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Comparative Analysis of Symmetrical and Asymmetrical Tall Buildings Under Wind and Seismic Loads

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Abstract: The rapid growth of urban infrastructure has led to an increasing demand for tall buildings, where structural performance under lateral loads becomes a governing design criterion. This study presents a comprehensive comparative analysis of symmetrical and asymmetrical tall building configurations subjected to combined wind and seismic loading conditions. A 20-storey reinforced concrete (RC) building model is developed and analysed using finite element-based structural analysis software. Wind loads are evaluated in accordance with IS 875 (Part 3), while seismic effects are determined using response spectrum analysis as per IS 1893 (Part 1).
The investigation focuses on critical performance parameters, including storey displacement, storey drift, and storey shear. The results indicate that symmetrical buildings exhibit more uniform stiffness distribution and reduced torsional effects, leading to improved structural stability. In contrast, asymmetrical configurations demonstrate significantly higher lateral displacements, particularly in the transverse direction, with peak displacement reaching nearly twice that of the symmetrical model. Additionally, increased shear forces and irregular force distribution are observed in asymmetrical structures due to mass and stiffness eccentricities. The findings highlight the importance of geometric regularity in enhancing the seismic and wind performance of tall buildings. The study concludes that symmetrical configurations offer superior structural efficiency and reliability, making them more suitable for high-rise construction in regions prone to lateral loading. These insights contribute to improved design strategies for resilient and performance-based tall building systems.
Keywords: Tall Buildings; Wind Load; Seismic Load; Structural Irregularity; Storey Displacement; Storey Shear; ETABS; Lateral Load Resistance; Structural Stability

I. INTRODUCTION

The increasing trend of urbanization and limited availability of land in metropolitan regions has necessitated the vertical expansion of infrastructure in the form of tall buildings. While such developments offer efficient land utilization and accommodate growing populations, they introduce significant challenges in structural design, particularly under lateral loading conditions such as wind and earthquakes (Taranath, 2016; Smith and Coull, 1991). Unlike low-rise structures, tall buildings are highly sensitive to dynamic effects due to their increased height, flexibility, and mass distribution, making lateral stability a critical design consideration (Chopra, 2017).

Wind loads act continuously on tall structures and tend to increase with elevation, inducing lateral displacement, acceleration, and potential serviceability issues such as occupant discomfort. Aerodynamic phenomena including vortex shedding, buffeting, and across-wind response further complicate the behaviour of high-rise structures (Holmes, 2015). On the other hand, seismic loads are transient but highly dynamic in nature, resulting from ground motion caused by tectonic activity. These loads induce inertia forces proportional to the mass of the structure, leading to complex responses that include storey drift, base shear, and modal participation effects (IS 1893, 2016; Chopra, 2017).

One of the most significant factors influencing the response of tall buildings under lateral loads is structural configuration. Symmetrical buildings, characterized by uniform distribution of mass and stiffness, tend to exhibit predictable and stable behaviour with minimal torsional effects. In contrast, asymmetrical or irregular buildings introduce eccentricities between the centre of mass and centre of stiffness, leading to torsional amplification and uneven force distribution (Paulay and Priestley, 1992; IS 1893, 2016). This often results in increased displacement, higher stress concentrations, and reduced overall structural efficiency.

The present study focuses on evaluating the influence of plan symmetry on the structural performance of a G+20 reinforced concrete building subjected to both wind and seismic loads. Two models—symmetrical and asymmetrical—are developed and analysed using ETABS software, incorporating relevant Indian Standard codes. The comparison is based on key response parameters such as storey displacement and storey shear, which are essential indicators of structural safety and serviceability. According to the analysed results, the asymmetrical building exhibits significantly higher lateral displacement (up to approximately 89.78 mm) compared to the symmetrical configuration (approximately 46.82 mm), indicating increased vulnerability under lateral loading.

This research aims to provide a deeper understanding of how structural irregularities affect tall building performance and to support the development of efficient and resilient design strategies. By integrating code-based analysis with comparative evaluation, the study contributes to the advancement of performance-oriented structural engineering practices for high-rise buildings.

II. LITERATURE REVIEW

The structural performance of tall buildings under lateral loads has been a subject of extensive research over the past decades, particularly due to the increasing vulnerability of high-rise structures to wind and seismic effects. Early foundational work by Smith and Coull (1991) established that lateral load resistance governs the design of tall buildings, emphasizing the importance of stiffness, strength, and stability in structural systems. Similarly, Taranath (2016) highlighted that as building height increases, the influence of wind and earthquake loads becomes dominant over gravity loads, necessitating advanced analytical approaches.

