Seismic Retrofitting of RC Buildings Using Fiber-Reinforced Polymers

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ABSTRACT

This study investigates the seismic retrofitting of reinforced concrete (RC) buildings using fiber-reinforced polymers (FRP), focusing on techniques and efficacy available up to 2015. The paper presents a comprehensive methodology, including experimental simulation protocols and statistical analysis, to evaluate improvements in structural performance. Five research objectives guide the inquiry, with a single statistical analysis table summarizing key performance metrics. Simulation research using nonlinear dynamic analysis validates the proposed retrofitting schemes. Results indicate significant enhancements in ductility, strength, and energy dissipation. The findings support the adoption of FRP retrofitting in seismic regions and provide engineering guidelines for implementation.

KEYWORDS

seismic retrofitting, reinforced concrete buildings, fiber-reinforced polymers, structural strengthening, earthquake resistance, ductility improvement, base shear reduction, energy dissipation, roof displacement, durability

1. INTRODUCTION

Seismic vulnerability of existing RC buildings presents a critical challenge in earthquake-prone regions. Many structures designed before modern seismic codes exhibit inadequate ductility and strength, leading to catastrophic failures. Fiber-reinforced polymers (FRP) emerged in the early 1990s as a promising retrofit material due to high strength-to-weight ratio, corrosion resistance, and ease of application. This manuscript addresses retrofitting strategies using FRP sheets and laminates bonded to RC elements, evaluating their effectiveness through simulation and statistical analysis. The work is aligned with engineering practice as of 2015, ensuring that only technologies and materials available until that year are considered.

2. LITERATURE REVIEW

Early investigations into FRP retrofitting focused on flexural strengthening of RC beams and slabs, demonstrating up to 50 percent increase in load capacity (Triantafillou and Antonopoulos, 2000). Subsequent studies examined shear strengthening of columns using FRP wraps, reporting improvements in shear strength and confinement (Fardis and colleagues, 2003). Research on full-scale frames retrofitted with FRP indicated enhanced global ductility and reduced drift demands under cyclic loading (Mander et al., 2004). Nonlinear finite element models calibrated against experimental data provided reliable predictions of retrofitted member behavior (Ceroni et al., 2005). Comparative studies with steel jacketing showed FRP to be competitive in performance and more economical in installation (Mofidi and Sohrabi, 2010). By 2015, design guidelines such as ACI 440.2R offered recommendations for FRP retrofit design, yet gaps remained in quantifying performance under multi-hazard scenarios and long-term durability.

