



Review of Backstay Effect in Tall Buildings with Podiums and Basements

Mr. Faisal Chogle

Post Graduate Student

Department of Civil Engineering

Pillai HOC College of Engineering and Technology

Rasayani, Raigad, India

choglefaisal@gmail.com

Dr. Madhulika Sinha

Assistant Professor

Department of Civil Engineering

Pillai HOC College of Engineering and Technology

Rasayani, Raigad, India

madhulikasinha@mes.ac.in

Abstract — This review paper comprehensively evaluates the phenomenon of Backstay Effect in tall buildings that include podium structures. The study includes fundamental mechanics, different modelling approaches, and the impact of the same in the structural behavior and seismic performance of the building. This section highlights the guidelines from the latest Indian standards along with well-known international references. It also explains how different parameters—such as podium height, diaphragm stiffness, and the overall tower configuration—can influence the structural response, providing a holistic understanding in optimizing design and safety improvements.

Keywords — Backstay Effect, Tall Buildings, Podium, Basements, Seismic Performance, Structural Modeling

I. INTRODUCTION

Tall buildings with integrated podiums often combining residential, commercial, and parking functions have become a practical solution for scarcity of urban land. However, this leads to a more complicated structural system affecting lateral load resistance. This causes Backstay Effect, where the stiffness of the podium can significantly influence the upper tower. Understanding this effect is essential for proper seismic design, structural safety and for proper modelling and assessment approaches. [1, 3, 5].

At the podium level, the floor diaphragm plays a much more important role than a simple horizontal slab. The diaphragm introduces significant lateral stiffness and load redistribution effects that modify the natural vibration periods and modal shapes of the building system. Ignoring these diaphragm-podium interactions by modeling the tower as a mere cantilever fixed rigidly at the base leads to underestimation of seismic demands on key lateral force-resisting components, particularly lateral forces and moment magnitudes at the junction between the tower and podium. [1]

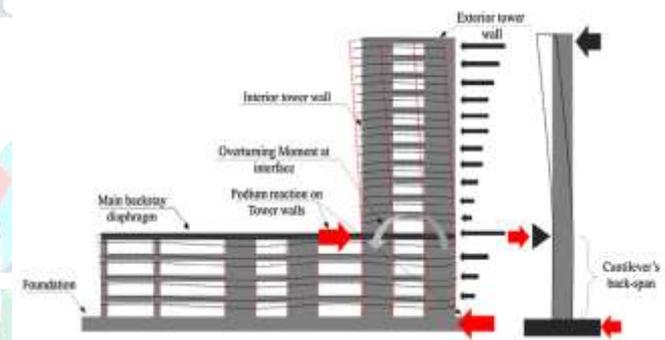


Fig. 1 Mechanism of backstay effect in Tall Buildings

The criticality of accounting for such stiffness interactions was starkly demonstrated during post-earthquake damage assessments of buildings in Christchurch (2011) and Mexico City (1985). Structures exhibiting irregular stiffness distributions at lower levels, analogous to podium-tower systems, were observed to experience concentrated damage and, in severe cases, collapse. These observations underscore the necessity of transcending simplified models to accurately capture the complex force transfer mechanisms inherent in such configurations. [4, 7, 5]

Recent investigations highlight that ignoring the podium-tower interaction may underestimate shear demands by up to 25% and alter fundamental periods by nearly 10–15% in tall structures [9,10]. These findings emphasize that simplified fixed-base models fails to provide an accurate seismic assessment.

Moreover, as urban development trends push for denser, taller structures integrated with large podiums or basements, the relevance of the Backstay Effect has become increasingly significant in both design and code development. As performance-based design becomes the industry norm, these effects must be considered early in conceptual design to avoid costly retrofits or underperformance during seismic events. [1, 8, 9]

II. FUNDAMENTALS OF BACKSTAY EFFECT

The Backstay Effect arises due to the differential stiffness between a tall tower and a lower podium structure, which can be idealized as a cantilever with a back span at the podium. Here, the podium behaves like a rigid or semi-rigid diaphragm spring supporting the tower from the side rather than from the base alone [5, 9].

