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Effect of Podium Configuration on Backstay Effect of Structure

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Abstract: Nowadays, Due to the increasing population and limited land availability, tall buildings have become a necessary feature in metropolitan areas. As a result, vertical expansion is often a more affordable and practical option than spreading out horizontally, particularly when considering proximity and accessibility to the city. Diaphragms function as lateral load-resisting systems by connecting the joints of a floor, thereby transferring inertial forces from one structural element to another. The podium's underground perimeter walls and diaphragm function together as a rigid box system. That enhances the lateral load resistance. The podium develops an internal resisting couple that produces an effect called the backstay effect, and its action is balancing in nature against the acting lateral forces, generated by wind and seismic activity. This article examines multi-Storey models that incorporate spring action at the podium level and investigates the effect of different podium shapes and grading in a vertical direction in accordance with IS: 16700:2017, "Criteria for Structural Safety of Tall Concrete Buildings," India, Bureau of Indian Standards, 2017. The study finds that semi-rigid action at the podium level enhances the backstay effect in comparison to traditional rigid action. Furthermore, the investigation shows that the podium shape and grading improve the shear-reversal effect, leading to reduced base shear and base moment.

Keywords: Back-stay effect, tall structures, large podium structures, shear-reversal.

I. INTRODUCTION

The 21st century has seen a surge in land prices and a growing desire to live in proximity to the urban centres that have led to a surge in vertical development in building infrastructure. As land within the city becomes increasingly expensive for horizontal development such as row houses or bungalows. Hence people are forced to look for alternative, affordable housing options that offer easy access to urban amenities. This trend has resulted in taller buildings that maximize the use of available space and offer more living units per square meter, Municipalities & corporations have also shown a preference for this type of development, as it enables efficient use of land and infrastructure and can help to reduce urban sprawl. The popularity of vertical building development is expected to continue in coming years, as more and more people seek out affordable and convenient housing options in urban areas.

With the concept of tall buildings has revolutionized urban development, but it has also brought new challenges that need to be addressed. One of the most significant challenges is the impact of wind forces on tall buildings. As a building gets taller, it is more susceptible to wind loads that can cause swaying and structural instability. To combat this, engineers design building with reinforced cores and exterior systems that can withstand high wind loads. Additionally, the seismic loads mainly lateral loads can also pose a significant challenge for tall buildings. As lateral forces can cause a building to potentially sway and collapse. Engineers mitigate these forces by using damping structures as base isolation and other structural measures. While tall building offers numerous benefits, it is important to address these challenges to ensure their safety and structural stability.

II. LITERATURE REVIEW

Nirav D. Bhatu et al.,[4] (**2022**) the Author discussed the structural performance of diagrid structures in tall buildings. They presented the characteristics of diagrid systems, focusing attention on the structural behaviour under gravity and lateral load and reviewing strength-based and stiffness-based design criteria. They also carried out the comparative analysis of the structural performance of some recent diagrid tall buildings Bhatu made a series of 16 models in total,

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with each model comprising a common podium tower with varying podium height, some comprising of purifier shear wall. Increasing no. of towers from a single tower with a podium to multiple towers with common podium-type structures, the top Storey displacement of the structure decreases. The increase in height of the Podium in towers with podium type of structures leads to an increase in Storey Shear at the main backstay diaphragm level. By increasing the no. of podium Storey, the Reversal of shear increases at the main backstay diaphragm level. It is observed that in Multiple towers with a common podium with a shear wall at the periphery of the podium and without a Shear wall at the periphery of the podium, the difference in Reversal of the Shear is small such as (3 to 6) %.

Yacoubian et al.,[31] (**2017**). Two models of a centrally positioned high-rise tower & an offset (edged) high-rise tower was studied. The finite element method assuming linear elastic behaviour & non-elastic behaviour was studied. Rigid diaphragm assumptions typically enforced in the design and assessment of high-rise buildings were assessed in the light of the podium-tower interferences as described. It was found that such (commonly used) assumptions may lead to a conservative representation of the shear force in the tower walls of a building. The author recommends Consideration of interactions between primary and secondary gravity systems in the lateral analysis of the type of buildings considered in this study.

Kishan B. Champaneriya et al., [5] (**2017**). In this paper, the scope of the authors was to understand the logical and reasonable behaviour of tower podium kind of structures under horizontal loads considering the effect of backstay/shear reversal as per IS: 16700 (2017). Sensitivity analysis was carried out as per Indian standards IS: 16700 (2017) provisions by considering the stiffness parameters given in code to understand the changes in the shear force assignment among structural components, when the tower and Podium are designed together & the changes in force assignment were compared with building structures without shear reversal effect. It concluded that with an increase in height of the podium/number of podium Storey backstay effect also increases. It was also deduced that the shear reversal effect and resistance to overturning moment increase with an increase in the thickness of the podium diaphragms and the area of the podium

III. BACK STAY EFFECT

The Backstay effect can cause a phenomenon called shear reversal in building structures, where the direction of the shear force is reversed due to the presence of large podium structures. Podium structures are susceptible to lateral loads such as wind or earthquake loads. Without a back-stay system, the tower super-structure above the podium would sway and deform under lateral loads, creating large shear forces at the base of the tower. Backstay offers extra lateral support to the system, allowing the shear force to change course and act in reverse, from the podium to the base of the building, by reducing the amount of shear exerted on the building and transferring the lateral shear to the perimeter walls.

A. *Membrane Floors*

In E.T.A.B.S, a membrane element is a structural support element that does not consider in-plane stiffness, meaning that the entire load applied to the slab in the form of Dead load, Live load, Superimposed load, or Floor finish is purely distributed as per the load distribution pattern described earlier, without any in-plane bending of the slab. This implies that a membrane element has zero theoretical bending stiffness. However, a membrane element is not effective in distributing loads to supporting columns without beams and walls, making it unsuitable for use in a flat slab system.

