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Seismic Analysis of R.C. Structure with Re-Entrant Corners and Bracing – A Critical Review

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ABSTRACT
This review paper critically examines the seismic analysis of reinforced concrete (RC) structures with re-entrant corners and the effectiveness of bracing systems in mitigating seismic risks. Re-entrant corners, often present in modern architectural designs, introduce significant challenges due to the irregularities they cause in the structural configuration. These irregularities lead to uneven force distribution and stress concentration, making such structures more vulnerable to seismic events. The paper synthesizes findings from numerous studies that employed various analytical methods, including response spectrum analysis, time history analysis, and equivalent static lateral force methods, to evaluate the seismic behavior of RC structures with re-entrant corners. Key parameters analyzed include storey displacement, inter-storey drift, base shear, and torsional irregularity. The review highlights the effectiveness of different bracing configurations—diagonal, chevron, V, and X— in enhancing the seismic performance of these structures. It is noted that while bracing significantly reduces displacements and inter-storey drifts, the choice of bracing type affects other critical responses such as base shear and column axial forces. Among the configurations, X-bracing demonstrates superior control over displacements but increases base shear and column forces. Additionally, the paper points out the limitations of current seismic design codes in adequately addressing the complex behaviors induced by re-entrant corners. In conclusion, this review underscores the necessity for advanced seismic design approaches and code modifications to incorporate the unique demands of RC structures with re-entrant corners. Through improved design strategies and the strategic use of bracing, the resilience of such structures against seismic events can be significantly enhanced. This paper provides a comprehensive reference for engineers and researchers aiming to develop safer and more resilient RC buildings in seismically active regions.
Keywords - Seismic Performance, Re-entrant Corners, RC Structures, Bracing Systems, Structural Irregularities

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I. INTRODUCTION

The seismic performance of reinforced concrete (RC) structures with re-entrant corners and bracing systems is a critical area of study in structural engineering. Re-entrant corners, which create inward-facing angles in building plans, introduce significant complexities in the distribution of seismic forces and stress concentrations. These irregularities often lead to an increased vulnerability of the structure during seismic events. Bracing systems, commonly used to enhance structural integrity, play a crucial role in mitigating these adverse effects. However, the effectiveness of various bracing configurations in RC structures with re-entrant corners remains a subject of extensive research and debate. The objective of this review paper is to critically examine existing literature on the seismic analysis of RC structures featuring re-entrant corners, with a particular focus on the role of bracing systems. This review aims to synthesize findings from various studies to provide a comprehensive understanding of how these structural elements interact under seismic loads. Key parameters such as story displacement, inter-story drift, torsional irregularity, and base shear are evaluated to assess the performance and efficacy of different bracing configurations. By highlighting the challenges and potential solutions associated with re-entrant corners and bracing in RC structures, this paper seeks to contribute to the development of more resilient building designs. The review also identifies gaps in current research and suggests areas for future investigation, aiming to inform and guide engineers and researchers in the field. Ultimately, this paper underscores the importance of considering plan irregularities and appropriate bracing strategies to ensure the seismic safety and durability of modern RC buildings.

II. LITERATURE REVIEW

A study is conducted to determine the most effective bracing configuration for concentrically steel-braced framed buildings with re-entrant corners. Six different building plans with re-entrant corner irregularities were considered and designed with diagonal, chevron, X, and V bracing configurations, resulting in 24 models for analysis. The research provides insights into the effectiveness of different bracing configurations in controlling various aspects of seismic response, such as story displacements, inter-story drift, translational and rotational accelerations, column axial forces, base shear, and torsional irregularity ratios. The X bracing configuration was found effective in controlling story displacements and inter-story drift, while the V bracing configuration was effective in controlling translational and rotational accelerations. However, models with X bracing had the highest base shear and column axial forces. The research contributes valuable insights into the seismic response of structures with different bracing configurations, providing a basis for optimizing building design to enhance structural performance under seismic loads [1].

A study investigates the seismic vulnerability of a nine-story reinforced concrete dual system building in Bucharest, focusing on plan irregularity. It discusses the effects of stiffness, mass, and strength eccentricity on seismic response, along with parameters like eccentricity, torsional radius, and radius of gyration. Previous research on torsional irregularity in buildings is reviewed, and the criteria for plan irregularity according to Eurocode 8, ASCE 7-16, and P100-12013 codes are applied and discussed. The study conducts detailed nonlinear static and dynamic analyses on the building model, assessing parameters like inter-story drifts, roof displacements, base shear force, and seismic vulnerability index (SVI). The seismic vulnerability index (SVI) values indicate the building's response ranges from 'Negligible to light damage' to 'Light for structural elements, and moderate for non-structural elements' under prescribed seismic loads. THA and pushover analyses show similar global performance levels based on SVI values, with slightly higher values in pushover analysis compared to THA. SVI values in the Y direction are greater than in the X direction for THA, possibly due to smaller torsional effects in the X direction [2].

