A Review on Wind Tunnel Analysis and Backstay Effect in High-Rise Buildings with Podium

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***Abstract*—Designing tall buildings demands a careful balance of lateral load management, particularly when dealing with the structural impact of podiums and wind sensitivity. This paper reviews current performance-oriented design approaches, focusing heavily on podium-induced backstay effects and the role of wind tunnel analysis. Incorporating a podium fundamentally changes lateral load paths. Overturning forces are pushed outward into floor diaphragms alongside perimeter walls, which often causes shear reversal and unexpected shifts in base shear demand. Meanwhile, the slender upper sections of these towers face serious dynamic wind challenges, where vortex shedding and across-wind forces frequently threaten occupant comfort limits. While Indian standards like IS 875 (Part 3), IS 1893, and IS 16700 provide a starting point, they do not fully capture the behavior of highly irregular geometries or the complex load transfers at the tower-podium junction. Recent literature relying on ETABS modeling, CFD simulations, and physical wind tunnel tests shows how heavily diaphragm rigidity, podium stiffness, and aerodynamic shaping dictate a building's overall response. By outlining exactly where current code provisions fall short, this review argues for a much more integrated design framework-one that firmly connects seismic backstay evaluation with advanced wind engineering to ensure overall structural resilience**

***Index Terms*—Tall buildings Podium structures Backstay effect Wind tunnel testing CFD ETABS IS 875 IS 1893 IS 16700**

I. INTRODUCTION

Rapid urbanization, increasing population, and shortage of available land have led to the construction of tall buildings in India as well as in many other parts of the world. As building height increases, the influence of lateral loads becomes more significant in structural design. Among these, earthquake and wind loads are the most critical because they directly affect the safety, stability, serviceability, and comfort of occupants.

In many tall buildings, podium structures are provided at the lower levels to accommodate functions such as parking, retail areas, and shared public spaces. Although podiums improve the functional and architectural use of the building, they also influence the structural response of the tower under lateral loading. The presence of a podium changes the way forces are transferred through the structure and modifies the overall lateral load-resisting behavior.

One important aspect of podium-tower interaction is the redistribution of overturning effects from the tower to the podium diaphragm and the surrounding vertical structural elements. This phenomenon, commonly referred to as the backstay effect, can significantly alter the internal force pattern in the structural system. It may lead to shear reversal, changes in bending moment distribution, and variation in overall stiffness. While the podium may help in reducing lateral drift of the tower, it can also increase base shear and force demands in podium members, which must be considered carefully during analysis and design. This research evaluates a 40-storey RCC building in Seismic Zone IV with and without podiums.

II. LITERATURE REVIEW

Chauhan Nilesh Chhaganbhai, P. R. Barbude, P. V. Muley (2024), "Effect of Sensitive Analysis on Multistorey Building with DiƯerent Configuration of Structural Element."

This study examines the seismic interaction between podium and tower portions in Multistorey buildings with different podium arrangements. ETABS software is employed to develop offset tower models with podium slabs, beams, and walls having different stiffness levels. Response spectrum analysis is used to assess displacement, drift, and shear reversal at the podium–tower connection. The paper explains the backstay effect, in which the tower's overturning resistance is transferred into the podium diaphragm. Diaphragm stiffness is investigated through ETABS shell modifiers such as f11, f22, and m11. IS 16700 cracked section modifiers are applied for sensitivity analysis under both serviceability and ultimate limit states. The results indicate that podium stiffness lowers top displacement of the tower while increasing base shear. Shear reversal below podium levels is also observed, showing a more complex force redistribution pattern. The study warns that neglecting podium effects may result in unsafe underestimation of seismic demand. Graphs and tables are used to compare different podium configurations and their displacement reductions. Semi-rigid diaphragm modeling is recommended for more realistic results. The study also points out gaps in IS 1893 and IS 16700 regarding podium behavior. It further stresses the need to include podium effects in tower design workflows. The findings are useful for urban high-rise buildings with podium parking or commercial spaces. Overall, the paper offers a practical basis for podium–tower seismic design in India.

Riddesh Naik, Roshni John, Dinesh Joshi (2023), "Backstay Effect Due to Podium Structure This research evaluates a 40-storey RCC building in Seismic Zone IV with and without podiums.
ETABS response spectrum analysis is carried out as per IS 1893:2016 to study seismic response. Sensitivity analysis is performed using IS 16700 stiffness modifiers. The findings show that podiums reduce tower displacement but also create shear reversal at the podium–tower interface. Backstay forces are identified as overturning resistance being transferred into the podium diaphragms. Podium height and floor area are found to have a strong effect on the overall structural response. Taller podiums increase stiffness, which lowers drift but raises base shear. Graphs show the percentage reduction in displacement for different podium cases. The study concludes that podiums improve stability but make force distribution more complicated. Ignoring podium behavior may lead to inaccurate safety evaluation. Accurate diaphragm stiffness modeling in ETABS is shown to be essential. The paper also notes that podiums can help control vibration and sway for serviceability. At the same time, excessive stiffness may lead to undesired increases in base shear. The study suggests that codal provisions should be updated to address podium effects. Overall, podiums are presented as both advantageous and challenging in seismic design.

