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Seismic Analysis of Bundled Tall Building Connected with Outrigger System

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Abstract: Due to increase in population, there is need to develop the residence for all of them. In present era, it is not possible to expand in lateral direction, hence it is utmost important to expand in vertical direction. So tall buildings are need of present era. At present tall buildings are being constructed as a single unit. To reduce the heavy effect of an earthquake, the structure has large dimension at the bottom and smaller dimension at the top. To avoid this condition and provide uniform size throughout along the height, it is required to secure lateral stiffness in the overall supertall buildings in order to resist lateral load effectively. In this study, a single-unit building is divided into three or more units, and they are connected by outriggers as a lateral load resisting system to enhance the seismic performance of the building. This paper also discusses the use of outrigger at various locations and the optimum position of outrigger to achieve the minimum deflection. In the present paper, an investigation has been performed to examine the behavior of a reinforced concrete structure with a central core wall with and without outriggers. The parameters discussed in this paper include variation of bending moments, shear force, lateral deflection of the core and inter-story drifts for static and dynamic analysis as per IS:1893 (Part-1) - 2016.

Keywords: Belt-truss System, Bundled Tall Building, Dynamic Analysis, Seismic Load, Outrigger System, Storey Displacement, Storey Drift.

I. INTRODUCTION

The construction of tall structures is more common for a number of reasons, including space limitations, Land is becoming more expensive and scarcer as cities become densely populated. Developers can fulfil the increasing demand for office, residential, and commercial space by building upwards in order to make the best use of limited space. Yet, it has been difficult to grow cities conventionally due to the restricted horizontal space in highly populated places. Because of this, architects and builders have resorted to vertical expansion, creating tall structures that soar upwards even higher. In urban areas, where there is a strong demand for space and a finite amount of land that can be developed, this strategy has grown in popularity. Due to the lack of horizontal space in this situation, tall structures have been built to make the best use of the land that is available and to keep up with the expanding urbanization needs. Buildings are exposed to two types of loads: vertical loads resulting from gravity and lateral loads due to wind and earthquakes.

To withstand lateral loads such as seismic and wind loads, a lateral load-resisting system is installed to resist and counteract lateral forces acting on a building, ensuring the structural stability and safety of the building.

In tall buildings, a more slender structure with a higher height-to-width ratio is more vulnerable to lateral forces in tall buildings. Buildings become more susceptible to lateral forces like wind and earthquakes forces as they grow higher and more slender. This is due to the fact that the forces pressing on the building grow with height while the buildings lateral stiffness diminishes.

Engineers frequently use the tapering effect to address this issue. The tapering effect is the gradual reduction in the size of a building's floor plates as it rises, resulting in a narrower building at the top than at the bottom. This design technique is used to reduce the building's lateral displacement or sway caused by wind or seismic activity. The weight of the structure is concentrated towards the base by tapering the building, making it more stable and resistant to lateral forces. Additionally, the reduction in floor area at higher levels can also reduce the lateral load on the building.

To rectify the tempering effect in tall buildings, the “Bundle Tall Building” technique or concept can reduce lateral load on the building and improve seismic performance without reducing floors size

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II. BUNDLED TALL BUILDING

In bundled tall building the individual buildings joined together to form a single unit. The number of frame tube type structure or building joined together with the help of different types of lateral load resisting system (Outrigger, Bracing, Deep Beam Outrigger (DB) and Diagrid System). To provide uniform floor plates size throughout along the height by using bundled tall building. In past, many research was done by Alberto Casali [1] and found conceptual design inspired by the bamboo biomimetics. To mimic the structural efficiency and functionally graded material organization of the bamboo plant, The present concept combines multiple types of Outriggers and Bracing System in building. This paper presents multiple types of Outrigger System i.e., Conventional and Virtual Outrigger Systems.

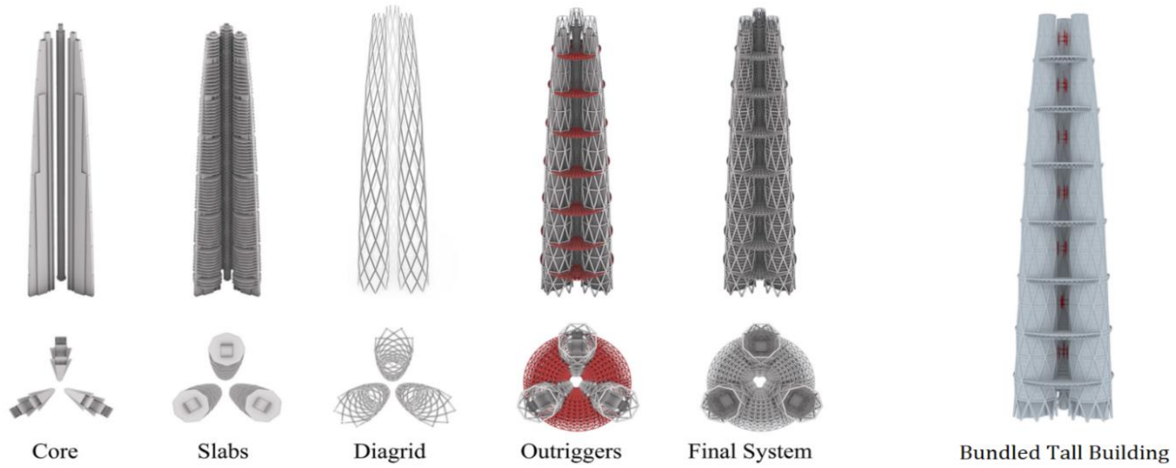

Figure 1 Components of Bundled tall building

A. Core Wall

Core walls are originated with combination of wall and arranged like a core located at the geometric center of the building. It is a type of shear wall simply the combination of shear wall. Core wall is constructed from the foundation and it is raised up to the building. In this type of building, the wall itself acts as a column. Core is used to install lifts, stair case, step wells and accommodate services. Core wall is constructed from the foundation and it is raised up to the building. In these types of building, the wall itself acts as a column

B. Belt-truss

The Belt truss system is made up of a series of diagonal members that form a truss pattern and are connected to a horizontal belt that runs the length of the structure. The belt truss system's purpose is to distribute loads evenly across the structure, helping in the support of the building's weight and resisting lateral forces such as wind or earthquake loads

C. Outrigger System

Outrigger are rigid horizontal structure designed to improve building overturning stiffness and strength by connecting core to outer column of the structure. It is also used to reduce the overall drift and core wind moment. It is also use to transfer the lateral forces to the foundation.

Types of Outrigger System:

1) Conventional Outrigger System
2) Virtual Outrigger System

1) Conventional Outrigger System

In the Conventional outrigger, the outrigger truss girders are connected directly to shear walls or braced frames at the core and to columns located outboard of the core. The forces transfer from core to outrigger column.

2) Virtual Outrigger System

In the Virtual Outrigger System, the outrigger beams or trusses are not physically connected to the core of the building,

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but are connected virtually through diaphragms, which transfer the overturning moment from the core to outboard using horizontal couple.

III. PARAMETRIC STUDY

For the parametric comparison, a symmetrical building is selected. RCC Building of 20, 25 and 30 story modelled, analyses and designed in ETABS-2019 for various structural system such as Core Wall, Deep Beam, Belt truss, Outrigger, Conventional Outrigger and Virtual Outrigger. Analysis and design are carried out for dead load, live load. For earthquake loads, both static and response spectrum analysis is performed. To consider extreme conditions of lateral load, the building is considered to be located in Zone V.

A. Building Configuration

Four Individual Building are connected and designed with different number of stories such as 20, 25 and 30 for Belt truss Outrigger System and Deep Beam Outrigger System. The physically properties and data of the building considered for the present study is as follows:

Table 1 Preliminary Building Data

Building Specifications	No. of Story		
	G+19	G+24	G+29
Plan Area	30m *x* 30m	25m *x* 25m	25m *x* 25m
Total Height of Building	60m	75m	90m
Typical Story Height	3m		
Grade of Concrete	M30		
Grade of Rebar	HYSD415		
Slab Thickness	150mm	120mm	120mm
Beam	350mm *x* 700mm		
Column	600mm *x* 600mm	750mm *x* 750mm	850mm *x* 850mm
Slab Thickness	150mm	120mm	120mm
External Wall	230mm		
Interior Wall	115mm		
Core Wall	-	300 mm	300mm
Outrigger	ISMB500	ISMB500	ISMB500
Deep Beam	-	300mm	300mm

Table 2 Loads and Seismic factors of models

Building Specifications	No. of Story		
	G+19	G+24	G+29
Location	Bhuj, India		
Seismic Zone	V		
Zone Factor	0.36		
Site Type	Type II Medium Soil		
Earthquake Load	As per IS 1893 (Part 1): 2016		
Importance Factor	1.5		
Response Reduction Factor	5		
Exterior Wall Load	10.58kN/m^2		
Interior Wall Load	5.29kN/m^2		
Floor Finish	-	1.5kN/m^2	1.5kN/m^2
Live Load	3kN/m^2	2.5kN/m^2	2.5kN/m^2
Roof Live Load	-	1.5kN/m^2	1.5kN/m^2
Limiting Storey Displacement & Drift	H/500 & 0.004h		

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B. Outrigger at different locations

For analysis of Bundle Tall Building Outrigger System is used at various locations and the optimum position of outrigger.

Table 3 Outrigger at various location

No.	Location of Outrigger
1	At 1/3 of Height
2	At 2/3 of Height
3	At Top Story
4	At Top Story and 1/3 of Height
5	At Top Story and 2/3 of Height
6	At 1/3 and 2/3 of Height
7	At Top Story, 1/3 and 2/3 of Height

C. Belt-truss Outrigger Building

The structural element like columns, beam and slab are consider of RCC while the Belt truss are assigned as structural steel properties. For the designed of Belt-truss ISMB 500 sections are used at different level of building. The typical plan, 3D views of a 20, 25 and 30 story Belt-truss Outrigger building.

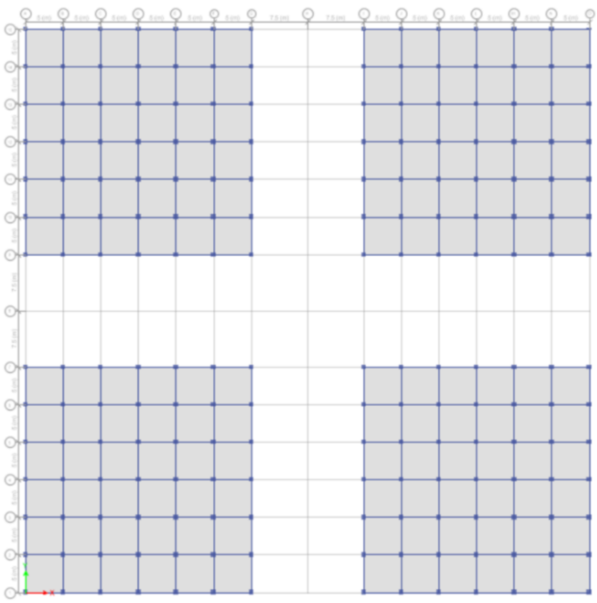

Figure 2 Typical floor plan of G+19 Belt-truss building

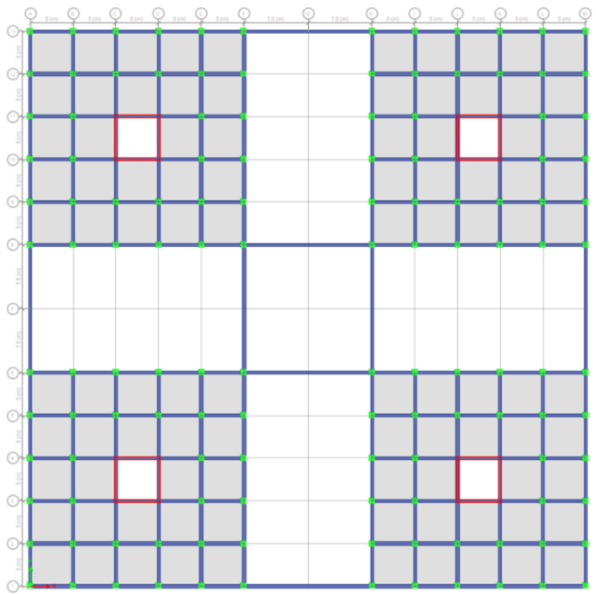

Figure 3 Typical floor plan of G+24 & G+29 Belt-truss building.

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The figure 2 & 3 above depicts a typical floor plan view of a Belt-truss building with G+19, G+24, and G+29 floors.