B. *Thin-Shell*

Thin-shell elements in E.T.A.B.S incorporate in-plane bending stiffness when distributing loads to supporting elements. This means that the load is distributed based on the relative stiffness of the supporting elements, although the actual distribution may not exactly match the theoretical distribution. The key distinction from the membrane element is that thin-shell elements also take into account out-of-plane bending.

Table I Shell Element Properties

Property of slab	In-plane bending	Out plane bending
Membrane	Yes	No
Shell	Yes	Yes
Rigid	No	Yes
Semi-Rigid	Yes	Yes

C. *Diaphragm Constrain*

The distribution of loads across a floor system is influenced by several factors, including the type of materials used, the spacing, the orientation of the structural elements, and the anticipated weight and usage of the space. Each diaphragm constraint connects a set of two or more joints. The joints may have any arbitrary location in space, but for best results,

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all joints should lie in the plane of the constraint. Floor diaphragms can be classified as rigid, semi-rigid or none at all. Rigid diaphragms assume that the floor plate moves in a planar direction and rotates about a vertical axis as a rigid body, disregarding in-plane deformations. This approach is computationally efficient but neglects in-plane deformations in diaphragm shear stresses or axial forces in horizontal members. Semi-rigid diaphragms have some stiffness and can resist in-plane deformations, allowing the entire body to rotate as a semi-rigid material and translate. Flexible diaphragms can transfer lateral loads to supporting members based on the tributary area. Multi-tower systems may use more than one rigid or semi-rigid floor diaphragm at a given Storey, subject to wind. A diaphragm is considered flexible if the midpoint displacement under lateral load exceeds twice the average displacement of the end supports.

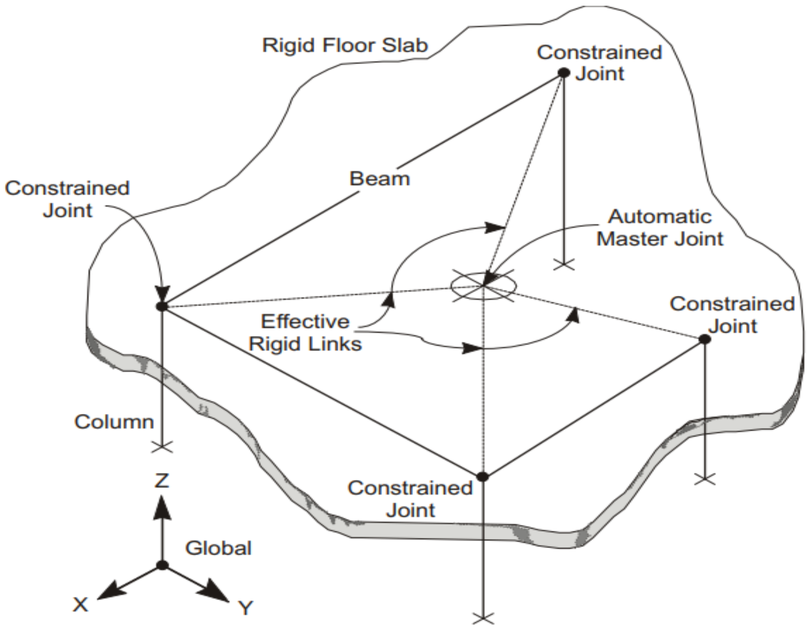

Figure 1 Diaphragm Constrain

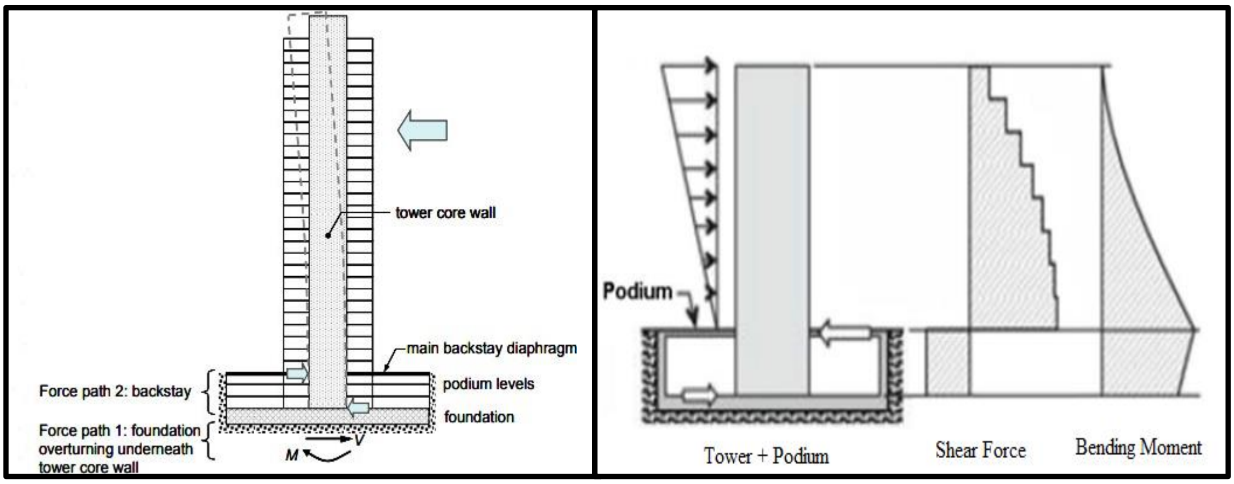

Figure 2 Back-Stay Effect

IV. STRCUTURAL DATA OF MODELLING

The focus of the current study is a 15-story building with a tower plan dimension of 25m x 25m and a podium size of 55m x 55m. The study considers various structural formations of podium design, and multiple models are prepared and analysed using the structural analysis and design tool E.T.A.B.S. The structures are analysed using static earthquake analysis and static wind response. Tables 2.1 and 2.2 provide sectional properties, loads, and seismic factors.

