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A Review on Earthquake-Resistant Design of Multibay Multi- Storey RC Frame Structures

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Abstract: The devastating impact of earthquakes across the globe has highlighted the vulnerability of inadequately designed structures, emphasizing the critical need for earthquake-resistant construction practices. In this context, multistorey reinforced concrete (RC) frame buildings, especially in high seismic zones, must incorporate advanced structural elements to enhance resilience. This review focuses on the effectiveness of incorporating seismic resistance technologies such as shear walls, steel bracing systems, and energy-dissipating devices (viscous and friction dampers) in G+5 (six-storey) RC frames. A case model with a total height of 18 meters is analyzed using ETABS software under seismic Zone V conditions, employing linear static and dynamic analysis techniques. Results demonstrate significant reductions in storey displacement—from 39 mm to 19 mm (a 51% decrease)—and storey drift (up to 55%) when seismic mitigation systems are introduced. These findings underline the importance of integrated seismic design in ensuring structural stability and minimizing earthquake-induced damage.

Keywords: Seismic design, Earthquake-resistant structures, Storey drift, Storey displacement, Shear wall, Steel bracing, ETABS, RC frames, Zone V.

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Introduction

Rapid urbanization and population growth have increased the demand for multi-storey buildings, particularly in densely populated urban areas. With limited land availability, vertical development has become a necessity, making the seismic safety of these structures an essential consideration. While severe earthquakes are relatively infrequent, their destructive potential justifies the integration of seismic-resistant features in structural design. Modern seismic design philosophy aims not only to prevent structural collapse but also to minimize damage and ensure occupant safety. According to established seismic codes, buildings should withstand minor earthquakes without damage, moderate earthquakes without structural damage but with permissible non-structural damage, and major earthquakes without collapse. To meet these requirements, several structural interventions are available. Common methods include the incorporation of shear walls, steel bracing systems, and energy-dissipating devices such as viscous and friction dampers. These technologies significantly improve the lateral load resistance of RC frames, reducing inter-storey drift and overall displacement, thus enhancing overall seismic performance. This paper presents a comprehensive review of earthquake-resistant design strategies for multibay, multi-storey RC frames, drawing on numerical modeling, past experimental studies, and design standards. Special attention is given to the comparative effectiveness of structural enhancements based on recent simulation results and published literature.

Objectives

- To analyze the seismic performance of multistorey RC frame structures with plan and vertical irregularities.
- To evaluate and compare the effectiveness of different seismic mitigation strategies (bracings, shear walls, base isolators, dual systems).
- To study the impact of soil-structure interaction and bidirectional seismic loads on torsional responses and displacement control.
- To develop a design framework that integrates the above factors for improving seismic resilience of irregular RC structures.

