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Cost Estimation for Retrofitting Multi-Storey Building Structures Using the Concrete Jacketing Method

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A B S T R A C T

This study investigates the effectiveness of concrete jacketing in increasing the structural capacity of a multi-storey reinforced concrete building and estimates the associated retrofit cost. The existing structure was evaluated using static nonlinear pushover analysis based on ASCE 41-17 provisions to identify seismic deficiencies. Concrete jacketing was then applied to critical columns to enhance structural performance. Post-retrofit analysis shows a significant improvement in lateral load capacity and overall seismic behavior. Retrofit cost estimation was conducted based on retrofit work volumes and standard unit prices. The results indicate that concrete jacketing provides an effective and economically feasible solution for strengthening existing multi-storey buildings in seismic regions.

INTRODUCTION

Indonesia lies along subduction zones and active fault systems that form part of the Pacific Ring of Fire. This condition makes Indonesia one of the most earthquake-prone regions in the world, with varying frequency and intensity across different areas. Exposure to seismic hazards is chronic and spatially diverse, meaning that earthquake characteristics such as frequency spectrum, source type, shaking duration, and impulsive components significantly affect structural design (BMKG & AIEC, 2025).

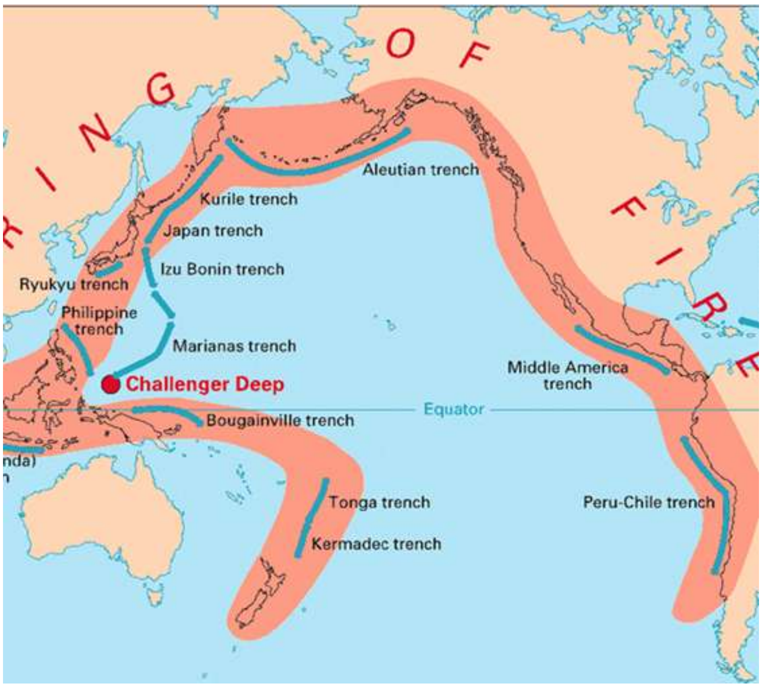


Figure 1. Ring of Fire

Existing buildings, particularly multi-story structures constructed before the adoption of modern seismic codes, exhibit various forms of structural vulnerability. Inadequate reinforcement detailing, limited shear capacity of columns, and soft-story mechanisms are common causes of damage. Major earthquakes in Indonesia have repeatedly revealed these failure patterns, underscoring the need to strengthen critical elements—especially columns—so that existing buildings can withstand seismic demands in accordance with current standards (Salim & Sidi, 2024).

Concrete jacketing is one of the most commonly adopted retrofit techniques for reinforced concrete structures. The method involves enlarging the cross-section of structural elements, typically columns, by adding new reinforced concrete layers. This technique effectively increases axial, flexural, and shear capacities while improving ductility and overall seismic performance. Compared to other retrofit methods such as steel jacketing or fiber-reinforced polymer (FRP) strengthening, concrete jacketing is often considered more economical and suitable for conventional construction practices (Zaiter & Lau, 2021).

Previous studies on concrete jacketing have primarily focused on structural performance improvement, such as increased load-carrying capacity and reduced story drift. However, studies addressing the economic aspect of seismic retrofit, particularly cost estimation based on actual retrofit needs, remain limited. In practice, retrofit decisions are strongly influenced by budget constraints, making cost estimation a critical component in retrofit planning.