Traditional modeling of tall buildings as fixed-base cantilevers fails to capture this phenomenon adequately, leading to potential underestimation of forces.[1, 2]

Research emphasizes the importance of considering diaphragm flexibility and soil-structure interaction to accurately model the stiffness contributions of the podium and its retaining walls [3]. Parametric analytical formulations show that the backstay force ratio rises with increasing relative stiffness of the podium relative to the tower and with increasing height-to-embed depth ratios. Effective diaphragm modeling options include rigid, semi-rigid, and flexible assumptions, with semi-rigid diaphragms often providing more realistic force distributions. [7, 11]

Further investigations reveal that the depth of basements or supporting subterranean structures plays a significant role in enhancing the backstay mechanism by engaging a greater portion of the retaining walls along with the surrounding soil mass. This interaction increases the overall lateral stiffness of the system but also results in higher base shear forces transferred to the foundation. The modified boundary conditions due to basement embedment typically reduce the fundamental period of the tower and redistribute forces along the shear walls, underscoring the critical need to incorporate realistic basement stiffness and soil-structure interaction models when evaluating the seismic performance of podium-tower assemblies. [17]

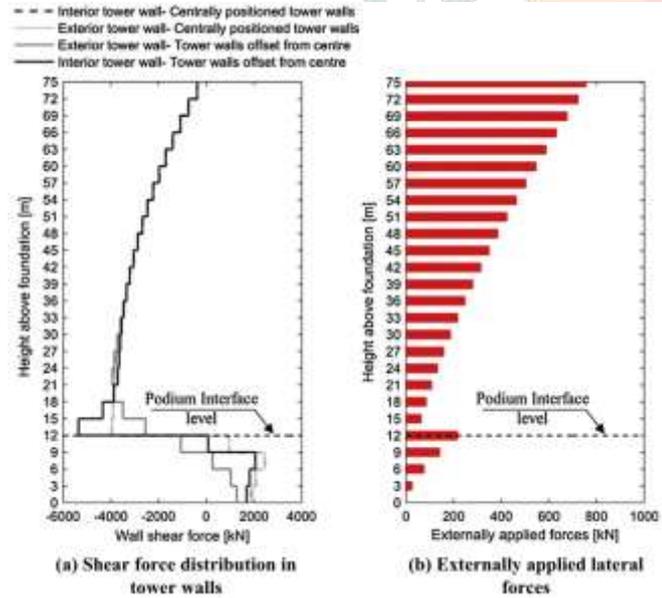


Fig. 2 Shear force distribution in tower walls

The Backstay Effect alters the lateral load paths significantly, transferring forces to the podium and its retaining structure rather than directly to the foundation, thus influencing design considerations for the entire system.[9]

Study	Model Type	Key Parameter	Observed Effect
Patel et al. (2022)	ETABS FEM Model	Podium height ratio (H/B)	Increase in base shear up to 25%
Karimi et al. (2020)	Core-wall FEM	K_{podium} / K_{tower}	Higher stiffness increases backstay forces

Nandi et al. (2020)	3D Model	Diaphragm flexibility	Semi-rigid diaphragm gives realistic results
Yacoubian et al. (2017)	FEA Study	Podium embedment	Deeper podiums amplify backstay effect

The behavioral mechanism is analogous to the "propped cantilever" concept in structural analysis. The tower (the cantilever) is partially propped by the stiff podium diaphragm, which provides rotational and translational restraint at an elevated level. The degree of this propping action is a function of the relative stiffness (K_{podium}/K_{tower}). This concept finds parallels in the analysis of outrigger systems [2, 20], where the podium acts similarly to a ground-level outrigger, engaging peripheral elements to resist overturning moments. [4, 6]