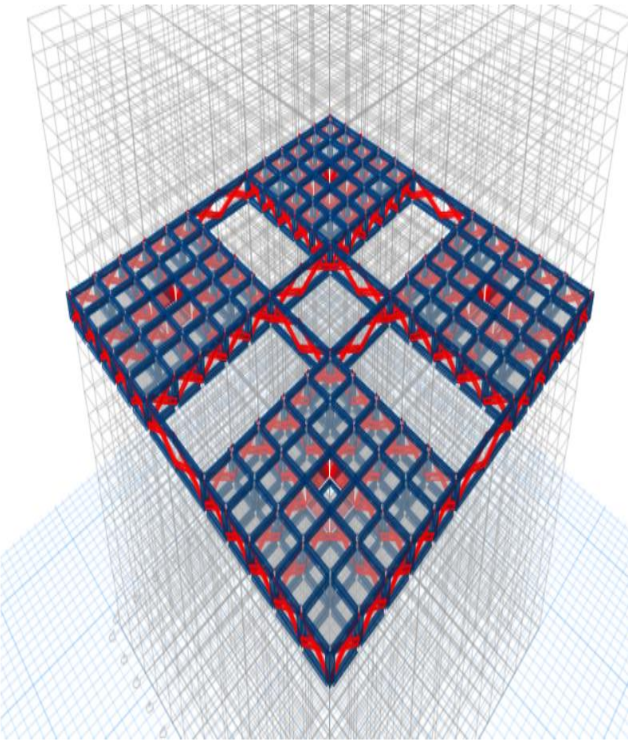

Figure 4 Belt-truss outrigger system

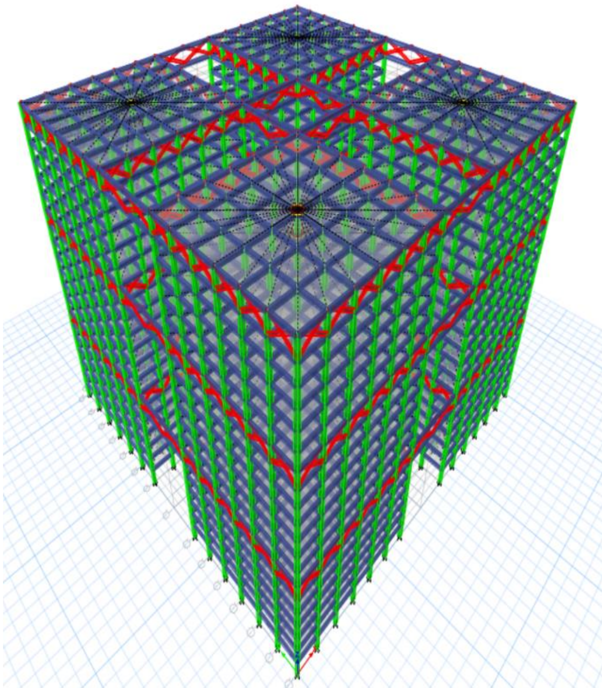

Figure 5 3D view of G+19 Belt-truss building

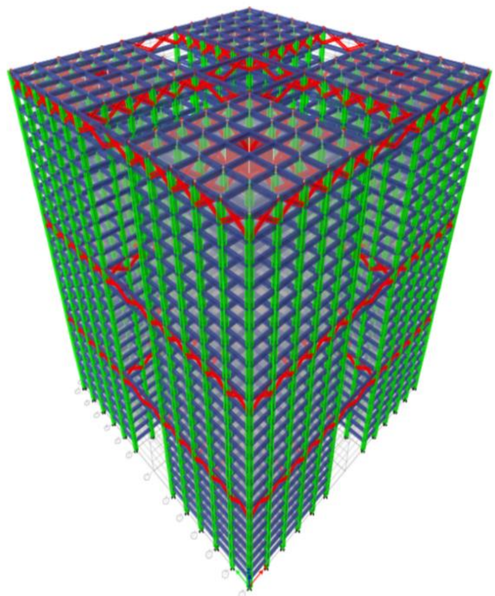

Figure 6 3D view of G+24 Belt-truss outrigger building

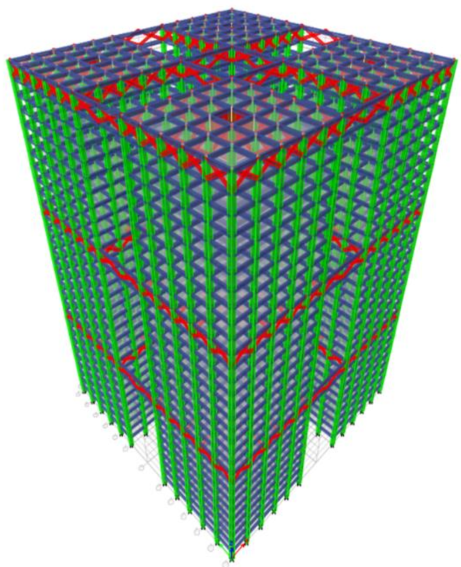

Figure 7 3D view of G+29 Belt-truss outrigger building

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D. Deep Beam Outrigger Building

The structural element like columns, beam, slab and Outrigger deep beam are consider of RCC. For the designed of Deep beam 300mm thick beam are used at different level of building. The typical plan, 3D views of a 25 and 30 story Deep Beam Outrigger building

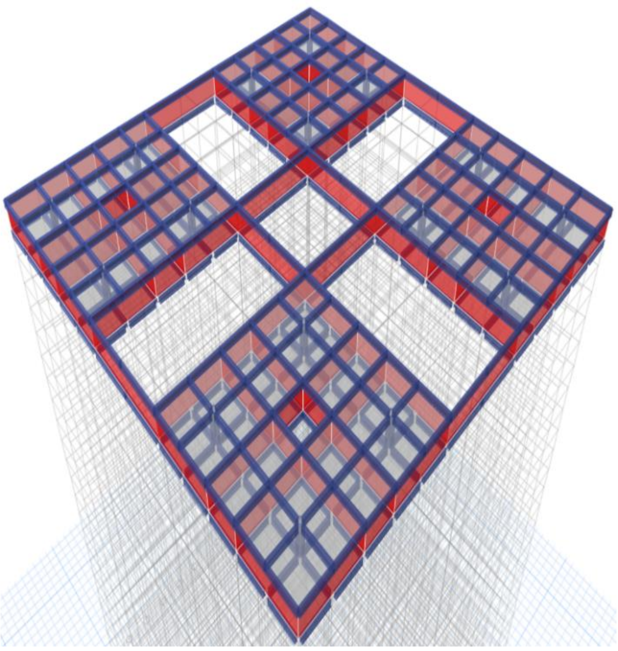

Figure 8 Conventional Outrigger

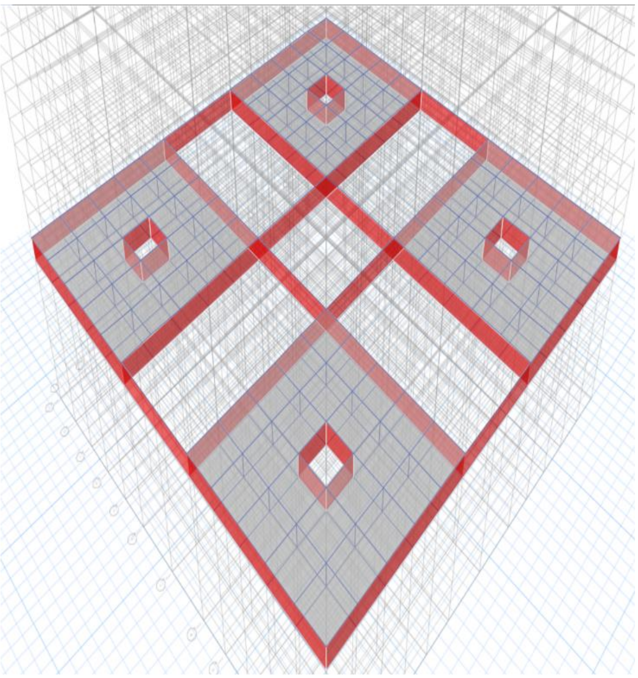

Figure 9 Virtual Outrigger

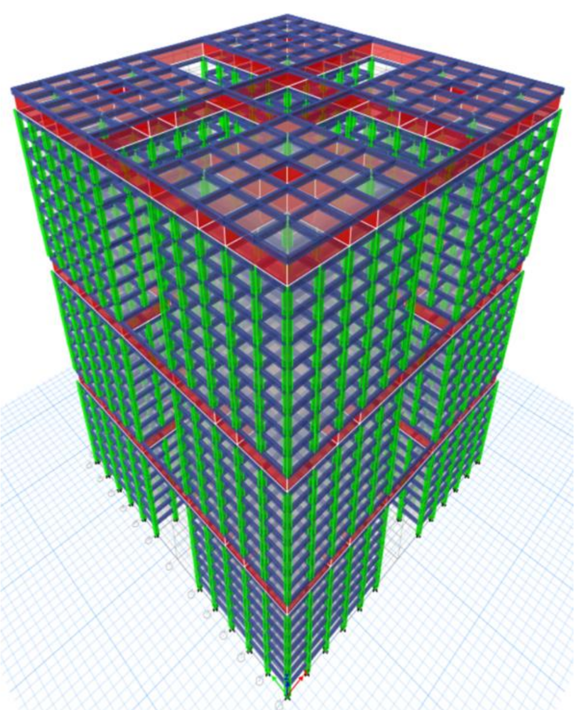

Figure 10 3D view of G+24

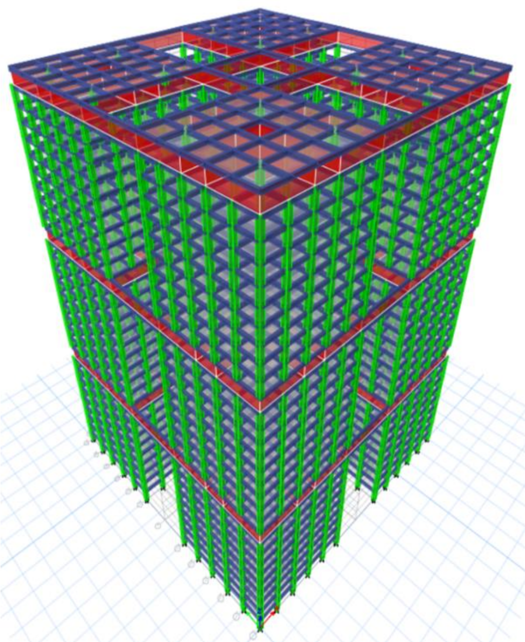

Figure 11 3D view of G+29

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IV. RESULTS AND DISCUSSION

The results of various parameters such as maximum top story lateral displacement, maximum story drift and maximum base shear. Since the structure symmetrical in both directions, all the structural system produces the same result in both axis X and Y.

A. G+19 Belt-truss building

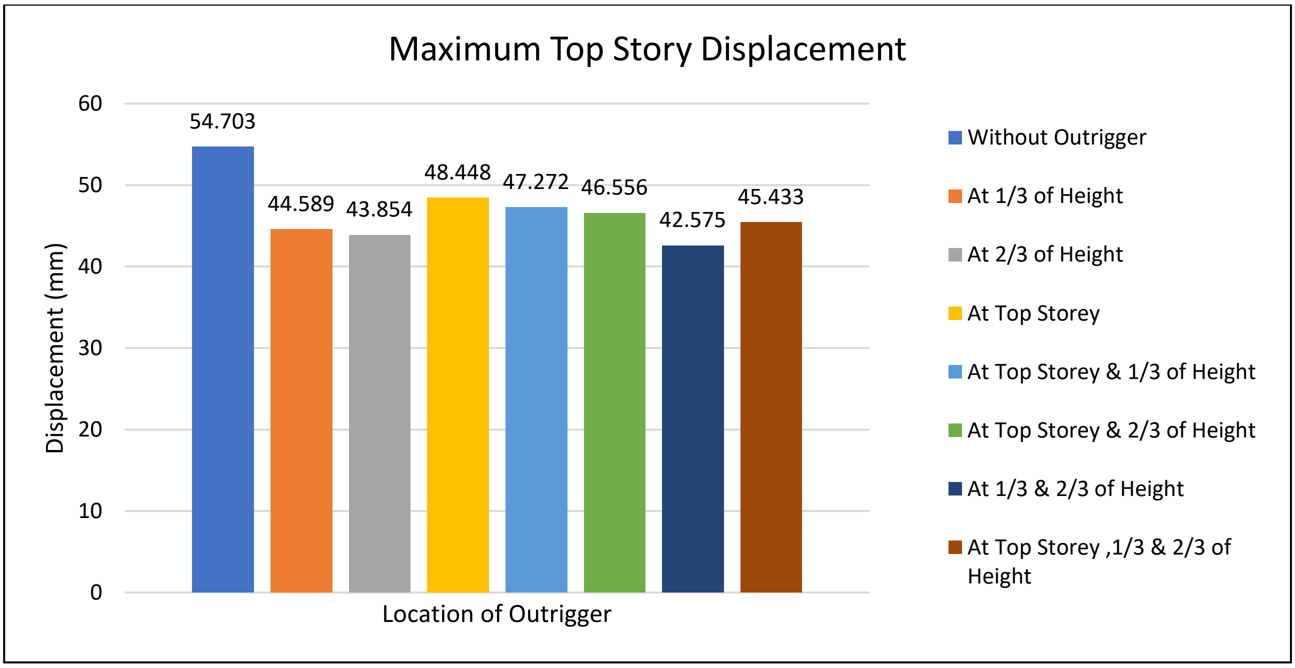

Figure 12 Maximum Top Story Displacement in EQ-X & Y (Earthquake Static)