Therefore, this study aims to estimate the seismic retrofit cost of a multi-story reinforced concrete building using the concrete jacketing method. The cost estimation is based on identified retrofit requirements derived from structural performance evaluation. The results are expected to provide insight into the economic feasibility of concrete jacketing as a seismic retrofit solution for existing buildings.

THEORETICAL REVIEW

Structural Capacity of Reinforced Concrete Buildings

Under strong earthquake conditions, reinforced concrete elements are designed to form plastic hinges at specific locations, such as beam ends, to withstand large deformations without global collapse. This mechanism allows energy dissipation through hysteresis, while capacity design directs the location of the hinges to control failure (Amini & Rajput, 2024). The distribution of stiffness and strength between stories influences global behavior, where imbalances can cause soft-story or short-column effects (Işık et al., 2024). The distribution of stiffness and strength between stories influences global behavior, where imbalances can cause soft-story or short-column effects (Shendkar et al., 2021).

The concepts of ductility, overstrength, and redundancy are fundamental principles of earthquake-resistant structures. Ductility reflects the ability to plastically deform before significant capacity loss, with ideal behavior being fully ductile, providing warning before collapse (Amini & Rajput, 2024).

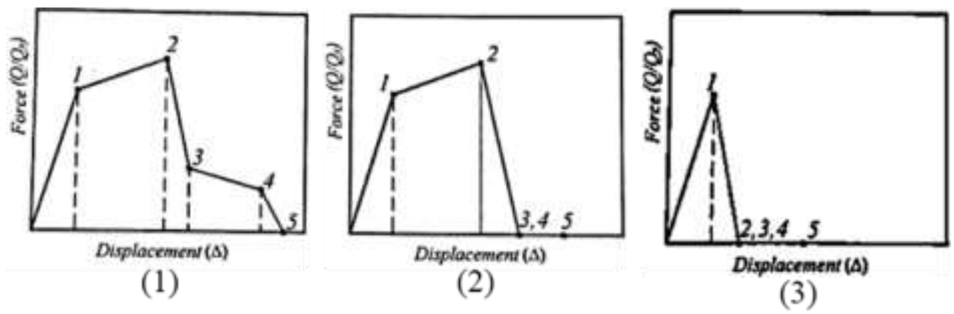


Figure 2. (1) Full Ductile, (2) Restricted Ductility, (3) Brittle Behavior

Concrete Jacketing

Concrete jacketing is a reinforcement method to increase the capacity of existing reinforced concrete elements by adding a layer of reinforced concrete by increasing the cross-sectional area, the number of reinforcement bars, the compressive strength, and providing additional confinement to the existing reinforcement (Villalba et al., 2024).

Retrofit Cost Estimation

Retrofit cost estimation typically includes material costs, labor costs, and construction-related expenses. For concrete jacketing, major cost components consist of concrete volume, reinforcement steel, formwork, and labor. Cost estimation based on work volume and unit prices provides a systematic approach to quantify retrofit expenses (Villalba et al., 2024).

METHODOLOGY

This study adopts a quantitative analytical approach by integrating seismic performance evaluation and retrofit cost estimation within a single research framework. The methodology was structured to systematically assess the existing structural capacity, design and evaluate the retrofit scheme using concrete jacketing, and estimate the associated retrofit cost based on actual strengthening requirements.

Research Object

The research object is an existing multi-story reinforced concrete building, which uses a reinforced concrete moment-resisting frame system and was designed based on existing seismic design requirements. Structural drawings, material specifications, and geometric data were obtained from existing building documents and field observations. These data served as the basis for developing an analytical structural model.

Evaluation of Existing Structural Capacity

The seismic performance of the existing structure was evaluated using static nonlinear pushover analysis in accordance with Tier 3 procedures of ASCE 41-17. Nonlinear behavior was represented through the assignment of plastic hinges at critical regions of beams and columns. Gravity loads were applied prior to the lateral loading procedure. The pushover analysis was conducted in the principal horizontal directions to obtain capacity curves, target displacements, and corresponding performance levels. The results of this analysis were used to identify structural deficiencies and critical elements requiring strengthening.

