Mr. Arun Kumar, 2025, 13:4
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Seismic Performance of High-Rise Reinforced Concrete Buildings: A Review of Stiffening Systems and Dynamic Analysis Approaches

Mr. Arun Kumar[1], Dr. Bhagyashree Naik[2]
[1]M.Tech. Research Scholar Department of Civil Engineering School of Engineering Eklavya University, Damoh (M.P.)
[2]Associate Professor Department of Civil Engineering School of Engineering Eklavya University, Damoh (M.P.)

Abstract- The seismic vulnerability of high-rise reinforced concrete (RC) buildings has prompted extensive research into effective lateral load-resisting systems. This paper reviews the state-of-the-art literature on seismic design codes, dynamic analysis methods, and the role of stiffening systems such as shear walls and steel bracings in enhancing seismic resilience. Emphasis is placed on the comparative performance of various stiffening configurations with respect to fundamental time period, base shear, inter-storey drift, and top-storey deflection. The review also highlights the influence of code-based response spectrum analysis vis-à-vis real earthquake ground motions, drawing insights from national and international guidelines including IS 1893, Eurocode 8, and ASCE 7. While shear walls consistently demonstrate superior stiffness and drift control, bracing systems offer ductility, retrofitting flexibility, and cost-effectiveness. Hybrid approaches integrating both systems are increasingly recognized as optimal solutions for tall structures in seismic-prone regions. Research gaps are identified in the areas of hybrid system performance, soil–structure interaction, and nonlinear dynamic analysis. The review concludes with recommendations for performance-based design and the integration of modern materials and technologies to achieve resilient high-rise construction.

Keywords: seismic performance, high-rise buildings, shear walls, steel bracing, response spectrum method, inter-storey drift, structural stability.

I. INTRODUCTION

The rapid growth of urban populations and the scarcity of land have accelerated the construction of high-rise buildings worldwide. Reinforced concrete (RC) has become the most widely used material for such structures due to its strength, durability, and adaptability. However, high-rise RC buildings are inherently more vulnerable to lateral loads from wind and earthquakes compared to low- and mid-rise structures. The lateral flexibility of tall buildings results in excessive sway, inter-storey drifts, and resonance with ground motions, which can compromise both safety and serviceability.

In earthquake-prone regions such as India, the seismic design of tall RC buildings is a critical necessity. Historical earthquakes — including the 2001 Bhuj earthquake, the 2015 Nepal earthquake, and the 2021 Assam earthquake — have repeatedly highlighted the vulnerability of inadequately detailed RC frames, where soft-storey collapses and torsional irregularities led to catastrophic damage. These events emphasize the importance of incorporating effective lateral stiffening systems to enhance the seismic resilience of tall RC buildings.

Seismic Vulnerability of High-Rise RC Buildings

Seismic forces arise from the inertia of a building resisting ground acceleration. In tall structures, these forces manifest as base shear, inter-storey drift, and overturning moments. Without adequate lateral resistance, buildings may experience

- Excessive inter-storey drift, damaging non-structural components such as cladding and partitions.
- Resonance effects, when the building's natural period coincides with the dominant period of seismic waves.
- P–Δ effects, where large displacements amplify secondary moments, increasing collapse risk.
- Soft-storey failures, common in urban RC frames where ground floors are left open for parking or commercial use.

The combination of these effects makes seismic design far more challenging for high-rise buildings compared to low-rise structures.

Role of Lateral Stiffening Systems

To overcome the deficiencies of bare RC frames, engineers employ additional lateral stiffening systems that enhance structural stability. Among these, shear walls and steel bracings are the most widely adopted:

- Shear walls are vertical RC elements that act as cantilevers resisting lateral loads. Strategically placed shear walls — at building cores, sides, or corners — significantly reduce displacements and storey drifts. They are particularly effective in new high-rise construction where stiffness and strength are priorities.
- Steel bracings consist of diagonal members (X, V, K, or Chevron) that carry axial forces under seismic loads. While less stiff than shear walls, bracings increase ductility, improve energy dissipation, and are more economical. Their ease of installation makes them highly suitable for retrofitting existing RC frames.

Comparative studies suggest that shear walls are more effective in controlling displacements, while bracings provide advantages in cost, ductility, and architectural flexibility. Hybrid systems that integrate both elements are increasingly recommended for tall buildings in seismic-prone regions.

