A REVIEW ON ASSESSING THE SEISMIC RESPONSE OF VARIOUS STRUCTURAL SYSTEMS IN RCC TALL BUILDINGS

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Abstract - *This study provides a comparative analysis of various structural systems, including Reinforced Concrete (RC) frames, shear walls, bracing systems, and outrigger systems, to assess their seismic performance as per IS 1893: 2016. The evaluation is conducted across seismic zones II, III, IV, and V to determine the efficiency of these systems in resisting earthquake-induced forces. Key parameters such as base shear, inter-story drift, and lateral displacement are analyzed using static and dynamic methods to assess the behavior of each structural system under different seismic intensities. The findings highlight the strengths and limitations of each system, offering critical insights to aid in selecting appropriate structural solutions for enhanced seismic safety and performance across varying zones.*

Key Words: Seismic performance, structural systems, RC frames, shear walls, bracing systems, lateral displacement, earthquake resistance.

1.INTRODUCTION

Seismic design has evolved significantly over time, driven by a deeper understanding of earthquake dynamics and the need for resilient structures. In India, traditional construction methods provided some resistance to seismic forces, but modern approaches have brought systematic improvements. Historical architecture, such as temples and forts, showcased durability through massive and solid designs, albeit without explicit seismic principles. Early construction relied on empirical methods until modernization highlighted the need for structured seismic design, leading to the adoption of global standards and localized strategies.

Major earthquakes have been pivotal in shaping India's seismic design practices. The 1934 Bihar-Nepal Earthquake (magnitude 8.0) underscored the need for robust engineering in vulnerable regions. The 1967 Shillong Earthquake (magnitude 6.7) emphasized seismic considerations in northeastern India. The devastating 2001 Gujarat Earthquake (magnitude 7.7) spurred a comprehensive overhaul of design codes, including stricter enforcement of regulations and updates to standards like IS 1893. These events have driven the evolution of seismic design, ensuring safer and more resilient structures across the country.

1.1 Structural Systems Overview.

Moment-Resisting Frames: Moment-Resisting Frames are structural systems that rely on rigid beam-column connections to resist lateral forces through bending, offering significant ductility to absorb seismic energy. They enable open floor plans, providing flexibility in architectural design. Classified into Ordinary, Intermediate, and Special Moment Frames based on ductility and seismic performance, they are widely used in earthquake-prone regions. However, these frames can be costly and complex to construct and may sustain damage during severe earthquakes. Modern advancements like seismic isolation and damping systems are increasingly integrated to enhance their resilience and efficiency.

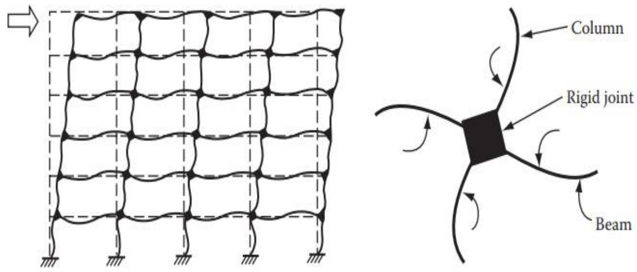

Fig -1: Moment Frame Structural System

Shear walls: Shear walls are vertical structural elements designed to resist lateral forces through shear and stiffness, commonly placed in building cores for stability. They are categorized into reinforced concrete, masonry, and composite shear walls. Renowned for their excellent lateral stability and efficiency in tall buildings, they offer a cost-effective solution when designed properly. However, shear walls can limit floor plan flexibility and demand precise construction techniques. Modern innovations emphasize the use of high-performance materials and advanced designs to enhance their strength and adaptability.