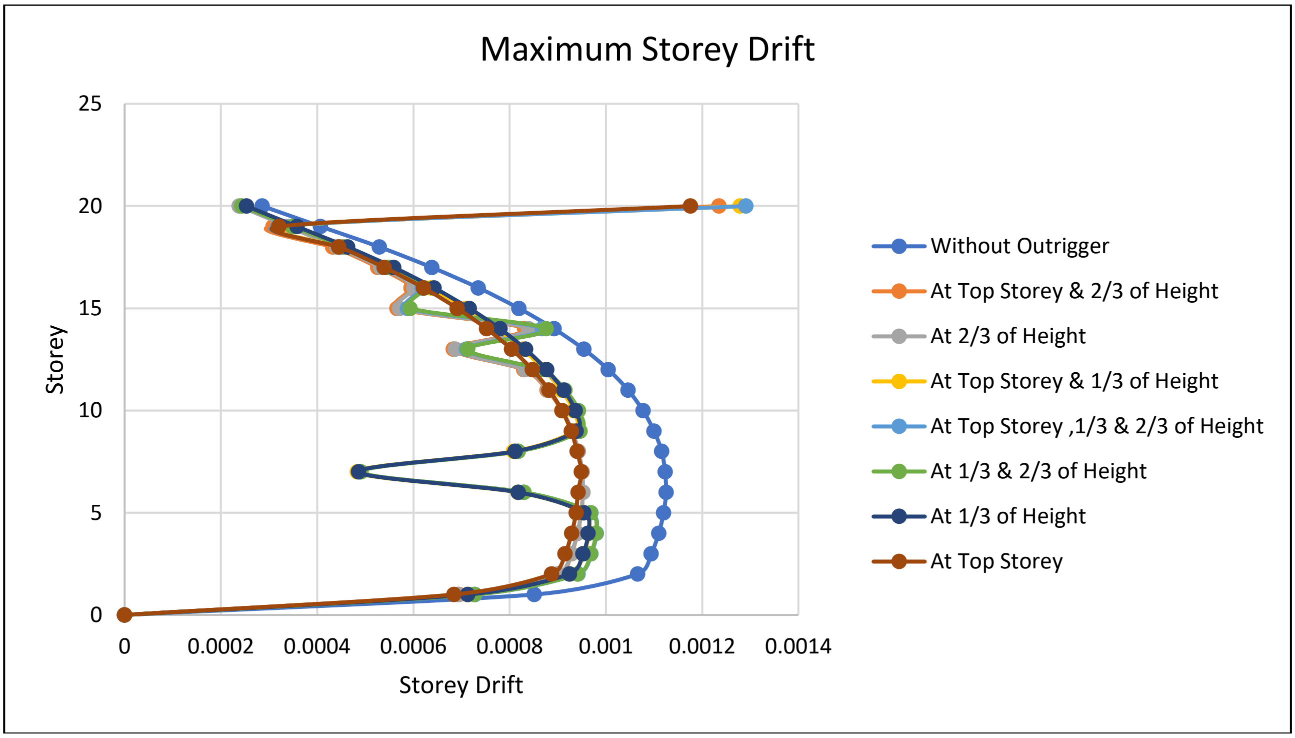

Figure 13 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

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Based on the figure 12 result, the reduction in displacement at H/3, 2H/3, Top Story, Top story & H/3, Top story & 2H/3, H/3 & 2H/3, and Top story & H/3 & 2H/3 is 18.49%, 19.83%, 11.43%, 13.58%, 14.89%, 22.17%, and 16.95%, respectively

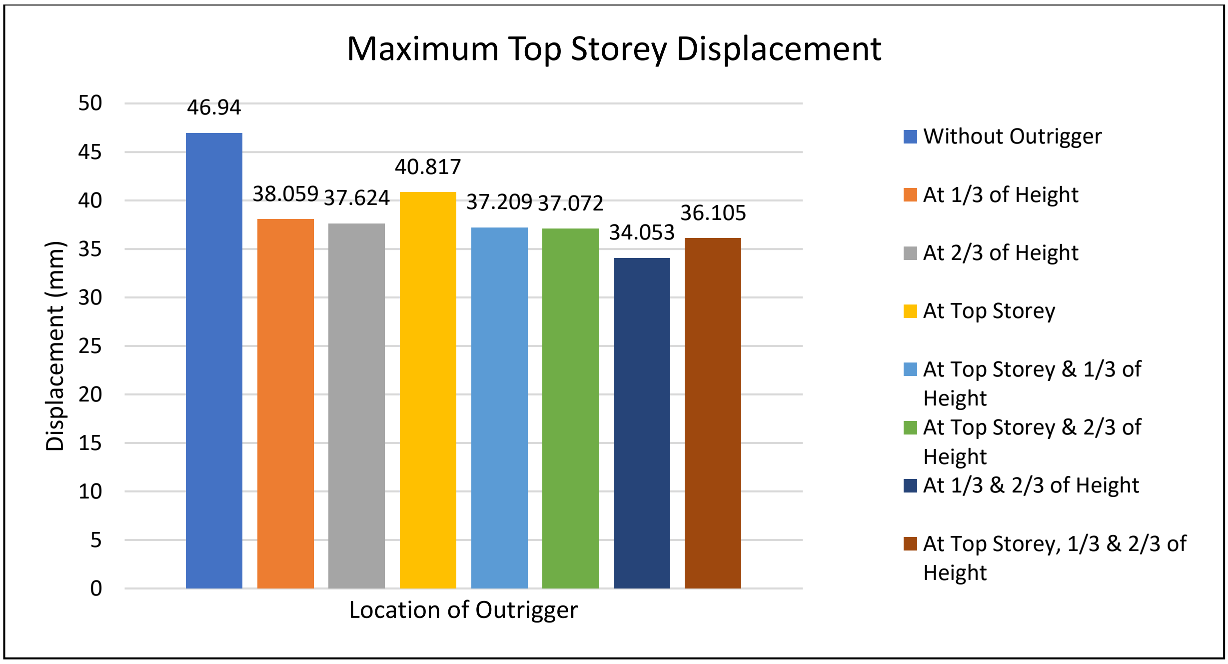

Figure 14 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

The above figure 14 shows the maximum storey displacement for outriggers provided at different floors

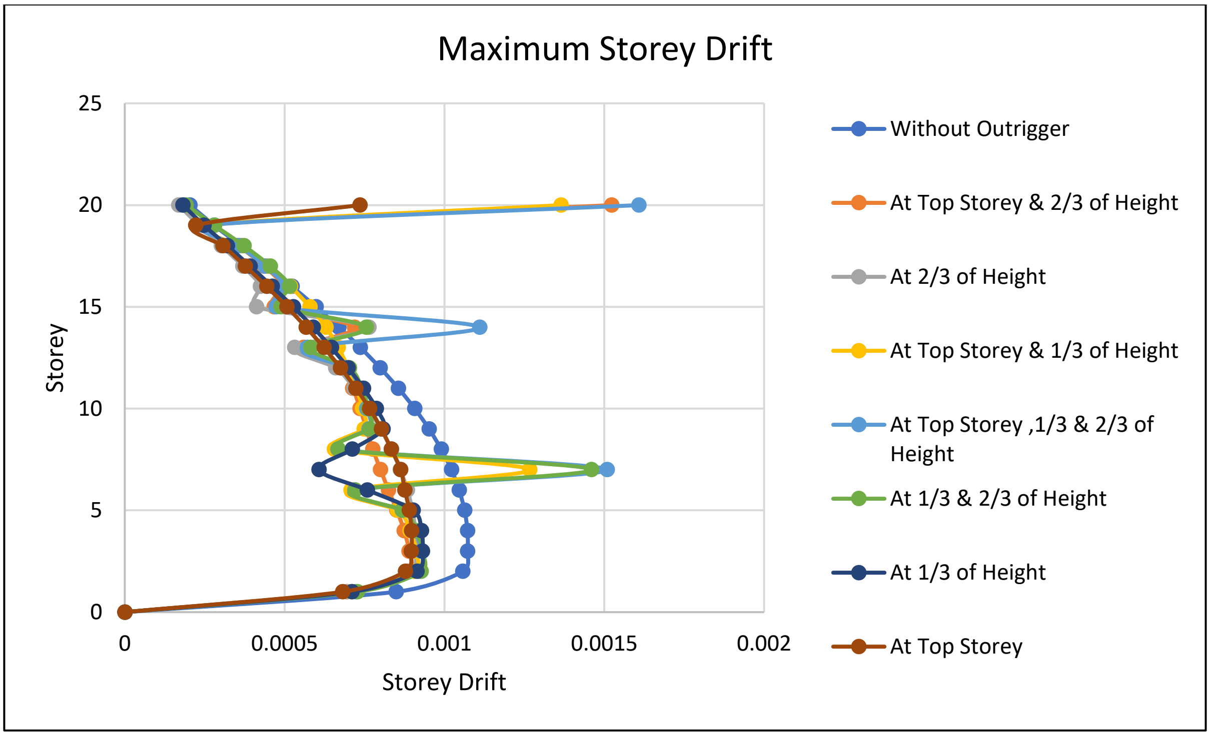

Figure 15 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

Figure 15 provides information on maximum story drift for outriggers provided at different floors

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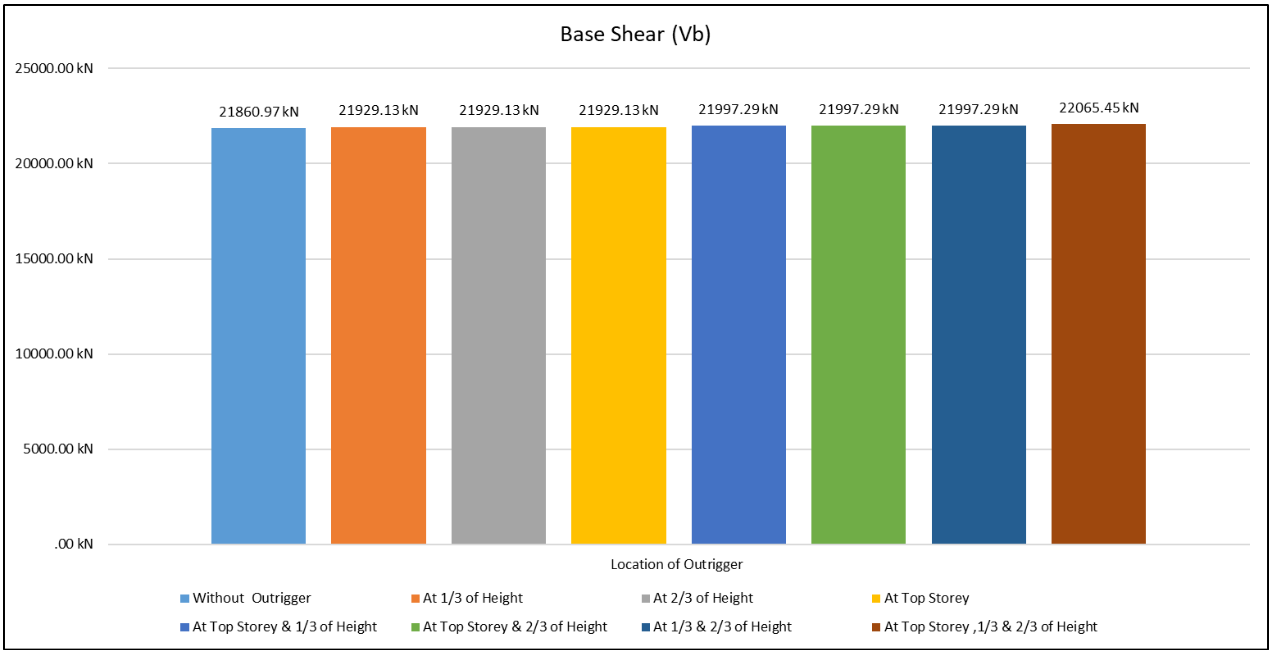

Figure 16 Base Shear

Figure 16 illustrates the base shear in both the X and Y directions under static earthquake conditions. As depicted in the figure, as the number of outriggers increases, the base shear also increases. This is because an increase in the mass leads to an increase in the base shear

B. G+24 Belt-truss outrigger building

The following results pertain to the behaviour of a reinforced concrete frame structure under earthquake conditions: The results provide information on the displacement in both X and Y directions. These findings can be used to evaluate the seismic performance of the structure and inform design decisions aimed at improving its resilience and safety.