Seismic analysis of high-rise buildings has been widely studied using both linear and nonlinear methods. Chopra (2017) demonstrated that dynamic analysis methods such as response spectrum analysis provide more realistic results compared to equivalent static methods, especially for taller and irregular structures. Paulay and Priestley (1992) further emphasized the importance of ductility and energy dissipation mechanisms in ensuring seismic safety. Their work established that irregular buildings are more susceptible to torsional effects due to eccentricity between the centre of mass and stiffness.

Recent studies have focused on numerical modelling using advanced software tools such as ETABS for evaluating structural performance. Reddy and Kumar (2019) analysed a G+30 building under seismic loads and concluded that lateral displacement and storey drift increase significantly with seismic zone intensity. Their findings also highlighted the importance of strong column–weak beam design philosophy to prevent progressive collapse. Similarly, Ankalkhope et al. (2021) investigated a multi-storey building under combined wind and seismic loads and reported that proper load combinations and modelling techniques are essential for achieving safe and economical designs.

The influence of structural configuration, particularly plan irregularity, has gained significant attention in recent years. Ala and Khare (2022) examined twisted tall buildings and found that increasing geometric irregularity leads to higher displacement, drift, and torsional response. Their study demonstrated that even moderate irregularity can significantly affect dynamic characteristics such as natural time period and modal participation. In a related study, Souhaibou and Li (2023) compared simplified analytical methods with ETABS results and concluded that while simplified approaches can provide reasonable estimates for regular buildings, they are inadequate for irregular configurations where higher-mode effects become significant.

Wind effects on tall buildings have also been extensively investigated. Holmes (2015) provided a comprehensive framework for wind load evaluation, emphasizing the importance of aerodynamic behaviour and dynamic response. More recent research by Kumar (2025) demonstrated that wind-induced displacements increase significantly with building height, particularly in upper storeys, which may lead to serviceability issues. Kuriakose et al. (2023) also reported similar findings, indicating that wind loads can govern the design of tall buildings in certain conditions, especially in moderate seismic zones.

A growing area of research is the combined or multi-hazard analysis of wind and earthquake loads. Rizzo et al. (2024) highlighted that although design codes typically consider wind and seismic loads separately, their simultaneous occurrence—even at moderate levels—can lead to amplified structural responses. Their study revealed that combined loading can significantly increase inter-storey drift and induce fatigue in both structural and non-structural components. Abdelwahab et al. (2023) further introduced the concept of performance-based wind design (PBWD), which integrates advanced simulation techniques such as computational fluid dynamics (CFD) and nonlinear analysis to improve accuracy and efficiency in design.

Comparative studies between different structural materials and systems have also contributed to the understanding of tall building behaviour. Vedha and Pasha (2019) compared RCC, steel, and composite structures and concluded that composite systems offer better performance in terms of strength-to-weight ratio and displacement control. Additionally, Parker and Cole (2025) demonstrated that integrating CFD, wind tunnel testing, and structural analysis tools provides a more accurate and reliable approach for evaluating wind effects on complex geometries.

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Despite the extensive research available, a significant gap remains in the comparative evaluation of symmetrical and asymmetrical building configurations under combined wind and seismic loading using a unified modelling framework. Most studies either focus on seismic or wind effects independently or investigate irregularity without a direct comparison to regular configurations under identical conditions. The present study addresses this gap by systematically analysing both symmetrical and asymmetrical tall building models using consistent parameters and codal provisions, enabling a clear understanding of the influence of structural configuration on overall performance.

III. METHODOLOGY

The present study adopts a systematic analytical framework to evaluate the structural response of tall buildings under combined wind and seismic loading conditions. The methodology is developed to ensure consistency in modelling, loading, and analysis so that a reliable comparison between symmetrical and asymmetrical configurations can be achieved.

A twenty-storey reinforced concrete building is selected as the reference structure, representing a typical high-rise configuration in urban environments. The total height of the building is 63 m, with a ground floor height of 4 m and typical storey height of 3 m. The structural system consists of reinforced concrete moment-resisting frames with beams, columns, and slabs designed using standard material properties. Concrete of grade M40 and reinforcement steel of grade Fe500 are adopted, ensuring adequate strength and stiffness characteristics for high-rise applications. The building is assumed to be located in a seismic region corresponding to Zone IV, with medium soil conditions and fixed base support, reflecting realistic boundary conditions commonly used in structural analysis .

