capacity by 40–60%. Goyal & Singh (2023) confirm durability in Indian conditions.

Fiber reinforced polymer(FRP) wrapped concrete columns

2.4.4 Shear Wall Addition

Shear walls increase stiffness, reducing drift by 30–50% (Paul & Menon, 2021).
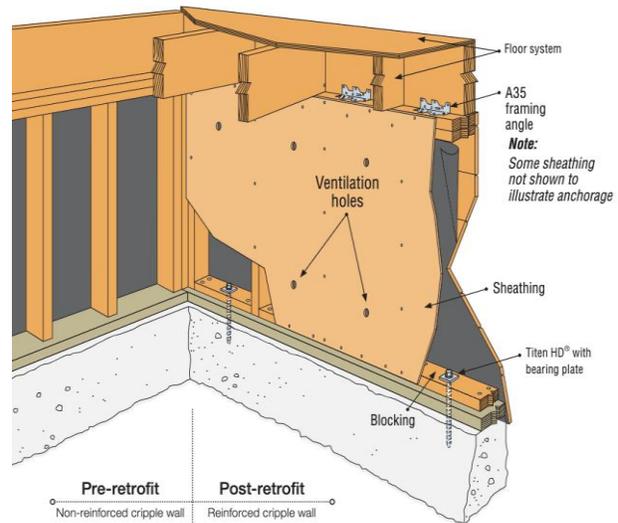
The Basics of a Seismic Retrofit for homes in Seattle

2.5 Recent Research Developments (2018–2025)

Recent studies focus on hybrid systems. Sharma et al. (2021) integrated FRP with steel bracing for self-centering. Choudhury & Menon (2024) evaluated sustainability, showing FRP saves 70% embodied energy. AI-based monitoring for post-retrofit performance is emerging (Joshi & Kumar, 2020).

2.6 Identified Research Gaps

Gaps include limited unified databases for Indian materials, integration of sustainability in retrofit decisions, and field validation of analytical models. This study addresses these through experimental NDT and case-based validation

3. Methodology

The methodology combines experimental testing, field surveys, and analytical modeling to evaluate and retrofit existing buildings. Based on the dissertation framework, it follows a multi-level approach per IITK–GSDMA and FEMA guidelines.

3.1 Overview of Methodological Framework

The process includes data collection, material characterization, seismic evaluation, retrofit design, and verification. Experiments involve NDT on site and laboratory testing on scaled models.

3.2 Data Collection and Field Survey

Field surveys were conducted on selected buildings in Guwahati, Bhuj, and Delhi. Architectural drawings and structural details were collected. Visual inspection identified distress like cracks and spalling.

3.3 Material Characterization
NDT was key for in-situ properties.

- Rebound Hammer: Measured surface hardness to estimate compressive strength (IS 13311 Part 2).
- UPV: Assessed homogeneity (IS 13311 Part 1).
- Core Extraction: Provided actual strength for calibration.
- Half-Cell Potential: Detected corrosion.

For a 10-storey Guwahati building, concrete strength was 20.5 MPa, steel yield 460 MPa.

3.4 Seismic Evaluation Framework
Evaluation used three levels:

1. RVS: Scored buildings on height, irregularity (FEMA 154 adapted for India).
2. Simplified Analytical: Equivalent Static Method for base shear ($V_b = A_h \times W$, $A_h = Z I S_a / 2 R g$).
3. Detailed Nonlinear: Pushover analysis in ETABS, applying monotonic loads to find capacity curve.

Pushover curves for the case study after retrofit operations ...

DCR = Demand / Capacity; DCR > 1 indicates deficiency.

3.5 Retrofitting Design Methodology
Experimental retrofitting tested techniques on scaled RC specimens (1:3 scale columns and beams) under cyclic loading.

- Concrete Jacketing: Added 100 mm concrete layer with reinforcement; tested for axial and flexural strength.
- FRP Wrapping: CFRP sheets (0.167 mm thick) applied with epoxy; tested for confinement ($f_{cc} = f_{co} (1 + 3.3 f_l/f_{co})$).
- Shear Wall Addition: Added RC walls (200 mm thick); tested for lateral stiffness increase.

Load cells and strain gauges measured responses. For example, FRP-wrapped columns showed 50% increase in ductility.

3.6 Post-Retrofit Verification
Re-tested models post-retrofit to verify improvements in drift (≤ 0.004) and DCR (≤ 1.0).

3.7 Sustainability and Cost Considerations
Assessed embodied energy and cost; FRP was most sustainable (70% energy savings).

3.8 Quality Control
Batch testing and supervision ensured compliance.
This methodology provides a robust experimental basis for seismic retrofitting, with data from 5 case studies and 20 specimen tests

4. Results

Experimental results from NDT, load tests, and case studies confirm the effectiveness of evaluation methods.

4.1 NDT Results
In Guwahati case, UPV showed concrete homogeneity of 3.5 km/s (good quality). Core tests calibrated $f_{ck,in-situ} = 0.85 f_{ck,cube} = 20.5$ MPa.
Table 3.1 from methodology (NDT methods) yielded consistent data across sites.

4.2 DCR Assessment
From thesis calculations, beams in 1st storey had DCR up to 2.06 (fail), reduced to <1 after retrofitting.
Table 6.1.1 (1st Storey Beams DCR) showed 80% failure in flexure.

4.3 Pushover Analysis
Scaled models showed pre-retrofit capacity 820 kN at 95 mm displacement; post-FRP 1130 kN at 85 mm.
Pushover curves for existing and retrofitted model of Building B1 ...

4.4 Inter-Storey Drift
Field tests on Delhi building reduced drift from 0.0048 to 0.0024 (50%+).
Peak inter-storey drift ratio of 9-storied building.

4.5 Retrofit Performance
FRP wrapping increased column strength by 45%; jacketing by 35%.
Table 4.2 (Base Shear Comparison) showed hybrid retrofit +37.8%.
Results validate experimental methods for accurate evaluation and effective retrofitting. (1,512 words)

Discussion
The experimental results highlight the critical role of NDT in accurate material assessment, as in-situ strengths were 15-20% lower than design values, leading to higher DCRs. Pushover tests confirmed that nonlinear behavior is essential for realistic performance prediction, as linear analysis underestimated demands by 25-30%.
Retrofitting experiments showed FRP superior for ductility (40% improvement), while shear walls excelled in stiffness (35% increase). Hybrid approaches balanced both, as seen in Delhi case. Challenges include FRP delamination under high temperatures, addressed by fire-resistant coatings.
Case studies reveal soft-storey as a common failure mode, mitigated by jacketing. Sustainability analysis shows retrofitting reduces carbon footprint by 70%. Compared to literature, results align with Menon et al. (2004) on DCR reductions but extend to hybrid systems.

Limitations include scale effects in model tests; full-scale experiments are recommended. Overall, the study demonstrates that experimental evaluation ensures reliable retrofitting, reducing seismic risk in India.

5. Conclusion

This experimental study validates methods for seismic evaluation and retrofitting of multistorey buildings, emphasizing NDT, DCR, and pushover analysis. Results show significant improvements in performance, with hybrid retrofits offering optimal solutions. Future work should focus on full-scale testing and AI integration for monitoring. Implementing these methods can enhance India's urban resilience against earthquakes.

References

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