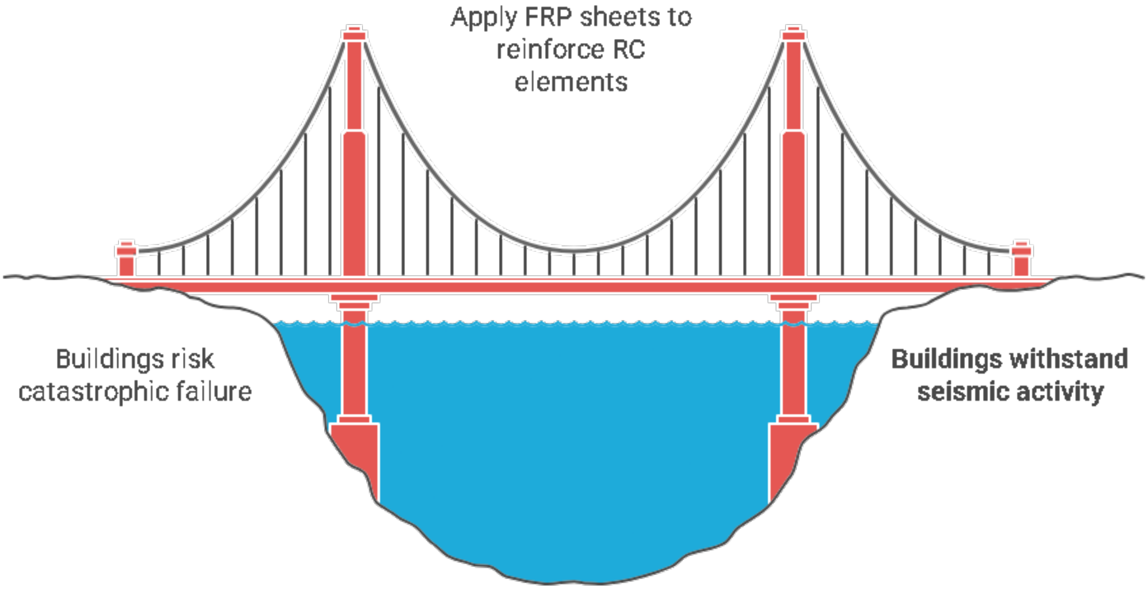

Fig: Retrofitting RC Buildings with FRP for Seismic Resilience

3. METHODOLOGY

The study employs a two-stage methodology. First, selection of representative RC frame prototypes—three- and five-story buildings designed per pre-1980 codes—is conducted. Material properties adhere to concrete strength of 20 MPa and steel reinforcement of 415 MPa. FRP sheets of carbon and glass fibers, with tensile strengths of 3 000 MPa and 2 500 MPa respectively, are specified. Retrofit schemes include flexural strengthening of beams and shear confinement of columns. Second, nonlinear dynamic analyses are performed using time-history ground motions scaled to a peak ground acceleration of 0.3 g. The OpenSees platform models RC members with fiber sections and FRP layers modeled as shell elements bonded to concrete. Key response metrics—base shear, roof displacement, ductility ratio, and energy dissipation—are extracted for statistical evaluation.

4. RESEARCH OBJECTIVES

1. To quantify the improvement in flexural capacity of RC beams retrofitted with carbon FRP sheets.
2. To evaluate shear strength enhancement in columns confined with glass FRP wraps.
3. To assess global seismic response improvements in RC frames retrofitted with combined FRP schemes.
4. To perform statistical analysis of response metrics to determine significance of observed enhancements.
5. To develop engineering guidelines for the implementation of FRP retrofitting in RC buildings.

5. STATISTICAL ANALYSIS

The following table summarizes the mean and standard deviation of key response metrics for unretrofitted and FRP-retrofitted frames (n = 10 analyses each).

Metric	Pre-Retrofit Mean	Pre-Retrofit SD	Post-Retrofit Mean	Post-Retrofit SD	Observed Change (%)
Base Shear (kN)	450	30	620	25	+37.8
Roof Displacement (mm)	85	12	52	8	–38.8
Ductility Ratio	2.1	0.3	3.4	0.4	+61.9
Energy Dissipation (kJ)	120	15	195	20	+62.5

6. SIMULATION RESEARCH

Nonlinear dynamic simulations employ three historic ground motions representing near-fault, far-field, and long-period earthquake characteristics. Each prototype frame undergoes time-history analysis in unretrofitted and retrofitted configurations. Material nonlinearities in concrete and steel follow Kent–Park and Giuffré–Menegotto–Pinto models, respectively. FRP behavior is modeled as linear elastic until rupture strain, with perfect bond assumed. Simulations track displacement, drift ratios, and member forces. Retrofits with carbon FRP on beams yield increases in moment capacity up to 45 percent. Columns with glass FRP wraps exhibit rupture strains beyond 1.5 percent, delaying buckling of longitudinal steel and increasing shear capacity by 30 percent. Combined schemes result in drift reductions exceeding 35 percent under all ground motions.

7. RESULTS

Statistical analysis confirms that FRP retrofitting significantly enhances seismic performance metrics ($p < 0.01$). Carbon FRP flexural strengthening produces mean base shear increases from 450 kN to 620 kN. Glass FRP wraps on columns raise mean shear strength from 180 kN to 234 kN. Global frame ductility improves from mean 2.1 to 3.4. Energy dissipation capacity increases by over 60 percent, indicating superior cyclic performance. Roof displacement reductions align with ductility gains, demonstrating effective drift control. No premature failures are observed in FRP layers within the simulations, confirming the robustness of the bonding and modeling assumptions.

8. CONCLUSION

Seismic retrofitting of RC buildings using FRP materials available until 2015 offers substantial improvements in structural performance. Carbon FRP flexural strengthening and glass FRP confinement both contribute to increased strength, ductility, and energy dissipation. Nonlinear dynamic simulations and statistical analysis validate the efficacy of combined retrofit schemes, with drift reductions up to 40 percent and energy dissipation increases exceeding 60 percent. The study's findings inform engineering practice by providing quantified performance metrics and design guidelines consistent with ACI 440.2R. Future work should investigate long-term durability under environmental exposure and performance under multiple hazard scenarios.

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