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The Backstay effect is a significant phenomenon that impacts the stability and safety of podium structures. To gain a better understanding of this effect, two models were developed: A) the hinged propped cantilever model and B) the spring cantilever model. Previous studies assumed hinged support to achieve the back-stay effect. In the present study, the author used a spring condition (where the story stiffness equals the spring stiffness) to simulate the soil support reaction condition.

To assess the impact of backstays on various podium designs, several models have been created. These models' details are: -

Table II Sectional Properties

Section	Properties
Size of beam	300mm X 600mm
Size of column	750mm X 750mm
Shear-wall thickness (core)	400mm
Shear wall thickness (peripheral)	350mm
Slab thickness	125mm, 150mm
Grade of concrete	M40
Grade of steel (Rebar)	Fe500

Table III Loading Parameters

Gravity & Lateral load Parameters	Factors
Dead load	1.5 kN/m^2
Live load	3 kN/m2
Wall load	12.42 kN/m
Parapet wall load	2.2 kN/m
Seismic zone	III
Seismic coefficient (zone factor)	0.24
Response reduction factor	5
Importance factor	1.2
Soil conditions	Medium
Wind Speed, V_b	50 m/s
Terrain Category	1
Risk Coefficient, k_1 Factor	1
Topography, k_3 Factor	1
Importance Factor	1
Windward Coefficient, C_p	0.8
Leeward Coefficient, C_p	0.5
Parapet Height	1 m

Model List,
Model A) Square Shaped Hinged Vs Podium Model
Model B) Square-shaped podium model.
Model C) Rectangular-shaped podium model with a complete retaining wall longer side (X-direction).
Model D) Rectangular-shaped podium model with a complete retaining wall longer side (Y-direction).
Model E) Rectangular-shaped podium model without a complete retaining wall longer side (X-direction).
Model F) Rectangular-shaped podium model with a complete retaining wall longer side (Y-direction).
Model G) Triangular-shaped podium model with a square-shaped tower.
Model H) Triangular-shaped podium model with square-shaped tower (back facing).
Model I) Triangular-shaped podium model with a triangular-shaped tower.
Model J) Triangular-shaped podium model with triangular-shaped tower (back-facing).
Model K) Hexagonal-shaped podium model.
Model L) Circular-shaped podium model.
Model M) Octagonal-shaped podium model.

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In this study, we use a grading scale of 10%, 20%, and 30%, as well as a non-grading model, to compare different models based on the cumulative increase in podium size. The investigation focuses on the relatively new concept of the multistep back-stay effect. By comparing the models, we aim to gain insight into their relative strength, weakness, stiffness, shear force, and drift criteria and determine which one is most effective in modelling the multi-step backstay effect. The ultimate goal of this research is to contribute to a better understanding of this complex phenomenon and improve future modelling efforts.

Isometric Views of all the models are as follows: -

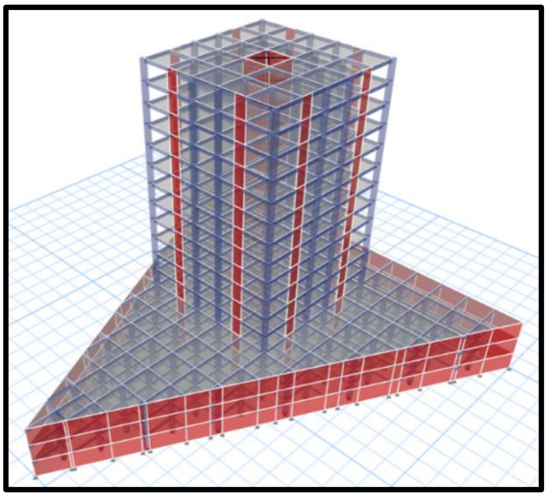

Figure 3 Triangular-shaped podium model with a squared-shaped tower.