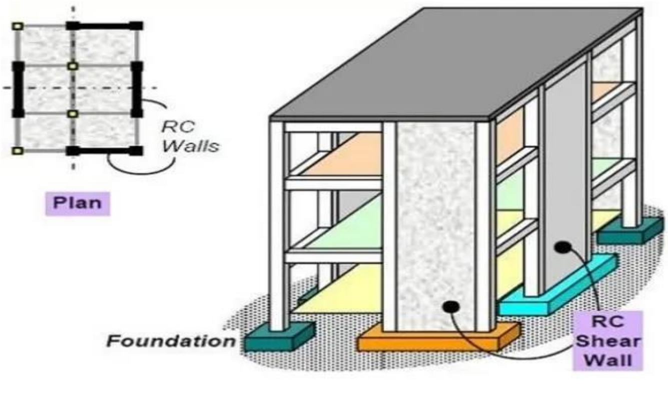

Fig -2: Shear Wall in Structural Engineering

Bracing: Bracing systems use diagonal elements to resist lateral forces by converting them into axial loads, providing enhanced stability and reducing building sway. Common types include X-Bracing, K-Bracing, Chevron Bracing, Eccentric Bracing, and Knee Bracing. These systems are cost-efficient and space-saving but may limit architectural flexibility and pose challenges in aesthetics and construction. Modern trends focus on incorporating smart sensors and hybrid designs with damping systems to optimize performance and resilience

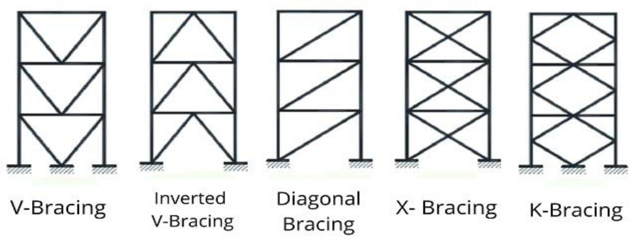

Fig -3: Shear Wall in Structural Engineering

Outrigger: Outrigger systems are structural solutions that connect a building's core to exterior columns using horizontal beams, significantly enhancing stability and reducing lateral sway from wind or seismic forces. By efficiently distributing loads, they enable taller, more resilient structures with reduced material usage, contributing to cost and resource efficiency. Configurations include single, multi-outriggers, outriggers with belt trusses, and hybrid designs, offering flexibility for various architectural and structural needs. However, they involve complex designs, high initial costs, and potential impacts on floor layouts and interior spaces. Modern advancements, such as smart monitoring systems, ultra-high-performance concrete (UHPC), and hybrid designs with damping systems, address these challenges effectively, optimizing performance and adaptability for modern high-rise structures.

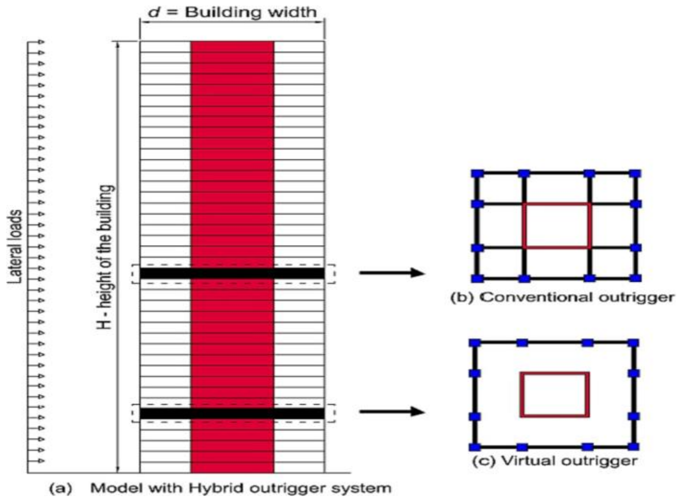

Fig -4: Shear Wall in Structural Engineering

2. LITERATURE REVIEW

Pramod Kumar Lodhi et al. (2024), the seismic performance of RCC buildings with and without X-bracing systems was analyzed using ETABS v2021. The analysis focused on various building models, including unbraced and X-braced structures located in seismic Zone III. The Response Spectrum Method (RSM) was applied to assess the structural behavior under seismic loads. The study compared key seismic parameters, such as maximum displacement, storey drift, time period, storey shear, and moment capacity. Results showed a significant reduction in displacement (up to 56.45%) and storey drift (up to 56.42%) in braced buildings compared to unbraced frames. The X-bracing system positioned at both the center and corners (Model-4) was found to be the most effective, reducing the time period by 32.44% and enhancing the moment and shear capacities. The study emphasizes the efficiency and economy of steel bracing systems in improving the earthquake resistance of RCC buildings in seismic zones, with Model-4 showing the best overall performance.

