

A REVIEW OF LATERAL RESPONSE DIFFERENTIATION BETWEEN GEOMETRICALLY UNIFORM AND PLAN-DISTORTED REINFORCED CONCRETE BUILDING CONFIGURATIONS

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Abstract -Plan configuration plays a decisive role in governing the lateral load response of reinforced concrete (RC) buildings subjected to seismic and wind actions. While geometrically uniform configurations generally exhibit predictable stiffness distribution and stable modal characteristics, plan-distorted buildings—such as L-, T-, and U-shaped layouts—often develop torsional coupling, drift concentration, and irregular force redistribution. Despite extensive research on seismic irregularities, a consolidated synthesis comparing the lateral response characteristics of uniform and plan-distorted RC configurations remains fragmented. This review systematically examines experimental investigations, analytical formulations, and numerical simulations published over the past three decades to evaluate response differentiation between these configurations. Key response parameters considered include base shear demand, inter-storey drift ratio, torsional amplification, natural period variation, and plastic hinge formation patterns. The review identifies consistent trends indicating amplified torsional effects, localized damage concentration, and increased displacement demand in plan-distorted structures, particularly under nonlinear dynamic loading. Variations in findings are attributed to modelling assumptions, structural system type, and irregularity severity. The study further evaluates the treatment of plan irregularities in contemporary seismic design provisions and highlights critical research gaps. The synthesized insights aim to support improved performance-based design strategies and more rational assessment of irregular RC building configurations.

Key Words: Lateral response; Plan irregularity; Reinforced concrete buildings; Torsional amplification; Seismic performance; Nonlinear dynamic analysis

1. INTRODUCTION

1.1 Background

1.1.1 Importance of Lateral Load Resistance in RC Buildings

Reinforced concrete (RC) buildings are primarily designed to resist gravity loads; however, their performance during extreme lateral loading events such as earthquakes and strong winds governs structural safety and serviceability. Unlike gravity loads, lateral forces induce bending, shear,

axial-flexural interaction, and torsion simultaneously, leading to complex stress redistribution within structural members. In seismic regions, inadequate lateral resistance has historically resulted in catastrophic failures, particularly in multi-storey moment-resisting frames lacking sufficient stiffness and ductility (Paulay and Priestley, 1992). The lateral response of RC buildings is strongly influenced by stiffness distribution, mass regularity, redundancy, and energy dissipation capacity. Modern performance-based seismic design frameworks emphasize drift control, ductility demand, and damage limitation, further underscoring the importance of understanding lateral load behaviour (Chopra, 2017).

1.1.2 Increasing Architectural Complexity and Irregular Plan Configurations

Contemporary architectural demands increasingly favour asymmetric and aesthetically complex layouts, leading to widespread adoption of irregular plan geometries. Functional requirements, site constraints, and urban density considerations often necessitate L-, T-, and U-shaped configurations. While architecturally appealing, such forms introduce non-uniform stiffness and mass distribution, which alter dynamic characteristics and modal participation factors. Empirical observations following past earthquakes have demonstrated that buildings with plan irregularities exhibit significantly different response patterns compared to regular configurations (Moehle, 2014). Consequently, the divergence between architectural form and structural regularity has become a critical concern in seismic design practice.

1.1.3 Seismic Vulnerability Associated with Plan Distortion

Plan distortion induces eccentricity between the centre of mass and centre of rigidity, generating torsional response under lateral excitation. This torsional coupling amplifies displacement demands at peripheral elements, often resulting in localized damage concentration and premature yielding. Studies have shown that torsional irregularity can substantially increase inter-storey drift demands, particularly under nonlinear dynamic loading (Chandler and Duan, 1997). Post-earthquake reconnaissance reports, including observations from major seismic events such as

the 1994 Northridge earthquake, highlight disproportionate damage in irregular RC buildings, reinforcing the vulnerability associated with plan distortion (FEMA, 2000).