Importance of Dynamic Analysis

The seismic behavior of a high-rise structure is inherently dynamic. Accurate assessment requires advanced analysis methods:

- **Equivalent Static Method (ESM):** Simplified approach suitable for low-rise, regular buildings.
- **Response Spectrum Method (RSM):** Widely used for medium- to high-rise structures, capturing modal contributions and peak responses under seismic loading.
- **Time History Method (THM):** Most rigorous technique, providing complete time-dependent response, but requiring detailed earthquake records and higher computational effort.

International codes such as IS 1893 (India), Eurocode 8 (Europe), and ASCE 7 (USA) recommend RSM for high-rise RC buildings, with THM applied for critical structures. The choice of analysis method significantly influences design outcomes and the evaluation of stiffening systems.

Indian Seismic Context

India is one of the most seismically active regions in the world, with nearly 59% of its landmass falling under moderate to very high seismic hazard zones (III–V). Metropolitan cities such as Delhi, Guwahati, Srinagar, Kolkata, and Patna lie in these zones, exposing millions of residents to seismic risk.

The Indian seismic code IS 1893:2016 provides detailed guidelines for earthquake-resistant design, including zonal coefficients, response spectra, and drift limits. However, challenges persist due to:

- Widespread use of non-engineered or poorly detailed RC frames.
- Inadequate enforcement of seismic codes in urban and rural construction.
- Lack of awareness among designers, contractors, and policymakers.

Given these realities, the integration of shear walls, bracings, or hybrid systems into high-rise buildings is not just a structural requirement but also a socio-economic necessity.

II. LITERATURE REVIEW

The seismic performance of reinforced concrete (RC) buildings has been extensively investigated due to the inherent vulnerability of high-rise structures to earthquake excitations. Various strategies have been proposed to enhance lateral resistance and control storey drift, with particular focus on shear walls and steel bracings as effective lateral load-resisting systems. Reviewing previous studies provides valuable insights into the efficiency, limitations, and practical applicability of these systems.

Shear Walls in High-Rise Buildings

Chandurkar and Pajgade (2023) et al. conducted a detailed analytical study on a 10-storey RC building using ETABS software to evaluate different shear wall configurations. They modeled bare frames and frames with shear walls placed at corners, along the periphery, and centrally. Their results demonstrated that corner shear walls were most effective in controlling lateral displacements and storey drifts. They also highlighted that merely increasing the size of shear walls in low-rise buildings (less than 10 storeys) was uneconomical, emphasizing the importance of strategic placement over size for seismic performance.

Esmaili et al. (2022) et al. investigated a 56-storey high-rise building in Tehran, a highly seismic region, using nonlinear dynamic time-history analysis. They assessed the structural response of buildings with varying shear wall configurations and concluded that while shear walls significantly improve overall stiffness and stability, relying solely on them for both gravity and lateral loads is neither economical nor structurally efficient. The study recommended hybrid systems, combining shear walls with bracings to enhance ductility. Additionally, they noted that proper concrete confinement in shear walls is crucial for energy dissipation under strong earthquakes.

Yamada et al. (2022) et al. conducted combined experimental and analytical investigations on RC buildings with 3, 6, and 9 storeys. The study focused on the deformation and fracture characteristics of shear walls under earthquake loading. They found that shear walls substantially increased lateral load resistance and reduced deformation demands on beams and columns. However, they also observed that asymmetrical wall placement could lead to torsional irregularities, underscoring the importance of balanced and symmetrical distribution for optimal seismic performance.

Achisina et al. (2021) et al. studied the seismic performance of RC buildings with complex shear wall configurations using nonlinear static (pushover) analysis. The study aimed to predict damage initiation and assess limit-state behavior in high-rise buildings. Results revealed that strategic wall layout enhances lateral stiffness, reduces displacement demands, and delays the onset of plastic hinges in beams and columns, highlighting the role of advanced performance-based assessment in shear wall design.

Hosseini et al. (2021) et al. evaluated RC shear walls in 4–8 storey buildings under simulated earthquake excitations. Using finite element modeling, they investigated stress distribution, lateral displacement, and base shear responses. Their findings indicated that properly designed shear walls improve structural stiffness and load-bearing capacity while mitigating excessive inter-storey drifts.