Mr. Mukesh R. Zambre et al. (2022) conducted a study on the effects of vertical alignment and bulk instability on multistorey structures subjected to variable loads, including seismic and wind loads. The research highlights the challenges in designing structures to withstand these high loads, particularly due to the flexibility in modern building designs. The authors selected three RC building frames for evaluation, using ETABS analysis to study migration patterns in a G+20 floor structure. The study examined both uniform height configurations and irregular configurations beginning from the 9th floor. The method of response spectrum analysis was employed to determine lateral loads and floor inspections due to earthquake impacts, supported by IS 1893 (Part 1): 2016 for dynamic analysis. The findings suggest limitations on upload combinations and recommend dynamic analysis for identifying critical load responses.

Dr. Vijaya G. S et al. (2021) examined the structural behavior of multi-storey buildings featuring coupled shear walls in seismic zones, using ETABS for analysis. They explored models with regular, mass reduction, and soft storey configurations across buildings with 30, 40, and 50 stories. The study revealed that axial forces increased with building height, rising by 30-35% every 10 stories. Soft storey and mass reduction models exhibited lower axial forces due to reduced stiffness, leading to potential cost savings in foundation work. V-bracing proved more effective than X-bracing in reducing bending moments and axial forces, while the regular model exhibited better lateral resistance due to increased stiffness. Shear walls contributed significantly to the overall load distribution, and V-bracing with coupled shear walls effectively minimized shear and axial forces, emphasizing the importance of selecting the right bracing system for optimal seismic performance.

Nilendu Chakrabortty et al. (2020) analyzed the seismic behavior of a G+3 reinforced concrete (RC) building across four seismic zones (II, III, IV, and V) in India using ETABS software. The study aimed to ensure that buildings could withstand minor earthquakes without significant damage and maintain stability during major seismic events. Findings showed that base shear was highest in Zone V, increasing by 72.2%, 55.56%, and 33.33% compared to Zones II, III, and IV. Floor displacement values were also greater in Zone V, with maximum displacements recorded at 39.79 mm, 30.77 mm, and 18.52 mm more than in Zones II, III, and IV. Additionally, steel quantity and support reactions were higher in Zone V, where the steel quantity required was 53.84%, 13.89%, and 8.31% greater than in Zones II, III, and IV, respectively. The study concluded that seismic forces in higher zones, particularly Zone V, demand increased structural reinforcement and lead to different structural behavior.

K.N. Jeevan Kumar et al. (2020) studied the seismic behavior of a G+15 storey RC building with various bracing systems using ETABS 18 software. The analysis involved seven structural systems, including an unbraced frame and six braced frames, to evaluate performance in terms of storey displacements, drift, natural time period, and base shear. The results showed that bracing systems effectively reduced storey displacement, storey drift, and natural time period. Among them, the Mega X-bracing system performed the best, reducing displacement by 52.93% in the X-direction and 49.41% in the Y-direction, and storey drift by 53.88% and 55.23% in the respective directions. Furthermore, Mega X-bracing increased seismic base shear compared to the unbraced building. The study concluded that the use of bracing systems significantly improves lateral load resistance, minimizing displacement and drift while enhancing structural stability.