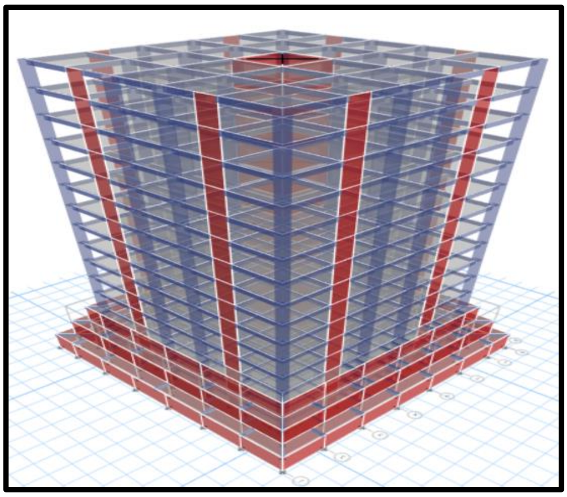

Figure 4 Podium structure model with 10% grading

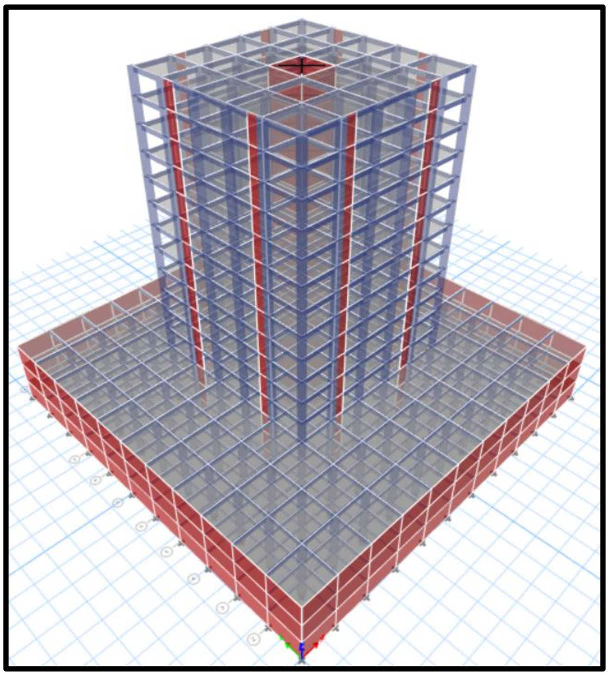

Figure 5 Squared Shaped Podium

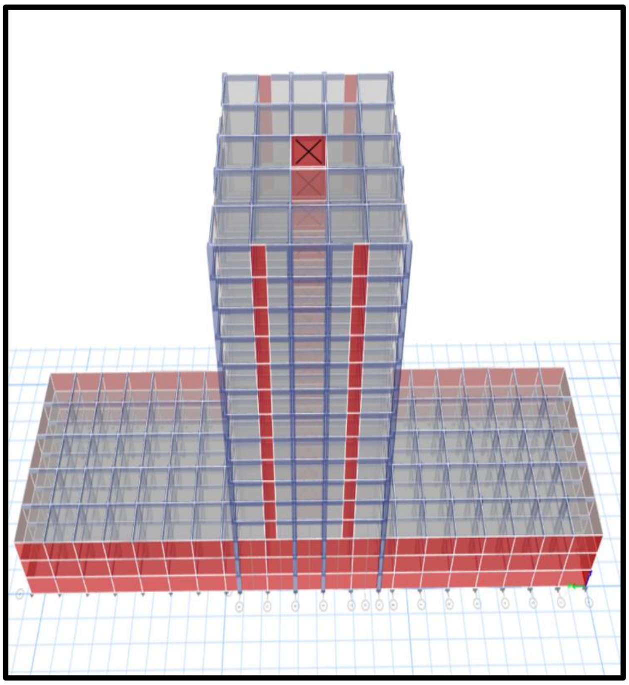

Figure 6 Rectangular-shaped podium model with a complete retaining wall on the longer side (Y-direction)

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V. RESULT & DATA ANALYSIS

This paper presents the results of a numerical investigation of several structural models created in the E.T.A.B software. The study evaluates the top storey displacement, storey shear(s), reversal of shear force at the main backstay diaphragm level, and reduction in an overturning moment due to the Backstay effect for each model. The equivalent static wind force technique was used to assess various parameters along the Global X-axis. The findings are then represented graphically and elaborated upon.

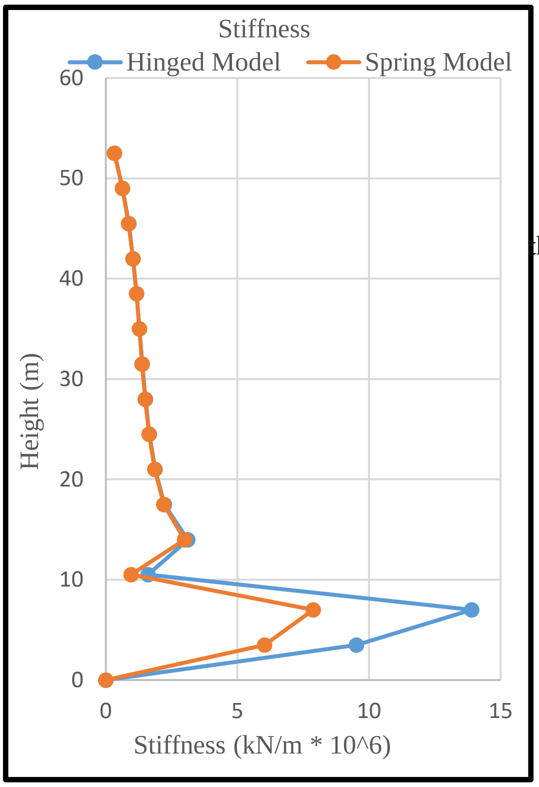

Figure 9 : Stiffness Graph (kN/m *10^6)