Retrofit Design Using Concrete Jacketing

Based on the performance evaluation results, columns exhibiting insufficient capacity were selected for retrofit. Concrete jacketing was designed by enlarging the existing column cross-sections and adding longitudinal and transverse reinforcement to enhance axial, flexural, and shear capacities. The jacket thickness, concrete compressive strength, and reinforcement detailing were determined to ensure adequate confinement and composite action between the existing concrete and the jacket. The retrofitted elements were then incorporated into the updated structural model.

Post-Retrofit Seismic Performance Evaluation

Following the retrofit design, the structural model was re-analyzed using static nonlinear pushover analysis with the same loading protocol applied to the existing structure. The post-retrofit capacity curves were compared with those of the original structure to quantify improvements in strength, stiffness, and global displacement capacity. Changes in performance levels and failure mechanisms were also evaluated to verify the effectiveness of the retrofit scheme.

Retrofit Cost Estimation

The retrofit cost was estimated based on the actual scope of strengthening required to achieve the targeted performance improvement. The volume of concrete jacketing was calculated from the difference between the original and enlarged column dimensions, while reinforcement quantities were determined based on the retrofit detailing. Unit prices for concrete, reinforcement, formwork, and labor were obtained from standard cost analysis references. The total retrofit cost was calculated by summing all cost components, providing an economic measure directly linked to the achieved increase in structural capacity.

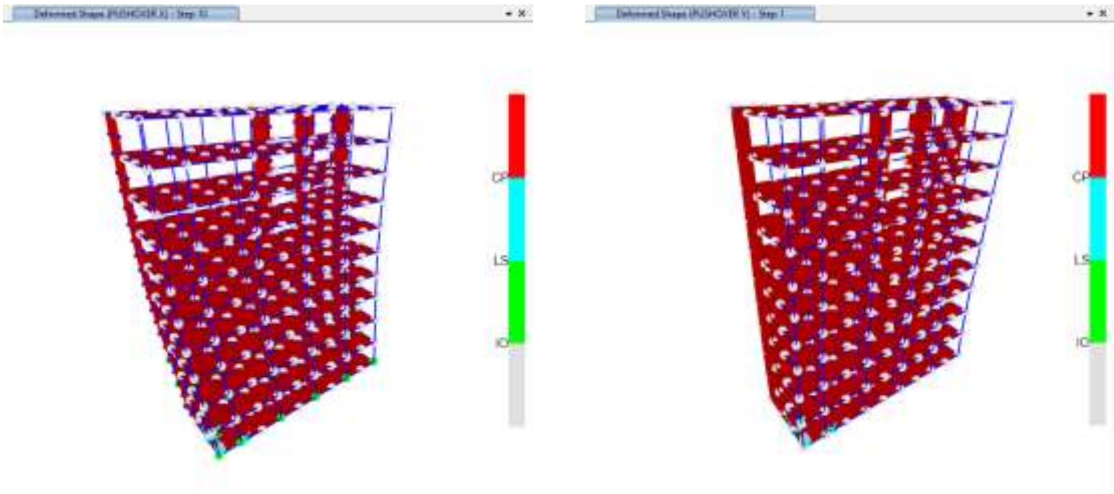
RESEARCH RESULTS

This section presents the results of the seismic performance evaluation and retrofit cost estimation. The results are organized to illustrate the improvement in structural capacity achieved through concrete jacketing and the corresponding retrofit cost required to attain the targeted performance level.

Existing Structural Performance

The pushover analysis results in the X direction indicate that at the BSE-1E earthquake level, plastic hinges form from the initial loading stage and develop into significant inelastic deformation after Step 10. However, up to the analysis limit at Step 26, there is no decrease in global capacity. Thus, the structure does not meet the Immediate Occupancy criteria, is at the Life Safety threshold, and meets the Collapse Prevention performance target.

Based on the Y-direction pushover analysis at the BSE-1E earthquake level, plastic hinges began to form from the initial loading stage (Step 1), but did not develop into significant inelastic deformation until the final analysis stage at Step 9. No reduction in capacity or indication of structural collapse was observed. Thus, the structure meets the Immediate Occupancy, Life Safety, and Collapse Prevention performance targets for the BSE-1E earthquake level in the Y direction.

