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Evaluation of Shear Walls and Bracings in Irregular Buildings Under Seismic Load

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Abstract

The structural integrity and stability of irregular buildings under lateral forces such as wind and seismic loads pose significant challenges in modern construction practices. Irregularities in a building's geometry and mass distribution can lead to uneven force distribution, making the structure more vulnerable to lateral displacement and potential failure. To enhance the resilience of such structures, shear walls and bracing systems are commonly employed to improve lateral load resistance. This study conducts a comparative analysis of shear walls and different types of bracing systems, focusing on their effectiveness in minimizing lateral displacement, reducing base shear, and enhancing overall structural stiffness. Using numerical modeling and finite element analysis, the research evaluates various configurations and placements of shear walls and bracings in irregular buildings. The study aims to identify the most efficient structural system for optimizing building performance under different wind and seismic loading conditions. The results provide valuable insights into the behavior of irregular buildings with shear walls and bracings, helping engineers and architects select the most suitable structural design to ensure safety, stability, and cost-effectiveness. The findings can contribute to the development of improved construction guidelines and design standards for irregular high-rise and mid-rise buildings in earthquake-prone and high-wind regions.

Keywords: Shear wall, bracing system, irregular buildings, wind load, seismic load, structural stability, lateral load resistance, base shear, structural stiffness, numerical modeling, earthquake-resistant design, high-rise buildings, structural optimization

INTRODUCTION

In recent years, the demand for high-rise and irregular buildings has increased due to urbanization, aesthetic preferences, and functional requirements. However, such structures are highly susceptible to lateral forces induced by wind and seismic activities. The presence of geometric and structural irregularities, such as mass asymmetry, plan irregularity, and vertical irregularity, leads to non-uniform force distribution, which affects the stability and performance of the building. To mitigate these effects, structural elements like shear walls and bracing systems are incorporated into building designs to enhance lateral load resistance and improve overall structural stability.

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Need for Lateral Load-Resisting Systems

Buildings subjected to lateral loads experience forces that can cause excessive deformation, base shear, torsional effects, and, in extreme cases, structural failure. In regular buildings, the forces are more evenly distributed, whereas, in irregular buildings, the presence of discontinuities in stiffness and mass results in localized stress concentrations. Therefore, adopting efficient lateral load-resisting systems is crucial for ensuring structural integrity. Shear walls and bracing systems are two commonly used techniques for resisting lateral forces:

1. Shear walls are vertical structural elements that resist lateral loads through in-plane shear and bending. These walls enhance rigidity and reduce lateral displacement, making them highly effective in earthquake-prone areas.
2. Bracing systems consist of diagonal members arranged in various configurations (such as X-bracing, V-bracing, and K-bracing) that provide additional lateral stability by redistributing forces. Bracings offer flexibility in design and can be incorporated into both steel and reinforced concrete structures.

To minimize the risk of structural failure, modern building design must focus on strength, ductility, and overall stability. Buildings should be designed in a way that ensures:

- *Adequate strength:* The structure must be capable of resisting seismic forces without excessive deformation or failure.
- *High ductility:* Ductility refers to the ability of a material or structure to undergo significant plastic deformation before failure. A highly ductile structure absorbs seismic energy efficiently, reducing the likelihood of sudden collapse.
- *Structural integrity and cohesion:* The entire building must behave as a unified system, with components working together to distribute seismic forces evenly. This is crucial in preventing partial collapses that may lead to progressive failure.

By incorporating seismic-resistant design principles, engineers can enhance the resilience of buildings, ensuring their ability to withstand large deformations while maintaining functionality. The use of structural reinforcements such as shear walls, bracing systems, base isolators, and energy dissipation devices can significantly improve a building's earthquake performance. Additionally, compliance with modern seismic codes and regulations ensures that structures are designed to endure seismic forces effectively, thereby safeguarding human lives and reducing economic losses in the event of an earthquake.

LITERATURE PAPERS

SSIM converts reliable structures into SSIS, ensuring safety against earthquakes. It uses curved contact surfaces and elastomeric devices, outperforming conventional methods in accelerations, shear, and moment responses [1].

