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A Study of soil structure interaction effects on earth quake response of RC frame structures

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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

1. 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.

1.1. 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

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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:

- 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.
- 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.

1.2. Challenges in Irregular Buildings

Irregular buildings exhibit complex dynamic behavior under lateral loads due to:

- Plan Irregularities: Asymmetric layouts cause unequal force distribution, leading to torsional effects.
- Vertical Irregularities: Sudden changes in stiffness or mass between different building levels create weak points, increasing vulnerability to seismic forces.
- Soft-Story Effects: Buildings with open ground floors (e.g., parking spaces) experience excessive deformation, which can lead to collapse during an earthquake.

To address these challenges, an in-depth study is required to compare the effectiveness of shear walls and bracing systems in irregular structures. The choice between these systems depends on several factors, including material constraints, cost considerations, and performance under specific loading conditions.

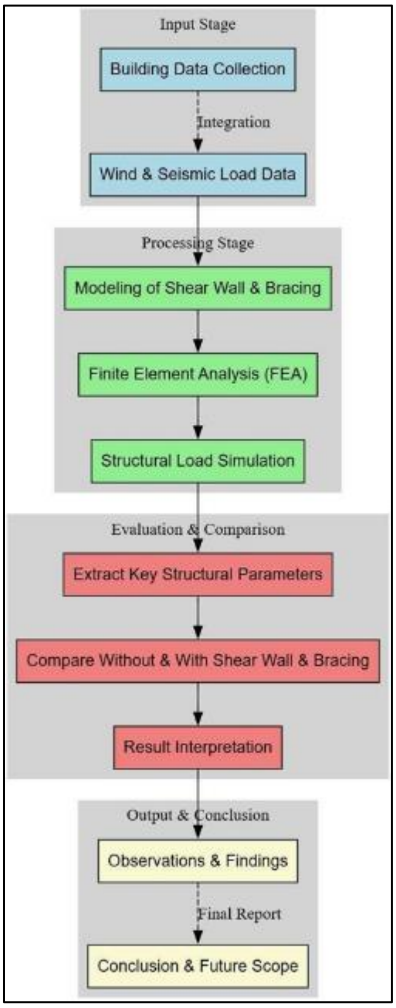

Figure 1 Flow of Work

Earthquakes are natural phenomena that originate within the Earth's crust due to the sudden release of accumulated tectonic stresses. These seismic events can lead to widespread destruction, resulting in the loss of thousands of lives and extensive property damage across different regions of the world. The most significant cause of casualties during earthquakes is the collapse or severe structural damage of buildings, which highlights the critical need for designing earthquake-resistant structures.

One of the primary concerns in structural engineering is lateral instability, which becomes particularly problematic in regions prone to high seismic activity. Buildings are subjected to intense lateral forces during an earthquake, which can compromise their structural integrity, leading to failures ranging from minor damage to total collapse. The extent of earthquake- induced damage depends on multiple factors, including:

- **Magnitude, Intensity, and Duration of Ground Motion:** The strength and duration of seismic waves significantly impact how a building responds to an earthquake.
- **Frequency Content of Ground Motion:** Different buildings resonate at different frequencies, and when the natural frequency of a building matches the dominant frequency of the seismic waves, severe structural damage can occur due to resonance.
- **Geological and Soil Conditions:** The nature of the underlying soil plays a crucial role in determining the intensity of shaking experienced by a structure. Soft soils tend to amplify ground motions, whereas rocky or hard soil foundations provide more stability.
- **Construction Quality and Structural Integrity:** Poor construction materials, lack of proper reinforcement, and non-adherence to building codes contribute to severe damage during an earthquake.

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.