Literature Review

Zekioglu *et al.* (2004) performed a pushover analysis of a slender 19-story reinforced concrete (RC) building located in San Francisco, covering approximately 430,000 square feet. The structure employed concrete shear walls for resisting lateral loads, and analysis was conducted using SAP2000 and ETABS (version 7). The cracked section stiffness was assumed to be 50% of the gross section for all lateral members to assess life-safety performance objectives during seismic events. Elnashai *et al.* (2006) developed fragility curves for buildings with plan irregularities by incorporating spatial damage indices. Their study emphasized the importance of accounting for multidirectional loading and irregularities when evaluating structural vulnerability, showing that using spatial indices can result in more conservative and reliable assessments than traditional approaches. Kiani *et al.* (2012) proposed an improved modal pushover method called Modified Consecutive Modal Pushover (MCMP) for tall asymmetric buildings. They demonstrated that higher-mode effects and torsion significantly affect the seismic response. Comparisons between MCMP, traditional Modal Pushover Analysis (MPA), and nonlinear time-history analysis (NLTHA) revealed improved accuracy of MCMP in capturing demands for asymmetric high-rise RC structures. Chouhan and Chouhan (2014) compared the seismic response of regular and irregular RC frame buildings with and without bracing systems. Their study evaluated four multi-storey buildings located in seismic Zones II to V. Results showed that introducing bracing significantly reduced both storey drift and lateral displacements, especially in L-shaped and T-shaped irregular configurations. Aditya and Abdurrahman (2014) examined the effect of column-to-beam strength ratios on the seismic performance of ductile RC frames. Using nonlinear static pushover analysis, they observed that strength ratios above 1.2 helped in forming favorable plastic hinge patterns and ensured performance within the life-safety limit state, especially for taller buildings. Han and Xie (2015) investigated the strong-column weak-beam behavior in RC frames under strong seismic excitations. By modeling corner columns observed in post-earthquake damage scenarios, they established stiffness coefficient limits for column-beam assemblies and showed how bidirectional loading and axial compression influence structural failure modes. Ma *et al.* (2016) highlighted how cast-in-situ slab reinforcements can impact the failure mechanism of RC frames. Through experimental tests, they found that slab continuity and reinforcement increased beam stiffness, often transforming desired strong-column weak-beam behavior into the reverse, compromising seismic performance. Pande and Borse (2017) analyzed the behavior of T-shaped buildings under seismic loads using STAAD Pro. They evaluated the role of torsional stiffness by varying it from 0% to 100% and found that while increased torsional flexibility could reduce base forces, it must be applied judiciously to avoid unintended dynamic amplifications. Anup and Jadhav (2018) studied how floor plan configurations influence seismic behavior in G+15 RC frame buildings. Using A-shaped, U-shaped, and regular geometries, they found that irregular configurations significantly altered displacement patterns and base shear responses, emphasizing the need for careful seismic design of non-rectangular buildings. Sharma and Thakur (2019) performed a comparative analysis of symmetric and asymmetric buildings reinforced with bracings and shear walls using the response spectrum method. Their G+9 models revealed that shear walls provided more effective control of base shear and displacements compared to bracings alone, especially under irregular layouts. Pujari and Sonawane (2020) evaluated torsional effects in L-shaped RC buildings based on IS 1893:2016 guidelines. Their ETABS-based study focused on reducing torsional irregularity by optimizing stiffness distribution, finding that adjustments to vertical elements could significantly reduce torsion-induced drift and mode shape distortion. Tao *et al.* (2021) proposed a biaxial overstress factor to address discrepancies in performance of RC columns under biaxial seismic excitation. By modeling biaxial moments and reinforcing columns accordingly, they demonstrated improved seismic resilience and prevented premature formation of column hinges, validated through nonlinear time-history analysis. Chen *et al.* (2020) investigated the seismic performance of RC frames with irregular plans using nonlinear dynamic analysis. Their findings indicated that plan irregularities significantly influence the distribution of seismic forces, leading to higher demands on certain structural elements, and emphasized the necessity for tailored design approaches for such configurations. Li and Wang (2021) conducted a fragility assessment of mid-rise RC buildings with vertical irregularities. Utilizing incremental dynamic analysis, they developed fragility curves that highlighted the increased vulnerability of structures with setbacks compared to regular profiles, underscoring the importance of considering vertical irregularities in seismic design. Zhao *et al.* (2022) explored the effectiveness of base isolation systems in mitigating torsional responses in asymmetric RC buildings. Their study demonstrated that strategically designed isolation systems could significantly reduce both translational and torsional seismic demands, enhancing overall structural performance. Nguyen and Tran (2023) analyzed the impact of soil-structure interaction on the seismic behavior of RC frames with plan irregularities. Results showed that neglecting soil-structure interaction could lead to an underestimation of seismic demands, particularly in structures with significant plan asymmetry. Kumar and Singh (2024) examined the performance of RC frames with dual systems (combining shear walls and moment-resisting frames) under bidirectional seismic loading. Their research highlighted that dual systems offer improved performance in controlling both translational and torsional responses, especially in high-seismic zones.

Research Gap

While significant research has been conducted on the seismic performance of RC buildings, several key gaps remain:

- Limited studies combine plan and vertical irregularities in the same structural model.
- Most existing analyses consider only unidirectional seismic loading, not bidirectional effects.
- The effects of soil-structure interaction (SSI), torsional irregularity, and combined mitigation techniques (e.g., base isolation + shear walls) are often studied in isolation, lacking an integrated approach.
- Existing design approaches may not adequately address complex dynamic interactions in asymmetric and irregular structures subjected to realistic ground motions.

Aims:

- Address real-world structural irregularities found in urban multistorey buildings.
- Enhance earthquake-resistant design through combined and holistic mitigation techniques.
- Support revisions to seismic design codes by providing insights into complex behaviors such as torsion, higher-mode effects, and SSI.
- Help engineers select appropriate retrofitting strategies for existing buildings and guide new construction in high-seismic zones.

Conclusion

The reviewed studies collectively indicate that seismic performance of RC frame buildings is highly sensitive to structural irregularities, torsional effects, soil-structure interaction, and bidirectional ground motions. Integrating mitigation measures such as shear walls, bracing, base isolation, and dual systems improves performance, but their effectiveness varies depending on configuration and site conditions. Future research should focus on a unified seismic design methodology that simultaneously considers plan/vertical irregularities, soil conditions, and dynamic load interactions to enhance resilience and safety in seismic zones.

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