Seismic Performance Assessment of a Soft-Storey RC Building Retrofitted with Steel Bracing, RC Jacketing, and RC Shear Wall

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ABSTRACT

Reinforced concrete (RC) structures in developing countries, such as India, had been constructed prior to the application of modern seismic codes and are vulnerable to earthquakes. Retrofitting must be performed to prevent deformation during seismic activity. This study focuses on the comparative evaluation of three retrofitting techniques, including steel bracing, RC column jacketing, and RC shear walls. These techniques are applied to a representative four-storey RC frame building located in Seismic Zone IV of India. Nonlinear static pushover and dynamic time-history analysis are performed to evaluate the structure and its seismic response prior to and after retrofitting. The evaluation metrics include the base shear capacity, inter-storey drift ratio, ductility, and stiffness. Specifically, the results indicate that all strategies improved the structural performance under seismic loading. RC infill shear walls demonstrated the most significant improvements in the base shear and drift reduction components. Steel bracing offered a balanced enhancement in strength and deformability. RC jacketing effectively strengthened ground-storey columns with a moderate overall impact.

Keywords-seismic retrofitting; soft storey; steel bracing; Rc column jacketing; Rc shear wall

I. INTRODUCTION

The seismic vulnerability of RC structures remains a pressing concern in earthquake-prone regions, where most structure constructions predate the implementation of modern seismic codes [1]. Major earthquake events, such as the Bhuj in 2001, the Nepal in 2015, and the Türkiye-Syria in 2023 have highlighted deficiencies, including soft-storey mechanisms, inadequate reinforcement detailing, poor lateral load resistance, and geometric irregularities. Post-Bhuj earthquake in India, the structural non-compliance, the aging infrastructure, and the widespread use of soft-storey configurations for parking or commercial spaces stress the need for seismic retrofitting [2]. Retrofitting is a practical and cost-effective strategy to improve the structural performance without a complete demolition. Depending on the level of intervention, the retrofitting strategies are broadly classified into two categories. Global methods improve the entire lateral load-resisting system and local methods focus on enhancing the strength or ductility of individual structural elements [3].

In global retrofitting techniques, steel bracing is adopted due to its simplicity, economic feasibility, and effectiveness in increasing the lateral stiffness and base shear capacity [4]. Bracing configurations, such as X, V, and post-tensioned systems, improve the stiffness and delay the column buckling under lateral loads. Similarly, RC shear wall provides a highly stiff load path, reduced inter-storey drift, and effective redistribution of the lateral forces. RC column jacketing is a local retrofitting method that enhances the axial, shear, and flexural capacity of existing columns, particularly at the ground storey, where soft-storey failures are most critical. This method involves adding a new layer of reinforced concrete around the existing members, significantly improving their ductility and preventing the shear cracks, column shortening, and brittle failure mechanisms [5]. The optimal retrofitting technique depends on the existing deficiencies, performance objectives, and constructability constraints. Analytical methods, such as nonlinear static pushover analysis and time-history dynamic analysis, complement additional information for the processes. The pushover analysis estimates the building's capacity and displacement demand. The time-history analysis accounts for the inertia effects and dynamic response under real ground motions [6, 7]. This study evaluates the seismic performance of a typical four-storey RC building retrofitted using three distinct techniques, including steel bracing, RC jacketing, and RC shear wall.

II. SEISMIC RETROFITTING

Seismic retrofitting is performed to increase the resilience of existing buildings. Conventional and non-conventional retrofitting is employed to increase the strength and ductility at the member and structure levels. Global retrofitting consists of two main strategies: (a) traditional techniques, such as RC shear walls and steel braces, which focus on strengthening the existing buildings against earthquakes and (b) unconventional techniques that aim on lowering the seismic requirements. In traditional methods, the design or construction implications are removed to improve the structure's seismic resilience. The seismically weak members are strengthened by local or member-level retrofitting, which are a more cost-effective method than the global. Three seismic retrofitting strategies are applied individually to the original building model. Ground floor soft storey constitutes retrofitted using steel bracing, RC jacketing, and RC shear wall in x direction due to a larger bay length of 7.5 m and a lower lateral stiffness compared to the higher stories.