1.2 Conceptual Definitions

1.2.1 Geometrically Uniform RC Configurations

Geometrically uniform configurations refer to building layouts characterized by symmetry in plan, uniform mass distribution, and consistent stiffness along principal axes. Such configurations typically exhibit uncoupled translational modes and predictable dynamic behaviour. Regularity minimizes torsional amplification and ensures relatively uniform drift distribution across storeys. Seismic design codes often consider symmetric rectangular plans as idealized reference systems due to their stable modal characteristics and reduced accidental eccentricity effects (CEN, 2004).

1.2.2 Plan-Distorted / Plan-Irregular Configurations

Plan-distorted configurations are defined by geometric asymmetry or discontinuities that disrupt uniform load paths. These distortions may arise from re-entrant corners, setbacks, diaphragm openings, or uneven distribution of vertical resisting elements. Structural irregularity modifies stiffness matrices and modal shapes, introducing coupled translational-torsional behaviour. The resulting dynamic interaction complicates force redistribution and increases sensitivity to ground motion characteristics (Tso and Wong, 1995).

1.2.3 Types of Plan Distortions

Common plan distortions include re-entrant corners (as in L-, T-, and U-shaped buildings), torsional eccentricity caused by non-coincident mass and stiffness centres, and diaphragm discontinuities such as large openings. Re-entrant corners generate stress concentration and diaphragm shear amplification at internal corners, whereas torsional eccentricity amplifies edge displacements. Discontinuous diaphragms interrupt force transfer mechanisms, affecting global lateral stiffness. Seismic provisions such as those in international standards categorize these configurations as plan irregularities requiring special design consideration (ASCE, 2016).

1.3 Problem Statement

1.3.1 Fragmented Knowledge Regarding Comparative Lateral Response

Although numerous studies have investigated plan irregularity, the literature remains fragmented across experimental, analytical, and numerical domains. Many investigations focus exclusively on specific irregular forms or particular analytical procedures, limiting comprehensive

comparison. Furthermore, variations in modelling assumptions, material properties, and ground motion selection hinder generalization of findings. As a result, a unified understanding of lateral response differentiation between uniform and distorted RC configurations remains incomplete.

1.3.2 Inconsistency in Evaluation Metrics Across Studies

Comparative assessment is further complicated by inconsistent response metrics. Some studies emphasize base shear and natural period variation, whereas others prioritize inter-storey drift, torsional amplification factors, or plastic hinge distribution. The absence of standardized quantitative indices for evaluating plan-induced irregularity limits objective cross-study synthesis. Additionally, nonlinear dynamic analyses often produce divergent outcomes depending on ground motion scaling procedures and damping assumptions (Shibata, 2010). This methodological diversity necessitates a structured synthesis.

2. REVIEW METHODOLOGY

2.1 Literature Search Protocol

2.1.1 Databases Consulted

The present review adopts a structured and replicable literature search strategy consistent with systematic review practices in engineering research. Major bibliographic databases were consulted to ensure comprehensive coverage of peer-reviewed publications. These included Scopus and Web of Science Core Collection, both recognized for indexing high-impact journals in structural and earthquake engineering. Supplementary searches were conducted through Google Scholar to capture early-view articles and conference proceedings that may not yet be indexed in primary databases. The use of multiple databases minimizes publication bias and enhances coverage across interdisciplinary domains (Kitchenham and Charters, 2007). Search strings combined keywords such as “plan irregularity,” “torsional response,” “reinforced concrete buildings,” “lateral load behaviour,” and “nonlinear dynamic analysis.”

2.1.2 Time Span Covered

The review primarily covers studies published between 1990 and 2025. The starting point aligns with the widespread adoption of performance-based seismic design principles and the advancement of nonlinear computational tools in the early 1990s. This period also corresponds with significant revisions in seismic design provisions worldwide. Emphasis was placed on literature published during the last fifteen years to capture developments in nonlinear time-history analysis, advanced finite element modelling, and performance-based evaluation approaches. Earlier

foundational studies were included selectively where they contributed substantially to theoretical understanding.