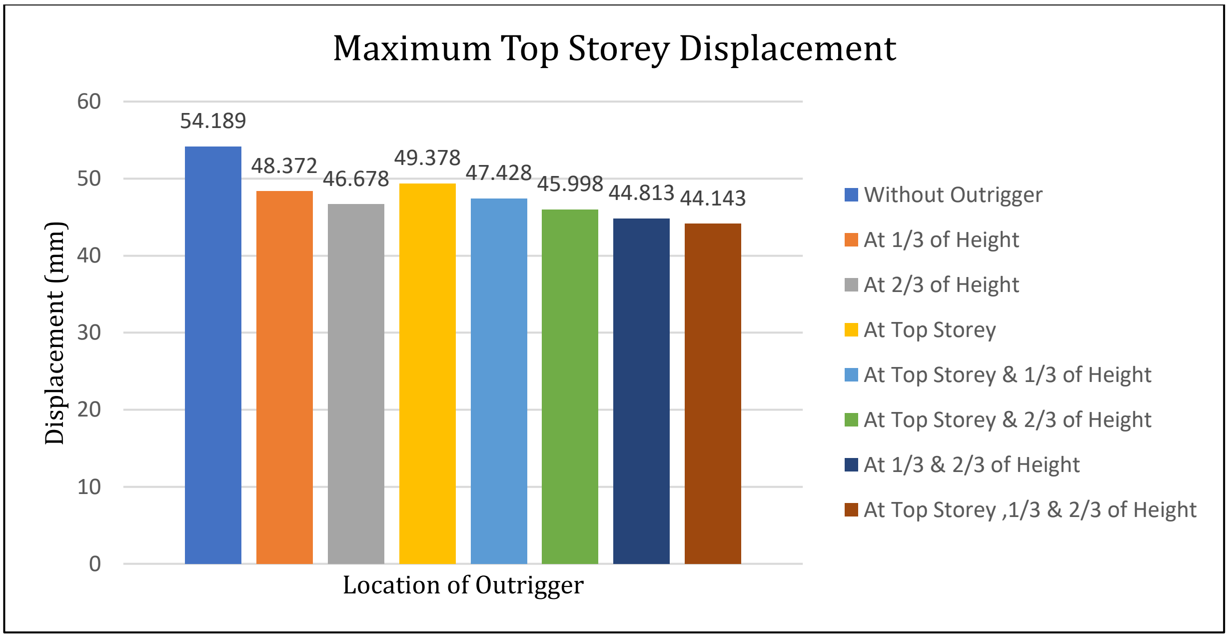

Figure 17 Maximum Top Story Displacement in EQ-X & Y Direction (Earthquake Static)

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Figure 17 shows maximum top story displacement in X & Y direction under static earthquake condition

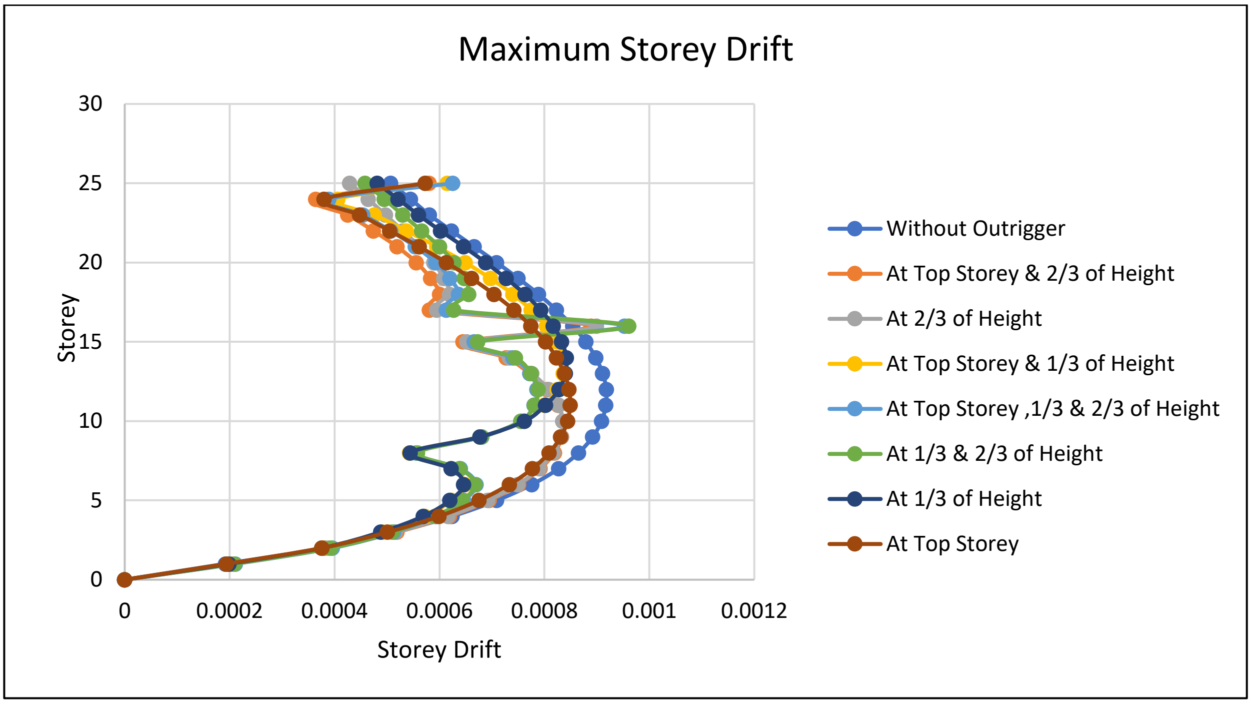

Figure 18 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

The above figure 18 shows the maximum story drift. To reduce the story drift and increase the stiffness of the structure, the provision of outriggers at different floors increases the stiffness of the floors at the location where the outrigger system is installed. This design approach has been shown to effectively enhance the lateral stability and overall seismic performance of tall buildings

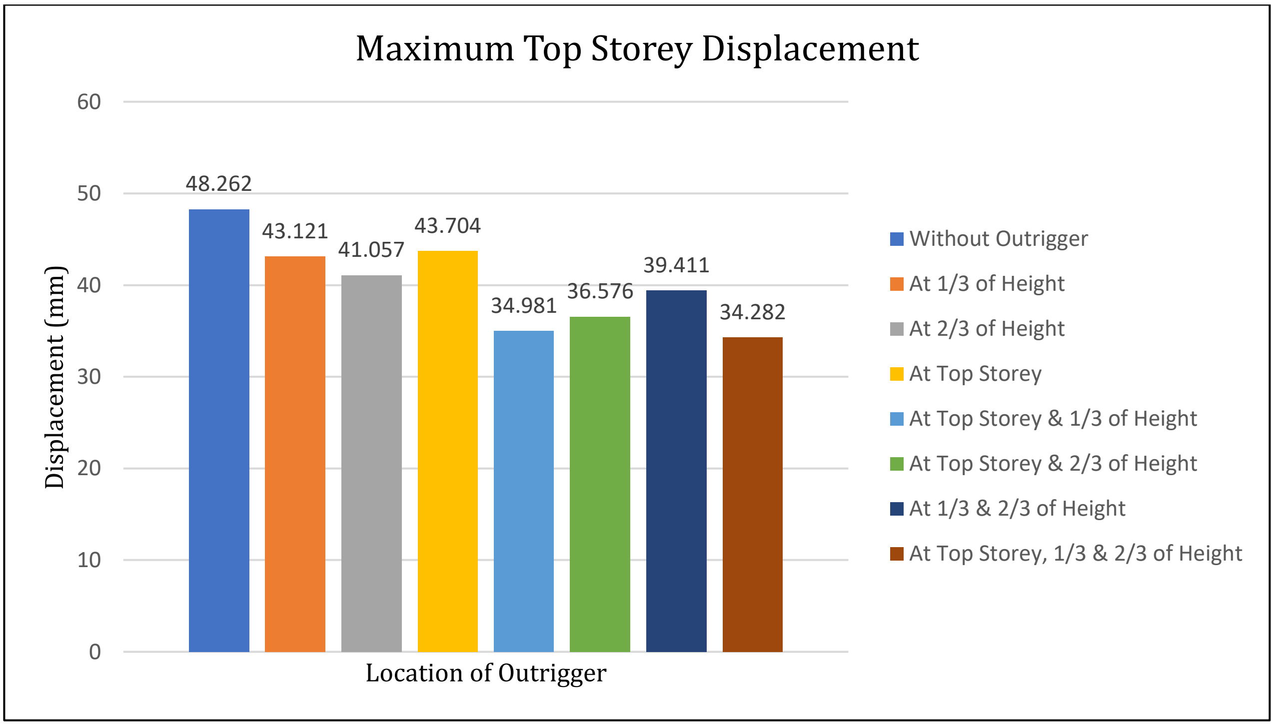

Figure 19 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

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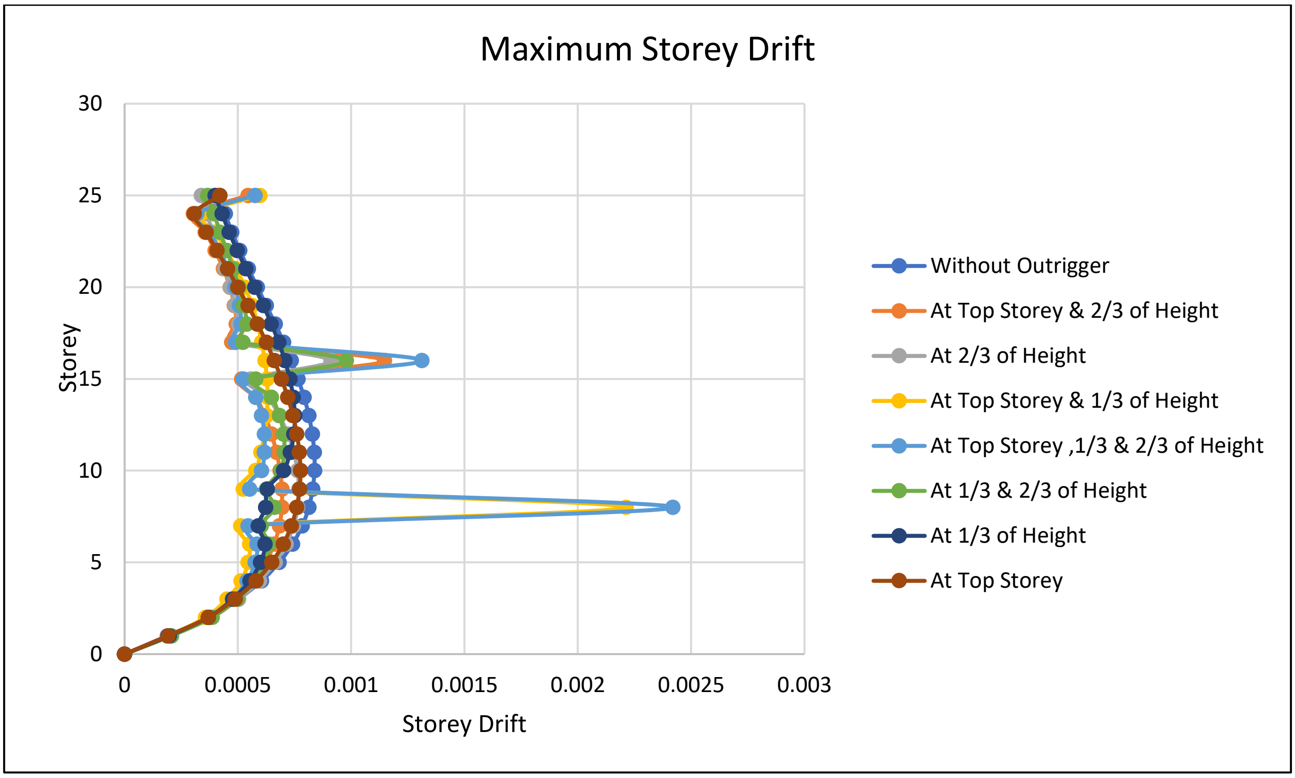

Figure 20 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

The above figure 20 provides information on maximum story drift for outriggers provided at different floors.

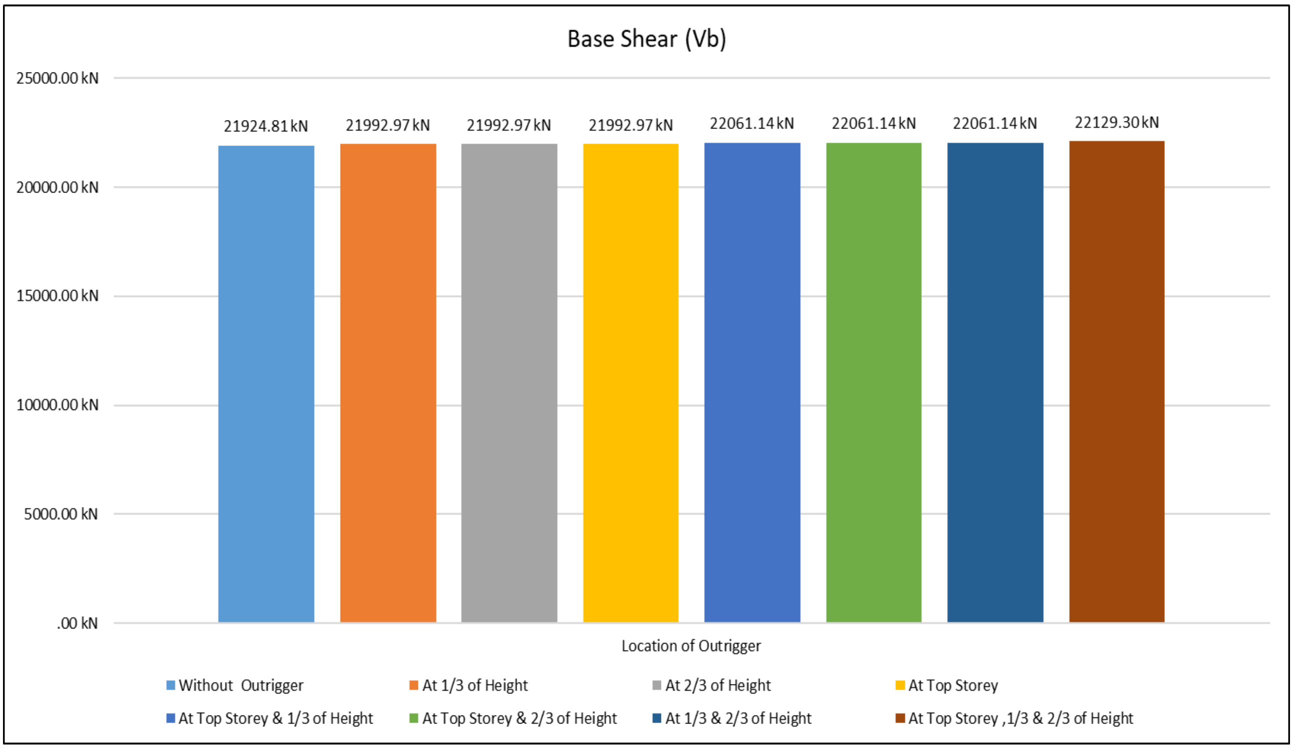

Figure 21 Base Shear

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Figure 21 illustrates the base shear in both the X and Y directions under static earthquake conditions. As depicted in the figure, as the number of outriggers increases, the base shear also increases. This is because an increase in the mass leads to an increase in the base shear