1.3. Behavior of structure during earthquake

When earthquake excitations occur it transmits seismic waves which in turn cause ground motion of the earth’s surface. As structures rests on the earth surface, this ground motion is also passed onto them. The base of the structure moves with the ground but the roof tends to retain its position. But the roof is also forced to move as the walls and columns of the structure are connected. Under this condition, the structures generally tend to collapse or undergo brutal damage. This can be prevented if the structure is ductile. Ductility is defined as an ability of a structure to face huge plastic deformation without loss in ultimate strength. The ductility of a structure enables to predict the amount of seismic energy that may be dissipated through plastic deformations, which is a very important factor for structural design under seismic loads

Over the past three decades, India has experienced number of earthquakes that caused large damage to residential and industrial structure. Today, over 60% of Indian land areas lies in

higher three seismic zone. only about 3% of build environment is properly engineered. India has potential for strong seismic shaking with large stock of vulnerable buildings. Thus, there is urgent need to introduce proper earthquake-resistant design and construction features. Earthquake ground motion may generate very large inertia forces that need to be resisted by structural element in a building. These forces produce large stresses, strains, deformation and displacement particularly in tall structures. It is necessary to keep the displacement within the limit. To keep this displacement within limit generally bracing and shear wall is provided structure. Shear wall & Bracings increase lateral-stiffness, lateral- strength as well as lateral stability of the frame. Under dynamic loading bracing act as good energy dissipater.

2. Literature papers

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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.

Xiao-Wei Zheng et al., [2023].

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.

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Kolla Sailaja et al., [2021, 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.

Waleed Alozzo Almorad et al., [2021], 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.

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T A Srirama Rao et al., [2021, 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.

Sandhya Nepal et al., [2020], 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.

Nancy Y. Nugroho et al., [2020], 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.

Mufedul Islam et al., [2020], 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.

Mircea Popa et al., [2020], 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.

Muhammad Jamaluddin et al., [2020], 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.

Syuan Shia et al., [2020], 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.

Lovneesh Sharma et al., [2020], 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.

Alena Favorskaya et al., [2019], 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.

Sayed Mahmoud et al., [2019], 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.

Sukhi V. Sendanayake et al., [2019], 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.

Ali Güngör et al., [2018], 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.

Dan Liua et al., [2018[, The study assesses seismic performance of an 11-story building using a hybrid coupled wall system, revealing it reduces interstory drifts by 24.5% and repair costs by 50.8% and 60.5% under MCE intensity.

D. Cancellara et al., [2016], The study compares the seismic response of a multi-storey reinforced concrete building base with a high damping hybrid seismic isolator, offering enhanced protection.

Ashish R et al., [2016], 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.

Wu Xingkuan et al., [2011], 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.

2.1. Objectives

- To analyze seismic behavior of L-shape of multistory building in high earthquake intensity region by software.
- To compare the displacement, Base shear and Storey drift of structure with and without shear wall and bracing system.
- To determine the most efficient location of shear wall and bracing system in building by using Computer Aided Program.
- To validate result of base shear obtained by software and analytical method.

2.2. Problem statement

This research aims to address this gap by systematically comparing the performance of shear walls and bracing systems in irregular buildings under lateral loads, identifying the most effective structural system based on lateral displacement, base shear, structural stability, and cost considerations. The findings of this study will contribute to the development of improved structural guidelines for engineers and designers working on irregular buildings in earthquake and wind-prone regions.

3. Research methodology

- Collection and study of literature.
- Study of effect of shear wall and bracing system.
- Planning of shear wall and bracing system in structure.
- Preparation of shear wall and type of bracing model for earthquake and wind load structure
- Earthquake and wind load analysis by using FEA for determination of fundamental natural time period, story drift, peak displacement, peak acceleration of structure.
- Compare, discussion of results for without shear wall and bracing system and with shear wall and bracing system
- Observation for the results obtained from software
- Conclusion and future scope