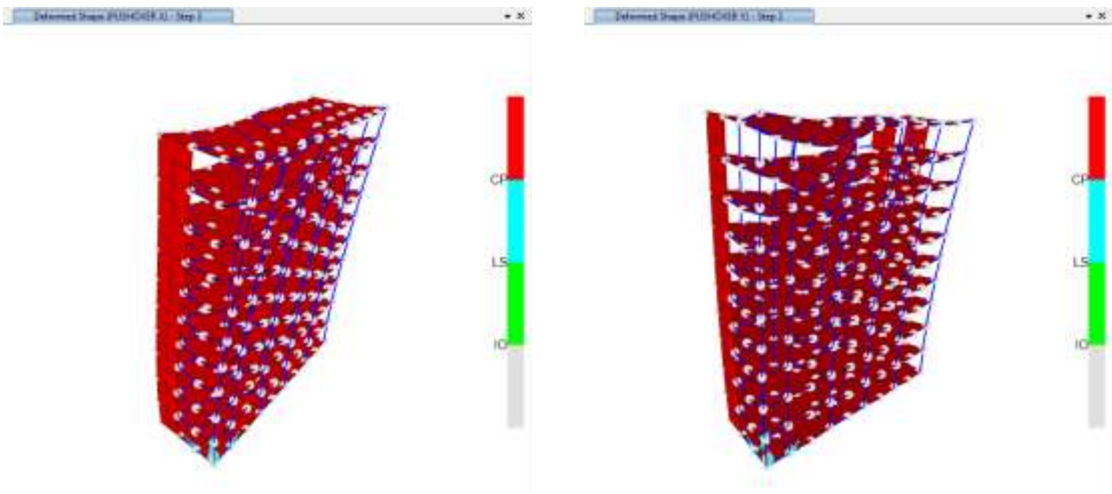


(1) (2)

Figure 3. Deformed Shape on Pushover X and (2) Deformed Shape on Pushover Y for BSE-1E

The X-direction pushover analysis results at the BSE-2E earthquake level indicate that the structure reaches significant deformation and its maximum capacity. So, the structure is unable to meet the BSE-2E performance target. Thus, the structure is expected to experience capacity loss or collapse before reaching the required displacement for the design earthquake.

The results of the Y-direction pushover analysis at the BSE-2E earthquake level indicate that the maximum displacement capacity. This indicates that significant deformation and indications of collapse, and the structure is unable to meet the BSE-2E earthquake performance target, because its capacity is only a very small part of the required demand.



(1) (2)

Figure 4. Deformed Shape on Pushover X and (2) Deformed Shape on Pushover Y for BSE-2E

Retrofit Work Volume

The retrofit work volume was determined based on the geometric differences between the existing and retrofitted column sections. The calculated concrete jacketing volume reflects the extent of cross-section enlargement required to meet the target performance criteria. In addition, reinforcement quantities were obtained from the detailed retrofit design, including longitudinal bars and transverse confinement reinforcement.

The results show that the retrofit scope was concentrated on a limited number of critical columns, indicating that targeted strengthening can effectively improve global structural performance without requiring extensive intervention across all structural elements.

Table 1. New Dimension

Analysis	Element	New Dimension	Volume (m^2)
Pushover X	K2-1 (400 × 800)	500 × 900	0,442
	K1-1 (400 × 800)	500 × 900	0,442
	K1-1 (400 × 800)	500 × 900	0,442
	K2-1 (300 × 800)	400 × 900	0,408
	K1-1 (300 × 800)	400 × 900	0,408
	K1-1 (300 × 800)	400 × 900	0,408
	K1-1 (300 × 800)	400 × 900	0,408
	K1-1 (300 × 700)	400 × 800	0,374
Pushover Y	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408
	K4-1 (300 × 800)	400 × 900	0,408

Structural Capacity Enhancement

The static nonlinear pushover analysis results indicate a clear improvement in the seismic performance of the structure after the application of concrete jacketing. In the existing condition, the structure exhibited limited lateral load capacity and experienced early formation of plastic hinges in critical columns, leading to an unsatisfactory performance level. After retrofit, the capacity curves show an increase in base shear capacity accompanied by an improvement in global stiffness and displacement capacity.

The post-retrofit analysis demonstrates a more favorable distribution of plastic hinges, with yielding predominantly occurring in beam elements rather than columns. This behavior indicates a shift toward a more desirable strong-column–weak-beam mechanism. Furthermore, the target performance level required for seismic safety was successfully achieved after retrofitting, confirming the effectiveness of the concrete jacketing scheme in enhancing overall structural capacity.