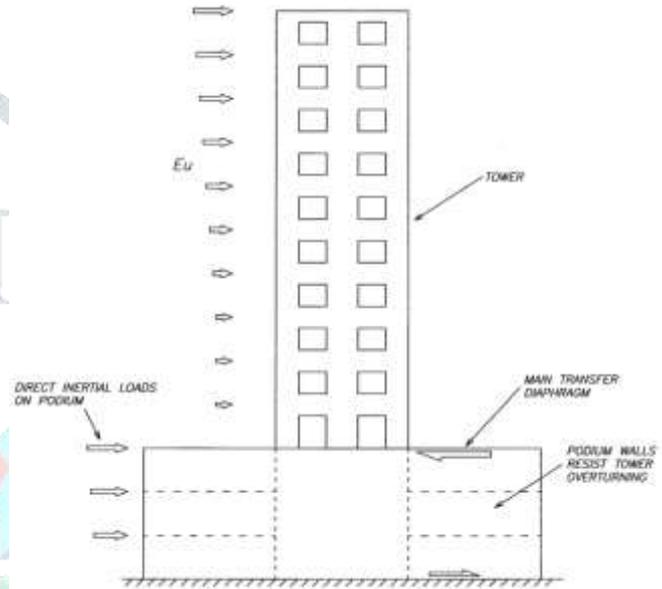


Fig. 3 Transfer forces in towers with podium

Studies have further indicated that the effect of diaphragm flexibility plays a dominant role in redistributing lateral loads, and modeling it as semi-rigid produces more realistic results.

Additionally, the influence of architectural features—such as transfer girders, stepped podiums, and irregular setbacks—can further complicate the backstay mechanism, often amplifying local demands and requiring detailed finite element analysis to avoid brittle failure.[5, 7, 11]

III. PREPARE IMPACTS ON STRUCTURAL BEHAVIOR AND SEISMIC RESPONSE

Incorporating the Backstay Effect generally increases overall system stiffness, which reduces top-story displacements and enhances seismic resilience. Nevertheless, this condition also results in higher lateral forces transferred to the podium and potentially to the foundations beneath it [1, 3, 9]. Increased diaphragm thickness and podium height significantly amplify these lateral forces, necessitating careful design of diaphragms, retaining walls, and foundation elements. [9]

Seismic analyses with backstay considerations reveal marked force reversal in shear forces, directly affecting overturning moments and foundation load distribution. The dynamic interaction between tower and podium may also affect natural frequencies and mode shapes, which are vital in response spectrum analyses. [7, 8]

Comparison of models with and without considering backstay often shows reduced base shear and moment demands on the tower foundation elements when properly accounted for, indicating more distributed load transfer through the podium system. [1, 3]

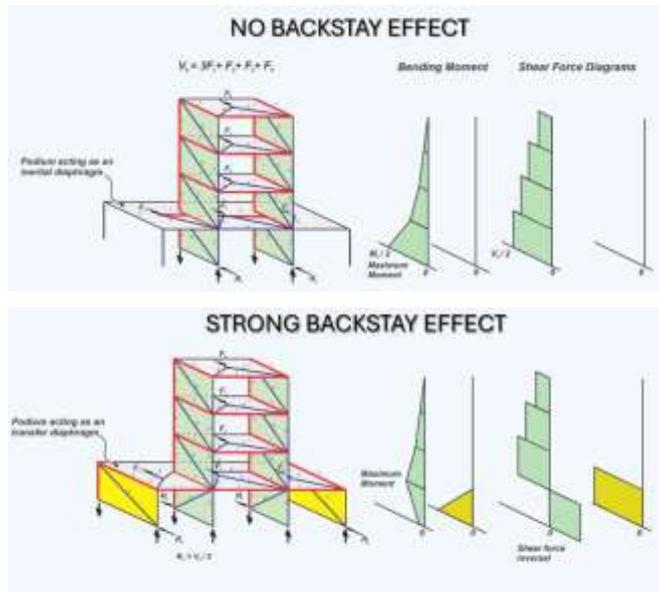


Fig. 4 Illustrative diagram showing effect of Backstay on Building (Ingham, J. and Restrepo, J.I., Introduction to the Strut-and-Tie Method of Analysis and Design.)

