Back-Stay Effect on Seismic Analysis of Tall Building

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Abstract- *The backstay effect is a phenomenon that occurs in tall buildings connected to a single podium. It refers to the tension that is created in the structural members of the building due to the earthquake and wind force acting on the building. When earthquake and wind blows against the building, the upper floors experience a lateral force that tries to push them over. This force is resisted by the building's structural members, including the columns, beams, and walls. However, this force also generates tension in the structural members, which can cause them to buckle or fail. The backstay effect is particularly relevant in areas with high earthquake and wind loads, where it can have significant implications for the design and construction of the building. The backstay effect is a complex phenomenon that depends on many different factors, including the building height, podium size, structural materials, and earthquake and wind load. To better understand the backstay effect, researchers have developed advanced computational models and simulations that can predict the behavior of tall buildings connected to a single podium under different earthquake and wind load scenarios. These models take into account the nonlinear behavior of the structural members, the dynamic response of the building, and the effect of earthquake and wind turbulence on the building's motion. The results of these studies have shown that the backstay effect has a significant impact on the structural integrity and stability of tall buildings connected to a single podium. For example, it has been found that the backstay effect can cause excessive tension in the structural members, which can lead to failure of the building's lateral support system. In addition, the backstay effect can cause excessive drift in the building's upper floors, which can make the building uncomfortable or even unsafe for occupants. In conclusion, the backstay effect is an important consideration for designers and engineers of tall buildings connected to a single podium. Understanding this effect and its implications for building design and construction can help ensure the safety, durability, and comfort of these structures. Further research in this area is needed to develop more accurate and reliable models for predicting the backstay effect and to refine the design codes for tall buildings connected to a single podium.*

Keywords- Tall Building, Backstay, seismic, wind, stiffness

I. INTRODUCTION

In recent years, the construction of tall buildings has increased due to urbanization and limited land availability. This study focuses on the backstay analysis of a unique tall building with two interconnected towers and a distributed shear wall system as a lateral load resisting system (LLRS). Backstay systems are crucial for mitigating wind or seismic-induced lateral forces. The building configuration poses structural challenges, and the distributed shear wall system enhances lateral stability. The study aims to analyze the backstay system's effectiveness, evaluate the structure's response to lateral loads, and provide insights for tall building design. The analysis includes theoretical exploration, numerical modeling, and simulation techniques considering wind and seismic effects. The findings will benefit structural engineers, architects, and developers involved in similar high-rise projects.

LATERAL LOAD RESISTING SYSTEM

Lateral Load Resisting Systems (LLRS) play a critical role in the design and construction of structures to ensure their stability and structural integrity under lateral forces, such as wind or seismic loads. These forces exert horizontal pressure on buildings, which can lead to structural damage or even collapse if not adequately addressed. LLRS are specifically designed to counteract these lateral forces, providing the necessary resistance and protecting the structure and its occupants.

The selection and implementation of an appropriate LLRS depend on various factors, including the building's height, location, function, and the magnitude and type of lateral loads expected. Over the years, numerous LLRS techniques and systems have been developed, each with its own advantages, limitations, and applicability to different structural configurations.

DISTRIBUTIVE SHEAR WALL SYSTEM

The Distributive Shear Wall System (DSWS) is an innovative approach used in the design and construction of buildings to enhance their lateral stability and resistance against wind and seismic loads. Shear walls are structural elements that primarily resist lateral forces acting on a building, and the DSWS takes this concept further by distributing these shear walls strategically throughout the structure. Traditional shear wall systems typically consist of concentrated vertical walls located at specific positions within a building. In contrast, the DSWS utilizes a distributed arrangement of shear walls, spreading them across multiple locations within the building's floor plan. This approach offers several advantages over the conventional concentrated shear wall systems.

One of the key benefits of the DSWS is improved load distribution. By distributing shear walls throughout the building, the lateral forces generated by wind or seismic events are more evenly spread across the structure. This leads to a reduction in localized stress concentrations and allows for better load sharing, resulting in enhanced overall structural performance.

II. MODELLING OF BUILDING

Creating a 3D model of a G+50 storied five building using ETABS software is a critical step in the analysis and design process of high-rise structures. ETABS is a widely utilized software tool that facilitates the precise and detailed creation of a building's 3D model. The modeling process involves defining various geometric parameters, including floor plans, column sizes, and beam dimensions. Once the fundamental geometry of the building is established, the software allows for the specification of materials and structural elements, such as concrete, steel, and shear walls.
The structure under evaluation, in terms of seismic activity, is a residential project with plan dimensions of approximately 45m x 30m for each building, with a floor-to-floor height of 3.3m. The specific details of the building are provided in Table 3.1, while the corresponding plan can be observed in Figures.