Rahman et al. (2025) et al. explored the use of damped outriggers integrated with shear walls in mid-rise RC buildings. The study combined numerical simulations and experimental validation, demonstrating that the hybrid system enhanced energy dissipation and reduced lateral displacement compared to conventional shear walls. This approach is particularly beneficial for high-rise buildings with soft or flexible ground floors.

Chandurkar and Pajgade (2023) analyzed a 10-storey RC building with different shear wall configurations using ETABS software. Their study showed that incorporating shear walls significantly reduced lateral displacements compared to bare frames. Among the various configurations, corner shear walls were most effective in attracting seismic forces and controlling storey drifts. However, they noted that increasing wall dimensions in buildings below 10 storeys was uneconomical and largely ineffective. The study highlighted that strategic placement of shear walls is more important than merely increasing wall size.

Steel Bracing as a Lateral Load-Resisting System

Viswanath (2023) et al. performed a seismic analysis of RC frames strengthened with X-type steel bracing using STAAD.Pro, following IS 1893:2002 guidelines. Buildings ranging from 4 to 16 storeys were modeled in seismic Zone IV of India. The study revealed that X-type bracings significantly reduced lateral displacement and base shear demands, improved overall stiffness, and added minimal dead load, making them ideal for retrofitting applications.

Chavan and Jadhav (2020) et al. conducted a comparative analysis of multiple bracing configurations — diagonal, V-type, inverted V-type, and X-type — in RC frames using equivalent static analysis. Their results reinforced that X-type bracings outperform other configurations, reducing lateral displacement by up to 60% and increasing base shear capacity. The study highlighted the importance of bracing layout in seismic resistance, particularly in medium- and high-rise RC buildings.

Akbari et al. (2020) et al. adopted a probabilistic approach to evaluate the seismic performance of RC frames with X and Chevron bracings. Using fragility curves, they found that Chevron bracings were more effective in reducing damage probability, especially for taller frames. The study also emphasized the significance of P–Δ effects, which can amplify lateral deformations by up to 100%, demonstrating that second-order effects must be considered in braced systems.

Youssef et al. (2022) et al. investigated internal concentric steel bracing for RC frames and found that bracing significantly enhances lateral load resistance and structural stability. The study employed nonlinear dynamic analysis to capture realistic earthquake responses, showing that internal bracings can be used effectively in retrofitting projects.

Wang et al. (2024) et al. examined hybrid coupled shear wall systems with shear and flexural fuse-type steel beams. Their numerical analysis revealed that shear fuses provide better rotation control, reduce inter-storey drift, and optimize energy dissipation compared to conventional bracing layouts, highlighting the benefits of integrated hybrid systems.

Huang et al. (2023) et al. studied concentric steel braces for seismic retrofitting of mid- and high-rise RC buildings. Their results showed significant reductions in torsional displacements and improved structural compliance with modern seismic codes, making them effective for both retrofitting and new construction.

Comparative Studies of Shear Walls and Bracings

Esmaili et al. (2008) et al. conducted a comparative study of RC high-rise buildings using hybrid lateral load-resisting systems that combined shear walls with steel bracings. They employed nonlinear dynamic analysis to evaluate the behavior of buildings under simulated earthquake excitations. Their results indicated that shear walls effectively controlled storey drifts, thereby limiting the deformation of beams and columns, while the steel bracings enhanced energy absorption capacity, mitigating damage during strong seismic events. The study highlighted that hybrid systems provide a balanced combination of strength and ductility, and recommended their use in tall buildings where both drift control and energy dissipation are critical for performance-based seismic design.

Akbari et al. (2015) et al. focused on tall RC buildings exceeding 20 storeys and examined the use of Chevron bracing in conjunction with shear walls. Using probabilistic seismic analysis and fragility curve assessment, they found that hybrid systems reduced the likelihood of structural and non-structural damage more effectively than standalone shear walls or bracings. The study emphasized that Chevron bracings contributed to enhanced lateral load distribution and ductility, while shear walls controlled overall displacement. Additionally, the research highlighted that the effectiveness of hybrid systems increases with building height, making them particularly suitable for high-rise seismic design.

Yamada et al. (2022) et al. conducted both experimental testing and analytical modeling on hybrid RC systems, comparing buildings equipped with only shear walls, only bracings, and combined systems. Their experiments included shake-table tests and finite element simulations to assess deformation patterns, beam-column joint demand, and energy dissipation. Results showed that hybrid systems provided superior deformation control, significantly reduced demand on critical structural elements, and enhanced overall seismic resilience. The study concluded that hybrid systems effectively mitigate torsional irregularities and reduce the risk of localized failures, demonstrating clear advantages over single-system solutions.