The paper presents a reliability-based approach for designing high-rise buildings in earthquake and strong wind regions, comparing failure probability with rational target value, improving future load combination criteria [2].

The study utilizes STAAD.ProV8i software to analyze precast and cast *in-situ* structures under dynamic earthquake loads, comparing static and dynamic elements and drawing conclusions [3].

The popularity of floating columns and shear walls in urban India is due to earthquakes, necessitating seismic analysis, time history investigation, reaction range examination, and ETABS programming [4].

The study explores the impact of soil types on tall buildings' performance during earthquakes, highlighting the need for seismic provisions in tall buildings to ensure safety and functionality during and after earthquakes [5].

Climate change necessitates high-rise residential building renovations to improve indoor conditions and reduce energy use, but UK and Canadian policies show limitations and inconsistent terminology [6].

The study explores the increasing popularity of composite structures in developing nations, emphasizing the safety and cost-effectiveness of steel and concrete over their design lifespan [7].

The study aims to improve base isolation systems by developing an external device with negative and positive springs, targeting small structures like computer servers and sensitive instruments [8].

High-rise buildings in Bandung, Indonesia, regulate thermal environment through wind turbulence, cooling, and heating, affecting design and environmental quality in tropical cities, with geometric and material parameters playing crucial roles [9].

The study examines a multi-storied Dhaka building's structural behavior under lateral load using lead rubber bearings and El Centro earthquake data, revealing a close displacement difference [10].

Urban agglomerations increase space demand, leading to high, slender structures with unusual shapes. Examining simple and compound section columns in a 40-storey office building [11].

The study examines the effects of 54 high-rise building aspects on sustainability, revealing that while they positively impact natural systems and human psychological needs, they also negatively impact human needs [12].

The design method uses a linear quadratic regulator control algorithm for seismic isolation in multiple-degree-of-freedom structures, adjusting performance based on user-defined weightings [13].

Pre-engineered buildings offer time-efficiency, cost-effectiveness, improved structural behavior, and advanced architectural views, making them a viable replacement for conventional steel buildings and promoting sustainable results [14].

The study numerically simulated dynamic wave processes in heterogeneous media and evaluated their impact on structures, using the grid-characteristic method to study earthquakes' effects on ground and underground structures, focusing on damage caused by seismic activity [15].

The study investigates the structural design of high-rise buildings under wind and earthquake loads, finding that sky-bridge location slightly influences dynamic load-induced responses [16].

The study showcases innovative steel plate and resilient layers connections for improved ductility and seismic energy dissipation, demonstrating superior dynamic performance and potential life safety improvements [17].

The study examines a hybrid composite isolation system for earthquake protection using ANSYS simulation software, comparing rigidly supported and isolated conditions. Results show reduced displacement and increased stiffness [18].

The study assesses seismic performance of an 11-story building using a hybrid coupled wall system, revealing it reduces inter-story drifts by 24.5% and repair costs by 50.8% and 60.5% under MCE intensity [19].

The study compares the seismic response of a multi-story reinforced concrete building base with a high damping hybrid seismic isolator, offering enhanced protection [20].

The study reveals that most building structures lack seismic resistance, causing damage during earthquakes. Base isolation, extending the structure's fundamental period, reduces acceleration and seismic forces [21].

The thesis investigates sustainable high-rise building development in Chinese cities, focusing on environmental protection, safety, and efficiency through green systems, revealing that base isolation devices and tuned mass dampers significantly reduce earthquake response [22].

METHODOLOGY

Building Model Selection

Several irregular 15-story building models were created, incorporating plan irregularities (like re-entrant corners) and vertical irregularities (such as setbacks and soft-story conditions). Modeling and analysis were carried out using software like ETABS and SAP2000 [23–29].

Structural Systems Analyzed

The study compared various lateral load-resisting systems:

- *Model 1:* Bare frame (no additional lateral system).
- *Model 2:* Frame with centrally positioned shear walls.
- *Model 3:* Frame with shear walls located along the building perimeter.
- *Model 4:* Frame integrated with X-type bracing.
- *Model 5:* Frame with V-type bracing.
- *Model 6:* Frame using K-type bracing.