Table 2. Capacity Fulfillment Recapitulation

Analysis	Element	$\frac{P_u}{P_n} + \frac{M_u}{M_n} > 1$	$V_c + V_s \geq V_u$
Pushover X	K2-1 (400 × 800)	qualify	qualify
	K1-1 (400 × 800)	qualify	qualify
	K1-1 (400 × 800)	qualify	qualify
	K2-1 (300 × 800)	qualify	qualify
	K1-1 (300 × 800)	qualify	qualify
	K1-1 (300 × 800)	qualify	qualify
	K1-1 (300 × 800)	qualify	qualify
	K1-1 (300 × 700)	qualify	qualify
Pushover Y	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify
	K4-1 (300 × 800)	qualify	qualify

After being reinforced with concrete jacketing, the X-direction pushover analysis showed a significant increase in the structure's capacity. The deformation capacity and spectral acceleration slightly exceeded the requirements for the BSE-2E earthquake, indicating that the structure was able to withstand earthquake loads better. Overall, these results demonstrate that after retrofitting, the structure successfully met the previously unattainable Collapse Prevention (CP) performance targets, while also confirming the effectiveness of concrete jacketing in improving the structure's deformation and energy capabilities.

This also occurred in the Y-direction pushover analysis. The previously unsatisfactory conditions have now been resolved, with no indication of premature failure. This improvement reflects the increased stiffness, strength, and ductility of the structural elements, resulting in the overall building meeting BSE-2E seismic performance after the retrofit.

Total Retrofit Cost

The total retrofit cost was obtained by summing the costs of all strengthened structural elements. The results show that the application of concrete jacketing leads to a measurable and quantifiable retrofit cost for the entire building. Despite the additional construction work involved, the total cost remains within a reasonable range when compared to the expected improvement in structural performance. This indicates that concrete jacketing can be considered an economically feasible solution for seismic retrofitting of existing multi-story reinforced concrete buildings.

Table 3. Total Retrofit Cost

No.	Description	Unit	Coefficient	Price per Unit	Total Price
A.	**Labor**				
1.	Worker	OH	0,875	Rp16.087,50	Rp14.076,56
2.	Craftsman	OH	0,875	Rp20.000,00	Rp17.500,00
3.	Foreman	OH	0,2917	Rp25.000,00	Rp7.292,50
	Total Labor Price				**Rp38.869,06**
B.	**Material**				
1.	Bonding agent/ epoxy anchoring	liter	2	Rp250.000,00	Rp500.000,00
2.	Jacket Longitudinal Reinforcement (D16)	kg	30	Rp15.500,00	Rp465.000,00
3.	Jacket Stirrup Reinforcement (Ø10-100)	kg	15	Rp15.500,00	Rp232.500,00
4.	Bending Wire & Spacer	kg	2	Rp25.000,00	Rp50.000,00
5.	Concrete f'c 24,9 MPa	m^3	0,24	Rp1.050.000,00	Rp252.000,00
	Total Material Price				**Rp1.499.500,00**
C.	**Tools**				
1.	Vibrator & Casting Tools	day	1	Rp300.000,00	Rp300.000,00
2.	Concrete Curing (plastic/spray)	m^2	7	Rp20.000,00	Rp140.000,00
	Total Tools Price				**Rp440.000,00**
D.	**Total A+B+C**				**Rp1.978.369,06**

DISCUSSION

The findings of this study confirm that concrete jacketing is an effective retrofit technique for increasing the structural capacity of multi-storey reinforced concrete buildings. The observed enhancement in lateral load capacity and improvement in global structural behavior indicate that enlarging column cross-sections and providing additional reinforcement significantly improve seismic resistance. This result is consistent with previous research reporting that concrete jacketing effectively increases strength, stiffness, and ductility of existing reinforced concrete structures.

The redistribution of plastic hinges after retrofit reflects a fundamental improvement in the structural failure mechanism. In the existing condition, early yielding and damage concentration in columns indicated a vulnerable structural hierarchy. After the application of concrete jacketing, plastic hinges predominantly developed in beam elements, demonstrating a shift toward a strong-column–weak-beam behavior. This mechanism is widely recognized as a desirable seismic response, as it enhances energy dissipation and reduces the risk of brittle column failure.