C. G+24 Conventional outrigger building

In this 25-story model, a conventional outrigger system is used. A deep beam, 300mm thick, outrigger system was employed and studied to evaluate its performance

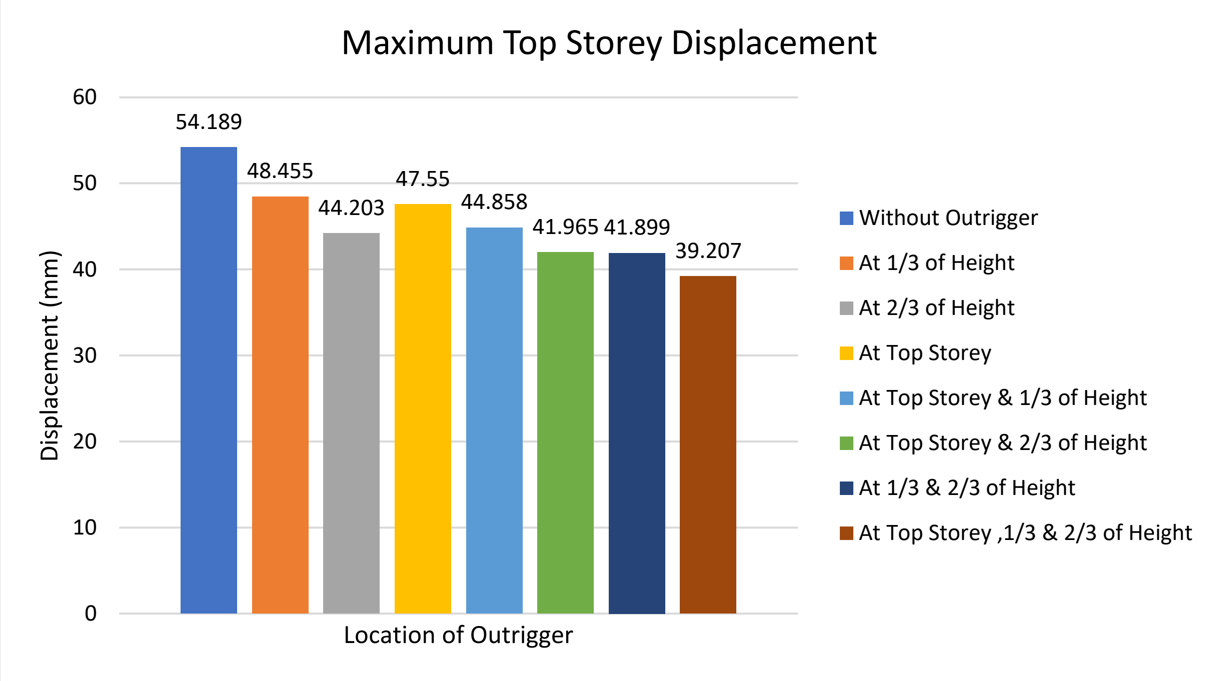

Figure 22 Maximum Top Story Displacement in EQ-X & Y Direction (Earthquake Static)

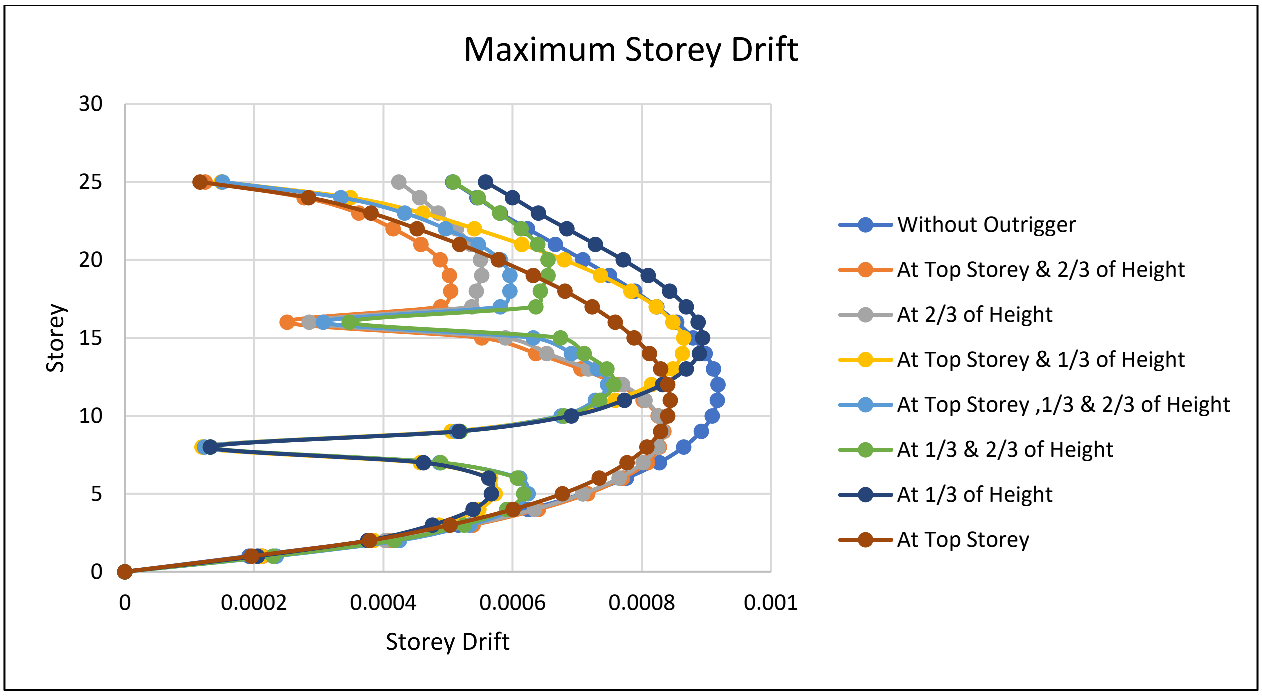

Figure 23 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

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Based on the results shown in figure 23 at the location where the outrigger system is installed, stiffness is increased and, as a result, drift is reduced at that particular location. This demonstrates the effectiveness of using an outrigger system to enhance the lateral stability and seismic performance of tall buildings.

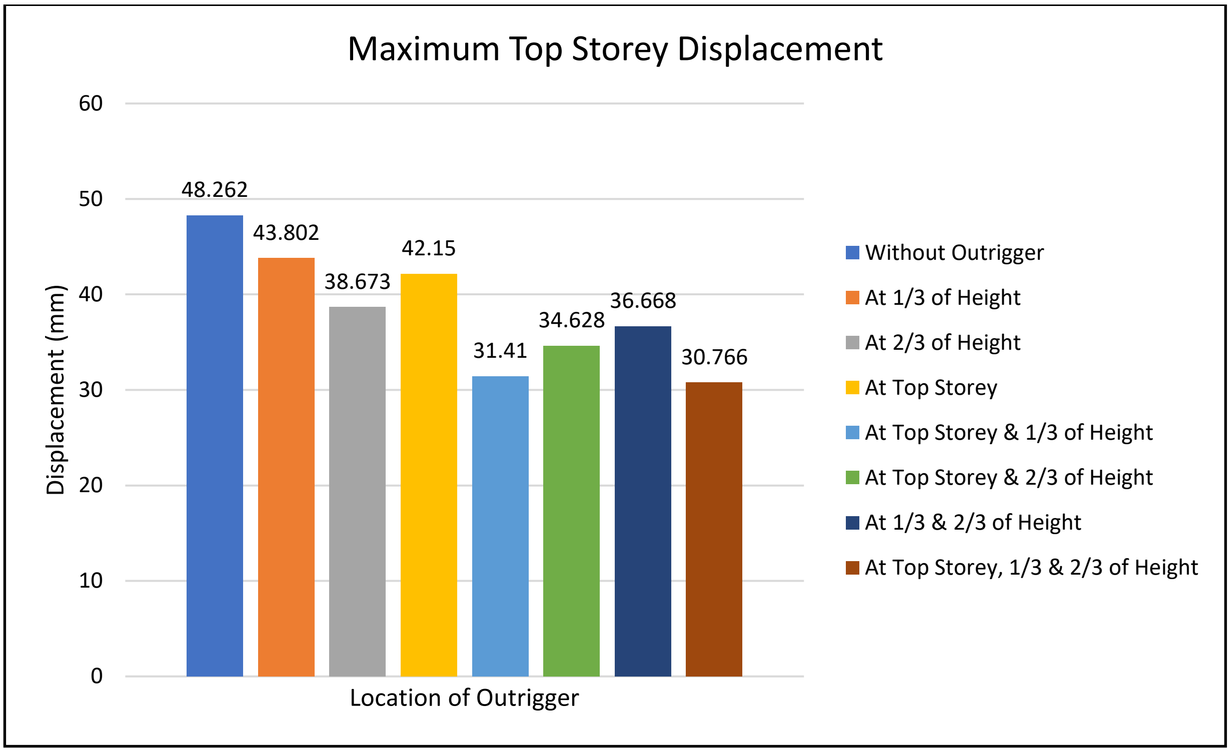

Figure 24 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

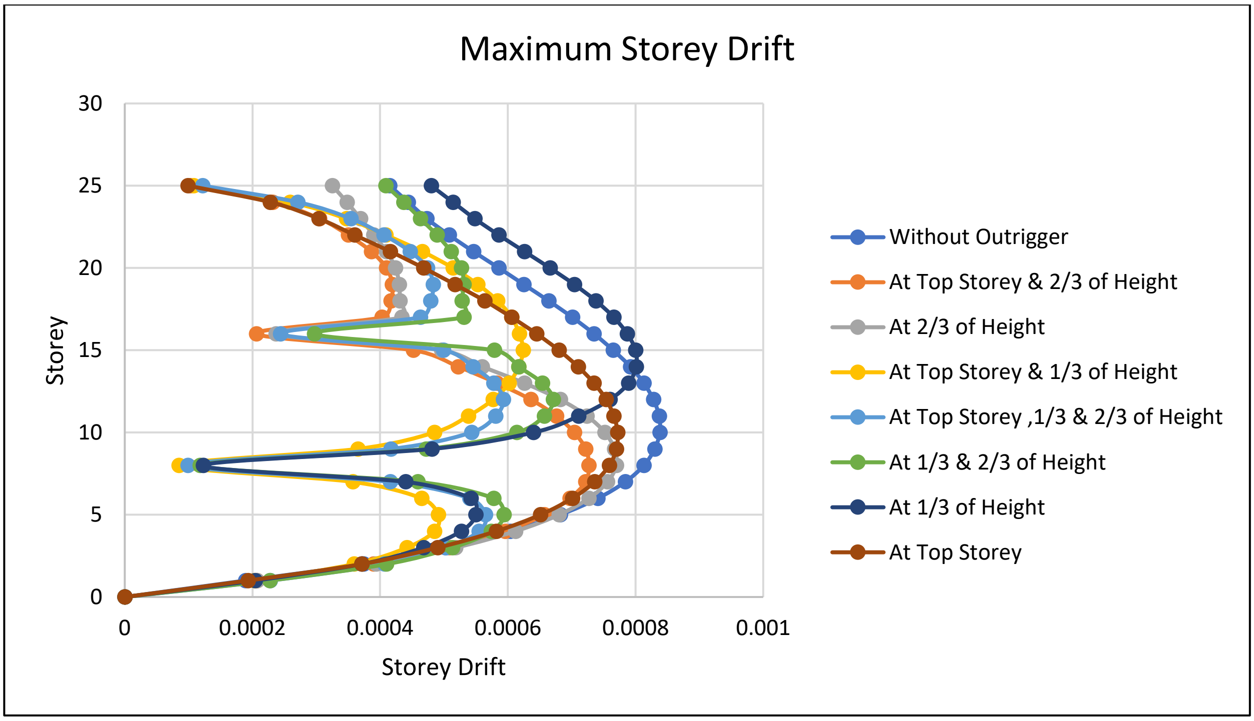

Figure 25 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

The above figure 25 provides information on maximum story drift for outriggers provided at different floors. The drift is decreasing at the outrigger location due to an increase in stiffness at that specific point.