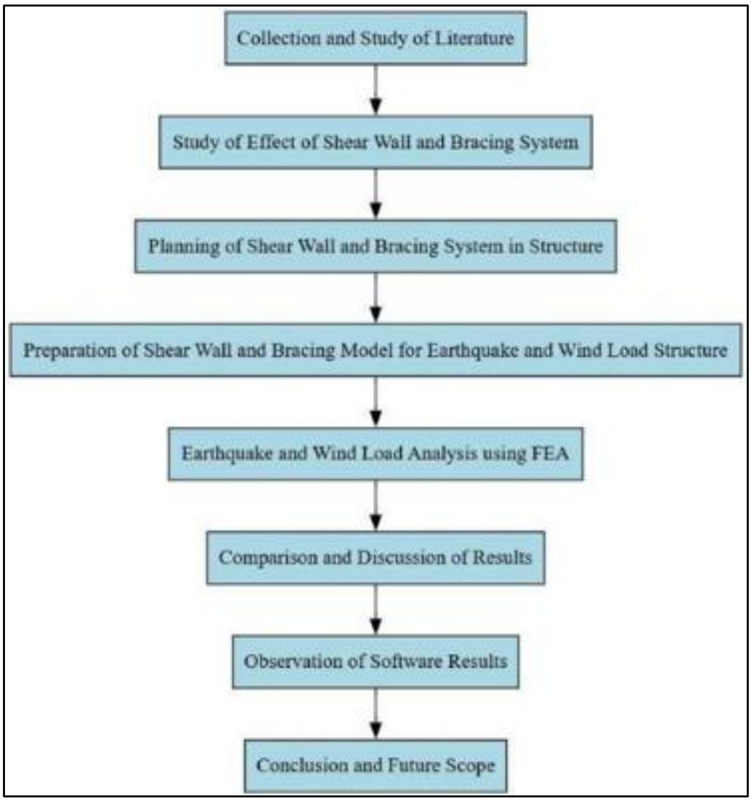

Figure 2 Methodology Flow Chart

3.1. Research Framework

Steps for Designing in ETABS

3.1.1. Step 1: Setting Up the Model

Define Grid and Story Levels

- Open ETABS and set up the grid system based on the building's dimensions.
- Define the number of stories and their respective heights.

Material Properties

- Define concrete properties (Grade of Concrete: M25, M30, etc.).
- Define steel properties (Rebar Grade: Fe415, Fe500).
- Assign material properties to structural elements like beams, columns, shear walls, and braces.

Section Properties

- Define beam and column cross-sections (e.g., 300×600 mm for beams, 400×400 mm for columns).
- Define shear wall thickness (e.g., 150 mm, 200 mm).
- Define bracing members (e.g., steel braces with appropriate cross-section).

3.1.2. Step 2: Assigning Structural Components

Define and Assign Beams and Columns

- Use the frame elements in ETABS to draw beams and columns based on the structural layout.
- Assign reinforcement details to the columns and beams.

Define and Assign Slabs:

- Use shell elements to define slabs.

- Assign slab thickness (e.g., 125 mm for residential, 150 mm for commercial buildings).

Define and Assign Shear Walls

- Use the wall section tool in ETABS.
- Assign shear walls at strategic locations to resist lateral forces.

Define and Assign Bracings

- Use diagonal or cross-bracing in frames.
- Assign steel sections (e.g., ISMB, ISA) for bracing elements.

3.1.3. Step 3: Load Definition and Assignment

Define Load Cases

- Dead Load (DL): Self-weight of structure (automatically calculated by ETABS).
- Live Load (LL): Defined based on building usage (e.g., 3 kN/m^2 for residential).
- Seismic Load (EQ): Define earthquake load as per IS 1893 (Part-1):2016.
- Wind Load (WL): Define wind pressure as per IS 875 (Part-3).

Assign Loads to the Structure

- Assign DL & LL to slabs and beams.
- Assign seismic loads using the Response Spectrum Method (RSM) (explained below).
- Assign wind loads to external walls and roof surfaces.

3.2. Response Spectrum Method for Seismic Analysis

3.2.1. Step 1: Define Response Spectrum Function

- Go to Define → Response Spectrum Function → Add New Function.
- Select the code as IS 1893:2016 or any other standard (ASCE, Eurocode, etc.).
- Input the site-specific spectral acceleration values (Sa/g) vs. Time Period (T).

3.2.2. Step 2: Define Load Cases for Response Spectrum Analysis

- Go to Define → Load Cases → Add New Load Case.
- Select Response Spectrum Analysis as the analysis type.
- Assign modal damping (5% for concrete, 2% for steel).
- Assign participation factors in X, Y, and Z directions.