From an economic standpoint, the estimated retrofit cost directly corresponds to the level of capacity enhancement required to achieve the targeted performance. The results indicate that significant improvements in seismic performance can be attained by selectively strengthening critical columns rather than applying uniform retrofit measures to all structural elements. This targeted retrofit strategy supports the principles of performance-based seismic retrofitting, where resources are allocated efficiently to address the most critical structural deficiencies.

The relationship between increased structural capacity and retrofit cost highlights the practical feasibility of concrete jacketing as a strengthening solution. Although the retrofit requires a measurable financial investment, the achieved performance improvement justifies the associated cost, particularly in regions with high seismic hazard. When compared to alternative retrofit techniques reported in the literature, concrete jacketing offers a balanced combination of constructability, effectiveness, and economic viability.

Overall, the integration of seismic performance evaluation and cost estimation provides a comprehensive and practical framework for retrofit decision-making. By explicitly linking structural capacity enhancement with economic implications, this study contributes to informed decision-making for the strengthening of existing multi-storey buildings and supports the application of concrete jacketing as a reliable and cost-effective retrofit method.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates that concrete jacketing is an effective retrofit technique for increasing the structural capacity of multi-storey reinforced concrete buildings. The seismic performance evaluation shows that the application of concrete jacketing significantly enhances lateral load capacity, improves global stiffness, and results in a more favorable structural behavior under seismic loading. The post-retrofit performance indicates that the targeted capacity level can be successfully achieved through appropriate strengthening of critical structural elements.

The retrofit strategy leads to an improved failure mechanism characterized by a strong-column–weak-beam behavior, which is essential for ensuring ductile structural response and preventing brittle column failure. This behavioral improvement confirms that concrete jacketing not only increases structural strength but also enhances the overall seismic resilience of the building.

From an economic perspective, the estimated retrofit cost reflects the direct consequences of the required capacity enhancement. The results indicate that targeted concrete jacketing applied to critical columns provides a reasonable balance between structural performance improvement and economic investment. The relationship between increased capacity and retrofit cost suggests that concrete jacketing is a technically and economically viable solution for strengthening existing buildings in seismic regions.

Based on the findings of this study, concrete jacketing is recommended as a practical retrofit option for multi-storey reinforced concrete buildings that exhibit insufficient seismic capacity. The integrated evaluation of structural performance and retrofit cost presented in this research may serve as a useful reference for engineers and decision-makers during the planning and implementation of seismic retrofit projects.

Future applications of this approach may incorporate more detailed economic analyses, such as life-cycle cost assessment or comparisons with alternative retrofit techniques, to further optimize retrofit strategies and enhance decision-making processes.

FURTHER STUDY

The results of this study demonstrate that seismic retrofit using the concrete jacketing method requires a measurable and systematically estimable cost based on actual strengthening demands. The estimated retrofit cost reflects the extent of structural deficiencies identified during the prior seismic performance evaluation. Buildings with insufficient column capacity require additional concrete and reinforcement, which directly increases the retrofit work volume and associated cost. This finding confirms that retrofit cost is strongly influenced by the required level of structural performance improvement.

The distribution of retrofit costs indicates that material components, particularly concrete and reinforcing steel, dominate the total expenditure. This cost pattern is consistent with the nature of concrete jacketing, where structural capacity enhancement is achieved through section enlargement and reinforcement addition. Consequently, optimization of jacket dimensions and reinforcement detailing plays a crucial role in improving cost efficiency without compromising structural safety.

From a performance–cost perspective, the retrofit investment using concrete jacketing is justified by the significant improvement in structural behavior. Strengthening critical columns enhances global stiffness and load-carrying capacity, which contributes to reduced structural demand under seismic loading. Although this study does not explicitly quantify performance gains in economic terms, the achieved target performance level indicates that the retrofit cost is proportional to the safety improvement obtained.

When compared with previous studies on seismic retrofitting of reinforced concrete buildings, the estimated retrofit cost in this study falls within a reasonable range. This confirms that concrete jacketing remains a practical and economically viable retrofit method, particularly for existing buildings requiring substantial capacity enhancement. In addition, the method is compatible with conventional construction practices, making it suitable for widespread application in developing countries.

Overall, the discussion highlights that concrete jacketing offers a balanced solution between structural effectiveness and economic feasibility. By linking retrofit cost estimation with performance-based retrofit requirements, this study provides practical insight for engineers and decision-makers in planning seismic strengthening projects under budget constraints.

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