

Comprehensive Analysis Of Backstay Effect In Tall Buildings With Podiums And Basements

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Abstract—Podium-tower systems with basements govern modern tall building design for parking and commercial needs, yet their seismic performance depends on stiffness variations and diaphragm behaviors that standard fixed-base models fail to capture accurately. The backstay effect emerges as a critical factor: stiff basement walls or podium slabs provide lateral bracing to the tower—like cables on a ship's mast—altering shear paths, inducing reversal at interfaces, and boosting overturning resistance. This comprehensive ETABS study analyzes seven models of a 105m, 25-story RC building, systematically varying basement embedment (0-2 levels), podium configurations (slabs alone or with shear walls), diaphragm flexibility, and stiffness reduction under IS 16700's upper-bound (0.5 modifier), lower-bound (0.15), and code-specified cracked conditions. Key results show notable shear reversal and force redistribution from core walls to frames in flexible diaphragms, with basements governing backstay action over podiums unless stiffened. These findings emphasize realistic modeling of floor stiffness and sensitivity analyses for rational, economical seismic design as per Indian and international codes.

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

I. INTRODUCTION

Podium-tower systems have become fundamental to contemporary tall building design due to functional requirements such as parking, commercial spaces, and common amenities. While architecturally efficient, podiums and basements introduce significant stiffness variations along the building height, strongly influencing seismic force transfer mechanisms. Conventional fixed-base assumptions often fail to capture these effects accurately.

Stiff basements featuring peripheral retaining walls, or podium levels equipped with enhanced in-plane stiffness, serve as key lateral restraints to the upper tower structure in tall buildings—a behavior researchers term the backstay effect. This dynamic interaction fundamentally reshapes the building's response to lateral loads like earthquakes or wind: it redirects the overall load path from a simple vertical flow, triggers significant redistribution of shear forces across structural elements, and frequently produces shear reversal right at the critical tower-basement or tower-podium interface. Overlooking this phenomenon in design models can yield dangerously non-conservative estimates of shear demands underpredicting forces in lower elements and distort calculations of the structure's overturning resistance, potentially compromising safety and efficiency.

Recent international seismic design guidelines (e.g., ASCE 7, Eurocode 8), alongside India's IS 16700:2023 (Criteria for Structural Safety of Tall Concrete Buildings), explicitly emphasize the necessity for realistic modeling practices. These include accounting for diaphragm flexibility (how floors deform and transfer forces), stiffness reduction from concrete cracking under load, and the complex interplay between podiums, basements, and towers. Rather than depending on oversimplified fixed-base assumptions, this study conducts a systematic, numerical evaluation of the backstay effect. Using ETABS software, it develops detailed analytical models of representative tall RC buildings, methodically varying key parameters: basement depth (0-2 levels), podium geometries (slabs alone vs. shear wall additions), diaphragm properties, and cracked-section stiffness modifiers (upper-bound at 0.5, lower-

bound at 0.15, and code-specified values). This approach reveals how configuration choices govern force paths, enabling safer, more economical designs.

II. OBJECTIVES OF THE STUDY

The primary objectives of this study are as follows:

- To investigate the development of the backstay effect in tall buildings with podiums and basements.
- To evaluate the influence of basement embedment and podium configuration on lateral force redistribution.
- To study the role of diaphragm in-plane stiffness in activating or suppressing backstay behavior.
- To assess the sensitivity of force distribution under upper-bound, lower-bound, and code-specified stiffness modifiers.
- To identify governing stiffness conditions for the design of diaphragms, vertical elements, connecting beams, and primary tower components.

III. SCOPE, LIMITATIONS AND STANDARDIZED PARAMETERS

Scope

- The study is carried out using ETABS software with linear static analyses.
- Multiple analytical models represent variations in podium presence, basement configuration, and stiffness modifiers.
- Seismic loading as per IS 1893 (Part 1): 2016.
- Stiffness modifiers as per IS 16700: 2023 are assigned, including upper-bound and lower-bound cracked conditions.
- Key response parameters - shear distribution, diaphragm action, and force transfer mechanisms are evaluated.

Limitations

- Soil-structure interaction is not modeled; basement effects are represented through retaining wall stiffness contribution.
- Material nonlinearity of shear walls and frame elements is not considered beyond stiffness modifiers.
- The study is limited to a single representative building geometry to maintain consistency across models.