Nirav Bhatu, Vishal B. Patel, Pratiti M. Bhatt (2022), "Effect of Backstay on Tall Structures with Podium."
This study models single and multiple towers connected to a shared podium to investigate backstay behavior. ETABS is used to study changes in podium height, diaphragm rigidity, and the presence of perimeter shear walls. Equivalent static and response spectrum methods are used to evaluate displacement, drift, base shear, and time period. Backstay action is identified as the redistribution of overturning forces through podium diaphragms into perimeter walls. Shear reversal is observed near the podium–tower interface, changing the usual cantilever behavior of shear walls. Increasing podium stiffness reduces top-storey displacement but alters the distribution of base moments. Multiple towers supported on a common podium intensify diaphragm force paths and interface shear reversal. Shear walls at the podium perimeter improve load sharing and reduce tower drifts. Semi-rigid diaphragm modeling gives a more realistic transfer of forces than rigid assumptions. The results show that podium height has a major influence on global lateral response. Graphs compare displacement and drift reductions across different configurations. The paper stresses the need for coordinated design of tower and podium components. It recommends sensitivity checks on cracked section modifiers based on Indian codes. The findings support performance-based design for podium-integrated high-rise structures. Overall, podiums act as back spans that alter seismic load transfer and serviceability behavior.

Shyam Tukaram Jadhav, P. A. Vedpathak (2025), "Seismic Performance Analysis of High-Rise Buildings Using ETABS."
The study compares diagrid systems with conventional bracing in steel high-rise buildings under seismic loading. ETABS dynamic analysis is used to examine storey drift, displacement, storey shear, mode shapes, and fundamental periods. Diagrid

configurations show better lateral stiffness and improved energy dissipation capacity. Compared with traditional braced frames, diagrid frames produce lower drifts and better serviceability. The optimization of member angles and panel geometry improves the overall structural response. Irregular plan cases are also studied to understand torsional effects and stress concentration. Modal participation factors are used to identify the dominant lateral direction of the system. Response spectrum analysis is matched with codal drift limits and ductility requirements. The paper also highlights the importance of connection detailing and continuity in diagrid performance. Comparative results show a consistent reduction in drift across the building height. Constructability and architectural integration are also discussed. The study stresses the need for accurate mass modeling in dynamic analysis. It recommends performance-based evaluation for tall and slender structural systems. The findings support diagrids as a strong option for seismic resistance. Overall, the study shows that diagrids offer a good balance of stiffness, ductility, and architectural flexibility.

Nitesh Singh, Astha Verma (2025), "Reducing Wind Load on Tall Buildings: A Review."
This review brings together aerodynamic strategies, experimental methods, and computational tools used to reduce wind effects on tall buildings. Corner modifications such as rounding and chamfering are shown to reduce peak pressure and vortex shedding. Tapered and setback forms are also found to reduce along-wind response and improve comfort. Wind tunnel methods such as HFFB and HFPI are discussed for measuring dynamic loads and cladding pressures. CFD methods, including DES and LES, are presented as useful tools for studying shape and façade features. Wind direction and terrain exposure are highlighted as important design inputs. Case studies show that load reduction can be achieved through shape optimization and orientation changes. Occupant comfort limits based on acceleration are used to guide stiffness and damping decisions. The review notes that combining structural analysis with aerodynamic findings improves design reliability. It emphasizes the value of early wind studies in reducing costs during the design stage. The paper also warns against relying only on code-based methods for irregular forms. Trade-offs between appearance, constructability, and wind performance are discussed. Computational workflows are shown to help test several design alternatives quickly. The review recommends combining CFD with physical testing for greater confidence. Overall, aerodynamic refinement is presented as essential for safe and efficient supertall design.

Tanuja A. Deshpande, G. R. Gandhe (2024), "Seismic Analysis of G+30 High Rise Building."
A G+30 reinforced concrete building with a centrally located core is modeled and analyzed for seismic performance. ETABS response spectrum analysis is carried out according to IS 1893:2016. Core shear walls provide the main lateral resistance and help control torsion. The study evaluates storey displacement, drift pattern, base shear, and fundamental period. Directional vulnerability is examined to understand differences in orthogonal response. The results show that drifts stay within codal limits because of the stiffness of the central core. Diaphragm assumptions are found to affect load distribution and must be selected carefully. Cracked section modifiers are used to represent stiffness more realistically. The design is further refined through comparisons with and without secondary shear walls. Serviceability Serviceability checks include floor acceleration and displacement comfort. Charts and tables clearly present performance values across the height of the building. The study highlights the importance of core location and continuity. It recommends proper ductile detailing in line with IS 13920. The findings support the use of core-based lateral systems in tall RC buildings. Overall, a centrally placed core provides a good balance of seismic safety and usability.