2.1.3 Inclusion and Exclusion Criteria

Inclusion criteria were established to maintain methodological consistency and relevance. Only peer-reviewed journal articles, authoritative technical reports, and recognized seismic code documents were considered. Studies were required to explicitly examine lateral response characteristics of reinforced concrete buildings with either geometrically uniform or plan-distorted configurations. Both linear and nonlinear analytical investigations were included, provided that response parameters such as drift, base shear, torsional amplification, or modal properties were reported.

Exclusion criteria eliminated studies focusing exclusively on vertical irregularities, material-level experimental investigations unrelated to global structural response, and research on structural systems other than reinforced concrete. Non-English publications and studies lacking sufficient methodological transparency were also excluded to maintain analytical reliability, following systematic review standards in engineering research (Snyder, 2019).

2.1.4 Screening and Selection Process

The screening process followed a multi-stage approach. Initially, titles and abstracts were reviewed to eliminate clearly irrelevant studies. Subsequently, full-text screening was conducted to assess methodological adequacy and alignment with the review objectives. Duplicate records were removed prior to evaluation. The final selection comprised studies that provided quantifiable comparative data or theoretical insight into lateral response differentiation. This structured filtering process enhances transparency and reproducibility, aligning with systematic synthesis practices commonly adopted in scientific reviews (Tranfield, Denyer and Smart, 2003).

2.2 Classification Framework

To facilitate coherent synthesis, selected studies were categorized based on methodological orientation and analytical depth. This classification enables structured comparison and identification of trends across research domains.

2.2.1 Experimental Investigations

Experimental studies include shake table tests, pseudo-static cyclic loading tests, and scaled model investigations examining torsional response and drift concentration in irregular RC configurations. These investigations provide empirical validation of analytical predictions and reveal realistic failure mechanisms such as edge column overstressing and diaphragm cracking. Experimental evidence is particularly valuable for understanding

nonlinear behaviour and damage progression under dynamic loading.

2.2.2 Numerical Simulations

Numerical investigations constitute a substantial portion of the literature, employing finite element modelling and structural analysis software to evaluate both linear and nonlinear responses. These studies typically incorporate response spectrum analysis, pushover analysis, and nonlinear time-history simulations to assess displacement demand, stiffness degradation, and torsional amplification. Numerical modelling allows parametric variation of irregularity severity, structural height, and ground motion characteristics, enabling systematic comparison between uniform and distorted configurations.

2.2.3 Analytical and Theoretical Developments

Analytical studies focus on mathematical modelling of torsional coupling, stiffness eccentricity, and modal interaction effects. These works develop simplified formulations or generalized dynamic equations to predict response amplification in asymmetric systems. Theoretical contributions are critical for understanding the mechanics underlying plan-induced irregularity and for deriving torsional irregularity indices used in design evaluation.

2.2.4 Code-Based Assessments

Code-based assessments examine how contemporary seismic design standards treat plan irregularity. These studies evaluate torsional amplification factors, accidental eccentricity provisions, and drift limitations prescribed in international guidelines. Comparative assessments of code requirements help identify potential inconsistencies between empirical evidence and regulatory frameworks, thereby informing improvements in performance-based design approaches.

3. THEORETICAL FRAMEWORK OF LATERAL RESPONSE IN RC BUILDINGS

3.1 Mechanics of Lateral Load Resistance

3.1.1 Stiffness, Strength, and Ductility Concepts

The lateral response of reinforced concrete (RC) buildings is governed by the interrelated parameters of stiffness, strength, and ductility. Lateral stiffness controls deformation demand under service-level loading and influences the natural period of vibration, thereby affecting spectral acceleration demand during earthquakes. Structural strength determines the maximum lateral force that the system can resist before yielding or failure. However, in seismic design, ductility—the capacity to undergo significant inelastic deformation without substantial loss of load-carrying capacity—is equally critical. Modern capacity

design principles prioritize ductile failure mechanisms, typically through strong-column-weak-beam hierarchies, to ensure energy dissipation through controlled plastic hinging (Paulay and Priestley, 1992). The balance between these three parameters defines the global performance level of RC structures under lateral excitation, as emphasized in structural dynamics formulations (Chopra, 2017).