Table 1 Standardized parameters

Parameter	Value	ETABS Assignment	IS code References
Concrete	M40 (E=31.62 GPa)	Material properties	IS 456: 2000
Rebar	Fe500	Material properties	IS 456: 2000
Floor DL+LL	7.75 kN/m ²	Shell loads	IS 875 – Part 1 & 2
Seismic	Zone III, I _e =1.2, R=4	Loads Patterns	IS 1893 2016
Mass	100%DL + 25%LL	Mass source	IS 1893 Cl. 7.3.1
Modifiers (baseline)	Beams:0.35, Walls:0.7, Slabs:0.25	Frame/shell	IS 16700 Cl. 7.2, Cl. 8.1.3.2
P-Delta	Included	Analysis options	IS 16700 Cl. 7.2, Cl. 7.3.9

IV. DESCRIPTION OF ANALYSIS MODELS

A systematic numerical modeling framework comprising seven structural configurations is adopted to investigate the influence of lower-level structural systems and stiffness assumptions on the lateral response of the tower. The configurations are developed by progressively modifying the presence of basement and podium levels, the provision of podium shear walls, and the stiffness modifiers assigned to selected structural components. Except for the parameters intentionally varied between models, the geometry, material properties, mass source, and applied loading are maintained consistently to enable direct comparison.

Model 1: Baseline Tower Configuration

Model 1 represents the reference configuration and consists of a conventional 25-story reinforced concrete (RC) tower with an overall height of 105 m. The tower is supported on a fixed base, with rigid diaphragms assigned at all floor levels. The lateral-force-resisting system comprises the core shear walls and moment-resisting frames. No basement or podium levels are included.

Cracked-section stiffness modifiers are assigned in accordance with the adopted provisions of IS 16700:2023, with values of 0.25 for slabs, 0.35 for beams, 0.7 for columns and shear walls under strength

design conditions. Seismic parameters are defined in accordance with IS 1893 (Part 1):2016. The mass source, wind loads, and earthquake loads are kept identical across all configurations.

Model 2: Basement Addition

Model 2 extends the baseline configuration by introducing two basement levels below the tower footprint, each having a maximum story height of 3.5 m. Peripheral retaining walls are modeled using shell elements along the basement perimeter.

The tower configuration, material properties, loading conditions, mass source, and remaining modeling assumptions are retained from Model 1. The model is used as the primary basement configuration for comparison with the baseline tower and subsequent lower-level configurations.

Model 3: Podium and Basement Integration

Model 3 is developed by adding three podium levels between the basement and tower, with a maximum story height of 4.2 m for each podium level. Podium slabs are modeled using shell elements without rigid diaphragm constraints. Podium columns are incorporated as frame elements, while the basement retaining walls remain consistent with Model 2. All other modeling parameters are maintained unchanged. This configuration provides a combined basement-and-podium arrangement for comparison with the basement-only configuration.

Model 4: Enhanced Podium Stiffness

Model 4 modifies Model 3 by introducing shear walls along the podium edges, positioned above the basement retaining walls. The additional walls are modeled using shell elements, while the remaining podium and tower components retain the assumptions adopted in Model 3.

The purpose of this configuration is to isolate the effect of introducing additional vertical stiffening elements within the podium region.

Model 5: Podium-Only Configuration

Model 5 is derived from the baseline tower by introducing three podium levels without providing basement levels. The podium slabs are modeled using shell elements without rigid diaphragm constraints, consistent with Model 3. No peripheral shear walls are introduced within the podium.

The configuration is used to examine the podium system independently of the basement retaining-wall system.

Model 6: Upper-Bound Stiffness Case

Model 6 adopts the same geometric configuration as Model 2 but uses higher stiffness modifiers for the diaphragms and perimeter walls. A stiffness factor of 0.50 is assigned to these components to represent the upper-bound stiffness condition adopted for the sensitivity study.

All remaining geometry, material properties, loading conditions, mass source, and modeling assumptions are maintained consistent with Model 2.

Model 7: Lower-Bound Stiffness Case

Model 7 also follows the geometric configuration of Model 2 but adopts reduced stiffness modifiers of 0.15 for the diaphragms and perimeter walls. This configuration represents the lower-bound stiffness condition considered in the sensitivity assessment.

Except for the specified stiffness modifiers, all other parameters are maintained consistent with Model 2.

V. METHODOLOGY

This study implements a rigorous numerical framework in ETABS 22.1.0 following IS 16700:2023 prescriptive requirements for tall RCC buildings. The analysis sequence systematically isolates backstay effects while ensuring parametric consistency across configurations.