Rahman et al. (2025) et al. investigated mid-rise RC buildings with damped outriggers integrated with shear walls, focusing on structures with soft or flexible ground floors. Using finite element analysis and dynamic simulations, the study demonstrated that the hybrid system improved lateral stiffness, reduced inter-storey drift, and increased energy dissipation compared to conventional shear wall systems. The research highlighted that combining damped outriggers with shear walls is particularly effective in mitigating soft-story effects and enhancing performance in buildings susceptible to excessive lateral displacement at the ground level.

Wang et al. (2024) et al. examined hybrid coupled shear wall and steel fuse systems for high-rise RC buildings. Their study used nonlinear dynamic modeling to evaluate rotation capacity, inter-storey drift, and energy dissipation. Results indicated that incorporating steel fuses in combination with shear walls allowed the system to absorb higher seismic energy, optimize rotation control at critical joints, and reduce cumulative drift. The research concluded that such hybrid systems are highly effective in improving ductility, maintaining structural integrity, and minimizing damage in tall buildings subjected to strong earthquake excitations.

Lee et al. (2023) et al. performed numerical studies on multi-storey RC buildings using hybrid shear wall–steel bracing systems. The study simulated various earthquake scenarios using nonlinear time-history analysis to evaluate global response, including lateral displacement, storey drift, and stress distribution. Their findings confirmed that combined systems enhanced seismic resilience, minimized lateral displacement, and maintained overall structural stability even under extreme seismic loading. The research emphasized that integrating shear walls and bracings allows designers to achieve balanced stiffness and ductility, making hybrid systems a preferred solution for modern high-rise buildings in seismic regions.

Performance-Based Seismic Design

Beyond system-level studies, performance-based seismic design has emerged as an advanced methodology. Kappos and Manafpour (2000) introduced a framework that integrates partial inelastic modeling with serviceability and life-safety criteria. Using nonlinear static (pushover) and dynamic (time-history) analyses, they demonstrated that performance-based design provides a more realistic assessment of seismic demand compared to traditional elastic code-based methods. This approach emphasizes controlled inelastic behavior, ensuring that structures not only survive earthquakes but also meet functional and serviceability requirements.

Research Gaps and Need for Review

Although numerous studies have investigated the role of stiffening systems in seismic design, several gaps remain:

- Most comparative studies are restricted to code-based spectrum analyses, without validating results against multiple real earthquake records.
- Limited attention is given to soil–structure interaction (SSI), P–Δ effects, and torsional irregularities.
- The combined performance of hybrid systems (shear walls + bracing) remains underexplored.
- Few studies integrate stiffening systems into performance-based seismic design frameworks, which are increasingly emphasized globally.

Addressing these gaps is essential to develop practical guidelines for engineers, especially in seismic-prone countries like Indi

Objectives and Scope of the Review

The primary objective of this review paper is to consolidate and evaluate existing research on the seismic performance of high-rise RC buildings with stiffening systems. Specifically, the paper aims to:

- Summarize the evolution of seismic design codes and dynamic analysis methods.
- Review the role of shear walls and steel bracings in improving seismic resilience.
- Compare findings from past studies with respect to fundamental time period, base shear, inter-storey drift, and top-storey displacement.
- Identify research gaps and propose future directions for integrating stiffening systems in seismic-resistant design.

By synthesizing dispersed findings, this review provides structural engineers, researchers, and policymakers with a comprehensive framework for selecting effective stiffening systems in seismic-prone regions.

III. PROPOSED METHODOLOGY

The present study adopts a systematic review methodology aimed at consolidating and critically evaluating existing research on the seismic performance of high-rise buildings with different lateral load resisting systems. The review emphasizes shear walls, steel bracings, and hybrid systems, as these are the most widely adopted strategies in modern seismic design practice. The methodological approach ensures that the selection, categorization, and analysis of literature are transparent, replicable, and comprehensive.