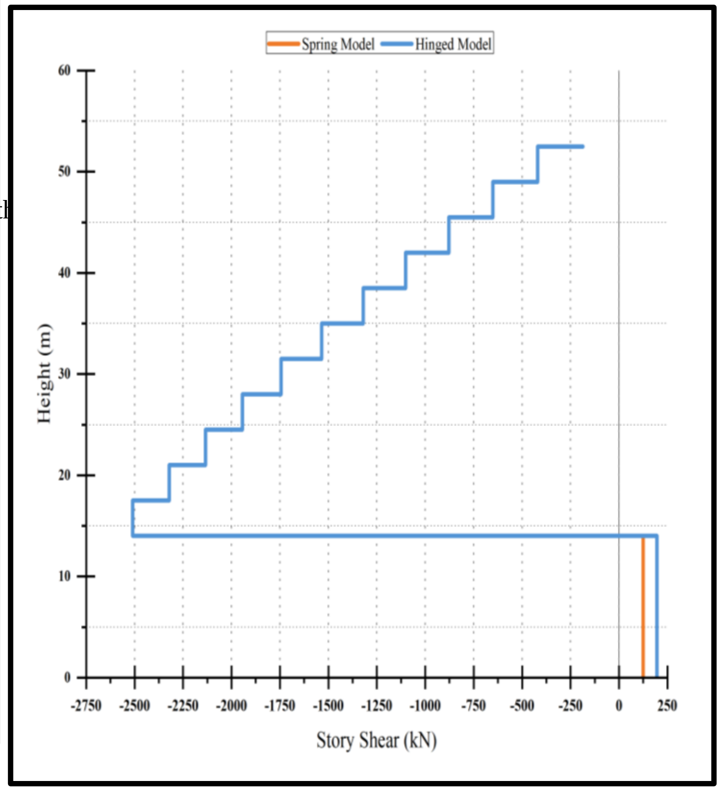

Figure 8 Storey Shear

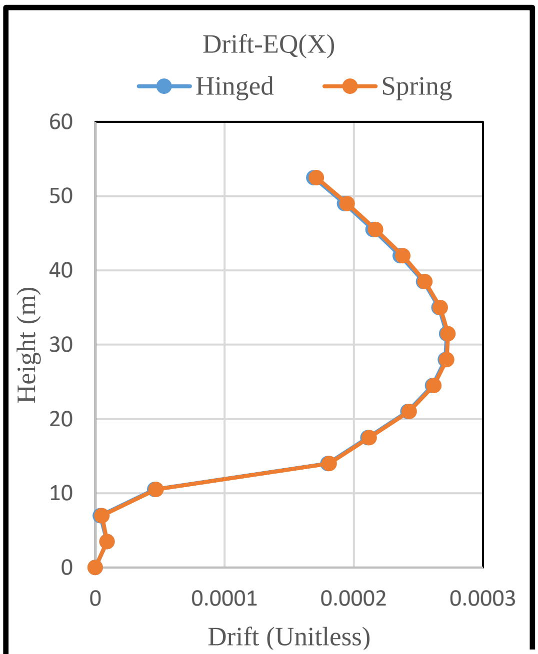

Figure 10 Storey Drift for EQ-(X)

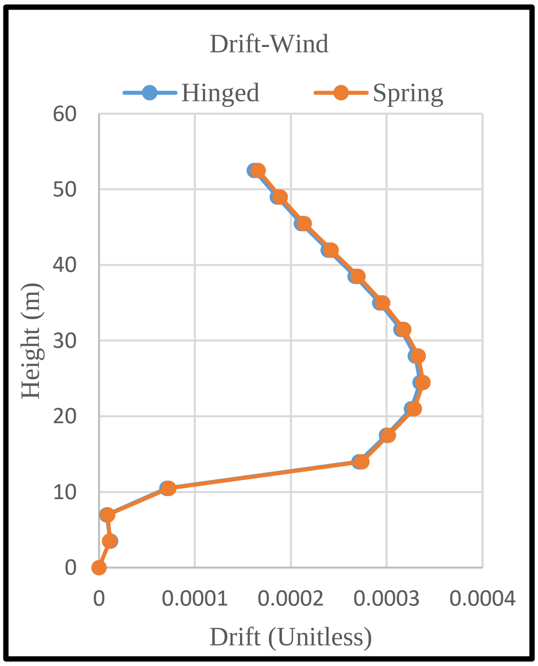

Figure 11 Storey Drift for Wind-(X)

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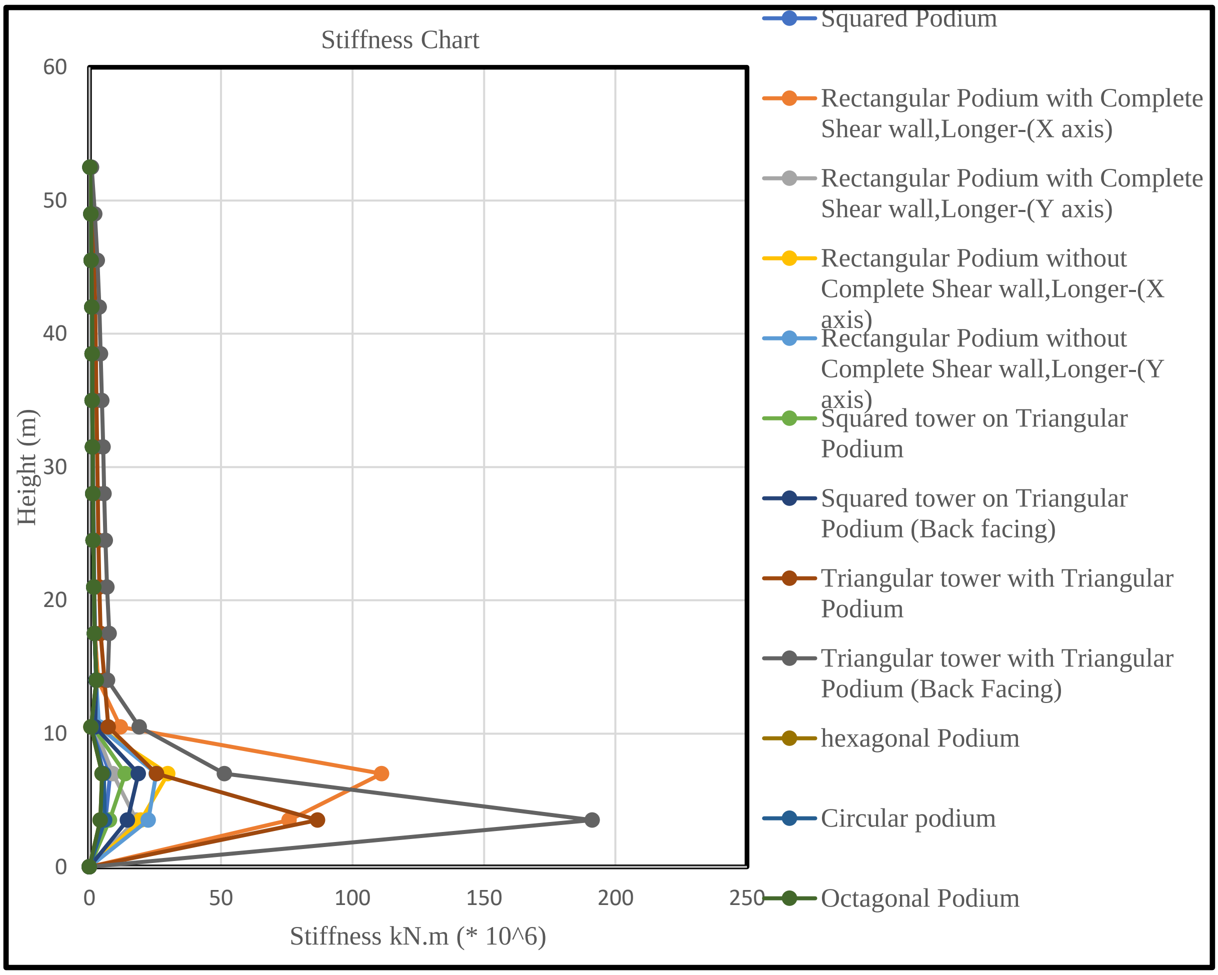