III. BUILDING DESCRIPTION AND MODELING PARAMETERS

This study considers a four-storey RC moment-resisting frame structure, typical of the mid-rise urban construction in India. The building had a symmetric plan layout of 22.5 m × 15 m with three bays of 7.5 m in the x direction and 5 m in the y direction. The floor-to-floor height is 4 m at ground level and 3.5 m at the upper floors, resulting in a total building height of 14.5 m. The structural elements included beams sized at 350 mm × 450 mm, with the original columns sized 400 mm × 400 mm and slabs 150 mm thick. The concrete and reinforcement grades are M30 and Fe415, respectively. The total seismic weight of the structure is derived from the imposed dead loads and 25% of live loads [8]. The structure is modeled in ETABS 2018, with a rigid diaphragm behavior. The model is analyzed for seismic Zone IV with seismic hazard conditions, such as a zone factor (z) value of 0.24 on medium soil, importance factor (I) of 1.0, and response reduction factor (R) of 5.0 [8]. Figure 1 presents the reinforcement details of the existing columns.

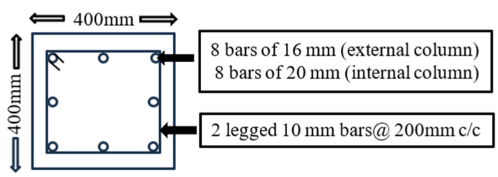

Fig. 1. Reinforcement details of existing columns.

The fundamental period is approximated by code expressions and verified by modal analysis. For the nonlinear analysis, plastic hinges are assigned at both ends of the beams and columns based on [6, 9] guidelines. These hinges capture the flexural behavior and allow the model to simulate inelastic deformation under increasing lateral loads. Subsequently, retrofitting is performed to minimize the inter-storey drift and maximum average displacement. The four-storey RC building is depicted in Figure 2.

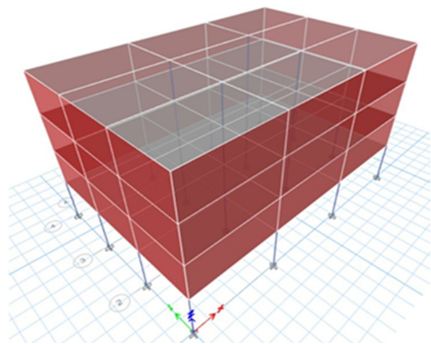

Fig. 2. Original G+3 RC building with soft storey on ground floor modeled in ETABS software.

IV. STEEL BRACING CONNECTION

Steel bracing is one of the most effective and economical retrofitting methods to enhance the lateral load resistance of buildings subjected to seismic or wind forces. It significantly increases the lateral stiffness and base shear capacity of both the concrete and steel structures [10]. Bracing systems can be installed externally, reducing the disruption to the interior. Two common bracing configurations are implemented to study the behavior of a laterally loaded braced RC frame: X-bracing and inverted-V (chevron) bracing. In the two methods, hollow steel square sections of 100 mm × 100 mm× 6 mm are modeled as axial members with pinned ends. The braces are installed in selected bays of the ground storey. Figure 3 illustrates Pattern-A bracing on exterior bays and Pattern-B introduced bracing in interior bays to ensure a symmetric stiffness distribution. All connections are designed as bolted gusset plate joints with 16 mm bolts, according to [11]. The frame featured two strong beams restraining a weak short column with a pair of steel braces. The latter are assumed to be rigidly attached to the structure and the column subjected to an axial load.

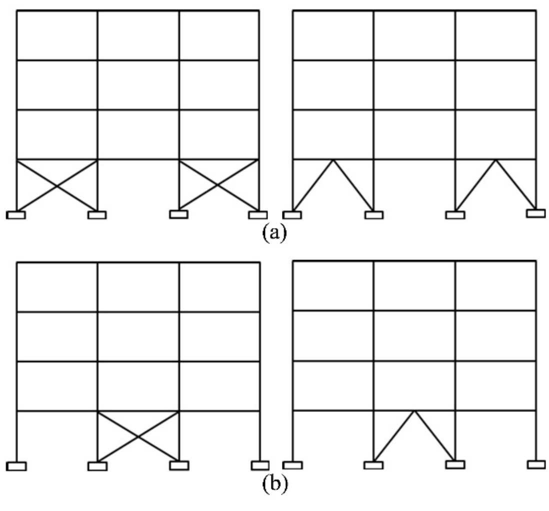

Fig. 3. Retrofitting of existing structure with X and inverted-V bracing connections with: (a) Pattern-A and (b) Pattern-B, respectively.