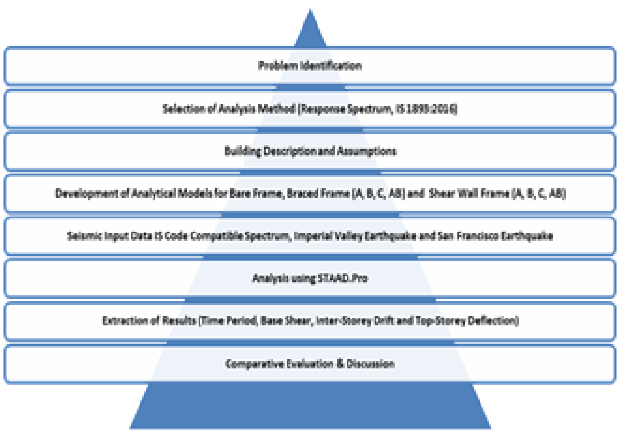

Figure 3.1 Research framework

Structural Description and Assumptions

The study analyzes a 12-storey unsymmetrical reinforced concrete building (42 m high, plan 15 m × 20 m) modeled in STAAD.Pro as a three-dimensional space frame. The work is divided into three parts: Bare frame analysis under three ground motions, Braced frame analysis, Shear wall frame analysis.

The structure was analyzed using the Response Spectrum Method as per IS 1893:2016, which accounts for higher mode effects and provides a realistic dynamic response compared to the equivalent static method.

The building has 3 bays along X (5 m each) and 4 bays along Z (5 m each). Key material and load specifications include M30 concrete, 0.45 × 0.25 m columns, 0.40 × 0.25 m longitudinal beams, 0.35 × 0.25 m transverse beams, 0.10 m slab thickness, unit weight of concrete 25 kN/m³, and live load 3.5 kN/m². The site lies in Seismic Zone IV with hard soil conditions and a damping ratio of 5%.

Figures (3.1 and 3.2) and Table 3.1 present the plan, 3D model, and detailed specifications.

Table 3.1 Specifications of the Building Model

Specification	Data
Number of Storeys	12
Storey Height	3.5 m
Overall Building Height	42 m
Plan Dimension (X × Z)	15 m × 20 m
Number of Bays along X	3
Number of Bays along Z	4
Bay Length along X	5 m
Bay Length along Z	5 m
Concrete Grade	M30
Column Size	0.45 m × 0.25 m
Longitudinal Beam Size	0.40 m × 0.25 m
Transverse Beam Size	0.35 m × 0.25 m
Slab Thickness	0.10 m
Unit Weight of Concrete	25 kN/m³
Live Load	3.5 kN/m²
Seismic Zone	Zone IV
Soil Condition	Hard Soil
Damping Ratio	5%

Figure3.2 Plan of the building

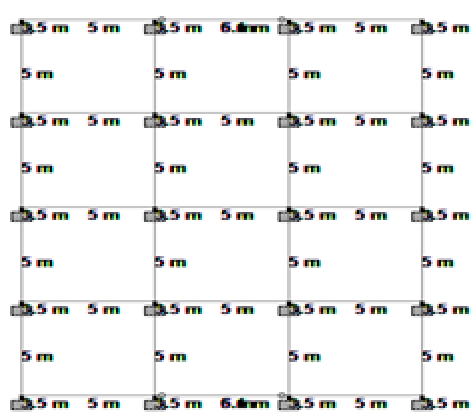

Figure 3.3 Model of the building

Seismic Input Data

The seismic input data for the present study has been adopted in accordance with the provisions of

IS 1893:2016 (Part 1): Criteria for Earthquake Resistant Design of Structures. This standard specifies the design response spectrum, seismic coefficients, and drift limitations for reinforced concrete (RC) buildings located in different seismic zones of India. To capture both codal compliance and realistic ground motion effects, three types of seismic inputs were considered in this research:

1. IS Code Compatible Response Spectrum (2016, Zone IV, Hard Soil)
2. Imperial Valley Earthquake Record (1940)
3. San Francisco Earthquake Record (1906)

This approach ensures that the analysis accounts for both the theoretical spectrum defined in Indian codes and the practical response obtained from actual earthquake records.