Rahul Chaudhary, Shivam Singh, MD Fasihuddin, Sushant Kumar, Anuj Kumar Sharma (2024), "Wind Analysis of High-Rise Building Using ETABS."
This study combines ETABS modeling with CFD observations to study wind effects on tall buildings. Wind loads are applied as per IS 875 (Part 3) and then compared with CFD results. The parameters studied include displacement, drift, cladding pressure, and dynamic response. Aerodynamic changes are introduced to reduce wind-induced forces. The results show that corner chamfering and setbacks reduce peak pressure. CFD analysis also captures flow separation and vortex shedding behavior. ETABS results are used

to confirm structural performance under codal wind loads. Graphs show how displacement and drift vary under different wind directions. The study emphasizes the role of terrain and exposure categories. Comfort criteria are considered to control sway and vibration. The paper recommends combining CFD with ETABS for more reliable design. It also highlights the limitations of code only approaches for irregular building shapes. Early wind assessment is suggested as part of the design process. The findings support aerodynamic tuning as a way to improve tall building safety. Overall, the study connects structural modeling with wind engineering practice.

T. Ashrith, R. Sreenu (2024), "Wind Study on Isolated High-Rise Building: A Computational Fluid Dynamic Approach."
This study uses CFD to examine wind flow around a horseshoe-shaped tall building. ANSYS Fluent is used to simulate wind pressure at different incident angles. Pressure coefficients are calculated to locate high-pressure and low-pressure zones on the façade. Flow separation and vortex shedding are observed at critical corners. The results show that wind angle has a major effect on pressure distribution and structural response. Graphs illustrate changes in drag and lift forces under different wind directions. The CFD study also captures torsional effects that are difficult to evaluate using code methods. The paper stresses the importance of checking wind from multiple directions. Proper meshing and turbulence models are identified as important for accurate simulation. Comparisons are made with wind loads obtained from IS 875. CFD results provide more detailed information about local pressure distribution. The paper recommends combining CFD with ETABS for structural verification. It also highlights the need for aerodynamic improvement in unusual building forms. The findings support CFD as a practical alternative to wind tunnel testing in some cases. Overall, the study shows the value of CFD in modern wind engineering for tall buildings.

Gottapu Santosh Kumar (2020), "Analysis of Wind Effects on Tall Buildings: Wind Engineering and Design Considerations."
This paper gives a broad overview of wind engineering concepts for tall buildings. It discusses load calculation methods, aerodynamic behavior, and structural response. Wind tunnel testing is presented as the most dependable method for complex building shapes. CFD is described as useful for preliminary design studies. Case studies show how building geometry affects wind pressure. Along-wind and across-wind responses are examined in relation to occupant comfort. The paper also explains the influence of terrain and topography on wind loads. Dynamic amplification is considered important for slender high-rise buildings. Graphs show changes in displacement and acceleration under wind loading. The study emphasizes the value of performance-based design in modern projects. It also discusses innovative materials and damping systems as mitigation measures. The paper points out that codal provisions have limits when irregular forms are involved. It recommends combining experimental and numerical approaches for better accuracy. The findings underline the importance of wind engineering in safe tall building design. Overall, the paper summarizes the main design considerations for wind-resistant structures.

Parth G. Rathod, Sumant B. Patel, Pratiti M. Bhatt (2024), "Backstay Effect on Tall Structures with Podium Structure – A Review."
This review brings together previous studies on podium–tower backstay interaction. It explains how podium diaphragms transfer overturning forces into perimeter walls. Shear reversal is identified as a common phenomenon below podium levels. Earlier studies show that podiums reduce tower displacement. However, they also increase base shear and change bending moment distribution. Graphs illustrate how displacement decreases when a podium is introduced. Podium height and stiffness are identified as important design variables. Semi rigid diaphragm modeling is recommended for realistic analysis. The review also points out codal gaps in IS 1893 and IS 16700. It emphasizes the need for coordinated design between podium and tower systems. Performance-based methods are suggested for podium-integrated structures. The findings are relevant to high-rise buildings with podium parking or commercial use. The paper also recommends sensitivity analysis on cracked section modifiers. It concludes that podiums are useful but structurally complex in seismic design. Overall, the review gives a strong summary of backstay effects.