To ensure an adequate performance under both tension and compression, the effective slenderness ratio of the bracing elements is set to low values. This ensures resistance to buckling and improved energy dissipation. Braced frames with rigidly connected members are designed to simulate real-world boundary conditions. The additional dead load due to bracing is included in the structural analysis through appropriate load combinations. The design parameters of bracing are shown in Table I.

TABLE I. MATERIAL PROPERTIES AND SECTIONAL DIMENSIONS OF BRACING ELEMENTS

Design parameter		Values
Thickness of gusset plate		12 mm
Bracing sections		100×100×6 mm (square hollow)
Hole diameter		18 mm
Bolt diameter		16 mm (grade 4.6)
Shearing strength of bolt		58 KN
Bearing strength of bolt		102.9 KN
Pitch of bolts		40 mm
End distance		27 mm
Number of bolts	Inverted V shape	4
	X shape	10

V. COLUMN RC JACKETING

RC jacketing is one of the most common retrofitting methods in retrofitting columns and beams. The main purpose of this technique is to increase the size of a member and, therefore, its stiffness, and decrease the deformation during seismic activity. Column jacketing improves the axial and shear strength, leading to an increased lateral load capacity of the column, while the flexure strength at the beam-column joint remains constant. The capacity of a column can be enhanced by reinforcing it with external binding. Jacketing improves the local column strength and ductility, ideal for space-limited cases [12]. Figure 4 depicts the cross-section of the column jacketing procedures. Additional reinforcement increases the column's capacity to withstand loads. Details of the design parameters of jacketing are presented in Table II.

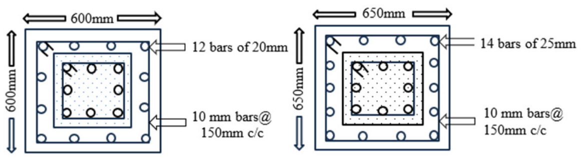

Fig. 4. Details of column jacketing reinforcement layout of external and internal column, respectively.

TABLE II. DESIGN PARAMETERS AND SECTIONAL DIMENSIONS OF EXTERIOR AND INTERNAL JACKETED COLUMNS

Parameter	Column	
	Exterior	*Interior*
Area of steel needed	4800 mm^2	8640 mm²
Area of steel provided	1608.5 mm^2	2514 mm²
Area of steel required	3192 mm^2	6126 mm²
Revised jacketing cross-section	600×600 mm	650×650 mm
Diameter of bars	20 mm	25 mm
Number of bars	12	14
Diameter of lateral tie	10 mm	10 mm
Spacing of bars	150 mm	150 mm

RC jacketing is applied to selected ground-floor columns to address the soft-storey vulnerability. A 100 mm thick jacket is added on all sides of the original 400×400 mm columns, increasing the cross-section to 600×600 mm for corner columns and 650×650 mm for the internal ones. The new longitudinal bars of 20 mm or 25 mm diameter and 10 mm transverse ties at 150 mm spacing are detailed. Dowels and shear keys are assumed to transfer loads between the jacket and existing concrete. The enhanced column sections are modeled as new RC elements with composite stiffness and added mass.

VI. REINFORCED CONCRETE SHEAR WALL

RC shear walls can withstand the lateral loads generated due to seismic forces along the direction of their length. Additionally, they act as stiff load paths drastically reducing the inter-storey drift. The columns on two sides of the shear walls behave as two boundary elements, significantly increasing the strength of the wall. The thickness of the RC shear walls must be less than 150 mm to prevent the lateral instability. Exceedance of 200 mm wall thickness or of $0.25\sqrt{f_{ck}}$, where f_{ck} is the characteristic compressive strength of concrete, factored shear stress requires two layers reinforcement. This reinforcement includes bars placed in transverse direction and longitudinal direction to enhance the shear strength of concrete by reducing cracking. The maximum spacing of reinforcement shall not exceed three times the thickness of the wall nor 450 mm [13]. The nominal shear stress (T_v) of the RC shear walls is described by:

$$T_v = V_u/(t_w \times d_w) \quad (1)$$

where V_u is the factored shear force, t_w is the web thickness, and d_w is the effective depth of the wall section, and it shall be at 0.8 of length of the web of the wall (l_w).