3.1.2 Load Path and Force Redistribution

Under lateral loading, forces are transmitted through diaphragms to vertical resisting elements such as moment-resisting frames and shear walls. The efficiency of this load path depends on diaphragm rigidity, connectivity, and continuity of structural elements. In idealized regular systems, lateral forces are distributed proportionally to the stiffness of vertical elements, resulting in predictable deformation patterns. However, once yielding initiates, redistribution occurs as stiffness degrades in selected members, altering internal force equilibrium. This nonlinear redistribution is central to performance-based seismic assessment and is strongly influenced by redundancy and structural configuration (Moehle, 2014). In irregular configurations, discontinuities may interrupt uniform force transfer, intensifying localized demand.

3.2 Torsional Response and Eccentricity

3.2.1 Accidental vs Inherent Eccentricity

Torsional response arises when lateral forces do not act through the centre of rigidity of a building. Inherent (or structural) eccentricity results from asymmetrical distribution of mass or stiffness within the plan, causing torsional rotation even under symmetric ground motion. Accidental eccentricity, in contrast, accounts for uncertainties in mass distribution, construction tolerances, and modelling approximations. Seismic design codes typically incorporate an additional accidental eccentricity factor to ensure conservative torsional demand estimation (ASCE, 2016). The combined effect of inherent and accidental eccentricities can significantly amplify edge displacements and member forces, particularly in plan-distorted configurations.

3.2.2 Coupled Translational-Torsional Modes

In symmetric buildings, translational modes dominate and torsional components remain minimal. However, in asymmetric systems, lateral translation becomes coupled with rotation about the vertical axis, resulting in complex modal interactions. This coupling alters modal participation factors and can lead to concentration of deformation at building extremities. Analytical studies demonstrate that torsionally flexible systems experience amplified displacement demands when the torsional frequency approaches the fundamental translational frequency, creating resonance-like effects (Tso and Wong, 1995).

Nonlinear time-history analyses further reveal that such coupling intensifies damage localization during strong ground motion.

3.3 Influence of Plan Geometry

3.3.1 Uniform Symmetry and Modal Regularity

Geometrically uniform buildings, typically rectangular with symmetric stiffness and mass distribution, exhibit decoupled translational and torsional modes. This modal regularity results in more uniform inter-storey drift distribution and reduced torsional amplification. The dynamic characteristics of such systems are relatively predictable, facilitating simplified analytical modelling and reliable response spectrum analysis. Regularity in plan also promotes balanced energy dissipation across structural elements, reducing the likelihood of premature localized failure (Chandler and Duan, 1997).

3.3.2 Distortion-Induced Stiffness Irregularities

Plan distortion disrupts uniform stiffness distribution, producing stiffness gradients and localized rigidity concentrations. Re-entrant corners and asymmetrical shear wall placement generate differential lateral displacement patterns, which in turn induce additional torsional moments. The resulting stiffness irregularity modifies natural periods and alters higher-mode participation, particularly in mid- to high-rise buildings. Research indicates that such irregularities may significantly increase inter-storey drift and plastic hinge concentration in peripheral columns under seismic excitation (Shibata, 2010). Consequently, plan geometry becomes a primary determinant of lateral response differentiation between uniform and distorted RC configurations.