Figure 12 Stiffness Chart for Different Podium Designs

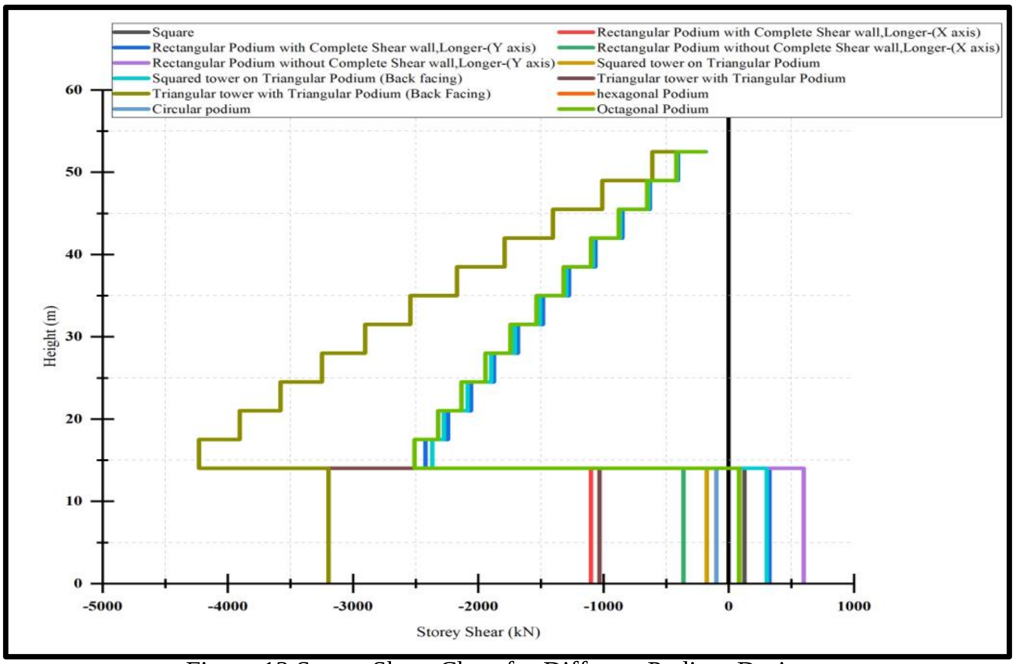

Figure 13 Storey Shear Chart for Different Podium Designs

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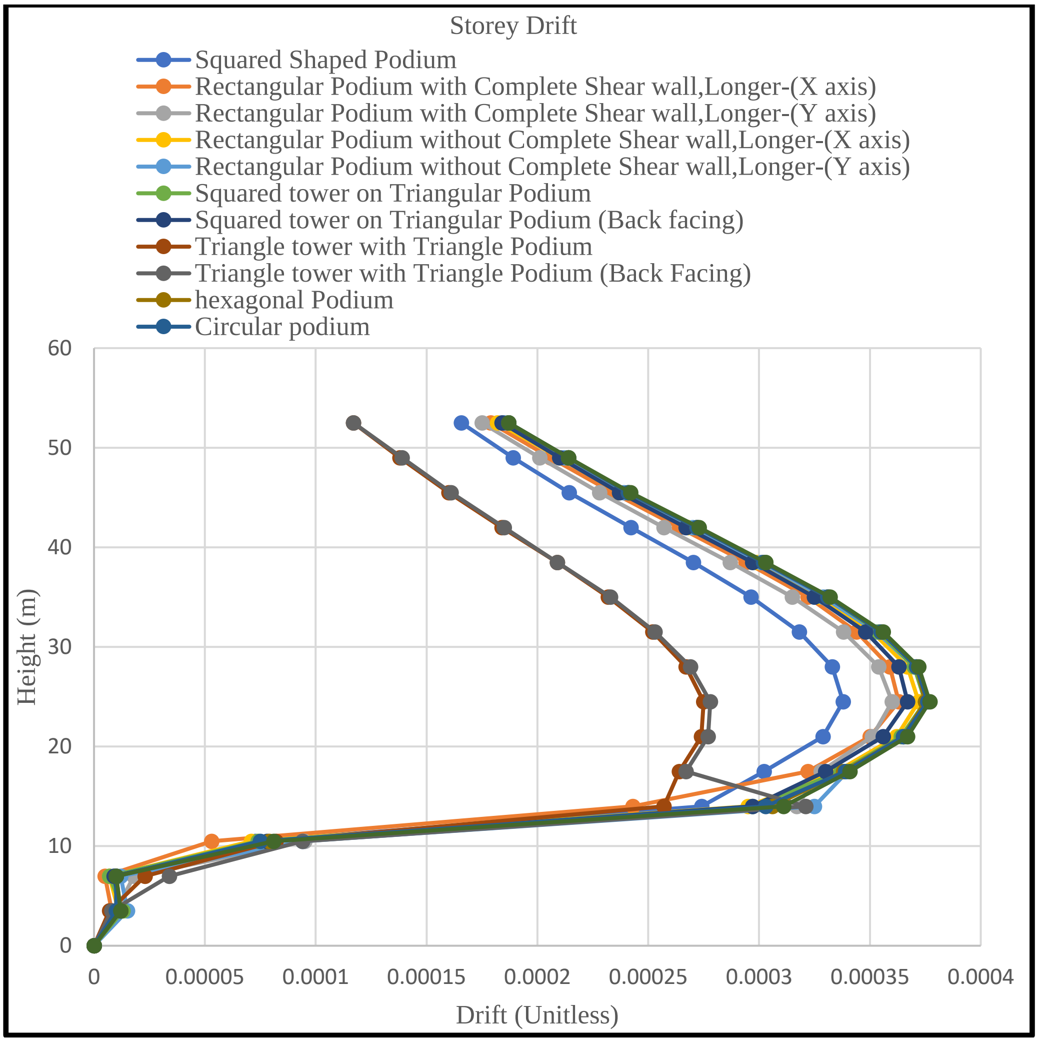