According to [13], only the web portion of the shear wall should be considered, excluding the flanges, regarding the shear capacity for the rectangular section. The wall section's moment of resistance can be computed similarly to that of the column under combined axial and bending loads. The flexural strain or flexural compression can cause a wall section to fail. When subjected to a steady rise in moment, it behaves as an uncracked planar concrete section. This is until the cracking moment is achieved or until the concrete undergoes severe fiber rupture in tension. If the reinforcement alone is able to withstand all the load to avoid a brittle failure, the section's fractured flexural strength should be higher than its uncracked flexural strength. To improve the flexural strength, vertical reinforcement should be concentrated at the ends of walls without border components of greater thickness.

The RC shear wall with a thickness of 150 mm is introduced in a central longitudinal bay on the ground floor. The RC shear wall is 7.1 m long and fully anchored to surrounding beams and columns. Double-layer reinforcement with 10 mm bars at 150 mm c/c in both directions ensured a ductile behavior. The RC shear wall is modeled utilizing shell elements with nonlinear material behavior. The wall's base is assumed to be fixed to the foundation. In addition, its added mass and stiffness are included in the dynamic model. No special boundary columns are required as the wall thickness satisfied the confinement requirements. The f_{ck} and yield strength of steel (f_y) are equal to 30 N/mm^2 and 415 N/mm^2, respectively. Since the factored compressive stress (F_c) is less than $0.2f_{ck}$, there is no need of boundary elements. In addition, since the thickness of the section is 200 mm, the reinforcement of steel should be used in two layers with a suitable cover, according to [14]. Furthermore, the minimum shear reinforcement required should be 0.25% of the total area [14]. The spacing of the bar can be calculated by:

$$\text{Spacing of bars} = \frac{1000\times A}{A_{st}} \qquad (2)$$

The steel required to resist the shear force with respect to spacing is 0.399 mm, satisfying the shear reinforcement requirement. There are no boundary elements; so, the entire vertical load coming on the wall will be borne by it and will not be distributed to the flanges. The moment resisted by the wall (M_u) is equal to 8807.6 KN/m. The M_u is greater than the moment acting on, and therefore it is considered safe. The design parameters of RC shear wall are displayed in Table III.

TABLE III. DETAILED DESIGN OF RC SHEAR WALL

Design parameter	Values
Wall thickness (t)	200 mm
Length (L)	7.1 m
Vertical load coming to wall	1676 KN
Shear stress	1.09084 N/mm^2
Ast min	500 mm^2 in 2 layers
Design shear strength of concrete	0.37 N/mm^2
Maximum shear stress of concrete	3.5 N/mm^2
Strength required of steel in shear	1023.6 KN
Steel required to resist shear force (Ah / Sv)	0.399 mm
Vertical reinforcement provided	10 mm bars at 315 mm c/c
Horizontal reinforcement provided	10 mm bars at 150 mm c/c

VII. RESULTS AND DISCUSSION

A. *Nonlinear Dynamic Analysis*

The nonlinear time-history analysis assesses the structural performance under real ground motion by solving the equations of motion using direct integration over time. This method, and particularly the Newmark-beta algorithm, is widely recognized for its reliability in nonlinear dynamic analysis [15]. In this study, nonlinear time-history analysis is conducted using the ETABS software. The selected input ground motion is the 1999 Chamoli earthquake, recorded at the Gopeshwar station, regionally relevant to the Indo-Gangetic belt. The record is scaled to match the design response spectrum for Seismic Zone IV of [8] at the building's fundamental period. The Newmark-beta method with a time step of 0.02 s is used for direct time integration.