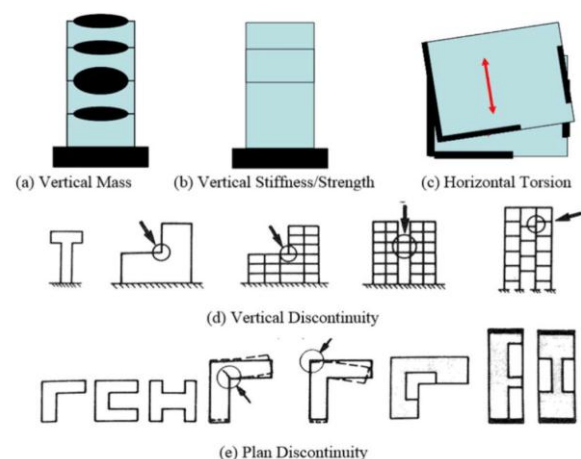


Figure-1: Types of Structural Irregularities

4. LITERATURE REVIEW

4.1 Early Investigations on Plan Irregularity

4.1.1 Foundational Studies Establishing Torsional Vulnerability

Systematic investigation into plan irregularity began with analytical studies examining torsional response in asymmetric structural systems. Early theoretical formulations demonstrated that eccentricity between the centre of mass and centre of rigidity produces coupled translational-rotational motion, leading to amplified edge displacements and non-uniform force demand. These pioneering works established that torsional flexibility significantly increases deformation demand when torsional and translational frequencies are closely spaced (Kan and Chopra, 1977). Subsequent analytical refinements confirmed that even moderate stiffness asymmetry can trigger substantial amplification under seismic excitation, particularly in systems with limited redundancy (De la Llera and Chopra, 1994). These foundational contributions provided the theoretical basis for later experimental and numerical research on torsional vulnerability.

revealed that asymmetric stiffness distribution modifies modal participation and accelerates damage progression in peripheral columns (Tso and Zhu, 1992). Pseudo-static cyclic loading experiments further clarified inelastic behaviour under torsionally coupled deformation, highlighting degradation in stiffness and strength with repeated displacement cycles (Fajfar, 2000). Experimental evidence consistently indicates that irregular configurations experience earlier onset of localized cracking and reinforcement yielding compared to symmetric counterparts.

4.2.2 Observed Drift Concentration and Failure Mechanisms

Observed failure mechanisms in plan-distorted specimens frequently involve concentration of inter-storey drift at re-entrant corners and building extremities. Diaphragm stress concentration and shear transfer irregularities intensify local demand, promoting premature hinge formation in edge columns. Laboratory investigations have also documented out-of-plane torsional rotation leading to differential axial force accumulation in vertical elements. These behavioural patterns confirm that irregular geometry fundamentally alters the internal force redistribution mechanism during strong ground motion (Penelis and Kappos, 1997).

4.3 Numerical and Analytical Studies

4.3.1 Linear Static and Response Spectrum Analyses

Linear static and response spectrum analyses constitute the earliest numerical approaches used to quantify torsional amplification. Such methods evaluate elastic response characteristics and provide preliminary assessment of displacement and base shear demand. Parametric studies using response spectrum procedures have shown that torsional irregularity indices increase with eccentricity ratio and stiffness asymmetry (Goel and Chopra, 1993). Although computationally efficient, linear analyses often underestimate displacement demand in highly irregular systems due to neglect of nonlinear redistribution effects.

4.3.2 Nonlinear Static (Pushover) Analyses

Nonlinear static or pushover analysis gained prominence as a practical tool for evaluating inelastic behaviour in irregular buildings. Through incremental lateral loading, pushover analysis reveals plastic hinge formation sequences and global capacity curves. Studies applying pushover procedures to L- and U-shaped RC buildings report uneven hinge distribution and reduced displacement capacity compared to regular plans (Kappos and Penelis, 2000). However, limitations arise from the inability of conventional pushover methods to capture higher-mode torsional effects accurately.