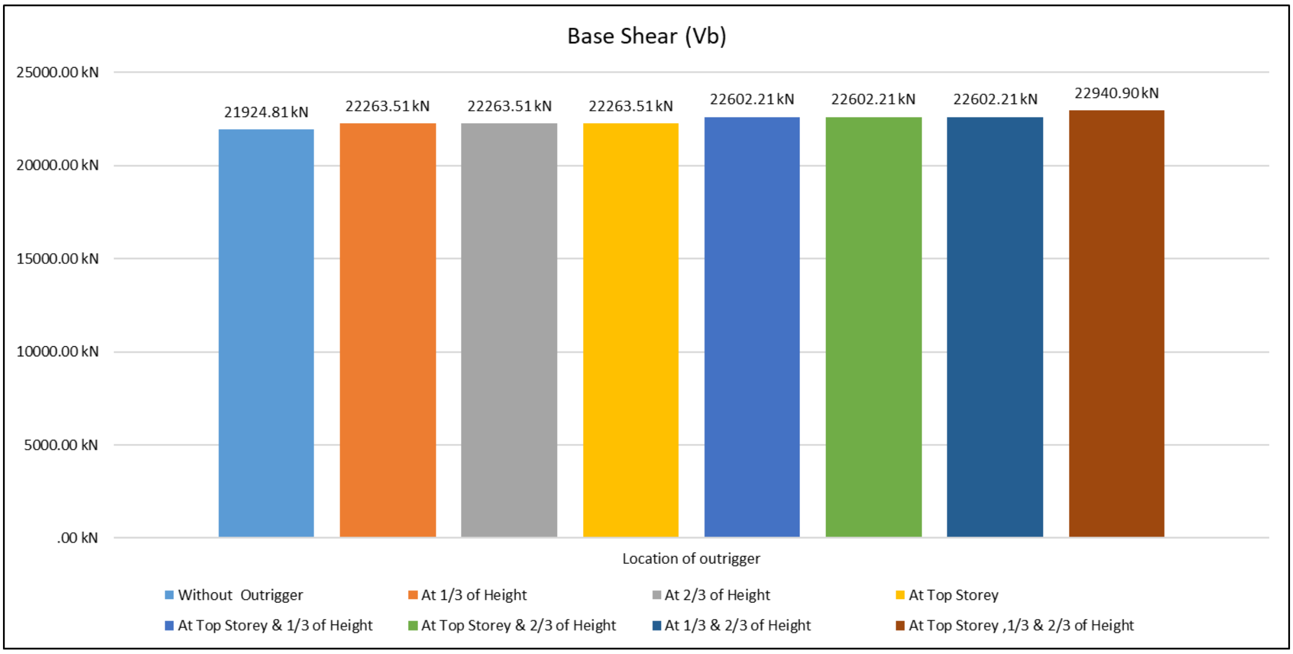

Figure 26 Base Shear

Figure 26 above displays the base shear for outriggers located at different levels within the building.

D. G+24 Virtual outrigger building

In this 25-story model, a virtual outrigger system is used. A deep beam, 300mm thick, outrigger system was employed and studied to evaluate its performance.

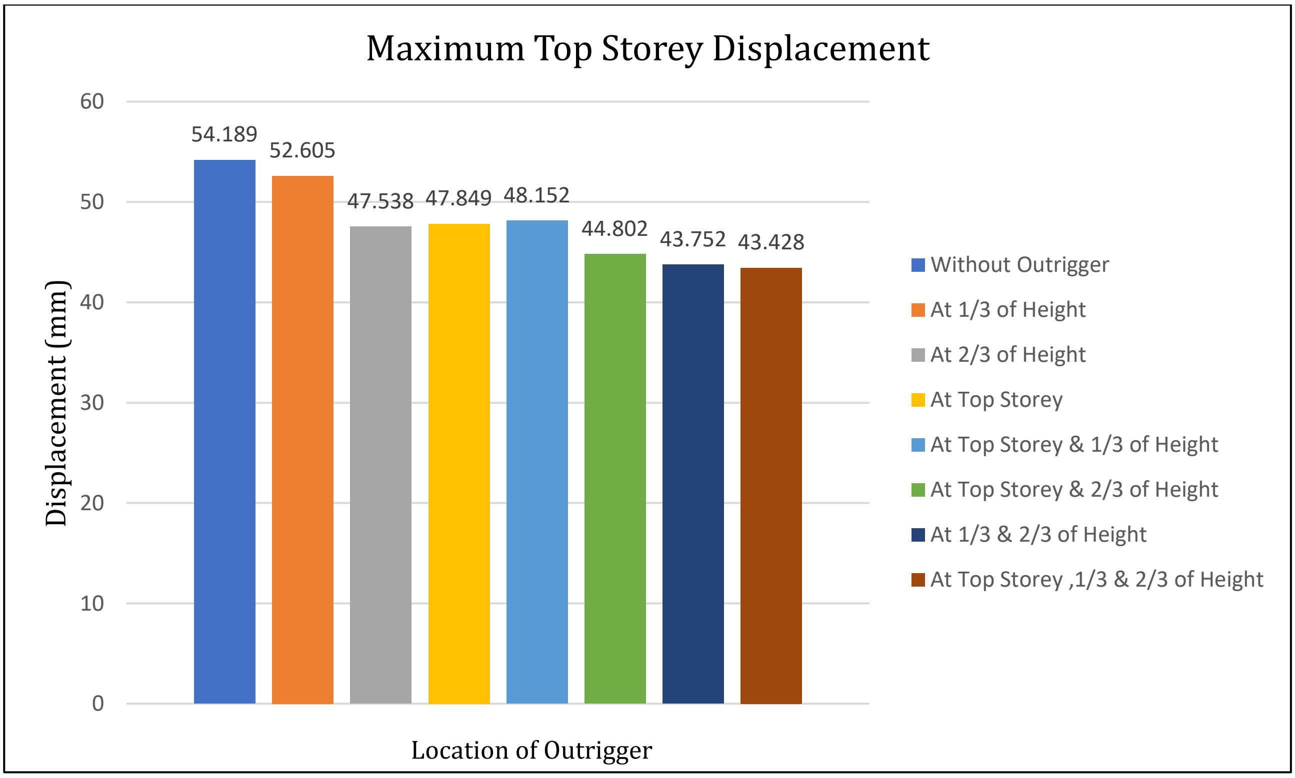

Figure 27 Maximum Top Story Displacement in EQ-X & Y Direction (Earthquake Static)

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The maximum top story displacement, for varying levels of implementation of the outrigger system in the building, is illustrated in figure 27 above.

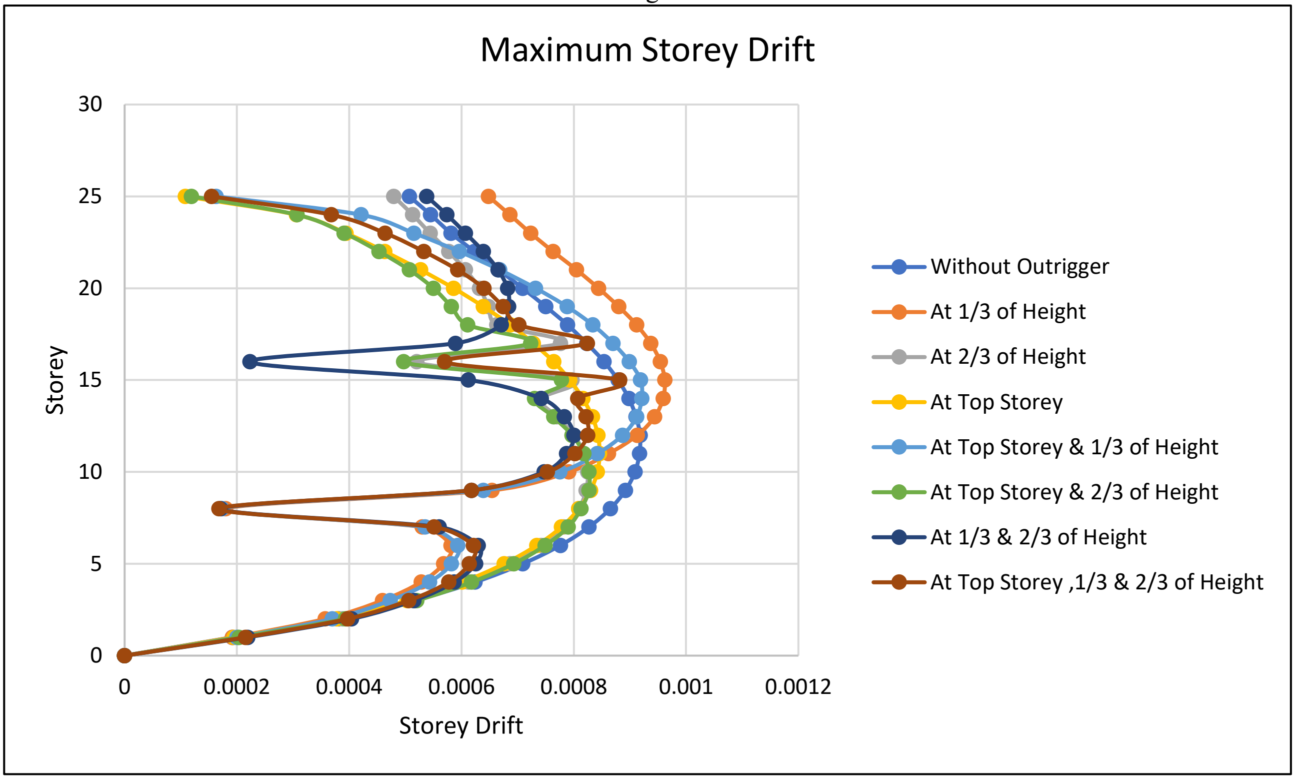

Figure 28 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

Figure 28 provides information on maximum story drift for outriggers provided at different floors

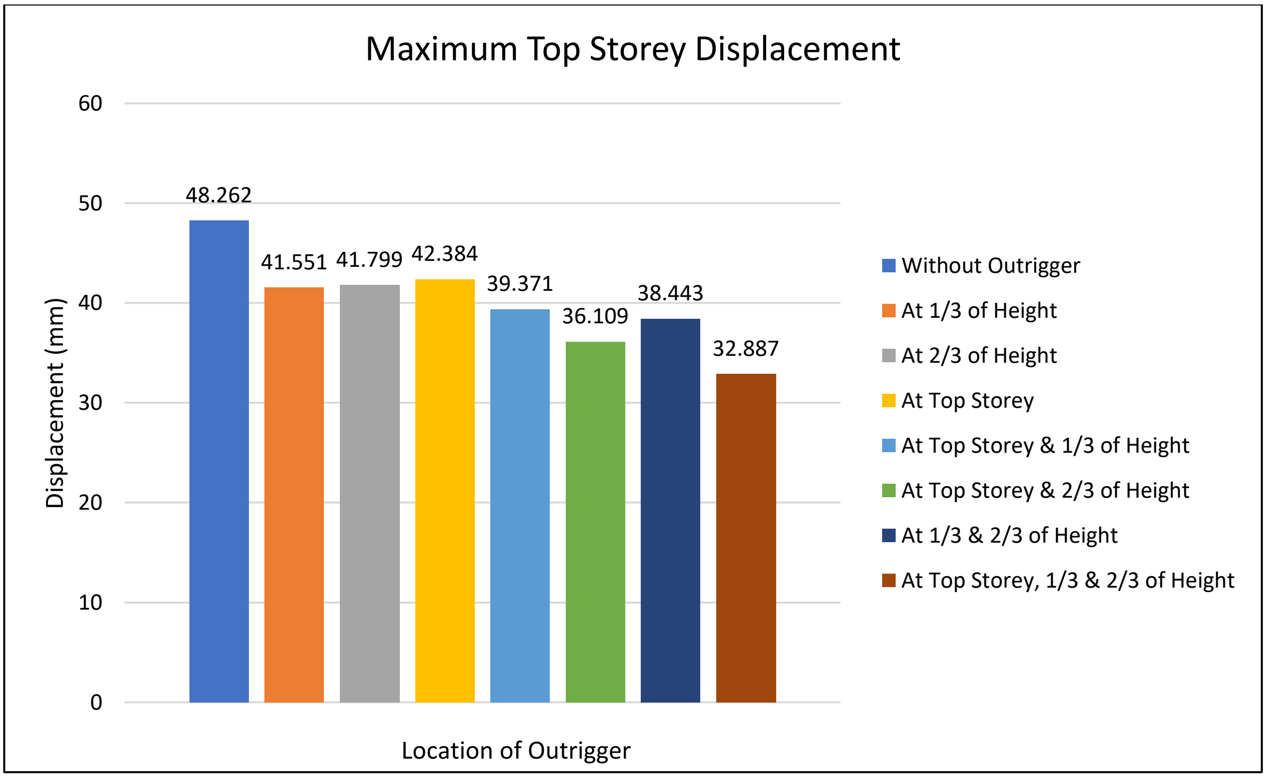

Figure 29 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

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The above figures 27 & 29 provides information on maximum story displacement for outriggers provided at different floors. Based on the results shown in figure at the location where the outrigger system is installed, stiffness is increased and, as a result, drift is reduced at that particular location.