Research indicates that ignoring the Backstay Effect can lead to a significant misestimating of forces. For instance, it has been demonstrated that simplified models can underestimate podium-level shear forces by 15-25% and overestimate tower base moments by up to 20%, depending on the system's aspect ratio and stiffness distribution [12]. This misestimating directly impacts the design of critical elements like shear walls and pile caps.

Moreover, the phenomenon of shear force reversal is of particular significance. The shear force experienced by the tower directly above the podium can reverse sign compared to a fixed-base model. Consequently, columns designed based on conventional analysis may be critically under-reinforced for the reversed cyclic demand. Nonlinear time-history analyses confirm that the Backstay Effect can relocate the formation of plastic hinges from the tower base to the podium-tower interface, fundamentally altering the failure mechanism and ductility demands [12]. This necessitates a performance-based design approach where a clear hierarchy of strengths (e.g., "strong podium-weak tower" or "strong tower-weak podium") is explicitly designed and detailed. [6, 10]

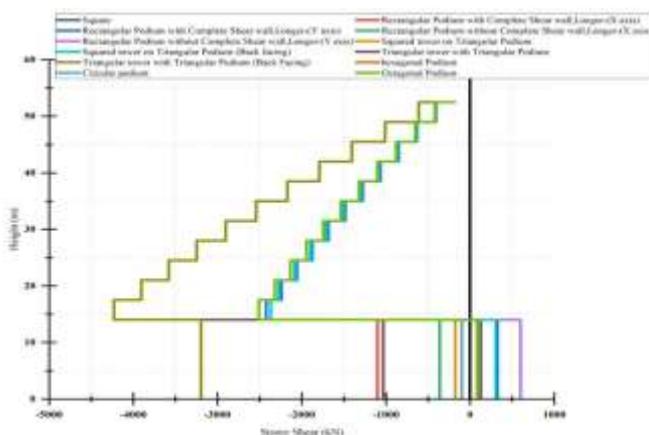


Fig. 5 Storey Shear variation for different configuration of podiums [5]

A comparative pushover analysis highlights that the presence of a podium significantly alters the nonlinear behavior of the system by relocating plastic hinge formation from the tower base to the podium-tower interface. This change modifies the failure mechanism, requiring focused ductility detailing in the transition zone. Although the podium increases initial stiffness, it marginally reduces ultimate displacement capacity, indicating a trade-off between stiffness gain and ductility. These effects emphasize the necessity of including nonlinear considerations in podium-tower seismic evaluations. [19]

It is also essential to consider the cumulative interaction effects in buildings with multiple towers over a shared podium. These configurations introduce load-sharing complexities that require system-level analysis. When appropriately designed, these systems can enhance redundancy and overall seismic robustness, but poor modeling may lead to localized overstress or collapse mechanisms. [3, 5, 9]

IV. USING MODELING AND ANALYSIS APPROACHES

Finite element software, such as ETABS, is widely used to model complex podium-tower assemblies, incorporating varying diaphragm stiffness and soil-foundation interaction. Sensitivity analyses employing stiffness modifiers from Indian standards IS 16700 and international codes provide bracketing of uncertainties related to diaphragm behavior and soil stiffness [2, 6, 7].

The use of semi-rigid diaphragms modeled through finite element meshing provides more accurate internal force prediction and realistic stiffness representation, as supported by Kennedy (2019) and Patel (2023).

Detailed analysis of diaphragm flexibility in high-rise podium buildings shows that the assumption of diaphragm rigidity significantly influences lateral stiffness, interstorey drift, and internal force distribution. Modeling the diaphragm as rigid tends to overestimate stiffness and underestimate torsional response, whereas semi-rigid diaphragm models capture these behaviors more accurately. This improved modeling approach is especially critical in performance-based design of podium-tower systems where lateral loads transfer through large transfer slabs or decks with variable stiffness. [18]

SAP2000, PERFORM-3D, and MIDAS are also used to model nonlinear behavior, particularly for time-history analysis and to capture hinge formation at the podium interface.[10][11]

Response spectrum and nonlinear pushover analyses are effective tools to assess performance levels, ductility demands, and failure mechanisms more realistically. These methods help in understanding the nonlinear response shifts caused by the rigidity of diaphragms and the podium-tower interaction.[8]

Isolation joints at podium interfaces might be used to eliminate backstay effects; however, they are typically avoided since they reduce system redundancy, potentially decreasing overall lateral stiffness and seismic robustness [8].