Backstay Assessment Methodology and Sensitivity Study:

Potential backstay elements capable of providing unintended lateral restraint to the primary tower structure were first identified from the overall structural configuration. These elements included basement retaining walls, podium slabs, connecting links, and foundation restraints that may participate in the lateral load-resisting mechanism despite not being intended as part of the primary seismic-force-resisting system. Since the presence and stiffness of such elements can significantly alter the dynamic characteristics and force distribution within the structure, a systematic sensitivity study was undertaken to quantify their influence on structural behaviour.

A reference finite element model was developed representing the intended structural system in accordance with the modeling requirements of IS 16700:2023. The model incorporated appropriate cracked-section stiffness modifiers for beams, columns, walls, and slabs, realistic diaphragm assumptions, gravity and lateral loading, and second-order ($P-\Delta$) effects. The baseline condition considered wall stiffness of $0.7I_g$, beam stiffness of $0.35I_g$, and slab stiffness of $0.25I_g$, consistent with the code provisions for structural design.

To evaluate the influence of unintended restraints, a series of sensitivity models were generated by modifying the identified backstay components. The investigated cases included complete removal of restraint, reduced stiffness conditions representing partially cracked behaviour, and alternative support or boundary assumptions. In addition, diaphragm modelling variations were considered, including rigid diaphragms at tower floors, semi-rigid diaphragm behaviour within podium regions, and shell-based representations of retaining walls and basement structures. Upper-bound and lower-bound stiffness scenarios were established in accordance with IS 16700:2023 Clause 8.1.3.2 to capture the likely range of structural response.

Each analytical model was subjected to identical gravity, wind, and seismic loading conditions. Modal analysis and response spectrum analysis were performed to evaluate the global dynamic characteristics, while maintaining a consistent mass source and loading framework across all models. For the tower part, the fundamental period and lateral force distribution were initially established using a standalone tower model.

The effect of backstay elements was quantified through comparison of major global response parameters, including fundamental natural period, modal participation ratios, storey displacement behavior, inter-storey drift ratios, storey shear distribution, base shear, overturning moment, and torsional response. Additional validation checks were performed using storey stiffness ratios, code-prescribed period limits, and serviceability and ultimate drift requirements. The results were further supplemented by examination of diaphragm strains, shear reversals response characteristics to identify changes in overall structural behaviour caused by variations in restraint conditions.

A detailed comparison of member-level force demands was also undertaken for critical structural components, including shear walls, coupling beams, columns, and foundation systems.

The results demonstrated that unintended restraint elements can materially influence both global dynamic response and local force demands by increasing lateral stiffness, reducing structural periods, altering diaphragm load transfer, and redistributing seismic and wind-induced forces between primary and secondary structural systems. Consequently, reliance on such restraint mechanisms may lead to unconservative estimation of design actions if not explicitly accounted for during analysis.

Table 2. Summary of Structural Models and Analysis Cases

Model	Configuration	Stiffness Case	Analysis Type
1-5	Varying geometry	Baseline	ESA/RSA
6	Basement (Model 2)	Upper-bound	ESA/RSA
7	Basement (Model 2)	Lower-bound	ESA/RSA

ESA- Equivalent Static Analysis

RSA- Response Spectrum Analysis

VI. RESULTS AND DISCUSSION

A. Baseline Behavior -Model 1

Model 1 produces Model 1 establishes the reference lateral-force distribution against which the remaining configurations are evaluated. Under the applied static seismic loading, the lateral shear demand in the core walls varies progressively along the height of the tower.

As illustrated in Figure 1, the wall shear follows a continuous distribution from the upper levels toward the foundation without an abrupt change in response. Since the baseline configuration does not contain a basement or podium interface, no lower-level stiffness discontinuity is introduced into the structural system. This response provides the reference condition for identifying changes in force distribution associated with the introduction of lower-level structural systems in the subsequent models.



Figure 1 Shear force in wall

B. Effect of Basement Addition – Model 2

The introduction of the two basement levels in Model 2 produces a distinct change in the lateral-force distribution compared with the baseline configuration. The larger plan dimensions of the basement and the presence of peripheral retaining walls provide additional structural components through which lateral forces can be transferred.

As shown in Figure 2, a reversal in wall shear occurs at the tower-basement interface. The change in force direction indicates interaction between the tower and the stiffer lower-level system.

The basement retaining walls participate significantly in resisting the lateral demand, with a substantial portion of the total base shear being transferred through the basement system.

The lowest connected tower level experiences the highest diaphragm force associated with this transfer. The basement diaphragms subsequently distribute the force toward the peripheral retaining walls.

The resulting restraint to tower overturning reduces the shear demand in the upper tower walls relative to the corresponding response of Model 1.

