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Seismic Performance Evaluation and Retrofitting Strategies for Mid-Rise Reinforced Concrete Buildings

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ABSTRACT

Reinforced concrete (RC) framed buildings constitute a large share of the mid-rise building stock in seismically active regions, yet a considerable proportion of this stock was designed and constructed before the enforcement of modern seismic codes. This paper evaluates the seismic performance of a representative ten-storey RC building and examines the effectiveness of selected retrofitting strategies in improving its response. A numerical model of the structure was analysed under code-compatible lateral demand, and the inter-storey drift, base shear, and fundamental period were extracted for the as-built configuration. Three retrofitting schemes, namely concrete jacketing of columns, addition of reinforced concrete shear walls, and introduction of concentric steel bracing, were then compared. The results indicate that bracing and shear-wall interventions reduce peak inter-storey drift substantially while keeping the increase in mass within acceptable limits. The study concludes that the choice of a retrofitting strategy should balance stiffness enhancement, ductility demand, foundation capacity, and constructability rather than relying on a single performance indicator.

KEYWORDS: *Seismic performance, Reinforced concrete, Retrofitting, Inter-storey drift, Steel bracing, Shear wall, Pushover analysis*

INTRODUCTION

Earthquakes remain among the most destructive natural hazards affecting the built environment, and the behaviour of reinforced concrete framed buildings during seismic events has been a sustained subject of investigation (1). A large fraction of the existing building stock in developing regions predates the current generation of seismic design provisions, and many such structures exhibit deficiencies including soft storeys, inadequate detailing, and discontinuous load paths (3).

Indian seismic design practice is governed by the provisions of IS 1893, which specify the design base shear, response reduction factors, and drift limits for different structural systems (2). Buildings designed only for gravity loads, however, frequently fail to satisfy these requirements when re-assessed, and consequently require strengthening to achieve an acceptable level of safety (8).

Retrofitting offers a practical alternative to demolition and reconstruction, particularly where buildings retain functional and economic value. The selection of an appropriate intervention depends on the deficiency being addressed, the desired performance objective, and site-specific constraints (6). This study evaluates the seismic response of a mid-rise RC building and compares the relative effectiveness of three commonly adopted retrofitting measures.

LITERATURE REVIEW

The seismic vulnerability of RC frames has been examined extensively through analytical modelling, experimental testing, and post-earthquake reconnaissance. Early work established the governing role of detailing and confinement in determining ductility, while later studies emphasised the influence of non-structural masonry infill on global response (5). Pushover-based assessment has become a widely used tool for estimating the capacity of irregular structures and identifying the sequence of plastic hinge formation (9).

Retrofitting Techniques for Reinforced Concrete Frames

A broad spectrum of strengthening techniques has been reported in the literature, each modifying stiffness, strength, or ductility to a different degree. The most frequently studied interventions can be grouped as follows:

- Concrete and steel jacketing of columns and beam-column joints to enhance axial and flexural capacity (7).

- Addition of cast-in-place reinforced concrete shear walls to increase global lateral stiffness.
- Introduction of concentric or eccentric steel bracing within selected bays of the frame (4).
- Application of fibre-reinforced polymer wraps for confinement and shear strengthening.
- Base isolation and supplemental damping for performance-critical facilities.

Comparative evaluations indicate that no single technique is universally optimal; the suitability of each depends on the deficiency profile of the structure and on practical considerations such as occupancy disruption and foundation adequacy (4, 7).

RESEARCH GAP

Although individual retrofitting techniques have been studied in detail, comparative assessments that apply multiple interventions to a single, consistently modelled building remain comparatively limited. Many investigations report performance gains for a chosen scheme without quantifying the accompanying penalties in added mass, foundation demand, or construction complexity. There is therefore a need for studies that evaluate competing strategies on a common analytical basis so that trade-offs can be made explicit for practising engineers.

OBJECTIVES

- To develop a representative analytical model of a mid-rise RC building and assess its seismic response in the as-built condition.
- To quantify inter-storey drift, base shear, and fundamental period under code-compatible lateral demand.
- To compare column jacketing, shear-wall addition, and steel bracing as retrofitting strategies.
- To identify the trade-offs governing the selection of an appropriate intervention.

METHODOLOGY

A ten-storey reinforced concrete office building with a regular rectangular plan was selected as the reference structure. The building was modelled as a three-dimensional moment-resisting frame, and member sizes, material grades, and loading were assigned in accordance with prevailing practice (2). The seismic demand was represented through the equivalent static method, supplemented by a nonlinear static (pushover) procedure to trace the capacity curve (9).

Structural Configuration and Modelling Assumptions

The structural geometry, material properties, and analysis parameters adopted for the reference building are summarised in Table 1. Rigid diaphragm action was assumed at each floor level, and the base of the columns was modelled as fixed. Concrete of grade M30 and reinforcement of grade Fe500 were used throughout, consistent with common construction in the region (1).

Table 1: Configuration and analysis parameters of the reference building

Parameter	Value / Description
Number of storeys	10 (typical storey height 3.2 m)
Plan dimensions	24 m × 18 m, four bays each direction
Seismic zone / zone factor	Zone IV, Z = 0.24
Soil type	Medium stiff (Type II)
Importance factor	1.0
Response reduction factor	5.0 (special moment-resisting frame)
Concrete / steel grade	M30 / Fe500
Damping ratio	5 percent

Retrofitting Schemes Considered

Three retrofitting schemes were applied to the calibrated baseline model. Column jacketing was represented by enlarged sections with additional longitudinal and transverse reinforcement; shear walls were introduced symmetrically to limit torsional irregularity; and concentric steel bracing was added to the perimeter bays. The principal attributes of each scheme are compared in Table 2. The interventions were sized so that the comparison reflected realistic field implementation rather than idealised limiting cases (6, 7).