Figure 14 Storey Drift for Different Podium Design

Table IV Podium Stresses

Stresses at Podium Interface			
Different Podium Designs	F11(kN/m)	SV(Mpa)	S11(Mpa)
Square shaped podium	155	0.02	1.7
Squared tower on Triangular Podium	166.032	0.03	1.42
hexagonal Podium	187.024	0.26	2.01
Octagonal Podium	219.995	0.05	2.11
Circular podium	173.874	0.03	1.89
Squared tower on Triangular Podium (Back facing)	169.399	0.02	1.84
Rectangular Podium without Complete Shear wall, Longer- (X-axis)	174.17	0.02	1.91
Rectangular Podium without Complete Shear wall, Longer- (Y axis)	216.269	0.03	2.1
Rectangular Podium with Complete Shear wall, Longer- (Y axis)	316.858	0.03	2.32
Triangle Tower with Triangle Podium	207.416	0.14	2.91
Triangle tower with Triangle Podium (Back Facing)	229.248	1.8371	7.99

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Table V Deflection Table

Deflection table (mm)	
Square shaped podium	11.45886
Rectangular Podium with Complete Shear wall, Longer- (X-axis)	12.182
Rectangular Podium with Complete Shear wall, Longer- (Y axis)	12.345
Rectangular Podium without Complete Shear wall, Longer- (X-axis)	12.619
Rectangular Podium without Complete Shear wall, Longer- (Y axis)	12.832
Squared tower on Triangular Podium	12.766
Squared tower on Triangular Podium (Back facing)	12.538
Triangle Tower with Triangle Podium	9.247
Triangle tower with Triangle Podium (Back Facing)	9.486
hexagonal Podium	9.485
Circular podium	12.806
Octagonal Podium	12.877

For Podium Grading,

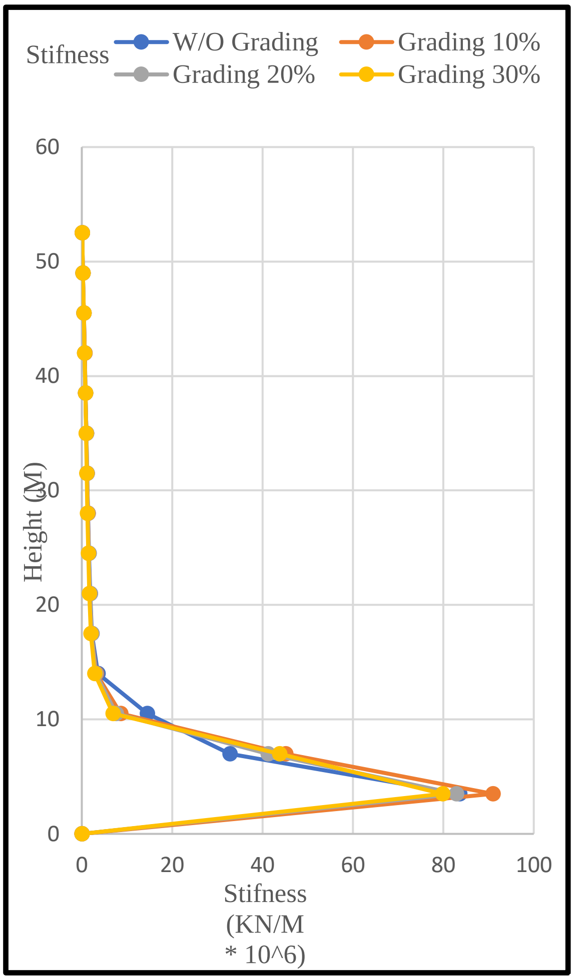

Figure 15 Stiffness chart (Grading)

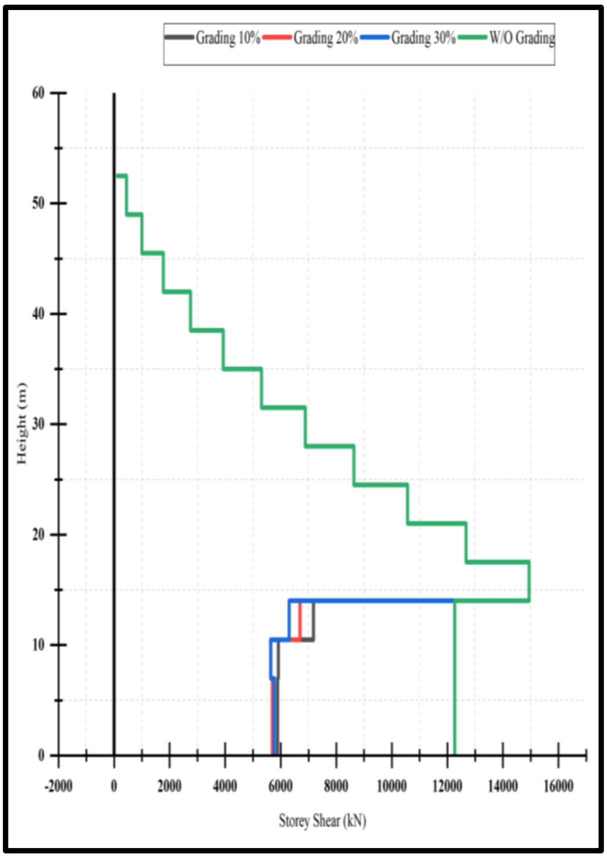

Figure 16 Storey Shear Chart (Grading)