This behavior demonstrates the backstay effect generated by the basement system, whereby the larger and stiffer lower-level structural system modifies the distribution of lateral forces within the tower.

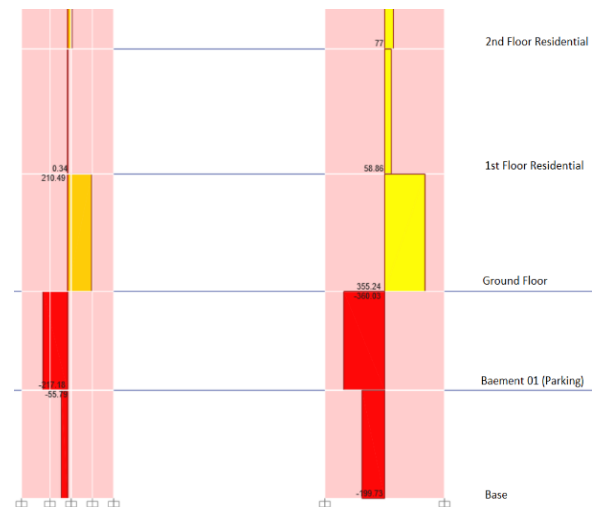


Figure 2 Shear force reversal at the tower-basement interface

C. Podium Performance – Model 3, 4 & 5

Model 3 incorporates three podium levels above the basement system. The addition of the podium changes the sequence through which lateral forces are transferred between the tower and the basement.

The podium columns contribute to the lateral-force resistance, while the basement retaining walls continue to provide the principal lower-level resistance. The podium slabs, modelled without rigid diaphragm, undergo in-plane deformation and therefore provide comparatively limited restraint to the tower.

As illustrated in Figure 3, the major change in force distribution remains concentrated around the basement area rather than being uniformly distributed through the podium levels.

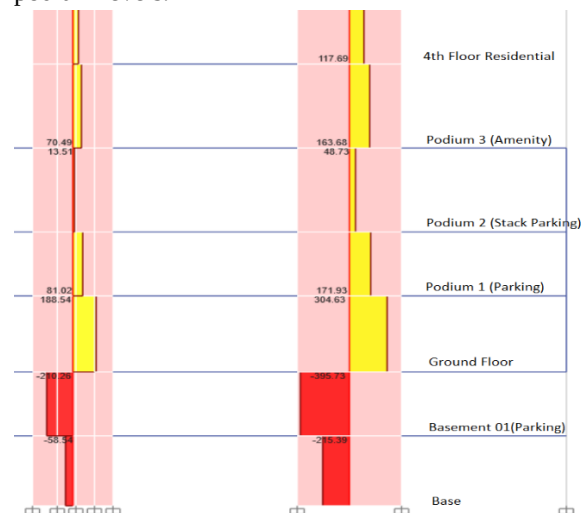


Figure 3. Shear force diagram for structure with basement and podium configuration

Model 4 has shear walls along the podium edges, which increases the vertical stiffness of the podium region.

This result shows a force distribution with a greater participation of the podium region when compared with Model 3. The stiffened podium region contributes significantly to the overall lateral resistance. The shear walls that were added at the podium edges provide a more direct load path between the tower and the lower-level structural system.

The result indicates that a podium can develop a backstay contribution as shown in Figure 4, when sufficient vertical and in-plane stiffness is provided. Thus, the effectiveness of the podium is governed not only by its presence but also by the stiffness and continuity provided by the lateral-load-resisting elements.

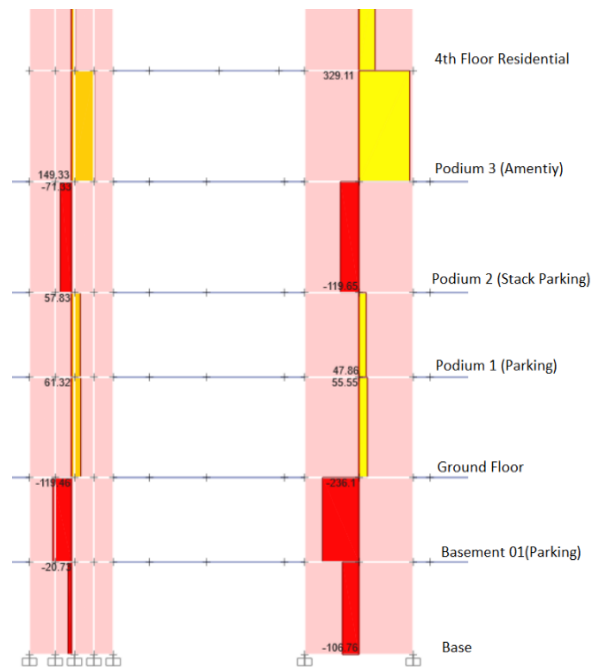


Figure 4. Shear force reversal at the tower-basement and tower-podium interface with introduction of podium-edge shear wall

In Model 5, the podium effect was isolated by removing the basement system while retaining three podium levels. In the absence of basement retaining walls and peripheral podium shear walls, the podium provides limited restraint to the tower. The lateral demand is mainly distributed through frame action, and the shear-reversal pattern that was present in Model 2 is not observed here.