Realistic modeling must integrate diaphragm deformations, retaining wall stiffness, and soil-structure interaction comprehensively to minimize errors in predicted seismic demands. [12, 14]

A critical aspect of modeling is the accurate representation of the podium diaphragm. While the assumption of a rigid diaphragm simplifies analysis, it can overestimate the Backstay Effect. The semi-rigid approach, achieved through

finite element meshing of the diaphragm, is recommended for superior accuracy. Guidelines in ACI 318 [15] and ASCE/SEI 7 [16] suggest that diaphragms should be considered flexible when their maximum in-plane deformation exceeds half the average story drift of the associated story. [1, 9]

For SFSI (Soil-Foundation-Structure Interaction), the continuum-based approach using Winkler springs (modulus of subgrade reaction) is common but can be enhanced with advanced 3D finite element models that capture the nonlinear, pressure-dependent stiffness of soil. The way kinematic and inertial soil–foundation–structure interaction (SFSI) influences the backstay mechanism is an important part of the discussion. In softer ground conditions, the overall building period can increase, which may reduce the seismic forces but at the same time cause larger displacements. This interacts complexly with the podiums restraining action..

Backstay behavior is especially sensitive to foundation embedment and retaining wall stiffness. Deeper podiums with stiff retaining walls tend to engage more of the backstay mechanism, potentially increasing base shears. Hence, foundation design must go hand-in-hand with diaphragm and lateral force-resisting system design for a holistic response model.[4, 10]

V. RESEARCH GAPS AND RECOMMENDATIONS

Despite significant progress in understanding the backstay effect, there are still several areas that need deeper investigation. One major gap is the limited exploration of nonlinear behaviour under severe earthquake events, especially when real soil conditions are considered. Existing studies and design models still work with assumptions consider linear elastic behaviour or rely on overly simplified assumptions regarding diaphragm stiffness. [7, 8]

Future research should focus on:

- Advanced modeling incorporating viscoelastic and pressure-dependent soil behavior,
- Time-dependent stiffness degradation of diaphragms and podium elements due to cracking and damage,
- Behavior under multi-hazard loading (e.g., seismic followed by wind or fire),
- And experimental validation through shake table testing, field instrumentation, and real-time monitoring [2, 5, 8].

Development of comprehensive performance-based design methodologies that integrate the Backstay Effect is critical for ensuring the structural safety, economic efficiency, and code compliance of future podium-tower buildings [7, 13].

Additionally, there's a need for developing simplified design procedures and code provisions that incorporate backstay effects without requiring complex analysis bridging the gap between research and practical application.[5, 9,11]

VI. CONCLUSION

The Backstay Effect significantly influences the seismic behavior and design of tall buildings with podiums by altering lateral force distributions and structural responses. To properly evaluate the behaviour of podium–tower systems, it's important to rely on advanced analysis methods that take diaphragm flexibility and soil–structure interaction into account.

Designers must carefully consider diaphragm thickness, podium height, and configuration to mitigate adverse effects while enhancing building resilience. As these types of developments become more common, it's crucial that design standards—both in India and internationally—begin explicitly

addressing the backstay phenomenon. Doing so will help ensure safer and more reliable performance.

Ultimately, the successful design of podium-tower structures must integrate architecture, geotechnical conditions, and structural systems cohesively—acknowledging the backstay effect not as a secondary phenomenon, but as a core driver of lateral force behavior and seismic performance.

Incorporating basement depth and the interaction between podiums and multiple towers early in the design process helps improve the accuracy of the model and the building's overall performance.

Going forward, it's important to develop simple and reliable design methods and to keep validating advanced nonlinear models to ensure safer and more efficient podium-tower-basement structures.