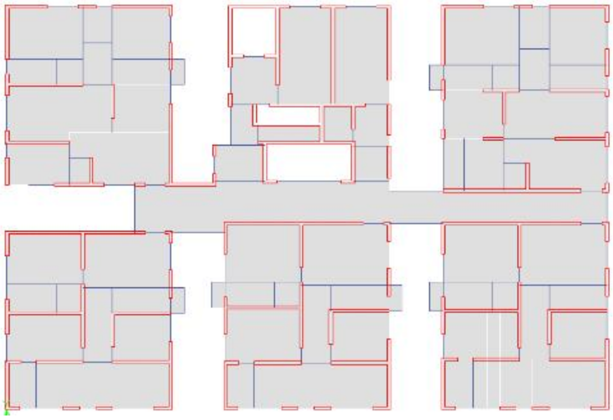


Fig 1.Plan of a building to be analysed

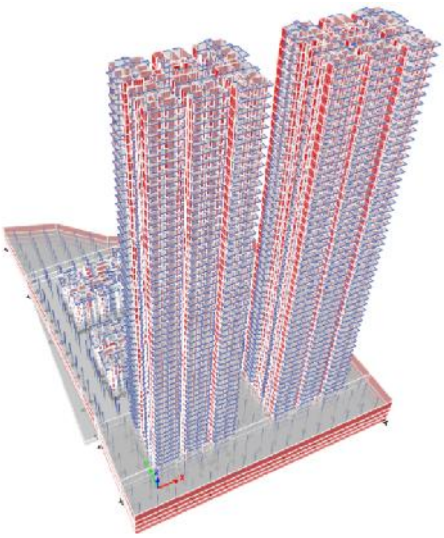


Fig 2. 3D view of building

III. SERVICEABILITY LIMIT STATE MODEL

The Serviceability Limit State (SLS) model for tall buildings is an essential aspect of the structural design process that focuses on the building's performance and functionality under normal service conditions. Unlike the Ultimate Limit State (ULS) model, which ensures the structural safety of a building under extreme conditions, the SLS model aims to guarantee occupant comfort, functionality, and durability throughout the building's lifespan. The SLS model takes into account various factors and considerations related to the building's behavior under typical service loads, such as occupancy loads, live loads, wind loads, temperature effects, and long-term effects of material properties. The objective is to ensure that the building maintains its functionality, aesthetics, and structural integrity without excessive deformations or discomfort to its occupants.

One of the primary concerns in the SLS model is the prevention of excessive deflections or deformations. Excessive deflections can lead to perceptible vibrations, cracking of non-structural elements, and discomfort for occupants. To address this, design codes and guidelines typically provide limits on the maximum allowable deflections, which are influenced by factors such as building function, occupant sensitivity, and aesthetic requirements. In addition to deflection limitations, the SLS model also considers other factors such as floor vibrations, floor flatness, and floor levelness. Floor vibrations refer to the perceptible movement or oscillation of a floor due to various dynamic loads, such as human activities, equipment, or wind-induced vibrations. Floor flatness and levelness relate to the evenness and flatness of the floor surfaces, ensuring smooth and safe movement for occupants.

The SLS model also includes considerations for the durability and long-term performance of the building. Factors such as creep, shrinkage, thermal effects, and material degradation over time are taken into accountto ensure that the building remains structurally sound and functional throughout its design life.

Property modifiers: (IS16700;2017)

i. Shear Wall: 0.9
ii. Column: 0.9
iii. Slab: 0.25
iv. Beam: 0.5
v. Retaining Wall: 0.01; f22 = 0.9

ULTIMATE LIMIT STATE MODEL

The Ultimate Limit State (ULS) model is a fundamental aspect of the structural design process for tall buildings. It is aimed at ensuring the structural integrity and safety of the building under extreme or limit load conditions. The ULS model analyzes the building's response to the most severe combinations of loads, such as dead loads, live loads, wind loads, and earthquake loads. By evaluating various failure modes and considering different structural elements, the ULS model ensures that the building can withstand these extreme loads without experiencing failure or collapse. In the ULS model, design codes and standards play a crucial role in determining the design loads and capacities of the structural elements. These codes provide specific limit states and associated safety factors that account for uncertainties in material properties, load magnitudes, and modeling assumptions. These safety factors are incorporated into the design process to ensure an appropriate level of safety and reliability.