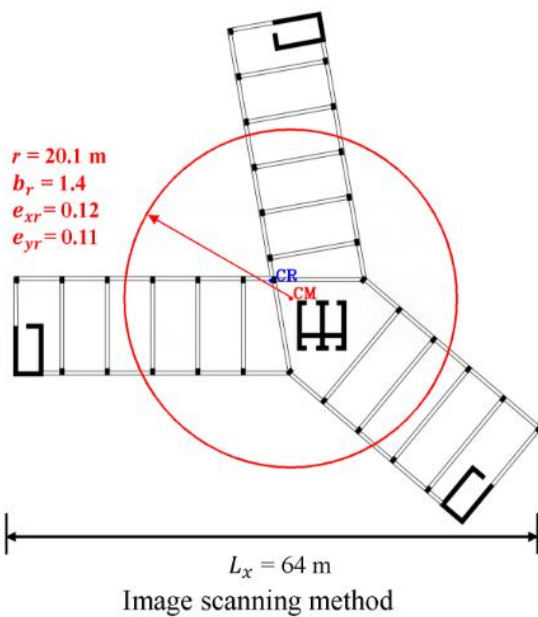


Figure-2: Torsional Drift

4.2 Experimental Studies

4.2.1 Shake Table and Pseudo-Static Tests

Experimental research has played a critical role in validating analytical predictions regarding torsional behaviour. Shake table tests on scaled RC building models with asymmetric layouts have demonstrated pronounced torsional rotation and drift concentration at flexible edges. Such studies

6.3.3 Nonlinear Time History Analyses

Nonlinear time history analysis provides the most comprehensive framework for evaluating dynamic response under realistic ground motion records. Advanced finite element modelling has demonstrated that plan-distorted buildings exhibit amplified torsional rotation, irregular drift patterns, and asymmetric damage concentration under bidirectional excitation (Rutenberg and Tso, 2006). Time history studies consistently show that nonlinear interaction between translation and torsion intensifies under near-fault ground motions, significantly influencing plastic hinge development and residual displacement.

4.4 Comparative Studies: Uniform vs Plan-Distorted Configurations

4.4.1 Direct Performance Comparisons

Comparative investigations explicitly evaluating symmetric and asymmetric RC buildings provide valuable insight into lateral response differentiation. Studies employing identical structural parameters except for plan geometry reveal that plan distortion primarily affects drift demand and torsional response rather than overall strength capacity (Chopra and Goel, 1991). Symmetric buildings generally exhibit uniform drift profiles, whereas distorted plans experience localized deformation concentration, particularly under nonlinear loading.

4.4.2 Quantitative Indicators of Response Differentiation

Researchers have proposed quantitative metrics such as torsional irregularity ratio, edge displacement amplification factor, and drift concentration index to characterize performance divergence. Analytical comparisons demonstrate that torsional irregularity ratios increase nonlinearly with eccentricity magnitude, indicating sensitivity of dynamic response to geometric asymmetry (De Stefano and Pintucchi, 2008). These indices facilitate objective comparison across studies and provide measurable criteria for evaluating design adequacy.

4.4.3 Sensitivity to Height, Aspect Ratio, and Structural System

Building height and aspect ratio significantly influence torsional response characteristics. Mid- to high-rise buildings exhibit increased higher-mode participation, which may amplify torsional-translation interaction. Parametric analyses indicate that irregularity effects intensify with increased slenderness ratio and reduced torsional stiffness (Valmundsson and Nau, 1997). Additionally, the type of lateral force-resisting system modulates the severity of response differentiation.

4.5 Influence of Structural System

4.5.1 Moment-Resisting Frames

Moment-resisting frames (MRFs) rely primarily on flexural action for lateral resistance. In asymmetric MRF systems, limited torsional stiffness may exacerbate rotational demand, leading to pronounced drift amplification at perimeter columns. Studies show that pure frame systems are particularly sensitive to stiffness eccentricity due to their comparatively lower torsional rigidity.

4.5.2 Shear Wall Systems

Shear wall systems enhance lateral stiffness and reduce overall drift; however, asymmetrical wall placement may intensify torsional effects. Analytical evaluations reveal that uneven distribution of walls can shift the centre of rigidity significantly, increasing rotational demand despite higher global stiffness (Moehle, 2014).

4.5.3 Dual Systems

Dual systems combining moment frames and shear walls generally provide improved redundancy and energy dissipation capacity. Comparative assessments suggest that dual systems mitigate torsional amplification more effectively than pure frame systems, though irregular wall placement can still generate stiffness imbalance. The interaction between frame flexibility and wall stiffness governs global response characteristics.