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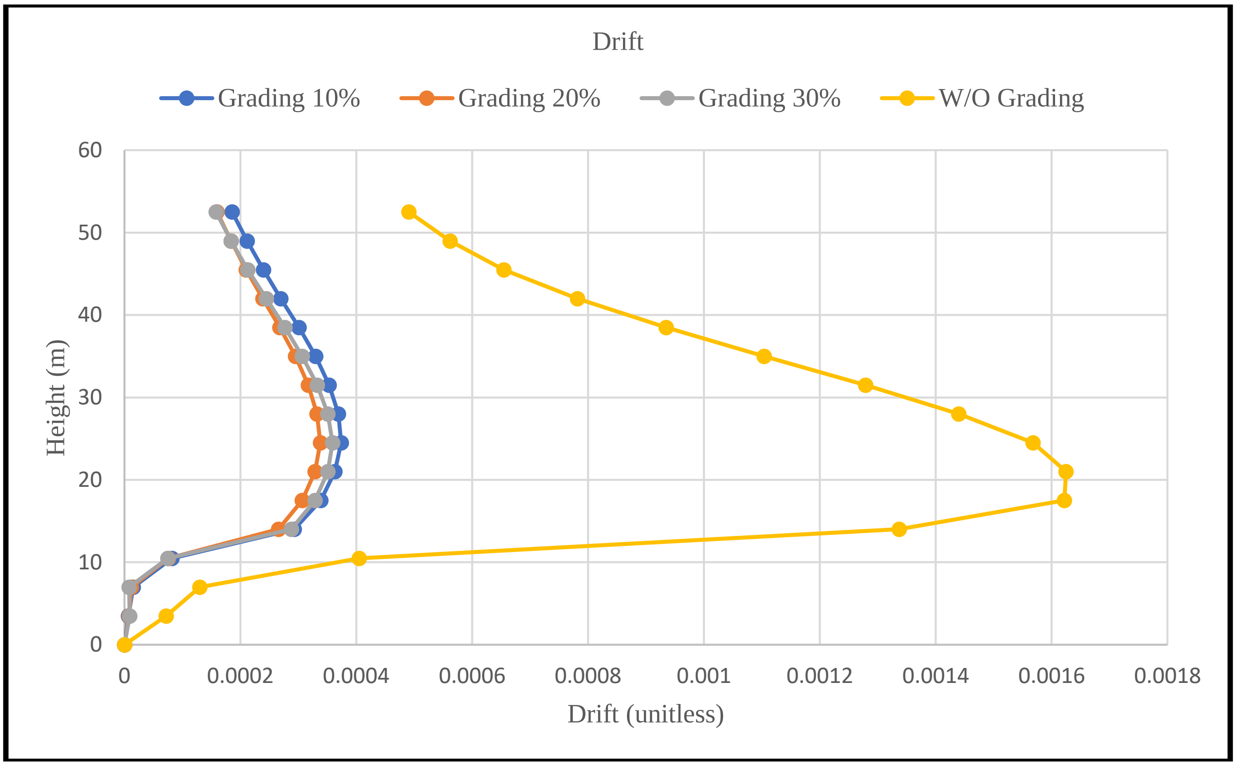

Figure 17 Drift (Grading)

VI. CONCLUSION & DISCUSSION

While the difference in overturning moments between the two models is relatively small i.e., 3.49%, the difference in shear force is larger i.e., 36.26% (Figure 8). Consequently, the methodology of the propped spring model is used for all of the examined models.

The soil in which the podium is embedded provides the reaction for the structure. The stiffness chart (Figure 7) reflects the elastic behaviour of the soil with the relative stiffness of the cantilever spring model being lower. Additionally, the use of spring support helps to emulate the elastic properties of the soil, as assumed by Terzaghi. Inter Storey drifts were identical and are within limits. Also, deflection has minor differences of 1.27%.

The study shows that variations in the substructure design, such as different podium shapes, have minimal impact on the stiffness of the tower superstructure (Figure 12). This suggests that a design philosophy can be developed by assuming a certain spring stiffness and designing the podium accordingly.

One can observe that the stiffer models, such as the rectangular podium with a complete shear wall on the periphery, longer side (X-axis), as well as the rectangular podium without a complete shear wall on the periphery, longer side (X-axis), performed poorly in terms of Storey shear. This is because the shear reversal is a function of Storey stiffness, and a flexible podium would be able to translate and create a resistance force. Among the models tested, the rectangular podium without a complete shear wall on the periphery, longer side (Y-axis), showed the best performance due to its larger surface area.

The multi-stage setback and multi-stage backstay effect concepts are introduced, which induce backstay effects at different levels. As this concept is relatively new, attempts have been made to study its effects. Models with the grading of 10%, 20%, and 30% about the podium have been created and evaluated.

When the stiffness effect (Figure 14) was considered, the 10% grading (Figure 4) model was found to be stiffer than the model without grading, which had an average stiffness. This study did not provide any conclusive evidence about the most effective percentage grading system in terms of stiffness. However, each model exhibited a similar trend in shear

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force and backstay effect, with the 30% grading model demonstrating the best effect, and the non-grading model exhibiting the least shear reduction (Figure 15).

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