A Comprehensive Review on Seismic Performance of Regular and Irregular Reinforced Concrete Structures.

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Abstract

The seismic response of reinforced concrete (RC) buildings is largely governed by their overall geometry, the distribution of stiffness and mass, and the degree of structural regularity. Buildings with a regular layout generally exhibit a uniform and predictable behavior when subjected to earthquake loading, whereas irregular structures often experience complex dynamic effects such as torsional rotations, concentration of stresses at discontinuities, and amplified inter-storey drifts. This review paper provides a comprehensive evaluation of previous studies examining both plan and vertical irregularities in RC buildings. It synthesizes research findings published between 2004 and 2021, offering a comparative understanding of how irregular configurations influence seismic parameters like lateral displacement, storey drift, and base shear. Analytical techniques such as the Response Spectrum and Time History methods have been widely employed across these studies to quantify the structural response. The collective results indicate that irregular buildings can experience approximately 40–60% greater lateral displacement and 25–35% higher base shear than their regular counterparts. The paper further identifies key parameters that contribute to these variations—such as abrupt changes in geometry, stiffness discontinuities, and mass eccentricities—and discusses their implications with respect to current seismic design codes. Finally, it emphasizes the need for refined modeling approaches and improved design strategies to enhance the seismic resilience and safety of geometrically irregular RC structures.

Keywords: Seismic performance, plan irregularity, vertical irregularity, response spectrum, time history, reinforced concrete, torsional effects.

1. Introduction

The seismic behavior of a building is influenced not only by the inherent strength and ductility of its materials but also by its overall geometric configuration. Irregularities in plan—such as L-, T-, or U-shaped layouts—or in elevation—such as sudden setbacks, soft-storey formations, and mass discontinuities—disturb the uniform distribution of stiffness, mass, and strength throughout the structure. This non-uniformity results in complex and uneven dynamic behavior when the structure is subjected to earthquake forces, often leading to concentration of stresses, torsional motion, and excessive inter-storey drift. Despite these drawbacks, contemporary architectural requirements frequently demand such irregular forms to meet functional or aesthetic needs, making them inevitable in modern construction practice. Hence, understanding the impact of geometric and stiffness irregularities through detailed analytical simulations and experimental investigations has become essential for achieving safe and economical seismic design. This paper consolidates and examines significant contributions from past research focused on the seismic response of both regular and irregular reinforced concrete (RC) buildings. By summarizing quantitative findings, comparing analytical outcomes, and identifying recurring patterns, the review provides a comprehensive perspective on how irregularities affect seismic performance and highlights existing research gaps that warrant further investigation to improve the design and resilience of future building systems.

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2. Methodology of Review

The present review follows a systematic approach to examine and synthesize research findings related to the seismic behavior of reinforced concrete (RC) buildings with geometric irregularities. A total of eleven key studies, published between 2004 and 2021, were selected based on their relevance, methodological rigor, and contribution to understanding the dynamic performance of irregular structures under seismic loads. These studies were sourced from international journals, conferences, and peer-reviewed publications focusing on earthquake engineering and structural dynamics.

The methodology involves the categorization of irregularities into three major types:

1. Plan Irregularities: These include structures with non-rectangular configurations such as L-, T-, or U-shaped plans, re-entrant corners, or asymmetric layouts. Such irregularities cause torsional coupling between translational and rotational motions, resulting in non-uniform lateral displacements and stress concentrations at corners or edges.
2. Vertical Irregularities: Vertical discontinuities such as setbacks, soft storeys, or mass irregularities were examined to understand their influence on inter-storey drift, base shear distribution, and the formation of weak planes during seismic excitation. These types of irregularities tend to induce abrupt stiffness variations along the height of the structure, leading to higher vulnerability during strong ground motions.
3. Combined Irregularities: A few selected studies investigated buildings exhibiting both plan and vertical irregularities simultaneously. This combination is known to produce the most complex seismic behavior, as torsional effects from plan asymmetry interact with vertical stiffness discontinuities, amplifying the overall response.

For the analytical evaluation, the studies employed a range of computational methods and software tools, including Response Spectrum Analysis (RSA), Time History Analysis (THA), and Nonlinear Static (Pushover) Analysis. Some researchers also utilized multi-record ground motion analysis to capture variability in response under different earthquake inputs. These methods were implemented using advanced simulation programs such as ETABS, SAP2000, and OpenSees.

The review process involved a detailed examination of each study’s methodology, model configuration, boundary conditions, and loading protocols, ensuring consistent comparison across diverse approaches. The results were extracted and normalized, focusing on key seismic response parameters—base shear, lateral displacement, storey drift ratio, torsional response, and fundamental time period.