REFERENCES

- [1] Parth G.Rathod, Sumant B.Patel and Pratiti M.Bhatt, "Backstay Effect on Tall Structures with Podium Structure -A Review", Indian Journal of Natural Sciences, Vol.14 / Issue 82 / Feb / 2024
- [2] Mahdi Karimi, Ali Kheyroddin and Hashem Shariatmadar , "Relationships for prediction of backstay effect in tall buildings with core-wall system", Advances in Computational Design, Vol. 5, No. 1 (2020) 35-54
- [3] Nirav Bhatu, Vishal B. Patel, Pratiti M. Bhatt, "Effect of Backstay on Tall Structures with Podium", SSRG International Journal of Civil Engineering, Volume 9 Issue 6, 47-61, June 2022
- [4] Champaneriya, Kishan B.; Patel, Vishal B.; Desai, Atul N. "Effect of Backstay on Tall Structure with Podium Structure" International Journal of Advanced Research in Science, Communication and Technology, Vol. 7, Issue 2, July 2021.
- [5] Solanki Chirag Lalit, Vishal Kumar B. Patel, Atul N. Desai, "Effect of Podium Configuration on Backstay Effect of Structure", International Advanced Research Journal in Science, Engineering and Technology, Vol. 10, Issue 5, May 2023
- [6] Nandi, Ankan Kumar; Jairaj, C. "Backstay Effect of Diaphragm in Tall Building" International Journal of Innovative Technology and Exploring Engineering (IJITEE), Vol. 9, Issue 3, Jan. 2020.
- [7] Restrepo, J. I. "Backstay Concepts in Buildings" Lecture material/White Paper, Nabih Youssef Associates, UC San Diego, 2000. (web or institutional material)
- [8] Khan, Iftekar S.; Shaikh, Sharif "Back-Stay Effect on Seismic Analysis of Tall Building" International Journal of Science and Advanced Research Technology, Vol. 9, Issue 5, May 2023.
- [9] Asher, Ankit M.; Zore, Vitthal D.; Murudi, Mohan M. "Seismic Performance Assessment of RCC Building with Podium" IOP Conference Series: Earth and Environmental Science, Vol. 1280, 2023.
- [10] Rangani, Hardik B.; Patel, V. R. "Effect of Backstay in Design of Tall Structure as Per IS 16700:2017" International Journal of Advanced Research in Science, Communication and Technology, Vol. 2, Issue 1, June 2022.
- [11] Yacoubian M, Lam N, Lumantarna E, Wilson JL. Effects of podium interference on shear force distributions in tower walls supporting tall buildings. *Engineering Structures*. 2017 Oct 1; 148:639-59.
- [12] J. Lee et al., "Modeling Flexible Diaphragms in Tall Buildings With Podiums," *Engineering Structures*, vol. 150, pp. 278-291, 2017.
- [13] R. K. Jain and K. Singh, "Nonlinear Pushover Analysis of Tall Buildings with Podiums Subject to Backstay Effect," *International Journal of Disaster Resilience in the Built Environment*, vol. 11, no. 3, pp. 343-360, 2020.
- [14] B. W. Kennedy, "Soil-Structure Interaction Effects on Tall Tower-Podium Systems," *Earthquake Engineering and Structural Dynamics*, vol. 48, 2019.
- [15] ACI Committee 318, *Building Code Requirements for Structural Concrete (ACI 318-19)*, American Concrete Institute, Farmington Hills, MI, 2019.
- [16] ASCE/SEI 7-22, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, American Society of Civil Engineers, Reston, VA, 2022.
- [17] Zhu, Y., et al. (2021). Influence of Basement Depth on Lateral Stiffness of Tall Structures. *Journal of Structural Engineering*, ASCE.
- [18] Patel, R., & Thakkar, S. (2022). Diaphragm Flexibility Analysis in High-rise Podium Buildings. *International Journal of Civil and Structural Engineering Research*.

[19] Gupta, D., et al. (2020). Comparative Analysis of Podium-Tower Systems Using Pushover Method. Engineering Science and Technology International Journal.

[20] Sharma, A., & Mehta, P. (2021). Parametric Study on Backstay Behavior in Tall RC Structures. Journal of Structural Engineering Research and Development.