The structural response is analyzed for both the original and retrofitted configurations of the building. Plastic hinge activation is tracked throughout the simulation to observe the onset and progression of inelastic behavior under cyclic seismic demand. The retrofitted frames suggested improvements in the seismic performance when compared to the original structure. Figure 5 presents the Inter-storey Drift Ratio (IDR) profiles for the original and retrofitted buildings. The original structure exhibited maximum IDR on the ground floor. Among the retrofitted models, the RC shear wall configuration presented the lowest IDR at the soft storey, followed by the X-braced frame, inverted-V bracing, and finally RC jacketing. Notably, the Pattern-A bracing layout exhibited significantly better drift control than Pattern-B. This is attributed to its placement on exterior bays, which aligned more effectively with the mass and stiffness center. The jacketed and braced models demonstrated a moderate increase in the IDR. Pattern-B braced configuration highlighted the lowest seismic weight and base shear. However, it effectively reduced the soft storey drifts. This highlights its efficiency as a lightweight retrofit option with substantial drift mitigation benefits.

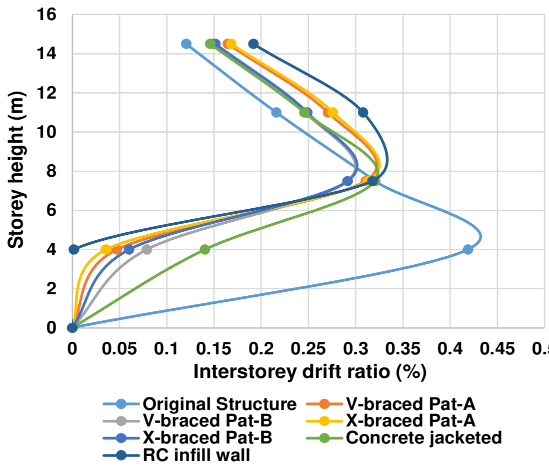

Fig. 5. Variation in IDR with the storey height for various retrofitted structures.

B. *Nonlinear Static Analysis*

Pushover analysis is conducted to evaluate the nonlinear behavior and displacement capacity of both the original and retrofitted RC frame structures under lateral seismic loading. Roof displacement is incrementally increased up to 4% of the total building height or until collapse indicators are triggered. At each step, the structural performance is assessed by tracking the base shear, roof displacement, and plastic hinge formation. The capacity curve is obtained from this analysis by plotting the base shear against roof displacement. Consequently, it helped define the performance parameters, including the yield strength, peak lateral capacity, initial stiffness, and ductility. The tangent at zero load level represented the initial stiffness. The curve's peak indicated a maximum lateral load resistance.

Plastic hinges are assigned at potential yielding locations in columns and beams, and their formation is closely monitored to identify the critical regions. The structure is assumed to reach collapse in the case of the observation of 75% strength degradation or exceedance of the maximum allowable roof displacement. The pushover capacity curves compare how the base shear capacity increases for retrofitted configurations compared to the original structure, as shown in Figure 6. In the original structure, the curve remained linear until the roof displacement reached 0.063 m beyond which the nonlinear inelastic behavior continued until 0.12 m. At this point, the hinge formation intensified, and the curve began to decline, indicating collapse onset. In contrast, the retrofitted configurations demonstrate enhanced performance in terms of strength and stiffness. Among these, the RC shear wall retrofit exhibited the highest base shear capacity with a 32% increase over the original and early stiffening, but a reduced displacement capacity due to increased stiffness. The inverted-V braced frame showed the highest base shear at the Immediate Occupancy (IO) limit, mitigating the early-stage damage. The RC jacketed configuration performed best at the Life Safety (LS) level offering a balanced improvement in strength and ductility. Despite the slightly reduced collapse displacements, the retrofitted structures sustained higher lateral loads, illustrating the beneficial trade-off between the stiffness gain and ductility reduction [16].

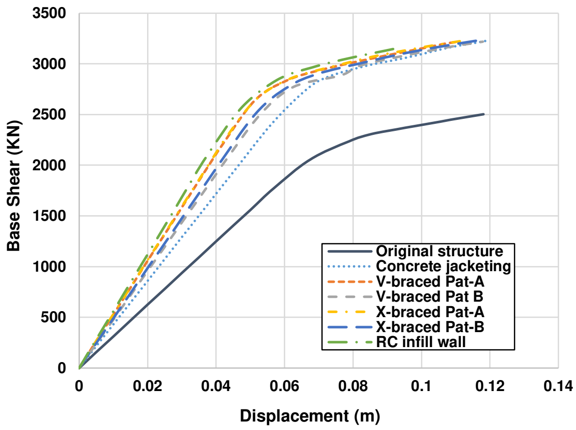

Fig. 6. Pushover curve of original and retrofitted RC structure.