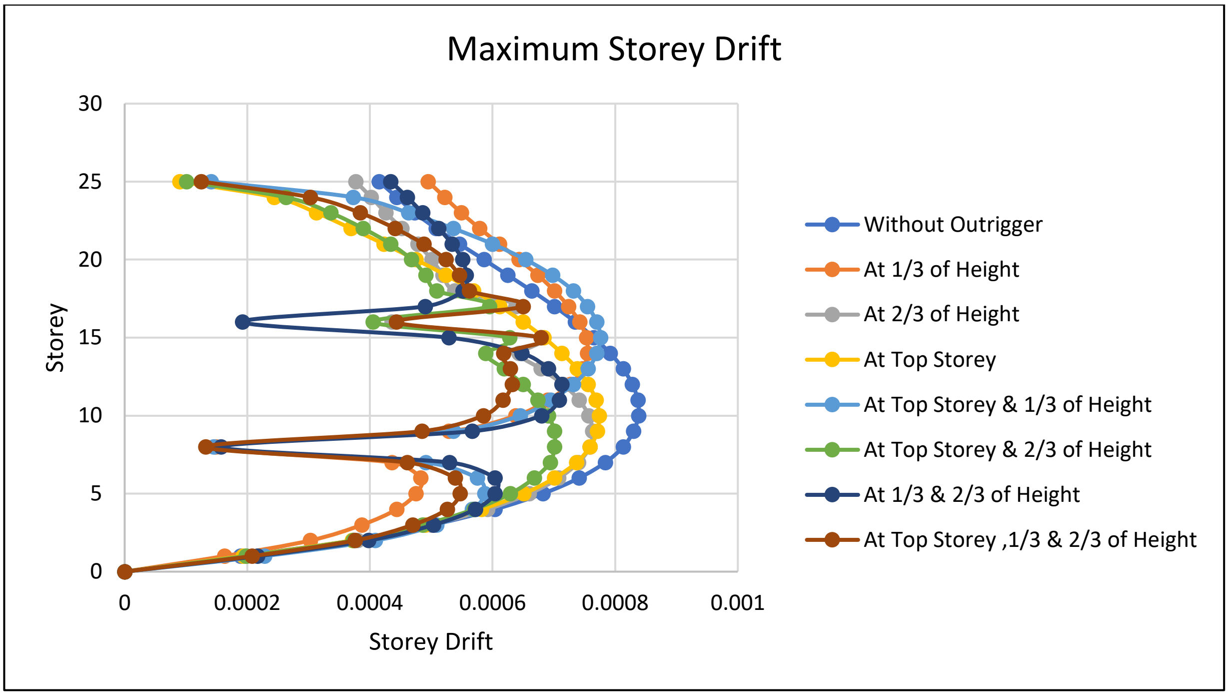

Figure 30 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

Figure 30 provides information on maximum story drift for outriggers provided at different floors

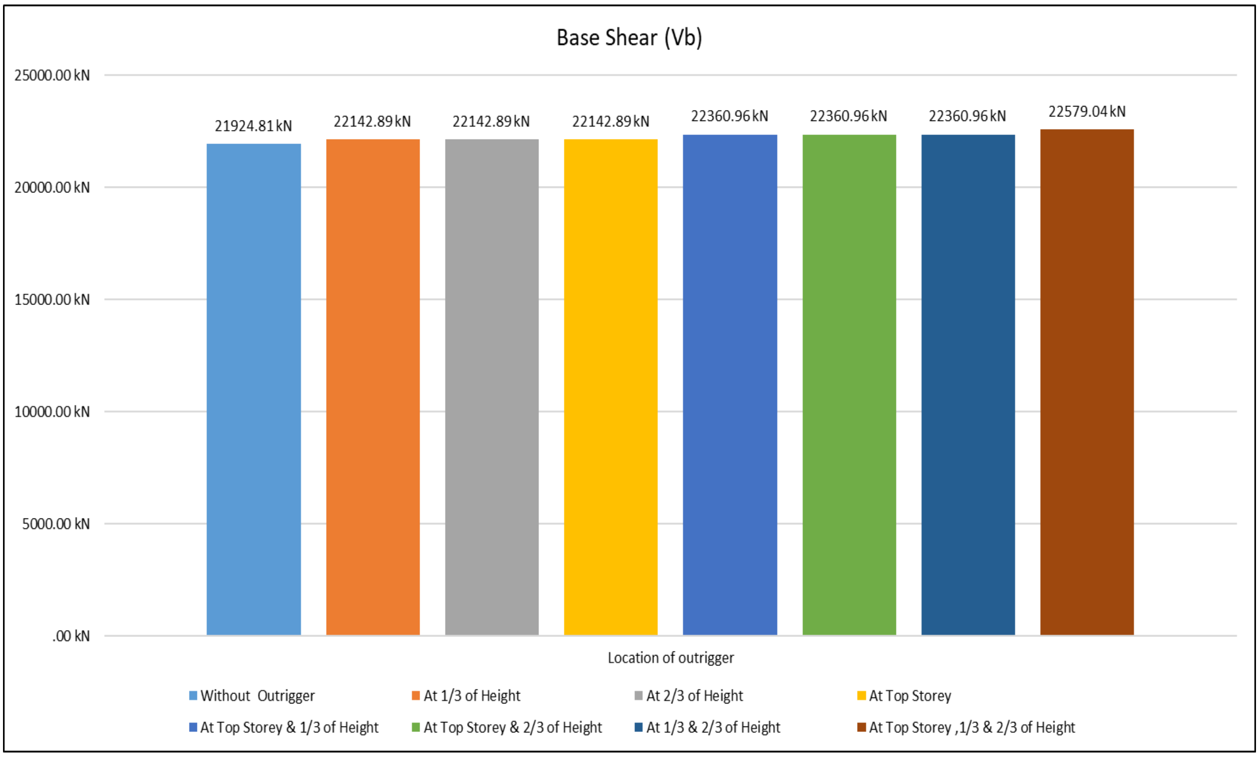

Figure 31 Base Shear

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Figure 31 illustrates the base shear in both the X and Y directions under static earthquake conditions. As depicted in the figure, as the number of outriggers increases, the base shear also increases. This is because an increase in the mass leads to an increase in the base shear.

E. G+29 Conventional outrigger building

In this 29-story model, a conventional outrigger system is used. A deep beam, 300mm thick, outrigger system was employed and studied to evaluate its performance.

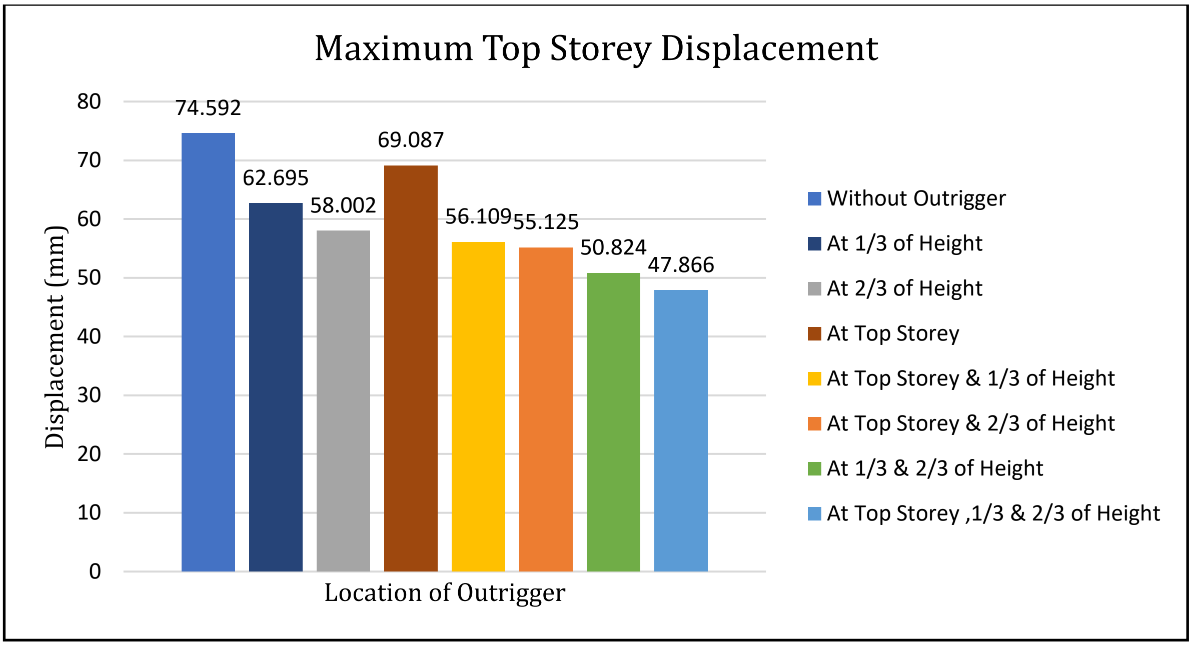

Figure 32 Maximum Top Story Displacement in EQ-X & Y Direction (Earthquake Static)

Figure 32 above displays the maximum displacement of the top story in both the X and Y directions under static earthquake conditions.

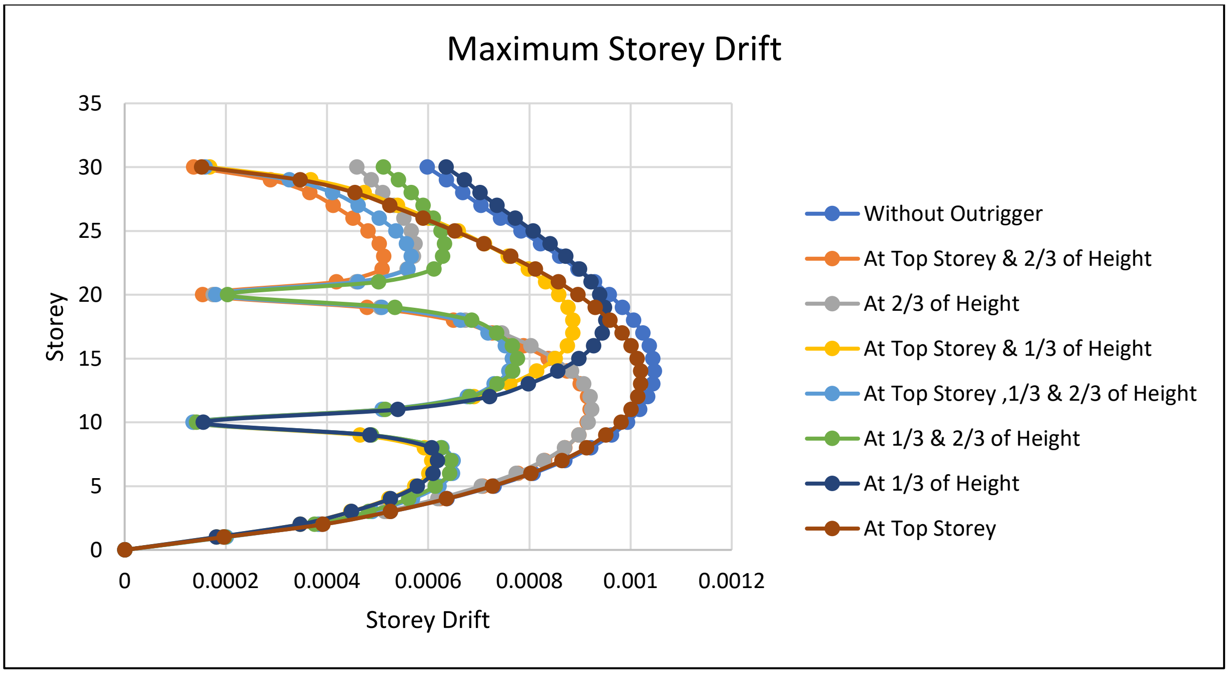

Figure 33 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

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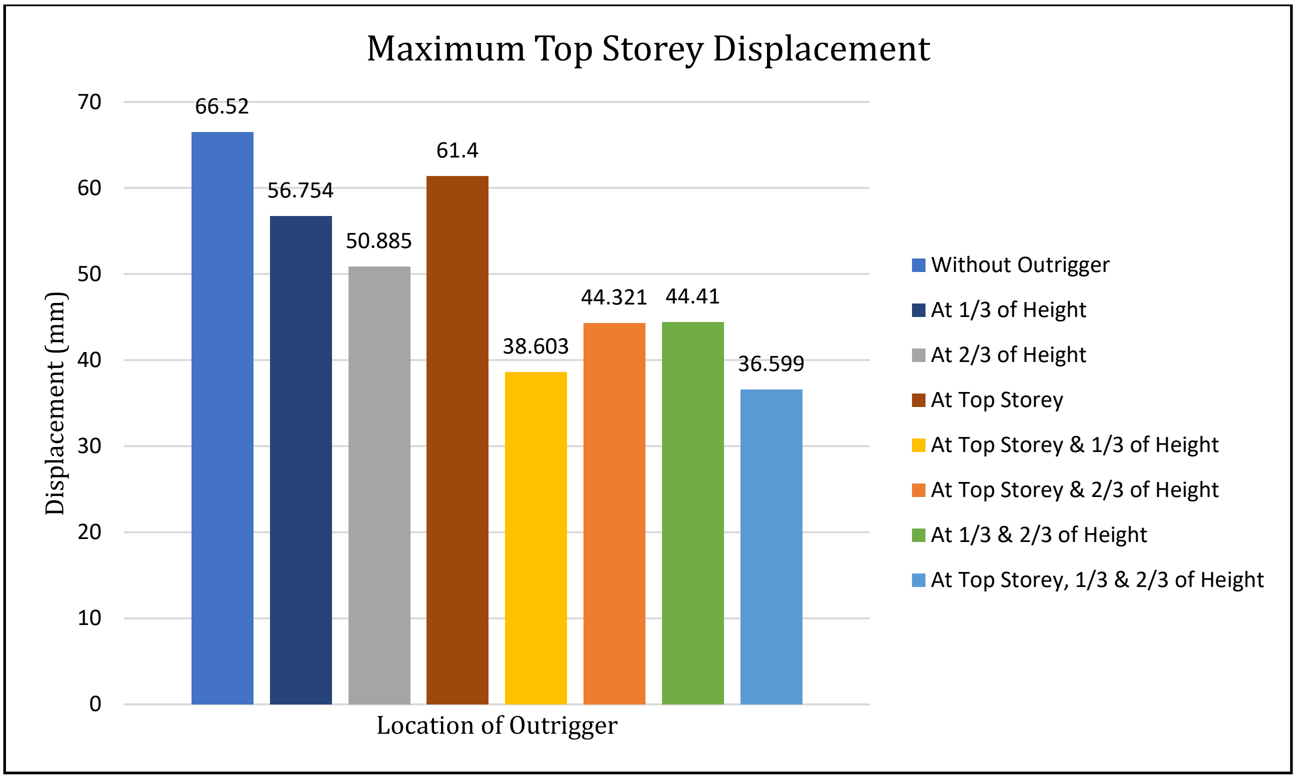