IS 1893:2016 Response Spectrum Parameters

For the IS code-compatible analysis, the following seismic parameters were adopted:

Seismic Zone (Z)	IV (Zone factor = 0.24)
Importance Factor (I)	1.0 (ordinary residential/commercial building)
Response Reduction Factor (R)	5.0 (special moment-resisting frame)
Damping Ratio (ξ)	5% of critical damping for RC structures
Soil Condition	Hard Soil (Type I as per IS 1893-2016)

The design horizontal seismic coefficient was calculated using:

$$A_h = \frac{Z}{2} \cdot \frac{I}{R} \cdot \frac{S_a}{g}$$

where Sa/g is the average response acceleration coefficient obtained from the response spectrum curves provided in IS 1893:2016.

MATLAB-Derived Time Periods of the Bare Frame

The natural time periods of the 12-storey bare frame up to the 12th mode were computed using MATLAB and are presented in Table 3.2. These periods served as input for generating response spectra for the selected ground motions.

Table 3.2 Time Periods of Bare Frame (MATLAB Calculation)

Mode	Time Period(s)
1	2.4297
2	0.8145
3	0.4943
4	0.3592
5	0.2860
6	0.2409
7	0.2112
8	0.1909
9	0.1769
10	0.1674
11	0.1613
12	0.1579

Imperial Valley Earthquake (1940)

The Imperial Valley earthquake record was processed to generate a response spectrum using MATLAB. The corresponding spectral acceleration values (Sa/g) were converted into acceleration values by multiplying with 9.81 m/s^2. The results for the first 12 modes of the bare frame are presented in Table 3.3.

Table 3.3 Time Period vs. Acceleration for Imperial Valley Ground Motion

Time Period(s)	Sa/g	Acceleration(m/s^2)
2.4297	1.61E+00	1.58E+01
0.8145	2.31E+00	2.27E+01
0.4943	2.14E+00	2.10E+01
0.3592	1.47E+00	1.44E+01
0.2860	2.11E+00	2.07E+01
0.2409	1.89E+00	1.85E+01
0.2112	1.47E+00	1.44E+01
0.1909	1.10E+00	1.08E+01
0.1769	1.12E+00	1.10E+01
0.1674	9.86E-01	9.67E+00
0.1613	8.31E-01	8.15E+00
0.1579	7.78E-01	7.64E+00

San Francisco Earthquake (1906)

Similarly, the San Francisco earthquake ground motion record was used to generate a response spectrum. The time period vs. acceleration values for the bare frame are shown in Table 3.4.

Table 3.4 Time Period vs. Acceleration for San Francisco Ground Motion

Time Period (s)	Sa/g	Acceleration (m/s²)
2.4297	1.03E+00	1.01E+01
0.8145	1.20E+00	1.18E+01
0.4943	1.23E+00	1.21E+01
0.3592	2.09E+00	2.05E+01
0.2860	3.13E+00	3.07E+01
0.2409	2.90E+00	2.85E+01
0.2112	2.12E+00	2.08E+01
0.1909	1.68E+00	1.64E+01
0.1769	1.63E+00	1.60E+01
0.1674	1.98E+00	1.94E+01
0.1613	2.28E+00	2.24E+01
0.1579	2.47E+00	2.42E+01

By adopting both codal and real earthquake response spectra, the study ensures that the seismic performance of the building is evaluated under a wide range of conditions—from the idealized design spectrum prescribed in IS 1893:2016 to realistic ground motion scenarios from historically significant earthquakes. This hybrid approach strengthens the reliability and applicability of the results.

Structural Modelling

To evaluate different lateral load resisting systems, several analytical models of the 12-storey RC building were developed in STAAD.Pro with identical geometry, materials, and loading. The models differed only by the addition of bracings or shear walls, with the bare frame serving as a reference.

Bare Frame Model: Conventional RC moment-resisting frame without stiffening elements, expected to show maximum displacements and minimum base shear.

Braced Frame Models: Four variations using ISA 60×40×6 steel bracings:

- Bracing A: Along X-direction.
- Bracing B: Along Z-direction.
- Bracing C: At corner bays (torsional control).
- Bracing AB: Along both X and Z directions.

Shear Wall Models: Four variations with 250 mm thick RC shear walls provided over full height:

- Shear Wall A: Along X-direction.
- Shear Wall B: Along Z-direction.
- Shear Wall C: At corners.
- Shear Wall AB: Along both X and Z directions.

Analysis Procedure

The seismic performance of the 12-storey RC building was analyzed in STAAD.Pro using the Response Spectrum Method (RSM) as per IS 1893:2016 (Part 1). This linear dynamic approach estimates maximum responses by combining modal contributions.