To investigate the influence of structural configuration, two distinct building models are developed: a symmetrical model with uniform plan geometry and evenly distributed structural elements, and an asymmetrical model with irregular plan configuration resulting in non-uniform mass and stiffness distribution. The modelling process is carried out using ETABS, a finite element-based structural analysis software widely used for high-rise building analysis. Three-dimensional models are created by defining grid systems, assigning structural elements such as beams, columns, and slabs, and incorporating material properties and sectional dimensions consistent with design requirements.

The loading conditions are defined in accordance with relevant Indian Standard codes to ensure accuracy and code compliance. Dead loads and live loads are applied as per IS 875 (Part 1 and Part 2), considering self-weight, floor finishes, and imposed loads. Wind loads are evaluated based on IS 875 (Part 3), incorporating parameters such as basic wind speed, terrain category, height variation, and exposure conditions. Seismic loads are applied using response spectrum analysis as per IS 1893 (Part 1), which accounts for dynamic characteristics of the structure including natural frequencies, mode shapes, and modal participation factors. The response reduction factor, importance factor, and zone factor are selected in accordance with codal provisions to represent realistic seismic behaviour. The analysis procedure involves both linear static and dynamic approaches. Initially, linear static analysis is performed to determine the distribution of internal forces such as axial forces, shear forces, and bending moments under gravity and lateral loads. This is followed by response spectrum analysis to capture the dynamic response of the structure under seismic excitation. The combination of these methods provides a comprehensive understanding of structural behaviour under different loading scenarios. Following analysis, key performance parameters are extracted for evaluation and comparison. These include storey displacement, storey drift, and storey shear, which are critical indicators of structural safety, serviceability, and lateral load resistance. Storey displacement is used to assess overall building flexibility, while storey shear represents the cumulative lateral forces transferred through the structure. The results obtained from both models are compared systematically to evaluate the effect of symmetry and irregularity on structural performance. The methodology ensures that both symmetrical and asymmetrical models are analysed under identical conditions, allowing for a direct and unbiased comparison. By integrating codal provisions, advanced analysis techniques, and detailed modelling, the study provides a robust framework for assessing the influence of structural configuration on the performance of tall buildings subjected to wind and seismic loads.

IV. RESULTS AND DISCUSSION

The structural response of the tall building models under combined wind and seismic loading is evaluated in terms of storey displacement and storey shear. The results obtained from ETABS analysis are interpreted to understand the influence of structural configuration on overall performance, with particular emphasis on the differences between symmetrical and asymmetrical buildings.

The variation of storey displacement along the height of the building exhibits a typical cantilever-type behaviour for both configurations, where displacement increases progressively from the base to the top.

In the symmetrical building, the maximum displacement is observed at the top storey with a value of approximately 46.82 mm, indicating a relatively controlled lateral response. The displacement profile remains smooth and uniform throughout the height, reflecting an even distribution of stiffness and mass. This behaviour is characteristic of regular structures, where lateral loads are resisted efficiently without significant torsional effects.

In contrast, the asymmetrical building demonstrates a markedly different response. The maximum displacement reaches approximately 89.78 mm in the Y-direction, which is nearly twice that of the symmetrical configuration . This substantial increase can be attributed to the irregular distribution of stiffness and mass, which introduces eccentricity between the centre of mass and centre of rigidity. As a result, torsional effects become significant, leading to amplified lateral deformation. Furthermore, the displacement variation in the asymmetrical model is less uniform, indicating localized flexibility and uneven load transfer mechanisms.

A notable observation is that while the symmetrical structure exhibits slightly higher displacement in the X-direction compared to the asymmetrical model, the overall performance remains superior due to balanced behaviour in both principal directions. The asymmetrical building, on the other hand, shows a pronounced directional dependency, with significantly higher displacement in one direction. This anisotropic behaviour highlights the vulnerability of irregular structures to directional loading effects, particularly under combined wind and seismic actions.

The analysis of storey shear further reinforces these observations. In both configurations, storey shear increases progressively from the top to the base, reflecting the cumulative effect of lateral loads acting on the structure. For the symmetrical building, the maximum storey shear at the base is approximately 3455 kN, with a consistent and uniform distribution across storeys. This indicates efficient load transfer through the structural system, with minimal irregularities in force distribution.