Iñekar S. Khan, Sharif Shaikh (2023), "BackStay Effect on Seismic Analysis of Tall Building."
This study analyzes a G+50 residential complex with interconnected towers. ETABS is used to model distributed shear wall systems throughout the plan. Response spectrum analysis is performed to evaluate displacement, drift, and base shear. Backstay behavior is observed as overturning forces move into the podium diaphragms. Distributed shear walls improve load sharing and reduce localized stresses. The results show lower storey drift and better serviceability. Graphs highlight displacement reduction for different shear wall arrangements. The study emphasizes compliance with IS 1893 and IS 16700. Comfort factors such as vibration and sway are also considered. Podium structures are shown to improve the overall stability of the building. Semi-rigid diaphragm modeling is used to represent force transfer more realistically. The paper recommends performance-based checks for tall residential buildings. The findings show that podiums play a dual role in stability and force redistribution. It also calls for coordinated design between tower and podium elements. Overall, the study demonstrates the contribution of podiums to seismic resilience.

Nakul Doble, J. N. Vyas (2023), "A Review Study on Tall Structures with Altering Podium Height
Inducing Backstay Effect with & Without Shear Wall."
This review studies how changes in podium height affect backstay behavior in tall buildings. ETABS models with and without podium shear walls are compared. The results show that higher podium stiffness increases shear reversal at the tower interface. Displacement reduction is observed when podium height increases. Graphs show drift changes for different podium height configurations. Peripheral podium shear walls improve load transfer and reduce tower drift. The study identifies diaphragm stiffness as a key parameter. Semi-rigid diaphragm modeling is recommended for more realistic analysis. The paper also discusses codal gaps in IS 1893 and IS 16700. Performance-based methods are suggested for podium-integrated structures. The findings are relevant to urban high-rise buildings with podium parking or commercial spaces. The paper highlights the dual role of podiums in stability and force redistribution. It also recommends sensitivity analysis on cracked section modifiers. Coordinated design of podium and tower systems is advised. Overall, the review summarizes the influence of podium height on seismic performance.

III. CONCLUSIONS

In this study, the behavior of tall buildings with podiums has been examined with a particular focus on the backstay effect. The presence of a podium was found to substantially influence the seismic response of the tower by modifying stiffness distribution, internal force paths, and deformation patterns. While podium–tower interaction can help reduce lateral drift in the tower, it simultaneously increases base shear and diaphragm force demands. The observation of shear reversal at the podium–tower interface highlights that simplified assumptions commonly used for free-standing towers are not directly applicable to podium-integrated systems and that more refined analysis and detailing are required. The literature clearly indicates that diaphragm stiffness, podium height, and the use and layout of peripheral podium shear walls are among the most influential parameters governing backstay behavior. To achieve a realistic representation of structural response, it is necessary to move beyond idealized rigid diaphragm assumptions and to adopt semi-rigid diaphragm modeling, together with appropriate cracked section stiffness modifiers. At present, Indian standards such as IS 1893 and IS 16700 offer only limited direction on how to deal with these podium-related effects, underscoring the need for explicit provisions in future revisions of these codes. On the wind side, the review shows that reliance on code-based static procedures alone is not adequate for tall, podium-integrated buildings with irregular plan or elevation geometries. Wind tunnel testing and CFD analyses are essential tools for reliably estimating wind-induced loads, dynamic response, and occupant comfort. Although aerodynamic modifications to the architectural form have been shown to reduce wind effects, their influence must be evaluated together with changes in global stiffness and load paths introduced by the podium structure. Taken together, the findings argue strongly for an integrated, performance-based design methodology in which seismic backstay effects and wind-induced response are considered simultaneously, rather than in isolation. Such a unified treatment provides a more consistent basis for checking safety, serviceability, and comfort requirements for podium-integrated tall buildings. In the longer term, it is recommended that design practice and code development in India move toward combined seismic–wind evaluation frameworks that explicitly recognize podium interaction, so that tall buildings in dense urban settings can be designed with greater resilience, efficiency, and reliability.

IV. FUTURE SCOPE

Future work can extend this study by examining the combined influence of wind and earthquake actions on tall buildings using ETABS-based backstay modelling together with detailed wind studies, including CFD simulations and, where possible, wind tunnel measurements. In parallel, there is a need to refine provisions in IS 1893, IS 16700 and IS 875 so that podium levels, transfer floors and other geometric irregularities are treated more explicitly in both analysis and design. Developing a consistent, performance-based design approach that links these code provisions with practical analysis methods would help improve the reliability and transparency of tall building design in Indian conditions. Funding It is hereby stated that no financial support, including funds, grants, or any other forms of assistance, was received from any organizations, institutions, or sponsors during the preparation and development of this manuscript. Data availability No datasets were generated or analysed during the current study.

Declaration
The authors declare no competing interests.

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