Research focuses on analyzing the effect of the position of steel bracing in L-shaped reinforced concrete buildings under lateral loading is been conducted. The study utilizes ETABs software to model L-shaped buildings with different braced configurations, observing seismic parameters like fundamental time periods, base shear, inter-story drifts, and torsional irregularity to understand the impact of inverted V bracings. A total of 12 models are considered, categorized into two cases (case I and case II), to comprehend the influence of steel bracings in irregularly shaped RC buildings. The lateral base shear value increases in L-shaped buildings when steel bracing is used, especially in Case II with an increase in the number of braced bays in both directions. The fundamental time period of structures decreases when steel bracing is employed in L-shaped buildings, indicating effectiveness. Steel bracings reduce maximum displacements in buildings, with Case II models showing a significant reduction compared to L1 model. Properly applied symmetric bracings reduce maximum displacements with minimal torsional effects. Steel bracings increase story stiffness and overall stiffness of buildings, especially when more bays are braced. Torsional irregularity ratios are crucial, with Case II showing better seismic behavior compared to Case I. Steel bracings affect column forces, with varying impacts on axial forces, moment, and capacity ratio in different columns [3]. A study focuses on the seismic response of a 10-storey Reinforced Concrete (RC) Moment Resisting Frame building with vertical irregularities in mass variation is conducted which compares the seismic response of irregular buildings with regular ones, highlighting the impact of irregularities due to aesthetic and functional needs in urban infrastructure. The study evaluates various seismic parameters like displacement, storey drift, inter-storey drift, and storey shear to understand the structural behavior under seismic loading conditions.

The research employs twenty-three earthquake ground motions to compare the seismic response of the irregular RC building with mass irregularities to a regular configuration, providing insights into the structural performance under seismic events. The governing case identified in the study is MM (1-5)2, while the minimum seismic response is observed in the MM(1-5)0.25 case, indicating varying structural behavior based on different mass ratios. Inelastic analysis shows that the maximum storey drift remains within codal prescribed limits, ensuring structural safety under seismic loading conditions. The study notes that different mass ratios considered in the analysis yield similar results compared to the base case model, highlighting the robustness of the structural response to seismic forces. Maximum storey shear from inelastic analysis aligns closely with the results obtained from linear dynamic analysis, showcasing consistency in the evaluation of structural performance under seismic events [4].

The study focuses on assessing the seismic behavior of buildings with re-entrant corners, which are prone to seismic vulnerability due to plan irregularities It investigates the impact of varying the Aspect Ratio to Length Ratio (A/L ratio) on the seismic response demands of L-shaped floor plan buildings with re-entrant corners. The research explores the effectiveness of different shear wall positions (center, periphery, or without shear wall) in mitigating seismic demands for structures with varying A/L ratios. The study provides insights into the optimal and economical placement of shear walls in buildings with re-entrant corners to enhance seismic resistance based on the A/L ratio of the structure. The study found that for structures without a shear wall, the most efficient position for the shear wall is at the periphery in models 4 and 5, while models 1, 2, and 3 performed well without a shear wall due to economic considerations. Maximum story drift for structures with shear walls was observed in model 4 in both X and Y directions, indicating that this model showed the highest displacement overall. Economic factors influenced the decision to place shear walls at the periphery rather than the center, as the former provided more efficiency while utilizing space effectively. The study highlighted the importance of considering modal participation ratios and various seismic parameters to determine the optimal placement of shear walls in buildings with re-entrant corners and varying A/L ratios [5].

The research work aims to identify the type of bracing that minimizes storey displacement and enhances lateral stiffness in steel buildings. This contributes to understanding the structural behavior of steel buildings under static and lateral loading conditions. The project provides a methodology for analyzing the structural performance of RCC buildings under lateral loading, offering insights for optimal structural design. The focus of the project is on concentric bracings, specifically exploring four types of concentric bracings for their effectiveness. This analysis can serve as a foundational dataset for future studies on different bracing arrangements and types. The work opens avenues for further research by suggesting testing under dynamic loading, wind loads, and different analysis methods like Response Spectra and Time History Analysis. Steel bracings, particularly K-bracing, demonstrate good performance in terms of maximum support reactions and maintaining the weight of the structure within a 2 percent change limit. Bracings distribute lateral forces to beams and columns, reducing flexure and shear demands while transferring lateral loads through axial load mechanisms. The use of steel bracing does not significantly alter the total weight of existing buildings, showcasing its advantage in strengthening or retrofitting structures. Braced buildings exhibit reduced lateral displacement, storey drift, shear forces, bending moments, axial forces, and increased base shear compared to unbraced buildings. X-bracing, in particular, significantly decreases all seismic parameters compared to other types of bracing, indicating its effectiveness in reducing seismic effects on structures. Overall, the study concludes that braced buildings outperform unbraced buildings, with X-bracing being the most effective in reducing seismic parameters [6].