The performance levels are established through the capacity spectrum method [7, 8]. Each retrofit system shifted the performance point favourably on the pushover curve compared to the original. The RC shear wall model reached Collapse Prevention (CP) at higher base shear levels. The braced models improved the elastic strength without significantly compromising ductility. Furthermore, the combined pushover curve confirmed that although the elastic and inelastic deformation ranges decreased in the retrofitted frames, the overall seismic resistance improved notably. These curves also help evaluate the hinge concentration zones and guide the retrofit designs accordingly. Table IV summarizes the key seismic performance parameters: base shear at IO, LS, and CP along with the initial stiffness and ductility for the original and retrofitted structures.

TABLE IV. SEISMIC PERFORMANCE METRICS OF ORIGINAL AND RETROFITTED STRUCTURES

Structure type	Base shear (KN)			Stiffness	Ductility
	IO	*LS*	*CP*		
Original	2055.48	2235.05	2501.71	30,672	2.36
RC jacketing	2407.87	2873.17	3234.68	43,000	2.64
V-bracing (A)	2633.38	2947.20	3219.64	51,627	2.71
V-bracing (B)	2500.91	2888.49	3218.22	47,189	2.78
X-bracing (A)	2643.14	2986.55	3232.46	51,823	2.67
X-bracing (B)	2511.60	3008.16	3229.36	48,288	2.83
RC shear wall	2574.13	2964.37	3235.97	53,625	2.86

Shear walls are the most effective retrofitting technique in enhancing the global seismic performance of the structure. They significantly increase the lateral stiffness and base shear capacity, effectively reducing the inter-storey drift. Steel bracing improves the stiffness and ductility, and remains relatively easy to implement with minimal disruption. RC jacketing strengthens the critical columns and preserves ductility. However, its impact on the overall global response is comparatively limited.

The base shear, a key indicator of lateral strength, presents its highest value for the RC shear wall model, followed by RC jacketing and X-braced Pattern-A. This indicates an improved lateral load resistance due to the increased stiffness and direct force transfer. IDR is reduced in the shear wall configuration, followed by steel bracing and RC jacketing due to the enhanced global stiffness and improved load redistribution. The RC shear wall yields uniform drift control and jacketing offered localized improvement. The ductility was improved in all retrofitted cases, with the shear wall achieving the highest value due to reinforced confinement. X and inverted V bracing also performed well. Although the original structure showed a low ductility factor, the early hinge formation limited its performance. RC jacketing increased the ductility by strengthening the column zones without compromising deformability. The initial stiffness, being the lowest in the original frame, was notably improved. Retrofit RC shear wall leads with a 75% gain, followed by X and V bracing, and RC jacketing. These results highlight the stiffness-ductility trade-off and the importance of optimized detailing in retrofit design.

VIII. CONCLUSION

This research presents a comparative evaluation of seismic retrofitting techniques. The nonlinear static and dynamic analyses demonstrate that all three retrofitting methods enhance the structural performance by increasing the base shear capacity, initial stiffness, and ductility while reducing the inter-storey drift.

The Reinforced Concrete (RC) shear wall improved the base shear and stiffness the most, compared to other methods. In addition, it demonstrated the most effective reduction in the inter-storey drifts, lateral displacement, and bending moment in frame members. However, all methods significantly increased the seismic weight, potentially increasing the seismic demand on the foundation. Steel bracing systems achieved a balanced improvement in the lateral strength, stiffness, and drift control, with a relatively moderate impact on ductility. Due to their ease of installation and low added weight, they are ideal for soft-story retrofits. The RC jacketing of columns effectively enhanced the local column capacity and retained ductility. Moreover, it provided a limited global stiffness gain, and it remains a practical solution for structures with identified weak members. The inverted V-type braces exhibit flexural moments in columns and beams caused by the concentric load at their attachment point. The X-bracing system exhibits lower moments when compared to alternative bracing methods.