4.6 Code Provisions and Design Implications

4.6.1 Treatment of Plan Irregularity in Seismic Design Codes

Modern seismic design codes incorporate specific provisions to address plan irregularity, including torsional amplification factors, accidental eccentricity requirements, and drift limits. For example, international standards prescribe amplification of design forces when torsional irregularity thresholds are exceeded. These provisions aim to compensate for uncertainties in modelling and construction tolerances (CEN, 2004).

4.6.2 Limitations and Inconsistencies

Despite these measures, inconsistencies remain between empirical findings and code formulations. Code-based torsional amplification factors are often derived from elastic analyses and may not fully capture nonlinear interaction effects observed in experimental and time-history studies. Furthermore, threshold-based classification of irregularity may oversimplify the continuum nature of geometric distortion (De Stefano and Pintucchi, 2008). These limitations underscore the need for refined performance-

based evaluation frameworks that integrate deformation-based metrics with torsional response indicators.

5. SYNTHESIS AND CRITICAL DISCUSSION

5.1 Emerging Trends

5.1.1 Consistent Patterns Across Methodologies

A synthesis of experimental, analytical, and numerical investigations reveals several consistent behavioural trends distinguishing geometrically uniform and plan-distorted RC configurations. Across methodologies, plan irregularity is repeatedly associated with amplified torsional response, uneven inter-storey drift distribution, and localized concentration of inelastic demand. Linear elastic analyses identify stiffness eccentricity as the primary driver of torsional coupling, whereas nonlinear procedures confirm that such coupling intensifies under inelastic deformation. Comprehensive reviews of irregular structures have demonstrated that deformation-based response parameters—particularly drift demand—are more sensitive to plan distortion than global force measures such as base shear (De Stefano and Pintucchi, 2008). Moreover, time-history simulations consistently indicate that response amplification becomes more pronounced under bidirectional ground motion excitation, highlighting the multidirectional sensitivity of asymmetric systems.

5.1.2 Dominant Failure Mechanisms in Distorted Plans

Distorted RC buildings exhibit characteristic failure patterns that differ from those observed in regular configurations. The most frequently reported mechanism involves plastic hinge concentration in perimeter columns located at flexible edges, often coupled with torsional rotation of floor diaphragms. Re-entrant corners tend to develop stress concentration zones, promoting early cracking and shear distress. In systems with asymmetric shear wall distribution, uneven axial force demand can accelerate compression failure in boundary elements. Experimental and nonlinear analytical studies confirm that these mechanisms are primarily deformation-driven rather than strength-controlled, emphasizing the vulnerability of distortion-induced stiffness gradients (Penelis and Kappos, 1997). Consequently, distorted plans display reduced deformation capacity and increased damage localization compared to symmetric counterparts.

5.2 Contradictions and Variability

5.2.1 Divergent Findings in Literature

Despite broad agreement on torsional amplification effects, the magnitude of response differentiation reported in the literature varies considerably. Some studies suggest that moderate eccentricity produces limited impact on global performance when torsional stiffness is sufficiently high,

whereas others report significant drift amplification even under small asymmetry ratios. Comparative pushover investigations have occasionally indicated minimal difference in base shear capacity between uniform and distorted plans, contradicting findings from nonlinear dynamic analyses that reveal substantial displacement amplification (Fajfar, 2000). These divergences stem from differences in evaluation criteria, ground motion selection, and structural modelling strategies.

5.2.2 Influence of Modelling Assumptions

Variability in modelling assumptions significantly influences reported outcomes. Key parameters include diaphragm rigidity representation, damping modelling, plastic hinge assignment, and ground motion scaling techniques. For instance, assuming rigid diaphragms may overestimate torsional demand in certain configurations, whereas flexible diaphragm modelling may redistribute forces differently. Additionally, higher-mode effects and bidirectional excitation are often neglected in simplified analyses, potentially underpredicting torsional-translational interaction (Chopra, 2017). Material nonlinearity models and confinement assumptions further contribute to discrepancies in predicted hinge formation patterns. Therefore, interpretation of comparative findings requires careful consideration of analytical framework and boundary conditions.