However, the asymmetrical building exhibits significantly higher base shear values, reaching approximately 6909 kN in the Y-direction . This nearly twofold increase is a direct consequence of irregular geometry, which leads to concentration of forces and uneven stiffness distribution. The presence of torsion results in additional internal forces that must be resisted by structural elements, thereby increasing the overall demand on the system. The shear distribution in the asymmetrical model is also less uniform, indicating potential zones of stress concentration that may compromise structural safety if not adequately designed.

The comparative results clearly demonstrate that symmetry plays a crucial role in enhancing the structural performance of tall buildings. Symmetrical configurations provide uniform stiffness and predictable load paths, which minimize torsional effects and ensure efficient distribution of forces. In contrast, asymmetrical configurations introduce complexities in structural behaviour, including increased displacement, higher shear forces, and significant torsional response.

From a design perspective, these findings have important implications. The increased displacement observed in asymmetrical buildings may lead to serviceability issues such as excessive drift and occupant discomfort, while higher shear forces demand stronger structural elements and foundations. Additionally, torsional effects can result in differential deformation, which may cause damage to both structural and non-structural components. Therefore, careful consideration of plan geometry and structural regularity is essential in the design of tall buildings subjected to lateral loads.

Overall, the results confirm that symmetrical buildings offer superior performance in terms of stability, efficiency, and reliability under combined wind and seismic loading. While asymmetrical designs may be architecturally desirable, they require additional design considerations, such as the incorporation of shear walls, bracing systems, or damping mechanisms, to mitigate adverse structural effects and ensure compliance with codal requirements.

V. CONCLUSION AND FUTURE SCOPE

A. Conclusion

This study presented a comprehensive comparative analysis of symmetrical and asymmetrical tall building configurations subjected to combined wind and seismic loading conditions using finite element-based modelling. The results clearly demonstrate that structural configuration plays a critical role in determining the overall performance, stability, and safety of high-rise buildings.

The symmetrical building exhibited a more uniform and predictable response under lateral loads, characterized by controlled storey displacement and consistent shear distribution along the height. The maximum displacement observed in the symmetrical model was approximately 46.82 mm, indicating adequate stiffness and effective load-resisting behaviour. The absence of significant torsional effects contributed to improved structural efficiency and reduced demand on individual elements.

In contrast, the asymmetrical building showed a substantially different response, with maximum displacement reaching approximately 89.78 mm, nearly twice that of the symmetrical configuration . This increase is primarily attributed to the irregular distribution of mass and stiffness, which introduces torsional effects and results in amplified lateral deformation.

Additionally, the asymmetrical model exhibited significantly higher storey shear values, with base shear approaching 6909 kN, indicating increased force demand on the structural system .

The findings highlight that while asymmetrical buildings may offer architectural flexibility, they are inherently more vulnerable to lateral loads due to complex load paths and uneven force distribution. Such configurations require additional design considerations, including enhanced lateral load-resisting systems and careful detailing to ensure safety and serviceability. On the other hand, symmetrical buildings provide superior performance due to their balanced geometry, making them more suitable for regions subjected to significant wind and seismic activity.

Overall, the study confirms that geometric regularity is a key factor in achieving efficient and resilient structural design. The results align with established structural engineering principles and reinforce the importance of minimizing irregularities in tall building design to enhance performance under dynamic loading conditions.

B. Future Scope

While the present study provides valuable insights into the comparative performance of symmetrical and asymmetrical tall buildings, several areas remain open for further investigation to enhance the depth and applicability of the research.

Future studies can incorporate nonlinear analysis methods such as pushover analysis and time-history analysis to capture inelastic behaviour and provide a more realistic assessment of structural performance under extreme loading conditions. The inclusion of soil–structure interaction effects would further improve the accuracy of the analysis, particularly for buildings located on soft or varying soil profiles.

The use of advanced structural systems, such as outrigger systems, diagrids, and composite construction, can be explored to improve the performance of asymmetrical buildings. Additionally, the implementation of damping devices, including tuned mass dampers and viscous dampers, may significantly reduce displacement and vibration in tall structures.

Another important area for future research is the consideration of multi-hazard scenarios, where wind and earthquake loads act simultaneously. Such studies would provide a more comprehensive understanding of real-world conditions and help in developing performance-based design approaches for tall buildings.