To conduct the ULS analysis, advanced computational tools are used, such as finite element analysis (FEA) or other methods. These tools enable to determine the internal forces and deformations within the structural elements under the most critical load combinations. By examining the strength, stability, and capacity of the structural elements, the ULS model ensures that they can resist the applied loads without reaching their ultimate capacity or causing excessive deformations. One important aspect of the ULS model is the consideration of structural strength. This involves evaluating the load-carrying capacity of various structural elements, such as columns and beams. The ULS model ensures that these elements have sufficient strength to withstand the maximum anticipated loads without failure. By analyzing the forces and moments acting on the structural elements, can determine their capacity and verify that it meets or exceeds the design requirements.

Property modifiers (IS16700;2017)

i. Shear Wall: 0.7
ii. Column: 0.7
iii. Slab: 0.01
iv. Beam: 0.35
v. Retaining Wall: 0.01; f22 = 0.7

LOWER BOUND ANALYSIS FOR BACKSTAY

Lower bound analysis for backstay refers to a specific method used to assess the stability and strength of backstay systems in tall buildings. Backstay systems are structural elements commonly employed in high-rise buildings to mitigate lateral forces induced by wind or seismic events. They provide additional stability and support to the structure by resisting the overturning and horizontal forces acting on the building. In lower bound analysis, the objective is to determine the minimum strength and capacity of the backstay system required for the structure's stability. This analysis approach assumes a conservative scenario where the applied loads and material properties are maximized, and any uncertainties or variations are considered in favor of the worst-case scenario. The lower bound analysis involves evaluating the critical failure modes of the backstay system and verifying that its strength and stiffness are sufficient to withstand the maximum anticipated loads without failure. The analysis typically considers factors such as the material properties of the backstay elements (e.g., steel cables), their connections to the structure, and the forces exerted on them.

To perform the lower bound analysis for backstay systems, its needed to employ various analytical methods, numerical modeling techniques, and structural principles. The analysis may include calculations and simulations to determine the forces and moments acting on the backstay system and its corresponding response. The analysis also considers the interaction between the backstay system and other structural elements of the building, ensuring their compatibility and overall stability.

Property modifiers (IS16700:2017)

i. Shear Wall: 0.7
ii. Column: 0.7
iii. Slab: 0.01
iv. Beam: 0.35
v. Retaining Wall: 0.15
vi. Backstay Diaphragms: 0.15 & Semi-Rigid

UPPER BOUND ANALYSIS FOR BACKSTAY

pper bound analysis for backstay is a method used to determine the maximum strength and capacity of backstay systems in tall buildings. Backstay systems are structural elements designed to mitigate lateral forces induced by wind or seismic events in high-rise structures. The purpose of the upper bound analysis is to ensure that the backstay system can withstand the most extreme loads without failure. In upper bound analysis, engineers consider an optimistic scenario where loads and material properties are minimized, while uncertainties are resolved in favor of the best-case conditions. The analysis involves evaluating critical failure modes of the backstay system and verifying that its strength and stiffness are sufficient to withstand the maximum anticipated loads.

The analysis process includes considering factors such as the material properties of the backstay elements (such as steel cables), their connections to the structure, and the forces applied to them. Engineers utilize analytical methods, numerical modeling techniques, and structural principles to perform the upper bound analysis. This may involve calculations and simulations to determine the forces and moments acting on the backstay system and its response. The interaction between the backstay system and other structural elements is also examined to ensure compatibility and overall stability. The objective of the upper bound analysis is to establish a safety margin by designing the backstay system with a capacity that exceeds the expected maximum loads. By incorporating this additional strength and capacity, the analysis aims to provide an increased level of safety and reliability, particularly during extreme conditions or unexpected loadings.

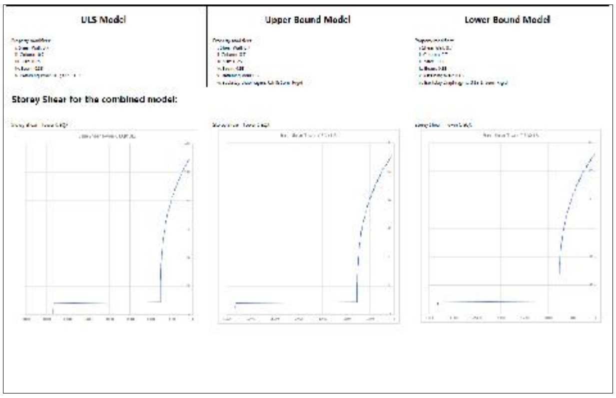
It is essential to adhere to applicable design codes and standards specific to the region or country where the building is located. These codes provide guidelines and criteria for evaluating the structural stability and strength of backstay systems, considering factors such as material specifications, load combinations, and safety factors.