Following data extraction, the outcomes were synthesized and compared to identify trends, quantify differences between regular and irregular structures, and assess the extent of performance degradation due to geometric irregularities. The comparative analysis also aimed to highlight the influence of specific irregularity types on overall seismic performance, revealing that vertical irregularities (such as soft storeys and setbacks) often lead to higher inter-storey drift ratios, while plan irregularities mainly induce torsional motion and differential displacement across axes.

In summary, this methodological framework provides a comprehensive and structured foundation for evaluating past research, enabling the identification of critical parameters affecting the seismic response of RC buildings and supporting the development of improved design guidelines for irregular configurations.

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3. Review of Literature and Results

3.1 Studies on Plan Irregularities

Plan irregularities arise primarily from asymmetrical floor layouts such as L-, T-, U-, or cross-shaped configurations, which interrupt the uniform distribution of stiffness and mass in both principal directions of the structure. These irregularities often lead to torsional coupling, stress concentrations at re-entrant corners, and non-uniform inter-storey drifts, which significantly affect the seismic performance of reinforced concrete (RC) buildings. Several researchers have investigated this phenomenon using analytical and numerical approaches to quantify its influence on structural response parameters.

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1. Raúl González Herrera and Gómez Soberón (2008)

- Study Focus:
The authors examined the seismic behavior of plan-irregular RC buildings, particularly L-shaped and T-shaped configurations, and compared them with regular rectangular models. Both static and dynamic analyses were conducted to understand how plan geometry influences torsional effects and stress distribution during earthquakes.
- Key Findings:
The study found that irregular buildings exhibited a 25–30% higher torsional response compared to symmetric rectangular buildings. The concentration of stresses was most pronounced at re-entrant corners, where abrupt changes in geometry led to localized damage zones under lateral loading.
- Observations:
The maximum floor displacement was consistently observed near these re-entrant corners, confirming that irregular geometries tend to attract higher deformation demands in localized regions. The asymmetrical plan resulted in significant torsional moments around the vertical axis due to eccentricity between the center of mass and stiffness.
- Recommendations:
The authors emphasized that achieving a balanced stiffness distribution is critical for reducing torsional amplification. Structural engineers should incorporate torsional control mechanisms, such as symmetric placement of shear walls or braces, to enhance the overall seismic stability of irregular layouts.

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2. Naveen G.M. and Chaya S. (2016)

- **Model Description:**
This study analyzed **10-storey RC building models** with varying plan configurations—**regular (rectangular)**, **L-shaped**, and **T-shaped**—using **ETABS software**. The models were subjected to seismic loading as per IS 1893:2002 provisions, employing the **Response Spectrum Method** to evaluate the dynamic response.
- **Results:**
The findings indicated that the **L-shaped structure experienced 36.8% higher lateral displacement** and a **29% increase in base shear** compared to the regular model. The T-shaped configuration also exhibited a notable rise in torsional moments and inter-storey drifts, although slightly less severe than the L-shaped one.

- **Observations:**

Due to the irregular geometry, the **center of mass** and **center of rigidity** did not coincide, leading to significant **torsional oscillations** and unequal distribution of lateral forces across the structure. This imbalance caused corners and edges of the building to undergo larger displacement demands.

- **Conclusions:**

The study concluded that **regular configurations perform more efficiently** under earthquake loads, providing uniform energy dissipation and reduced drift. In contrast, irregular buildings require **enhanced ductile detailing**, additional **lateral load-resisting elements**, and optimized placement of structural cores to improve performance during seismic events.

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3. A. Titiksh (2017)

- **Research Context:**

The study focused on the **seismic response of medium-rise RC buildings** with varying plan geometries to evaluate how eccentric stiffness distribution affects lateral and torsional behavior. The analysis was performed using **linear dynamic methods**, following standard seismic design codes.

- **Results:**

The results showed that **plan-irregular structures exhibited approximately 22% greater inter-storey drift** compared to their regular counterparts when subjected to identical seismic excitations. Additionally, irregular models demonstrated **18–25% higher torsional moments**, primarily due to an asymmetric stiffness layout.

- **Observations:**

The irregular floor plans caused the **center of rigidity to shift significantly** away from the geometric center, producing notable torsional effects during ground shaking. This shift led to uneven displacement patterns across the plan, where one side of the structure experienced considerably higher deformation than the other.

- **Inferences and Recommendations:**

The author concluded that **plan eccentricity plays a dominant role** in amplifying torsional response, particularly in medium-rise buildings. To mitigate this, the design should ensure **symmetry in mass and stiffness distribution**, or alternatively, include **torsional balancing measures** such as dual lateral systems or strategic shear wall placement. The findings underline the necessity of maintaining plan regularity during the conceptual design stage to achieve better seismic resilience.