5.3 Quantitative Indicators of Lateral Response Differentiation

5.3.1 Drift Ratio Amplification

Inter-storey drift ratio remains the most widely adopted deformation-based performance indicator for evaluating lateral response differentiation. Synthesized results indicate that plan-distorted buildings frequently exhibit amplified drift at flexible edges, often exceeding average storey drift by significant margins. Drift concentration factors have been proposed to quantify this amplification, demonstrating nonlinear correlation with stiffness eccentricity magnitude. Elevated drift ratios are directly associated with increased damage probability and reduced serviceability performance, particularly in mid-rise asymmetric structures (De la Llera and Chopra, 1994).

5.3.2 Torsional Irregularity Indices

Torsional irregularity indices provide quantitative measures of rotational amplification relative to translational displacement. Common metrics include the ratio of maximum edge displacement to average storey displacement and normalized eccentricity parameters. Parametric analyses reveal that torsional irregularity ratios increase disproportionately with eccentricity when torsional stiffness is low, indicating heightened sensitivity in flexible systems (Tso and Wong, 1995). These indices facilitate objective

cross-study comparison and support performance-based classification of irregular configurations.

5.3.3 Period Elongation Trends

Plan distortion also influences dynamic characteristics through modification of effective stiffness and modal coupling. Nonlinear response often produces period elongation due to stiffness degradation, which may differ between symmetric and asymmetric systems. In distorted configurations, coupling effects can alter higher-mode participation and shift effective modal periods under inelastic response conditions. Observed period elongation trends suggest that reliance solely on initial elastic periods may underestimate displacement demand in asymmetric RC buildings (Rutenberg and Tso, 2006). This observation reinforces the importance of nonlinear dynamic evaluation when assessing plan-induced irregularity effects.

6. CONCLUSION

This review synthesizes three decades of analytical, experimental, and numerical research examining lateral response differentiation between geometrically uniform and plan-distorted reinforced concrete (RC) building configurations. The collective evidence consistently demonstrates that plan distortion primarily influences deformation-based performance indicators rather than global strength parameters. While overall base shear capacity may not vary substantially between symmetric and asymmetric layouts, inter-storey drift amplification, torsional rotation, and localized plastic hinge concentration are markedly more pronounced in distorted configurations. Coupled translational-torsional modes, stiffness eccentricity, and diaphragm discontinuities emerge as the principal drivers of response amplification. Nonlinear time-history analyses reveal that these effects intensify under bidirectional and near-fault ground motions, underscoring the limitations of purely elastic or simplified static procedures.

Comparative studies further indicate that response differentiation is sensitive to building height, aspect ratio, and structural system type. Moment-resisting frames exhibit higher torsional flexibility, whereas dual systems provide improved redistribution capacity, though irregular wall placement may still induce stiffness imbalance. Despite codified torsional amplification provisions, discrepancies remain between regulatory simplifications and observed nonlinear behaviour. The synthesis highlights the need for deformation-based evaluation metrics, unified torsional irregularity indices, and performance-based assessment frameworks that explicitly account for plan-induced asymmetry. Overall, the findings reinforce that geometric regularity enhances predictability and seismic robustness, whereas plan distortion necessitates refined analytical scrutiny to ensure reliable performance under extreme lateral loading.

7. LIMITATIONS OF THE REVIEW

This review is limited to peer-reviewed English-language publications and selected international code documents, which may exclude region-specific research contributions. Variability in modelling assumptions, ground motion selection, and performance metrics across studies constrains direct quantitative comparison. Additionally, the synthesis relies primarily on published analytical and numerical investigations, as full-scale experimental data on irregular RC buildings remain limited. Finally, emerging topics such as soil-structure interaction and advanced material systems were beyond the defined scope of this review.

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