Property modifiers (IS16700:2017)

i. Shear Wall: 0.7
ii. Column: 0.7
iii. Slab: 0.01
iv. Beam: 0.35
v. Retaining Wall: 0.5
vi. Backstay Diaphragms: 0.5 & Semi-Rigid

V. ANALYSIS RESULTS

The results of the analysis conducted on the tall building structure, focusing on the various aspects studied and the outcomes obtained. The analysis aimed to evaluate the structural behavior and performance of the building under different loading conditions, considering factors such as wind loads, seismic forces, and the effectiveness of the backstay system as a lateral load resisting element. Throughout the analysis process, comprehensive numerical modeling and simulation techniques were employed to assess the dynamic response and stability of the building. The results obtained from these simulations provide valuable insights into the structural behavior, deformation patterns, and stress distribution within the building components..



ULS Model

Upper Bound Model

Lower Bound Model

Storey Shear for the combined model:

Fig 3. Storey shear comparison

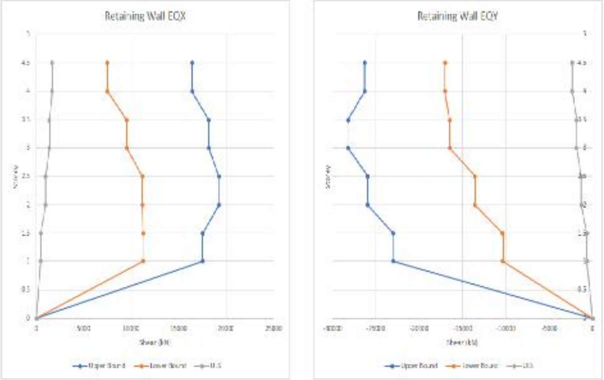


Fig 4. Shear forces

Fig 5. Torsional Irregularity check

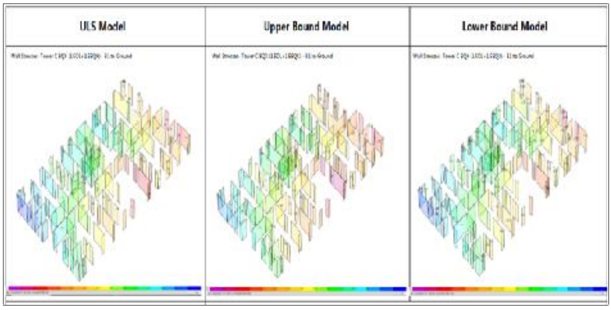


Fig 6. Wall stress for distributive shear walls

VI. CONCLUSION

1) Analysis of the combined model of the tall building with the distributed shear wall system (LLRS) incorporating backstay elements reveals that there is no indication of shear reversal in the storey shear. This implies that the lateral forces acting on the structure are effectively resisted without any sudden changes in the distribution of shear forces.
2) The pier force plot for each tower in the combined model demonstrates interesting behavior at the backstay level. It shows a reduction in shear force or even a sign change, indicating the significant contribution of the backstay system in redistributing the forces and improving the overall stability of the structure.
3) In the Ultimate Limit State (ULS) analysis, comparing F11 and F22 (forces in slab) at the ground floor among the ULS, upper bound, and lower bound models, it is observed that their values are almost similar. The maximum F11 force is only approximately 8% higher in the upper bound model compared to the lower bound model. This indicates that the structure maintains its strength and capacity within an acceptable range in different analysis scenarios.
4) The maximum unfactored F11 force obtained in the analysis is approximately 280 kN for the EQX (earthquake) case. This value provides valuable information regarding the expected loads and forces that the structure will experience during seismic events.
5) Analyzing the stress in the shear wall of Tower C, it is observed that the upper bound model exhibits approximately 10% higher maximum stress compared to the lower bound model. This highlights the importance of considering the upper bound scenario when assessing the capacity and performance of the shear walls.
6) Based on the observations, it can be concluded that the presence of the backstay system does not have a major impact on the overall structural behavior and stability of the tall building. The towers can be analyzed as individual units, taking into account the adjacent connected bays within the model of each tower. This simplifies the analysis process without compromising the accuracy of the results.
7) Additionally, it is concluded that there is no necessity for the inclusion of expansion joints in the construction. Instead, the construction can be carried out with delayed pour strips around each tower, allowing for the accommodation of early thermal effects while maintaining structural integrity.

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