- Model Preparation: The bare frame was modeled with fixed supports and rigid floor diaphragms.
- Seismic Parameters: Zone IV (Z = 0.24), Importance factor (I = 1.0), R = 5.0 (SMRF), 5% damping, and hard soil were adopted. Seismic mass included self-weight, 2.5 kN/m² dead load, and 3.5 kN/m² live load.
- Load Cases & Combinations: Dead, live, and earthquake loads were applied with IS 1893:2016 combinations such as 1.5(DL+LL), 1.2(DL+LL±EL), etc.
- Response Spectrum Input: Spectra were applied for (i) IS 1893:2016 Zone IV, (ii) Imperial Valley 1940, and (iii) San Francisco 1906 earthquakes. MATLAB-generated spectra were used where required.
- Analysis Process: Modal properties were extracted, seismic response was computed for each mode, and modal contributions were combined using the Complete Quadratic Combination (CQC) method.
- Results Extracted: Fundamental time period, base shear, inter-storey drift, and roof displacement.

Parameters for Evaluation

Four key response parameters were selected for evaluating seismic behavior across bare, braced, and shear wall models:

- Fundamental Time Period (T): Indicates stiffness and flexibility. Computed in STAAD.Pro and validated against IS 1893:2016 empirical formula:
- T_a= 0.075h^0.75

where h = building height in meters.

- Base Shear (Vb): Represents overall seismic demand. RSM values were compared with Equivalent Static Method as per IS 1893:2016. Codal requirement: RSM base shear ≥ 80% of static base shear.
- Inter-Storey Drift (Δ): Relative lateral displacement between two floors. Limited to 0.004h (IS 1893:2016). Used to assess serviceability and potential damage.
- Top-Storey Displacement: Roof deflection under seismic loads. No direct codal limit, but excessive values imply discomfort or instability. Compared across all structural systems.

IV. CONCLUSION AND FUTURE SCOPE

Conclusion

The review highlights that lateral load–resisting systems play a crucial role in improving the seismic resilience of reinforced concrete buildings. Studies consistently show that:

- Bare frames provide minimal resistance, resulting in higher displacements, drifts, and longer fundamental time periods.
- Braced frames significantly enhance stiffness and reduce inter-storey drifts by transferring lateral loads through axial action. Their efficiency depends on bracing configuration and placement.
- Shear walls are highly effective in minimizing lateral displacement and top-storey sway due to their large in-plane stiffness, but they may attract higher base shear forces.
- Hybrid systems combining bracings and shear walls achieve superior performance, offering both drift control and enhanced energy dissipation, thus aligning well with performance-based seismic design objectives.

Overall, it can be concluded that the integration of multiple lateral load–resisting systems provides a balanced solution to improve both strength and serviceability under seismic excitation. This makes hybrid systems a promising direction for high-rise construction in earthquake-prone regions.

Future Scope

While significant progress has been made, several research gaps and opportunities remain:

- Nonlinear Performance Assessment: Most studies rely on linear dynamic analysis. Future research should employ nonlinear time-history analysis to capture inelastic behavior, damage progression, and residual drift.
- Optimization of Hybrid Systems: Further work is needed to determine the optimal combination, placement, and proportion of bracings and shear walls for different building geometries and soil conditions.
- Material Innovation: The use of high-performance materials such as fiber-reinforced concrete, composite bracings, and energy-dissipating dampers can be explored to enhance resilience.
- Life-Cycle Performance: Research should consider durability, repairability, and life-cycle cost analysis of hybrid systems under repeated seismic events.
- Performance-Based Design Frameworks: Future work can focus on developing simplified design methodologies and codal guidelines that integrate hybrid systems into performance-based seismic design.
- Experimental Validation: Large-scale shake table tests and hybrid simulation studies are necessary to validate analytical findings and strengthen the reliability of numerical models.

REFERENCE

1. Kent, J., Zhong, C., & Christopoulos, C. (2023). Steel flexure and shear yielding base-mechanism for enhanced seismic resilience of RC core wall high-rise structures. Earthquake Spectra, 39(1).
2. Zhao, L., et al. (2024). Experimental Investigation on the Seismic Performance of Novel Prefabricated Composite RC Shear Walls with Concrete-Filled Steel Tube Frame (CCRCSW-CFST). Buildings, 14(9), Article 2673.
3. Alhussein, M. A. A., Nugroho, G., Wahiddin, W., & Nursetiawan, N. (2024). Concentric Bracing Frame in Earthquake-Resistant High-Rise Buildings. Semesta Teknika, 27(1), 81–97.