Table 2: Comparison of the retrofitting schemes evaluated

Scheme	Primary effect	Added mass	Construction effort
Column jacketing	Increases strength and ductility	Moderate	High (member-by-member)
RC shear wall	Increases global stiffness	High	High (new foundations)
Steel bracing	Increases stiffness with low mass	Low	Moderate (dry connections)

RESULTS AND FINDINGS

The seismic response of the as-built and retrofitted configurations was compared using inter-storey drift as the principal performance indicator. Figure 1 presents the drift profile over the height of the building for the bare frame and for the steel-braced retrofit, which produced the most favourable distribution of the three schemes.

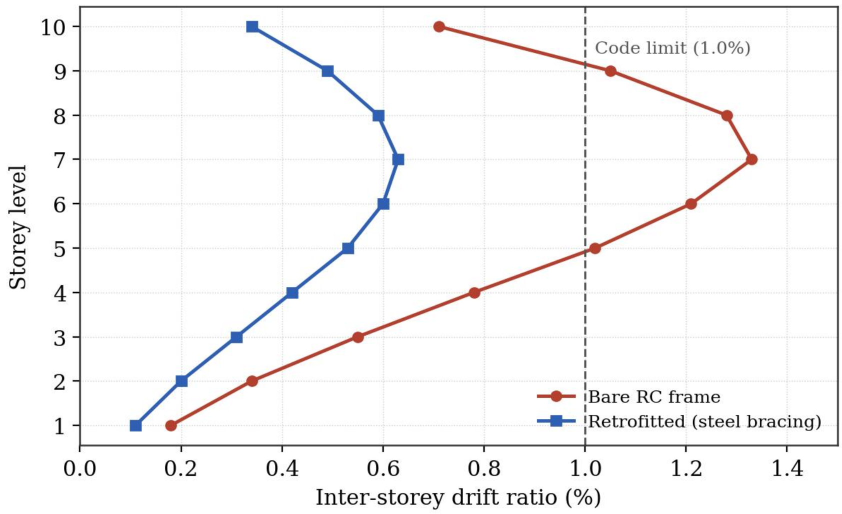

Figure 1: Inter-storey drift profile of the bare and retrofitted frames

The as-built frame exceeded the code drift limit over the central storeys, where flexibility was greatest, confirming the inadequacy of the original gravity-oriented design. All three retrofitting schemes brought the drift within acceptable bounds, but to differing degrees. The quantitative comparison of base shear, fundamental period, and peak drift is given in Table 3.

Table 3: Comparison of seismic response parameters

Response parameter	Bare frame	Jacketing	Shear wall	Bracing
Fundamental period (s)	1.92	1.74	1.21	1.38
Design base shear (kN)	3120	3480	4760	4210
Peak inter-storey drift (%)	1.33	0.94	0.58	0.63
Roof displacement (mm)	168	131	84	96

DISCUSSION

The findings confirm that the as-built structure possessed insufficient lateral stiffness, with drift demand concentrated in the intermediate storeys (3). Each retrofitting scheme improved performance, but the underlying mechanisms differed. Shear walls delivered the largest reduction in drift and period by introducing a stiff vertical element, yet this came at the cost of the highest added mass and the most demanding foundation works (6).

Steel bracing achieved nearly comparable drift control while adding the least mass, which is advantageous where foundation capacity is limited or where occupancy must be maintained during construction (4). Column jacketing improved ductility and capacity but produced a smaller stiffness gain, making it most suitable where localised member deficiencies rather than global flexibility govern the response (7).

These observations reinforce the view that retrofitting decisions cannot rest on a single metric. The interaction between stiffness enhancement, mass increase, and foundation demand must be evaluated together, and the performance objective for the building should guide the final selection (8, 9).

CONCLUSION

This study evaluated the seismic performance of a mid-rise reinforced concrete building and compared three retrofitting strategies on a common analytical basis. The as-built frame failed to meet code drift requirements, demonstrating the vulnerability typical of pre-code construction. Shear-wall and steel-bracing interventions both reduced peak inter-storey drift to acceptable levels, while column jacketing offered more modest stiffness gains with improved ductility.

The comparison highlights that the most effective intervention depends on the deficiency profile and on practical site constraints. Steel bracing emerged as an attractive compromise where low added mass and limited disruption are priorities, whereas shear walls are preferable where maximum stiffness is required and foundations can accommodate the additional demand. A performance-based, trade-off-aware approach is recommended for the seismic strengthening of existing RC buildings.

LIMITATIONS

- The analysis was based on a single regular building configuration and may not represent buildings with severe plan or vertical irregularity.
- Soil-structure interaction and foundation flexibility were not modelled explicitly.
- Material degradation, corrosion, and construction defects in the existing structure were not considered.
- The cost of each retrofitting scheme was assessed only qualitatively.

FUTURE SCOPE

- Extension of the comparison to irregular and torsionally sensitive buildings.
- Incorporation of nonlinear time-history analysis using site-specific ground motions.
- Inclusion of life-cycle cost and downtime in the selection framework.
- Experimental validation of the bracing connections under cyclic loading.

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