The current study underscores the importance of selecting retrofit strategies based on specific structural deficiencies, performance objectives, and practical constraints. The findings contribute to the understanding of retrofit effectiveness and support informed decision-making for enhancing the seismic resilience of existing RC buildings, particularly in high-risk seismic zones.

REFERENCES

[1] P. S. Badal and R. Sinha, "A performance-based rehabilitation strategy for RC frame buildings in moderate seismic regions," *Bulletin of Earthquake Engineering*, vol. 22, no. 6, pp. 2925–2949, Mar. 2024, https://doi.org/10.1007/s10518-024-01884-2.

[2] R. S. Patel and A. K. Sinha, "Seismic magnitude homogenization by unified regression method and its effect on seismicity parameters," *Journal of Seismology*, vol. 28, no. 2, pp. 417–437, Mar. 2024, https://doi.org/10.1007/s10950-024-10197-5.

[3] K. Aljawhari, R. Gentile, and C. Galasso, "A fragility-oriented approach for seismic retrofit design," *Earthquake Spectra*, vol. 38, no. 3, pp. 1813–1843, Aug. 2022, https://doi.org/10.1177/87552930221078324.

[4] M. Saadi and D. Yahiaoui, "The Effectiveness of Retrofitting RC Frames with a Combination of Different Techniques," *Engineering, Technology & Applied Science Research*, vol. 12, no. 3, pp. 8723–8727, June 2022, https://doi.org/10.48084/etasr.4979.

[5] K. M. Ro, M. S. Kim, and Y. H. Lee, "An Experimental Study on Torsional Behavior of Reinforced Concrete Columns Retrofitted with Hybrid Concrete Jackets," *Materials*, vol. 16, no. 3, Feb. 2023, Art. no. 1256, https://doi.org/10.3390/ma16031256.

[6] *Prestandard and Commentary for the Seismic Rehabilitation of Buildings*, 356, Federal Emergency Management Agency, Washington, DC, MD, USA, 2000.

[7] *Seismic Evaluation and Retrofit of Concrete Buildings*, 40, Applied Technology Council, Redwood City, CA, USA, 1996.

[8] *Criteria for Earthquake Resistant Design of Structures*, *IS 1893 (Part 1):2016*, Bureau of Indian Standards, New Delhi, India, 2016.

[9] *Seismic Evaluation and Retrofit of Existing Buildings*, ASCE/SEI 41-17, American Society of Civil Engineers, Reston, VA, USA, 2017.

[10] H.-P. Nguyen and P.-C. Nguyen, "The Impact of Different Bracing Ratios on the Structural Performance of Planar Steel Frames," *Engineering, Technology & Applied Science Research*, vol. 15, no. 3, pp. 22388–22393, June 2025, https://doi.org/10.48084/etasr.8928.

[11] *General Construction in Steel, Code of Practice*, IS 800:2007, Bureau of Indian Standards, New Delhi, India, 2007.

[12] S. Bousias, A.-L. Spathis, and M. N. Fardis, "Seismic Retrofitting of Columns with Lap Spliced Smooth Bars Through FRP or Concrete Jackets," *Journal of Earthquake Engineering*, vol. 11, no. 5, pp. 653–674, Aug. 2007, https://doi.org/10.1080/13632460601125714.

[13] *Plain and Reinforced Concrete, Code of Practice*, IS 456:2000, Bureau of Indian Standards, New Delhi, India, 2000.

[14] *Ductile Detailing of Reinforced Concrete Structures Subjected to Seismic Forces*, IS 13920:2016, Bureau of Indian Standards, New Delhi, India, 2016.

[15] E. Yildirim and I. Esen, "Dynamic Behavior and Force Analysis of the Full Vehicle Model using Newmark Average Acceleration Method," *Engineering, Technology & Applied Science Research*, vol. 10, no. 1, pp. 5330–5339, Feb. 2020, https://doi.org/10.48084/etasr.3335.

[16] A. K. Chopra, *Dynamics Of Structures: Theory and Applications to Earthquake Engineering*, 4th ed. New York, NY, USA: Pearson, 2012.