The paper presents a comparative Parametric Study of Performance-Based Seismic Design (PBSD) of Plan Irregular RC Frames in the Indian Scenario, highlighting the limitations of existing building codes. It addresses the inadequacy of current Indian seismic codes, which assume linear behavior and do not specify performance criteria for individual structural members, leading to plastic hinge formation beyond the collapse prevention state. The research compares the seismic performance of G+4 regular and five types of plan irregular RC frames, shedding light on the challenges faced in retrofitting existing structures for better earthquake performance. The study emphasizes the need for Performance-Based Seismic Design (PBSD) in plan irregular RC frames due to the limitations of current building codes, which do not consider the nonlinear behavior of structures during earthquakes. Retrofitting existing structures to improve their seismic performance under severe earthquakes has been found to be uneconomical, highlighting the importance of incorporating better design strategies from the initial stages of construction. The research underscores the significance of conducting comparative studies to assess the seismic performance of different types of RC frames, providing valuable insights for enhancing seismic design practices and retrofitting strategies in earthquake-prone regions like India [7].

The study evaluates the response of reinforced concrete moment-resisting frame (SMRF) buildings using ETABS v.15 software, considering the effect of re-entrant corners as plan irregularities with varying percentages (0, 10, 15, 25, and 35) and different numbers of stories ranging from four to thirty-two stories incrementally. The research investigates the effects of seismic design categories (SDCs) B, C, D, and E, along with different seismic analysis procedures like Equivalent Lateral Force (ELF), Response Spectrum (RS), and Response Time History (TH) methods. The paper presents detailed data on horizontal displacement, drift ratio, and column shear force responses obtained through ELF, RS, and TH methods for buildings with different re-entrant corner percentages and heights, showcasing the differences in shear forces among columns based on the analysis method and building characteristics [8].

The study focuses on analyzing the seismic performance of plan irregular structures under earthquake forces, considering parameters such as displacement, base shear, storey drift, moment, and end forces.

The research compares beam end forces among different structures, highlighting the differences in beam end forces values and their distribution along the height of the structures.

The paper also examines the relationship between storey height and displacement, showcasing the variation in displacement along the height of buildings with plan irregularities.

Additionally, the study evaluates the moment capacity of different structures at various heights, emphasizing the importance of moment distribution for seismic resistance.The data used includes results obtained from Time History Analysis conducted using STAAD.PRO V8i software to assess the seismic behavior of the structures under consideration. The paper analyzes the relationship between storey height and displacement, showing that irregular structures like the 'L' shaped one exhibit the highest displacement at the top floors, while symmetric and 'O' shaped structures have the least displacement at the top stories.

It compares base shear values, indicating that the symmetric structure has the highest base shear, while the L-shaped structure shows the lowest base shear among the structures studied. Plan irregular structures often suffer severe damage during earthquakes, with irregularities impacting the seismic behavior significantly. Time history analysis is deemed more precise than response spectrum analysis for analyzing and designing earthquake-resistant structures. Regular structures may exhibit higher base shear and displacement values, but they ensure even load transfer throughout the structure, crucial for safety during earthquakes. Irregularities like re-entrant corners affect load paths, with L-shaped structures showing the least performance during earthquakes, especially impacting the top stories of high-rise buildings [9].

The study evaluates the seismic performance of L-shaped irregular buildings with moment-resisting frames. This data includes measurements of inter-storey drift, storey shear force, overturning moment, torsion-moment responses at the base and along the building height, top-floor displacement, and torsional irregularity coefficient. The research focuses on the effects of irregularities on seismic response demands. Data on stress concentration and coupled lateral-torsional behavior in irregular buildings is analyzed to understand their vulnerability to earthquake damage. The data used in the study helps in comparing the vulnerability of irregular buildings to those with a regular configuration. It highlights the challenges posed by configuration irregularities in seismic design and the need for constructive research to reduce potential damage in buildings with re-entrant corners and torsional irregularities. The presence of irregularities introduces challenges in seismic design, necessitating a deeper understanding of stress concentration and torsional effects to mitigate potential damage in building structures [10].

III. CONCLUSION

This review highlights the critical impact of re-entrant corners and bracing configurations on the seismic performance of reinforced concrete (RC) structures. Re-entrant corners introduce significant stress concentrations and irregular force distributions, increasing vulnerability during seismic events. The seismic analysis of reinforced concrete (RC) structures with re-entrant corners reveals that these structures face challenges due to irregularities, leading to uneven force distribution and stress concentration, making them more vulnerable to seismic events. Various analytical methods like response spectrum analysis, time history analysis, and equivalent static lateral force methods have been employed to evaluate the seismic behavior of RC structures with re-entrant corners, focusing on parameters such as storey displacement, inter-storey drift, base shear, and torsional irregularity.

Different bracing configurations (diagonal, chevron, V, and X) have been studied to enhance the seismic performance of structures with re-entrant corners. While bracing reduces displacements and inter-storey drifts, the choice of bracing type impacts other critical responses like base shear and column axial forces. X-bracing shows superior control over displacements but increases base shear and column forces. This review also emphasizes the limitations of current seismic design codes in addressing the complex behaviors induced by re-entrant corners, highlighting the need for advanced seismic design approaches and code modifications to enhance the resilience of RC structures in seismically active regions.

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