P. Gwalani et al. (2020) investigated the seismic behavior and collapse vulnerability of reinforced concrete (RC) dual system buildings designed according to Indian standards, with an emphasis on the use of RC shear walls combined with moment-resisting frames for lateral load resistance. While Indian codes focus on capacity design for moment frames, they provide limited guidance on shear wall design. The study employed a fiber-hinge model and bi-directional incremental dynamic analyses (BIDA) with far-field ground motion records to assess the performance of these structures. The results suggested that the shear wall area should be at least 0.9% to 1% of the building's plan area in both directions to ensure adequate performance during maximum considered earthquake (MCE) conditions. Increasing the shear wall area was found to enhance the building's collapse capacity, with structures where shear walls contribute more than 70% of lateral resistance potentially not needing a strong column-weak beam configuration. A shear wall area ratio of 0.45% was considered insufficient for safety, while 0.9% to 1.35% was identified as optimal for ensuring robust seismic performance.

E. Dileep Kumar et al. (2019) conducted a comparative study on earthquake-resistant building design using bracing and shear wall systems, utilizing ETABS software for analysis. The study modeled a G+10 storey building and performed push-over analysis to compare the performance of general, steel-braced, and shear-wall buildings in a high seismic zone. Key findings included that both steel bracings and shear walls effectively reduce story drift, shear, and bending compared to general buildings. Shear walls were found to reduce torsion and increase stiffness, while steel bracings resulted in a larger reduction in shear in both X and Y directions. Additionally, the study revealed that building with shear walls had a higher torsion and reduced time period compared to bracing systems, but overall, the shear wall system was more advantageous in terms of stiffness and performance, with the shear wall buildings showing up to 75% less model stiffness than general buildings. In conclusion, both systems offer substantial improvements over general buildings, with shear walls providing superior stability and stiffness.

Abdul Halim Etemad et al. (2019) compared the structural efficiency of tubular, outrigger, and bracing systems for stabilizing high-rise buildings, using a 42-story concrete building model analyzed with ETABS 2016. The study found that the outrigger system with core shear walls and two outriggers at H/3 and 2H/3 from the top of the building provided the best performance in terms of time period, lateral deflection, and base shear, although it led to architectural disturbances. The steel bracing system, specifically the inverted V-bracing, exhibited minimal lateral drift but was more flexible, resulting in higher lateral deflections and reduced lateral stiffness compared to the outrigger system. The tubular system, while offering good space utilization due to its perimeter columns, had higher base shear than the outrigger system, but it remained within an acceptable range. The outrigger system, despite causing some architectural challenges, was found to be more effective in reducing base shear by 43.17% compared to the tubular system, making it the superior option for lateral stiffness and structural performance.

Harshitha M.K. et al. (2018) conducted a study on the seismic performance of reinforced concrete (RC) framed structures incorporating structural steel braces using ETABS software. The research aimed to evaluate the effectiveness of various bracing systems in improving the seismic behavior of RC buildings. A G+10 building located in seismic zone IV was analyzed with 16 different models, including a bare frame configuration. The study assessed key parameters such as lateral displacement, base shear, and time period. The results indicated that the introduction of bracing significantly improved the seismic performance of the structure. Among the various bracing systems, inverted V-braces and X-braces showed the most effective reduction in lateral displacement, offering better resistance to storey displacement. Additionally, while the incorporation of braces increased the base shear, the X-braced frame exhibited the smallest increase. The analysis also revealed a decrease in the structure's time period due to the increased stiffness provided by the braces, highlighting the critical role of steel bracing in enhancing the seismic resilience of RC framed buildings.

Dharanya et al. (2017) conducted a comparison study on the seismic performance of shear walls and cross bracings in a multi-storey residential building under seismic loading. The study focused on a G+4 storey residential reinforced concrete (RC) building with a soft storey, analyzed using ETABS software as per the IS 1893:2002 code provisions. The building was modelled with X-bracing at the outer periphery of the columns and shear walls at the corners. Key parameters such as lateral displacement, base shear, storey drift, axial force, shear force, and time period were compared. The results revealed that the incorporation of shear walls significantly increased the base shear, improving the structure's stability against seismic forces. The structure's natural time period was notably reduced with the addition of shear walls, enhancing its seismic resistance compared to the bracing system. Furthermore, the structure with shear walls exhibited the least lateral displacement, demonstrating superior lateral stability compared to the braced and bare frame configurations. The study concluded that shear walls are more effective in improving the lateral stability of a structure than bracing systems under seismic loading.