3.2.3. Step 3: Run Modal Analysis

- ETABS will compute the fundamental natural time periods and modal shapes.
- Check mode shapes and mass participation factors (should be ≥ 90% for accuracy).

3.3. Structural Analysis in ETABS

3.3.1. Step 1: Run Analysis

- Click Run Analysis to compute structural responses under applied loads.
- Check deformed shape, reaction forces, and internal stresses.

3.3.2. Step 2: Interpretation of Key Results

- Fundamental Natural Time Period (Tn): Lower values indicate a stiffer structure.
- Story Drift: Should not exceed 0.004 times story height (IS 1893:2016).
- Base Shear: Compare the obtained base shear with IS 1893 guidelines.
- Peak Displacement & Acceleration: Should be within permissible limits.

3.4. Comparison of Shear Wall & Bracing System

Table 1 Comparison of Shear Wall & Bracing System

Parameter	Without Shear Wall/Bracing	With Shear Wall	With Bracing System
Time Period (s)	Higher	Lower	Moderate
Story Drift	Higher	Lower	Moderate
Base Shear (kN)	Lower	Higher	Moderate
Peak Displacement (mm)	Higher	Lower	Moderate
Structural Stability	Poor	Very Good	Good
Construction Cost	Lower	High	Moderate
Architectural Flexibility	High	Low	Moderate

An earthquake is a natural disaster that throughout recorded and unwritten history has been responsible for the loss of millions of lives. An earthquake is a disruptive disturbance that causes shaking on the surface due to movement of the subsurface rock along a fault line or activity of volcanoes. The forces that are produced are dangerous and only last for a short period of time.

The ambiguity of its nature and the time at which it occurs has humans scratching their heads. On the other hand, as a result of the gradual accumulation of new information over the course of time, a level of probabilistic predictability has been established.

The frequency and intensity of earthquakes in a particular region can now be more accurately predicted, but this only solves one half of the problem: knowing what's going to happen! The second phase is the design of the structure's seismic resistance in order to withstand the storm.

This aspect of the issue has progressed throughout the course of the last century, with new developments in design philosophy and methodology being regularly researched, presented, and put into practice. This chapter presents an overview of the concept of foundation isolation as it relates to the design of earthquake-resistant structures. The modeling and investigation of multi-story structures, bridges, and all provide convincing evidence that seismic isolation is beneficial.

In modern times in India, there has been a boom in the popularity of constructing high-rise buildings out of RCC. It is highly lovely from an aesthetic point of view, but it is risky from a structural point of view because of the high story building's provision of many various facilities such as swimming pools, gardens, and so on.

4. Method of Seismic Design that is Common

The ductility contributes to the dispersal of energy while simultaneously causing enormous irreversible deformations that result in damage that may be too expensive to repair. The protection of life is given explicit precedence above the conservation of nonstructural content by this technique. In certain environments, such as data centers, nuclear plants, and laboratories, the cost of having no structural damage can sometimes be higher than the cost of having structural damage.

The ductility of this theory comes from the behavior of inelastic materials and the finer features. For the purpose of determining lateral design forces, the Indian code makes use of the seismic coefficient technique. It is essential to have a solid understanding of how this tactic instills ductility. The seismic coefficient method calculates base shear by employing the structure's fundamental mode alone in the calculation. Nevertheless, the performances of predicted ductile buildings during major earthquakes have been poor and significantly below predictions. Due to the existence of barriers, it is possible that the ideal strong-column weak-beam mechanism will not materialize in the real world.

- Difficulty grouting, particularly at beam-column connections, as a result of ductility design requirements.

- Column shears failure as a result of inappropriate short-column effect geometric proportions. Therefore, it is necessary to locate a method that circumvents the problems with ductility.
- An alternative and imaginative method increases the degree of uncertainty in both the design of ductility and the performance levels.

5. 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.

5.1. 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.

Compliance with ethical standards

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No conflict of interest to be disclosed.

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