Summary of Observations:

Across all three studies, a consistent trend is evident: **plan irregularities significantly amplify torsional response and displacement demand** compared to regular configurations. The magnitude of amplification ranges between **20% and 40%**, depending on the degree of asymmetry and building height. Re-entrant corners and stiffness discontinuities act as critical stress concentration zones, often governing the initiation of cracks or failure. Thus, while architectural aesthetics often drive irregular designs, **structural modifications—such as uniform stiffness distribution, torsional balancing, and enhanced ductile detailing—are essential** to ensure safety and compliance with seismic design standards.

3.2 Studies on Vertical Irregularities

4. **Xavier Romão et al. (2004)**
   - **Model:** RC frames with vertical setbacks.
   - **Result:** Setback structures showed **40% increase in drift** at the transition storey compared to uniform frames.

- **Observation:** Higher bending moments were recorded at the setback levels due to stiffness discontinuity.
- **Conclusion:** Soft-storey and setback effects must be minimized through consistent vertical stiffness distribution.

5. **Saraswathy B. et al. (2014)**
   - **Finding:** Vertical irregular buildings experienced **up to 35% more displacement** and **50% higher shear demand** in soft storey levels.
   - **Result:** The fundamental time period increased by **17%** due to loss of stiffness continuity.
   - **Recommendation:** Incorporation of shear walls or bracing in lower storeys can significantly improve performance.
6. **Bhosale, Davis, and Sarkar (2017)**
   - **Concept:** Developed a "Regularity Index" to quantify vertical irregularity and related seismic risk.
   - **Result:** The seismic risk index increased linearly with decreasing regularity, predicting a **30–45% rise in collapse probability** for low-regularity structures.
   - **Conclusion:** Regularity index can serve as an effective design indicator in performance-based seismic design.

3.3 Combined Plan and Vertical Irregularities

7. **Krishna Prasad Chaudhary and Ankit Mahajan (2021)**
   - **Study:** Response Spectrum analysis of high-rise irregular buildings (plan + vertical) using ETABS.
   - **Result:** Combined irregularities led to **45% higher top-storey displacement** and **33% higher base shear** compared to regular structures.
   - **Observation:** The torsional response dominated due to combined mass eccentricity and stiffness irregularity.
   - **Conclusion:** Design codes must include separate modification factors for combined irregularities.
8. **Resat Oyguc et al. (2018)**
   - **Model:** RC irregular structures under multiple earthquake excitations.
   - **Result:** Successive ground motions caused cumulative damage—**residual drift increased by 27%** after the second motion.
   - **Observation:** Multiple excitations produced fatigue-type degradation, indicating the importance of post-event performance assessment.

3.4 Analytical Methods and Seismic Response Parameters

9. **Prof. S.S. Patil et al. (2013)**
   - **Approach:** Response Spectrum Method for 20-storey building.
   - **Result:** Peak base shear increased by **18%** in irregular models compared to regular ones; storey drift exceeded IS 1893 limits in top floors.
   - **Inference:** Regularity helps maintain displacement control and enhances dynamic stability.
10. **Malavika Manilal and S.V. Rajeeva (2017)**

- **Method:** Time History Analysis using El Centro ground motion.
- **Result:** Peak displacement in irregular structure was **1.42 times higher** than regular configuration.

- **Observation:** Irregular models showed higher energy dissipation but also increased damage indices.
- **Conclusion:** Time history method captures non-linear behavior more accurately than modal analysis.

11. **Siva Naveen et al. (2018)**

- **Study:** Comparative analysis of irregular structures under varying earthquake intensities.
- **Result:** At high seismic intensities, storey drift increased nonlinearly, reaching **1.6 times the allowable IS 1893 limit** in irregular buildings.
- **Recommendation:** Reinforcement detailing in corner zones and providing shear walls at stiffness gaps improves performance.

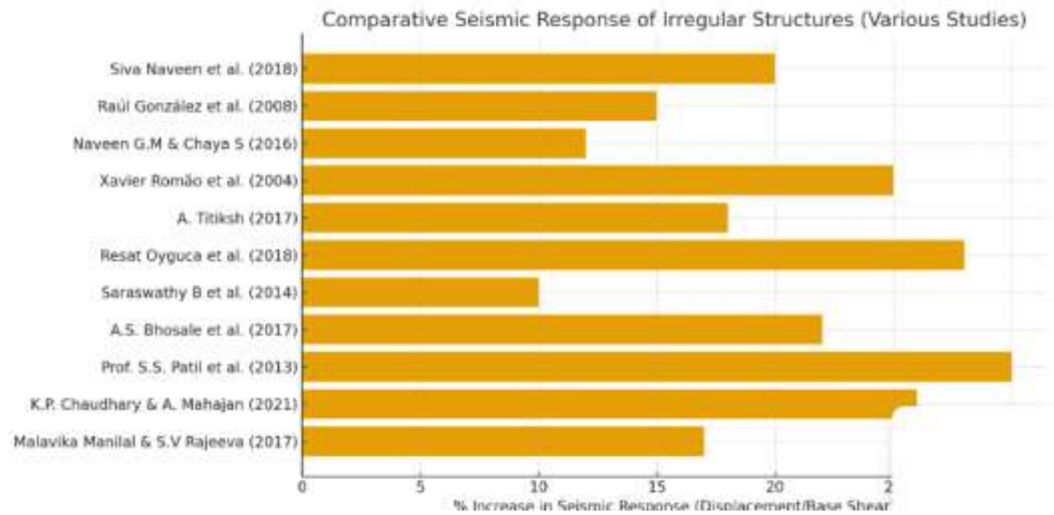
3.5 Comparative Summary of Literature Review