Furthermore, the integration of computational fluid dynamics (CFD) and wind tunnel testing with structural analysis can enhance the accuracy of wind load estimation, particularly for complex geometries. Optimization techniques using artificial intelligence and machine learning may also be employed to develop efficient and economical design solutions.

In conclusion, future research should focus on advanced analysis techniques, innovative structural systems, and multi-disciplinary approaches to improve the safety, performance, and sustainability of tall buildings in increasingly complex urban environments.

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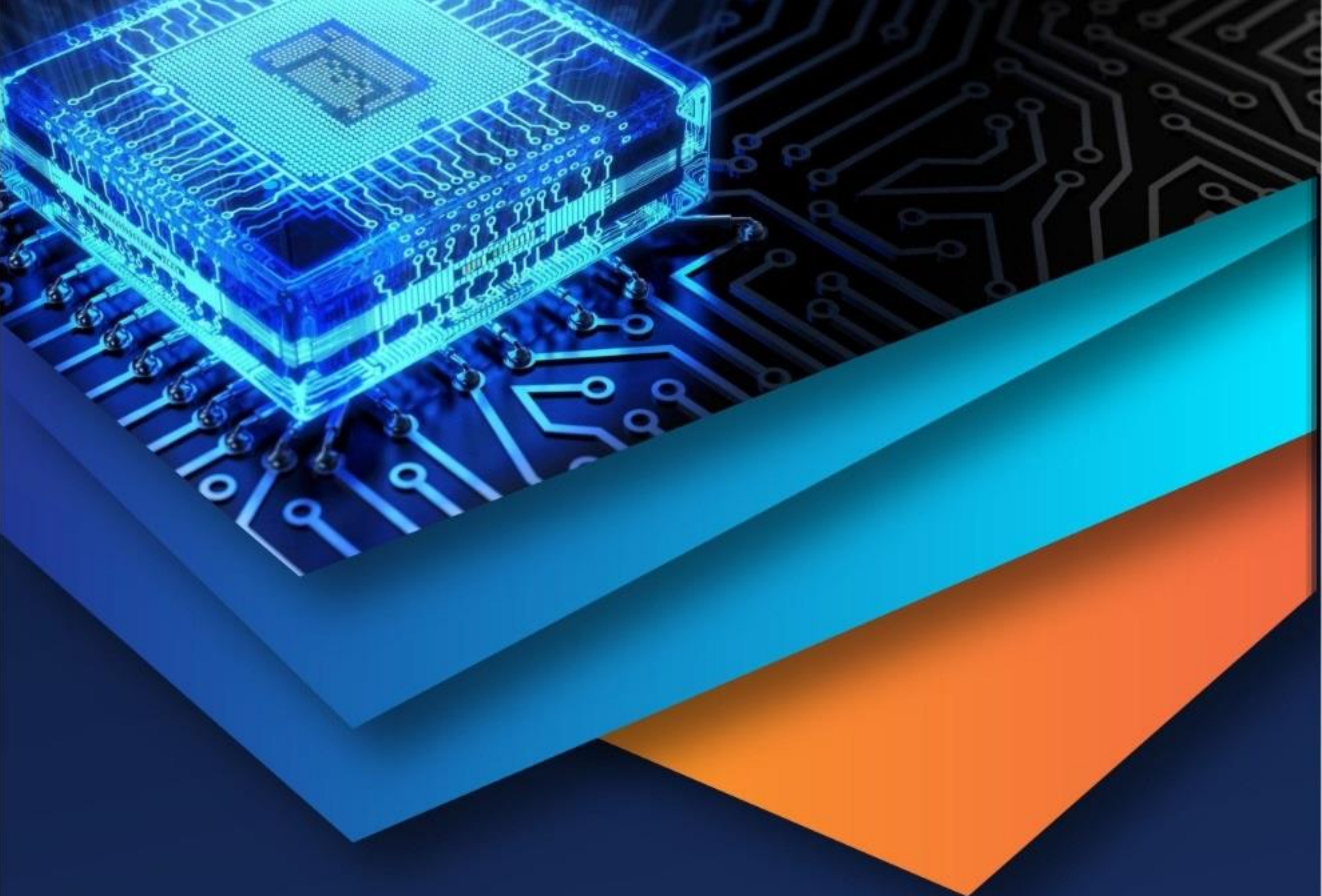

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