Narla Mohan et al. (2017) conducted an analysis of a G+20 reinforced concrete building subjected to earthquake loads in different seismic zones using ETABS software. The study focused on understanding the building's response to lateral loads induced by seismic forces, specifically addressing the effects of base shear, displacement, storey drift, and torsion. The results revealed that as the seismic zone increases, the base shear, displacement, storey shear, and torsional effects also increase. For example, base shear increased by more than 350% when moving from Zone II to Zone V. Similarly, displacement and storey drift values were higher in higher seismic zones and increased with wind pressure. Torsion effects were most pronounced at the base of the building, showing a significant rise as both seismic and wind loads increased. The study highlighted that structural performance, in terms of lateral stability, shear, and drift, was greatly influenced by the seismic zone and wind pressure, emphasizing the importance of these factors in the design and analysis of earthquake-resistant structures.

S. Monish et al. (2015) focused on the effects of two types of plan irregularities—diaphragm discontinuities and re-entrant corners—on the seismic response of frame structures. Models incorporating these irregularities were developed according to Clause 7.1 of IS 1893:2002 (Part 1) and analyzed using static and dynamic methods in ETABS. Key parameters, such as base shear, displacement, and natural period, were evaluated to identify the most vulnerable models under severe seismic loading. The research underscored the increased failure risk associated with certain irregularities in earthquake-prone areas.

Abdul Karim Mulla et al. (2015) studied the impact of outrigger systems on the seismic performance of tall RC structures, comparing regular and irregular buildings with and without outriggers, incorporating centrally rigid shear walls and steel bracings. Using ETABS, equivalent static and response spectrum methods were applied to analyze lateral displacement, drift, base shear, and natural periods. Results showed that outriggers significantly improved stiffness and reduced base shear, with concrete outriggers outperforming steel outriggers (X-bracing) in minimizing displacement. Mid-floor outriggers were more effective than top-floor placement, and irregular buildings with vertical irregularities demonstrated better performance due to reduced self-weight. Outriggers also reduced inter-storey drift, enhanced load-resisting capacity, and decreased natural periods, making them effective in high-seismicity zones.

P.M.B. Raj Kiran Nanduri et al (2013) investigated the efficiency and optimal placement of outrigger and belt truss systems in 30-storey high-rise RCC buildings subjected to wind and earthquake loads. Nine 3D models were analyzed to evaluate lateral displacement reduction with varying outrigger configurations. Results showed that incorporating an outrigger system significantly increases structural stiffness and minimizes lateral displacement. A 23% displacement reduction was achieved by placing the first outrigger at the top and the second at mid-height, demonstrating optimal performance. The study concluded that the ideal outrigger placement is at 0.5 times the building height, with additional benefits observed when using a second outrigger with or without a belt truss.

Kiran Kamath et al. (2012) conducted an investigation to study the static and dynamic behavior of outrigger structural systems in reinforced concrete buildings using ETABS software. The study examined different 3D models with and without outriggers, varying the relative flexural rigidity from 0.25 to 2.0 and the relative height of the outrigger from 0.975 to 0.4. The analysis focused on parameters such as bending moments, shear force, lateral deflection, peak acceleration, and inter-storey drifts for both static and dynamic conditions. The results indicated that the performance of the outrigger system was most efficient when placed at mid-height (relative height of 0.5). The study concluded that the outrigger system significantly improves the building's stiffness and lateral load resistance. While placing the outrigger at the top reduced the effectiveness compared to the mid-height position, it still resulted in up to a 50% reduction in drift. For peak acceleration design, placing the outrigger at the top reduced it by up to 30%. Additionally, the introduction of outriggers substantially reduced forces in the core, especially bending moments, and also helped in controlling top displacements and inter-storey drifts.