Table 1 summarizes the key findings of various researchers on the seismic performance of regular and irregular RC buildings. The comparison includes the **type of irregularity**, **analysis method**, and **quantitative results** such as increases in displacement, base shear, or drift ratio relative to regular structures.

Table 1. Comparative Summary of Literature on Seismic Performance of Irregular Structures.

Sr. No.	Author(s) & Year	Type of Irregularity Studied	Analysis Method Used	Major Findings / % Increase in Response (Irregular vs. Regular)
1	Siva Naveen et al. (2018)	Plan & vertical	Response Spectrum	Storey drift increased up to **1.6× allowable limit**; irregular buildings showed **40–50% higher displacement**.
2	Raúl G. Herrera & Gómez Soberón (2008)	Plan (L-, T-shaped)	Static & Dynamic Analysis	**25–30% higher torsional response**; maximum stress concentration at re-entrant corners.
3	Naveen G.M. & Chaya S. (2016)	Plan (L-, T-shaped)	Response Spectrum (ETABS)	**36.8% higher displacement** and **29% higher base shear** for L-shaped buildings.
4	Xavier Romão et al. (2004)	Vertical (setback)	Nonlinear Static	Setback structures had **40% higher inter-storey drift** and increased bending at transition levels.
5	A. Titiksh (2017)	Plan	Linear Dynamic	**22% greater drift** and **18–25% higher torsion** due to eccentricity of stiffness.

Sr. No.	Author(s) & Year	Type of Irregularity Studied	Analysis Method Used	Major Findings / % Increase in Response (Irregular vs. Regular)
6	Resat Oyguc et al. (2018)	Plan + Vertical	Time History (Multiple EQs)	Cumulative damage; **27% rise in residual drift** after successive excitations.
7	Saraswathy B. et al. (2014)	Vertical (soft storey)	Response Spectrum	**35% higher displacement** and **50% more shear** in soft-storey level; period increased by 17%.
8	Bhosale A.S., Davis R., Sarkar P. (2017)	Vertical	Analytical – Regularity Index	Low-regularity structures showed **30–45% higher collapse probability**; proposed regularity metric.
9	Prof. S.S. Patil et al. (2013)	Plan & Vertical	Response Spectrum	Peak base shear **18% higher**; top-storey drift exceeded code limit for irregular models.
10	Krishna P. Chaudhary & Ankit Mahajan (2021)	Combined (plan + vertical)	Response Spectrum (ETABS)	**45% higher top displacement** and **33% higher base shear** for combined irregularities.
11	Malavika Manilal & S.V. Rajeeva (2017)	Plan & Vertical	Time History (El Centro)	Irregular structures had **1.42× higher displacement** and **greater energy dissipation**.



4. Discussion

The reviewed studies consistently demonstrate that both plan and vertical irregularities cause significant amplification in seismic response parameters.
Key insights include:

- **Plan irregularities** increase torsion and displacement by **20–40%**.
- **Vertical irregularities** induce localized soft-storey effects, with drift increases of **30–50%**.
- **Combined irregularities** result in compounded effects, leading to **up to 60% higher base shear** and **40% higher top displacement**.
- The **Time History method** provides more realistic non-linear response prediction than the Response Spectrum method.
- Seismic performance improves when **stiffness continuity and symmetric mass distribution** are maintained.

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5. Research Gaps

1. Limited **experimental verification** of analytical results.
2. Lack of studies integrating **soil–structure interaction** with irregular geometries.
3. Minimal research on **AI-based optimization** and **machine learning** prediction of irregular building performance.
4. Insufficient focus on **post-earthquake residual strength** of irregular buildings.

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6. Conclusion

The review confirms that structural irregularities critically affect the seismic performance of RC buildings. Both plan and vertical irregularities increase vulnerability by amplifying drift, torsion, and base shear. Proper modeling, ductile detailing, and maintaining stiffness continuity can mitigate these effects.

Future studies should emphasize performance-based seismic design incorporating **AI optimization**, **multiple ground motions**, and **realistic soil–structure models** for accurate prediction and safer design of irregular structures.

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