4. Hulagabali, A., Manjunath, Y. M., Akki, S., & Nayak, A. (2024). Effect of Bracings on the Performance of High-Rise Structure Considering the Influence of Earthquake. Innovation in Smart and Sustainable Infrastructure, Lecture Notes in Civil Engineering, Vol. 485, pp. 321–336.
5. Hasan, N., Islam, M. S., & Anam, I. (2024). Performance of Concurrent Shear Wall as a Bracing System to Resist Lateral Load on Supertall Structures. In Proceedings of CICM 2023 (pp. 19-27).
6. Xiong, Z., Liang, J., & Chen, X. (2025). Seismic Performance Evaluation of Reinforced Concrete Frame–Shear Wall Structural Systems in Thermal Power Plants. Buildings, 15(3), 419.
7. Zhang, Wenying; Lan, Xing; Mahsa Mahdavian; Cheng Yu. (2023). Seismic performance cold-Formed steel framed shear walls using in-Frame corrugated steel sheathing. Advances in Structural Engineering, 26(11).
8. Liu, Yibin; Cao, Wanlin; Yang, Zhaoyuan; Bian, Jinliang; Bao, Xin. (2024). Seismic Performance of Recycled-Aggregate-Concrete-Based Shear Walls with Concealed Bracing. Buildings, 14(9), 2987.
9. Todea, V. et al. (2023). Numerical Study on the Seismic Performance of Hybrid Shear Walls with Centered Openings. Journal of Applied Engineering Sciences, 13(2), pp. 281-288.
10. Osman, A., & Farouk, A. E. (2023). The use of steel X-bracing combined with shear link to seismically upgrading reinforced concrete frames. Journal of Engineering and Applied Science, 70, Article 150.
11. Dou, L.; Huang, Z.; Liu, Y.; Wang, Y.; Zhao, L. (2024). Experimental Investigation on the Seismic Performance of Novel Prefabricated Composite RC Shear Walls with Concrete-Filled Steel Tube Frame (CCRCSW-CFST). Buildings, 14(9), 2673.
12. Xiong, Z.; Liang, J.; Chen, X. (2025). Seismic Performance Evaluation of Reinforced Concrete Frame–Shear Wall Structural Systems in Thermal Power Plants. Buildings, 15(3), 419.
13. Kent, J.; Zhong, C.; Christopoulos, C. (2023). Steel flexure and shear yielding base-mechanism for enhanced seismic resilience of RC core wall high-rise structures. Earthquake Spectra.
14. Lu, H.; Su, M.; Wang, Y.; Zhou, Y.; Shen, S. (2024). Seismic Performance of Embedded Connections for Precast Hybrid Coupled Wall Systems: Experimental Study and Theoretical Analysis. Buildings, 14(8), 2503.
15. Hasan, N.; Islam, M. S.; Anam, I. (2024). Performance of Concurrent Shear Wall as a Bracing System to Resist Lateral Load on Supertall Structures. In: Proceedings of the 2nd International Conference on Advances in Civil Infrastructure and Construction Materials (CICM 2023), Vol. 2, LNCE Vol. 512. Springer.
16. Hejazi, F.; Farahpour, H.; Ayyash, N. (2024). Seismic performance of structure equipped with a new rubber bracing damper system. Archives of Civil and Mechanical Engineering, 24, 46.
17. Arabian Journal for Science and Engineering (2024). Seismic Retrofitting of Existing Reinforced Concrete Buildings Using Aluminium Shear Links and Eccentric Steel Chevron Braces.
18. Ahed Habib; Zaid A. Al-Sadoon; Murat Saatcioglu; Ausamah Al Houri; Mohamed Maalej; Salah Al-Toubat; Mazen Shrif (2025). Seismic Behavior of Squat Reinforced Concrete Shear Walls: A State-of-the-Art Review. Structural Durability & Health Monitoring, Vol. 19, No. 3, pp. 417-439.
19. Helal, Y.; Garcia, R.; Imjai, T.; et al. (2024). Seismic behavior of Exterior RC beam-column joints repaired and strengthened using post-tensioned metal straps. Bulletin of Earthquake Engineering, 22, 3261-3286.