The comparison between Models 3 to 5 indicates that the contribution of a podium is mainly dependent on its

stiffness and connectivity to the tower. A conventional podium without proper stiffening elements provides considerably less restraint than a configuration with stiff vertical elements or basement retaining walls.

D. Stiffness Sensitivity Analysis - Model 6 & 7

Models 6 and 7 are used to determine the impact of the assumed stiffness of diaphragms and perimeter walls on the lateral-force distribution.

Model 6: Upper-Bound Stiffness Case

In Model 6, a stiffness modifier of 0.50 has been adopted for the diaphragms and perimeter walls. This resulted in increased stiffness, which in turn led to the greater participation of the wall system in resisting lateral forces.

The corresponding force transfer through the diaphragm and collector elements for the upper-bound stiffness case is illustrated in Figure 5.

The core walls carry the major portion of the total shear. The relatively stiff diaphragms provide a more effective transfer of force between the tower and the vertical resisting elements.



Figure 5 Forces transfer through diaphragm and collector elements for the upper bound stiffness case

Model 7: Lower-Bound Stiffness Case

Model 7 has a reduced stiffness modifier of 0.15 for the diaphragms and perimeter walls. The reduction in stiffness increases the flexibility of the lower bound and alters the participation of walls and frames. The resulting reduction in forces transferred through the diaphragm and collector elements for the lower-bound stiffness case is illustrated in Figure 6.

The perimeter frames show greater participation in resisting the total shear, while the contribution of the core wall system decreases. This indicates a redistribution of lateral forces from the wall system toward the frame system.

distribution of lateral forces between the wall and frame systems.

4. Modeling Essential: Shell-based semi-rigid diaphragms capture realistic force transfer not represented by rigid diaphragm assumptions

Table 4. Comparative Summary of Shear Redistribution and Backstay Effects Across Structural Models

Model	Structural Configuration	Backstay Interface	Shear Behaviour	Observation
Model 1	Tower only	None	Continuous increase toward base	Conventional cantilever behaviour. No shear reversal observed.
Model 2	Tower + Basement	Basement	Strong shear reversal	Basement retaining walls attract significant earthquake shear with strong shear reversal, reducing tower-wall shear demand.
Model 3	Tower + Podium + Basement	Podium & Basement	Moderate shear redistribution	Basement dominates the backstay effect, while podium contributes limited restraint.
Model 4	Tower + Stiffened Podium + Basement	Podium & Basement	Pronounced shear reversal	Podium shear walls activate backstay action and substantially increase lateral restraint.
Model 5	Tower + Podium	Podium	Minor redistribution	Without basement restraint and a stiff podium, the podium provides limited backstay action.
Model 6	Tower + Basement Upper-Bound Stiffness	Basement	Maximum shear concentration	Higher diaphragm and perimeter-wall stiffness increases core-wall participation.
Model 7	Tower + Basement Lower-Bound Stiffness	Basement	Reduced wall shear	Flexible diaphragm redistributes earthquake forces toward perimeter frames.

VII. CONCLUSIONS

1. **Basement Backstay Effect:** Basement retaining walls provide significant backstay restraint to the tower and alter the lateral-force distribution through the development of shear reversal and force transfer at the tower-basement interface.
2. **Podium Contribution:** Podium slabs alone provide limited backstay restraint when modelled without stiff diaphragm action. Greater podium participation is achieved when shear walls are provided along the podium edges and connected effectively with the lower-level structural system, as demonstrated in Model 4.
3. **Stiffness Sensitivity analysis:** The stiffness assumptions specified in IS 16700 for diaphragms and perimeter walls significantly influence the distribution of lateral forces. The upper- and lower-bound cases show that the force distribution associated with the backstay effect varies with the assumed stiffness.

4. **Diaphragm Modelling:** Shell-based semi-rigid diaphragm modelling provides a more realistic representation of in-plane force transfer through diaphragms and collector elements compared with rigid diaphragm assumptions.

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