Load Conditions

The following loads were applied to the models:

- Wind loads according to IS 875 (Part 3):2015.
- Seismic loads based on IS 1893 (Part 1):2016, considering seismic Zone IV. Both static and dynamic load combinations were used:
- Dead Load + Live Load;
- Dead Load + Live Load + Wind Load; and
- Dead Load + Live Load + Seismic Load (EQx and EQy directions).

Analytical Approach

- Linear Static Analysis was performed initially.
- Response Spectrum Analysis (RSA) was carried out for dynamic seismic evaluation. Performance metrics for comparison included:
  - Maximum lateral displacement (story drift).
  - Maximum base shear.
  - Story stiffness distribution.
  - Fundamental time period of vibration.

Material Specifications

- *Concrete:* M30 grade.
- *Reinforcement:* Fe500 grade steel.
- *Floor-to-floor height:* 3.2 m.
- *Total building height:* approximately 48 m.

Model Validation

To ensure accuracy, simple symmetrical building models were analyzed and cross-checked with manual calculations before proceeding with complex irregular models.

DISCUSSION

Lateral Displacement Control

- Shear walls significantly reduced lateral displacements compared to frames without additional systems.
- Among bracing types, X-bracing achieved the best reduction in lateral movements, followed by V-bracing and then K-bracing.
- Placing shear walls along the building’s perimeter was more effective in resisting lateral sway than positioning them centrally.

Table 1. Performance summary.

Rank	Structural system	Performance effectiveness
1	Shear walls (perimeter placement)	Best performance for both wind and seismic loads
2	X-Bracing system	Highly effective for seismic resistance
3	V-Bracing system	Moderate performance
4	K-Bracing system	Relatively lower efficiency
5	Bare frame	Poor performance under lateral loads

Base Shear Impact

- Buildings equipped with shear walls experienced higher base shear due to increased stiffness.
- Frames with X-bracing had slightly lower base shear values but displayed effective energy absorption during seismic events.

Story Stiffness Enhancement

- Perimeter shear walls contributed significantly to increased stiffness, particularly at lower stories, minimizing the risk of soft-story failures.
- X-bracing systems helped maintain a more uniform stiffness distribution across all floors.

Vibration Time Period

- Structures incorporating shear walls had shorter fundamental periods, resulting in a stiffer overall behavior.
- Braced frames, especially those with X-bracing, also reduced the time period but maintained better flexibility compared to solid shear walls.

Performance Under Different Loads

- Under seismic loads, systems that allowed controlled flexibility, such as bracing systems, were more effective due to their energy-dissipating properties.
- For wind loading, stiffer systems like shear walls performed better by minimizing building sway.

Table 1 shows the performance summary of the structural systems.

CONCLUSION

Study on Shear Walls and Bracings in Irregular Buildings

- Highlights importance of structural reinforcements for stability and performance.
- Shear walls and bracings improve lateral load resistance, reducing drift and displacement.
- Shear walls are effective in high-rise buildings due to superior stiffness.
- Bracings offer flexibility for retrofitting existing structures.
- Selection should consider building height, irregularities, and load conditions for optimal safety and cost-effectiveness.

Future Scope

Advanced Hybrid Structural Systems Research

- Exploring efficiency in hybrid structural systems combining shear walls and bracings.
- Studying impact of emerging materials like high-performance concrete and smart dampers on irregular buildings.
- Incorporating AI-based optimization techniques for more resilient, cost-effective structures.
- Investigating response of irregular buildings under dynamic loading for enhanced design methodologies.

Limitations

- Limited to numerical simulations and theoretical analysis.

- May not fully capture real-world complexities like construction quality and material variability.
- Soil-structure interaction influences not extensively considered.
- Focuses on conventional shear wall and bracing configurations.
- Innovative structural solutions like tuned mass dampers or energy dissipation devices require further exploration.

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