3. SUMMARY OF LITERATURE REVIEW

The literature review concluded as part of study reveals The seismic performance of structures has been extensively analyzed using advanced modelling tools, focusing on bracing systems, shear walls, outriggers, and their combinations to improve earthquake resilience. Key findings include:

1. **Bracing Systems:**
    - X-bracing, V-bracing, and Mega X-bracing improve seismic stability by reducing storey displacement and drift.
    - Mega X-bracing is particularly effective, reducing displacement and storey drift by significant amounts.
2. **Shear Walls:**
    - Shear walls improve lateral stability, reduce torsion, and increase stiffness.
    - They are often more effective than bracing systems in enhancing seismic performance, particularly in reducing lateral displacement.
3. **Outrigger Systems:**
    - Outriggers placed at mid-height increase structural stiffness, reduce base shear, and minimize displacement.
    - Optimal placement of outriggers provides the best performance for high-rise buildings in seismic zones.
4. **Seismic Zone Impact:**
    - Buildings in higher seismic zones (Zone V) require more reinforcement and exhibit higher displacement and base shear compared to buildings in lower zones (Zones II-IV).
    - Higher seismic zones demand stronger structural systems to handle the increased seismic forces.
5. **Impact of Design Irregularities:**
    - Buildings with diaphragm discontinuities or re-entrant corners are more vulnerable to seismic forces.
    - Irregularities increase failure risks, especially in earthquake-prone areas.

4. GAPS IN LITERATURE REVIEW

After extensive review of numerous review papers, several significant gaps have been identified;

1. **Research on Various Structural Systems Remains Limited**:
    - While there is substantial research on common structural systems like bracing and shear walls, there is a lack of extensive studies comparing a wider range of structural systems, particularly in the context of complex or high-rise buildings. More in-depth research is needed on advanced or hybrid systems that could potentially offer superior seismic performance. This could include innovative bracing configurations, advanced materials, or emerging technologies that are not yet widely studied.
2. **Study Across Various Seismic Zones Needs to Be Done**:
    - Many studies focus on seismic behavior in specific zones, but the effects of different seismic zones (ranging from low to high seismic activity) on various structural systems are not thoroughly explored. A comprehensive study across all seismic zones would provide valuable insights into how different building types, structural systems, and materials perform in regions with varying earthquake risk. This would lead to more tailored and region-specific seismic design guidelines, improving overall building safety.
3. **Limited Analysis Addressing Vertical Irregularities in Structures**:
    - While lateral irregularities are well-documented in seismic studies, vertical irregularities (e.g., varying story heights, soft storeys, or large mass differences between floors) are often underrepresented in the analysis. These vertical irregularities can significantly impact the distribution of seismic forces and lead to unexpected structural behavior, such as increased torsion or disproportionate settlement. More research is needed to understand how vertical irregularities affect the dynamic response of buildings under earthquake loading and to develop design strategies that mitigate these effects.

4. **Limited Studies Conducted Using Architectural Plans**:

   - Much of the existing seismic research is focused on simplified or idealized building models, which may not fully reflect the complexities found in real-world architectural designs. There is a gap in studies that integrate actual architectural plans, which include intricate details such as openings, irregular layouts, and non-structural elements. Understanding how these architectural features interact with structural systems during seismic events is crucial to improving the accuracy of seismic analysis and ensuring more reliable earthquake-resistant designs.

5. **Economic Feasibility is Not Done**:

   - Many seismic studies focus on the technical performance of various systems but do not evaluate the economic feasibility of implementing these systems on a large scale. Cost analysis, including construction, maintenance, and operational expenses, is essential to determine the practicality of advanced seismic solutions for different building types and regions. Without considering the economic implications, it is difficult to ensure that the most effective seismic strategies are also financially viable, particularly for large-scale or public infrastructure projects.

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