Figure 34 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

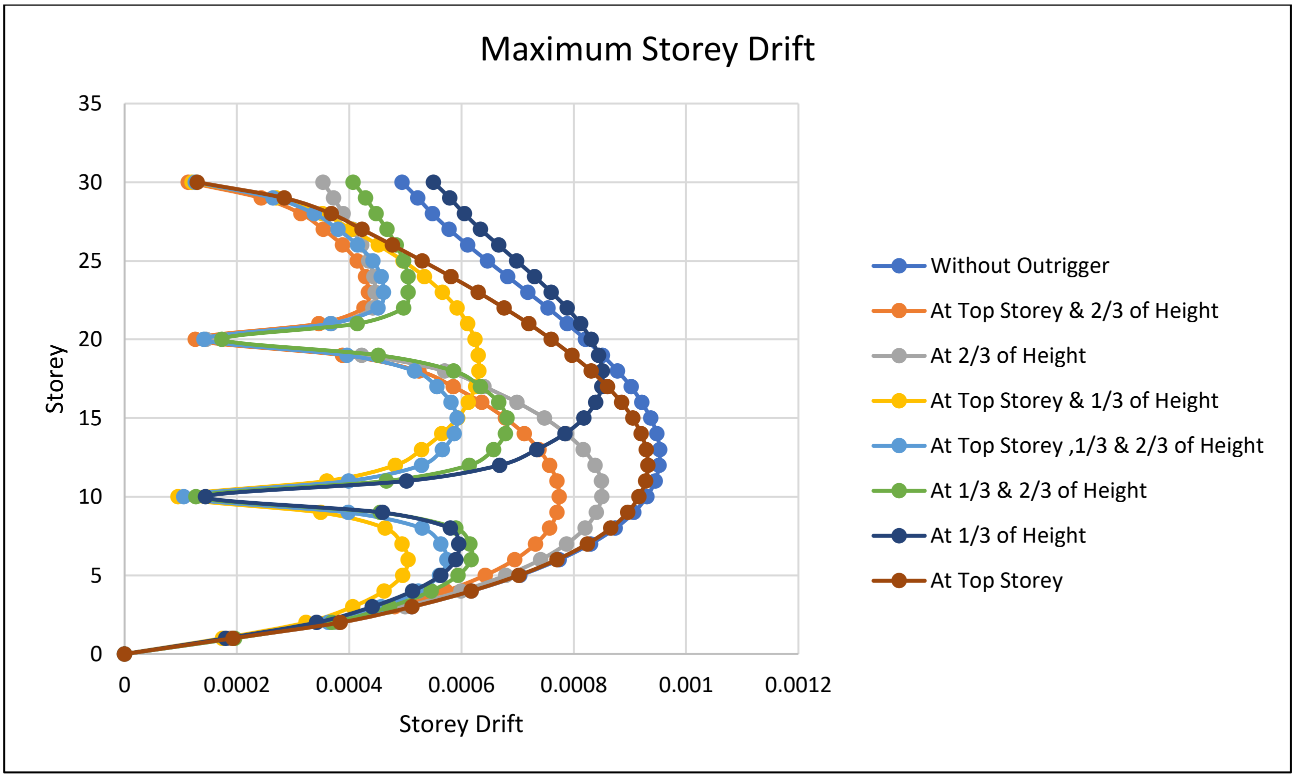

Figure 35 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

Figures 33 & 35 provides information on maximum story drift for outriggers provided at different floors. To reduce the story drift and increase the stiffness of the structure, the provision of outriggers at different floors increases the stiffness

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of the floors at the location where the outrigger system is installed. This design approach has been shown to effectively enhance the lateral stability and overall seismic performance of tall buildings.

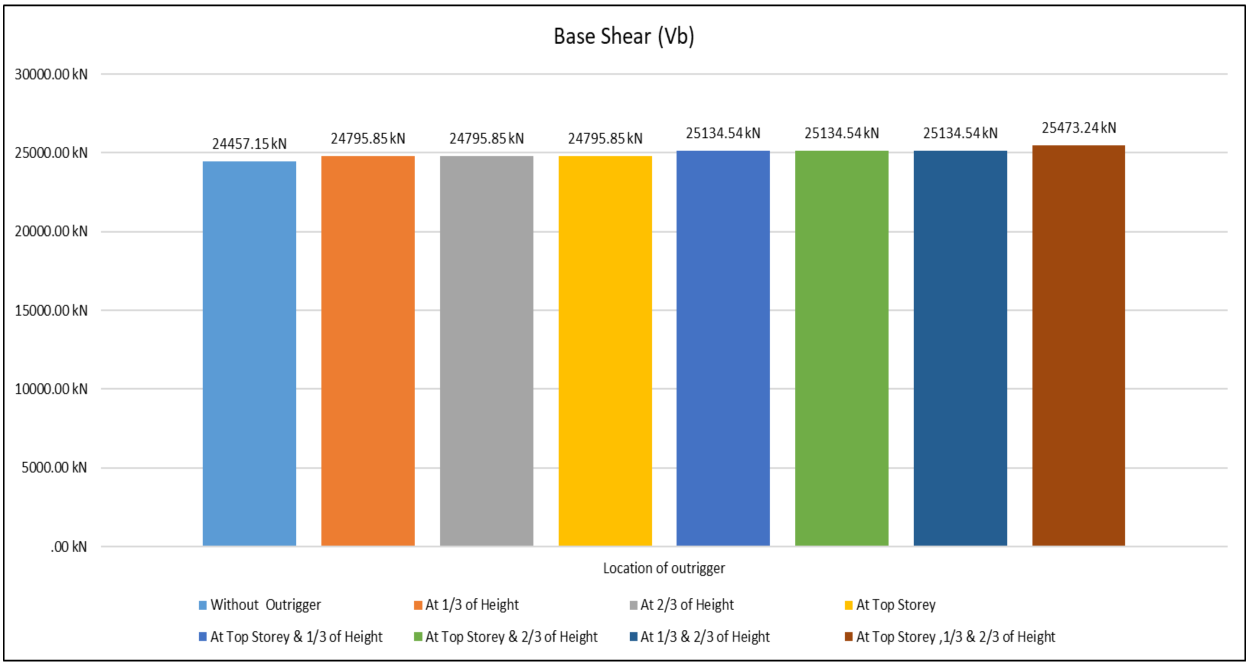

Figure 36 Base Shear

Figure 36 above displays the base shear for outriggers located at different levels within the building

F. G+29 Virtual outrigger building

In this 29-story model, a virtual outrigger system is used. A deep beam, 300mm thick, outrigger system was employed and studied to evaluate its performance

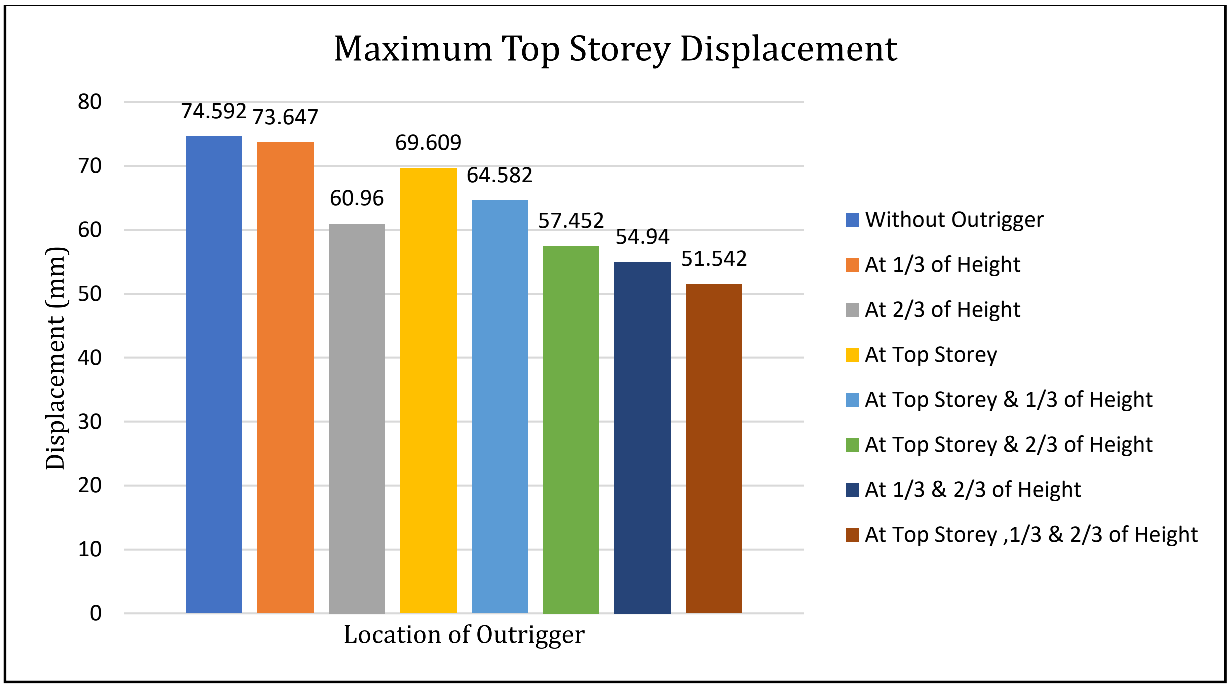

Figure 37 Maximum Top Story Displacement in EQ-X & Y Direction (Earthquake Static)

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Figure 37 above illustrates the maximum displacement at the top story of the building in both X and Y directions under static earthquake conditions

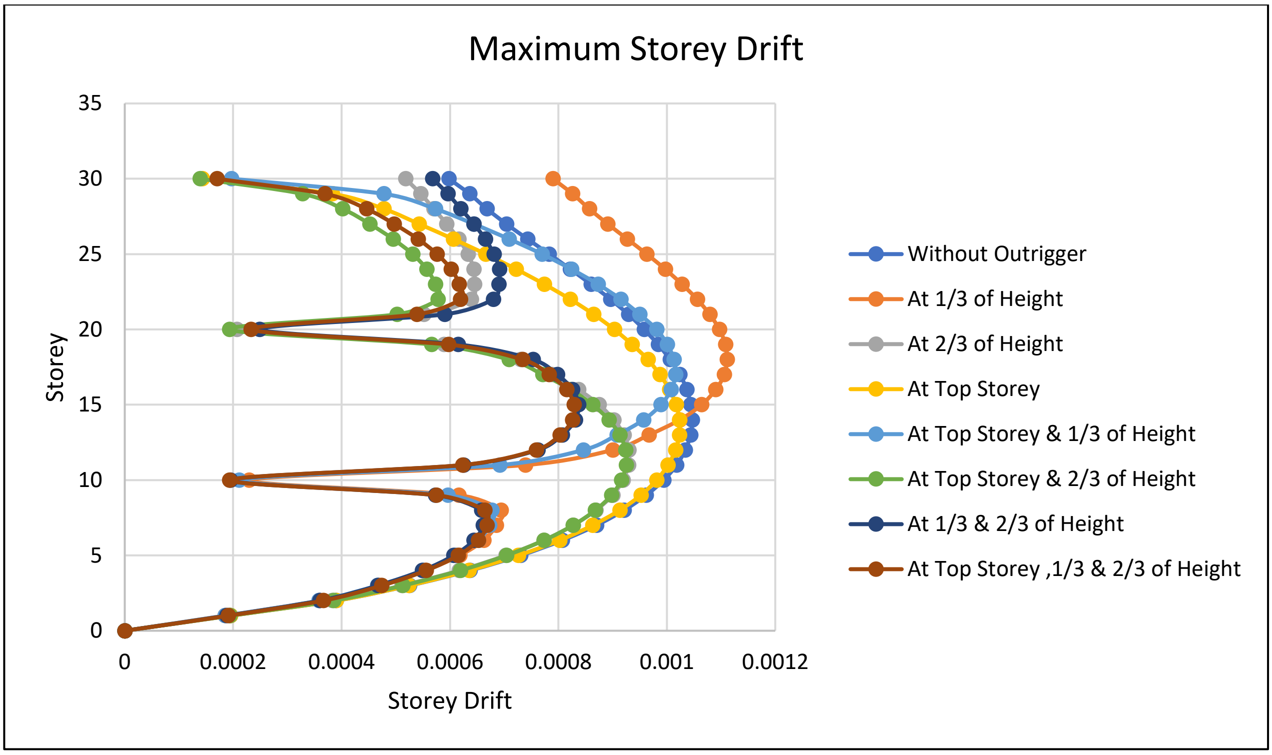

Figure 38 Maximum Story Drift in EQ-X & Y Direction (Earthquake Static)

The above figure 38 provides information on maximum story drift for outriggers provided at different floors.

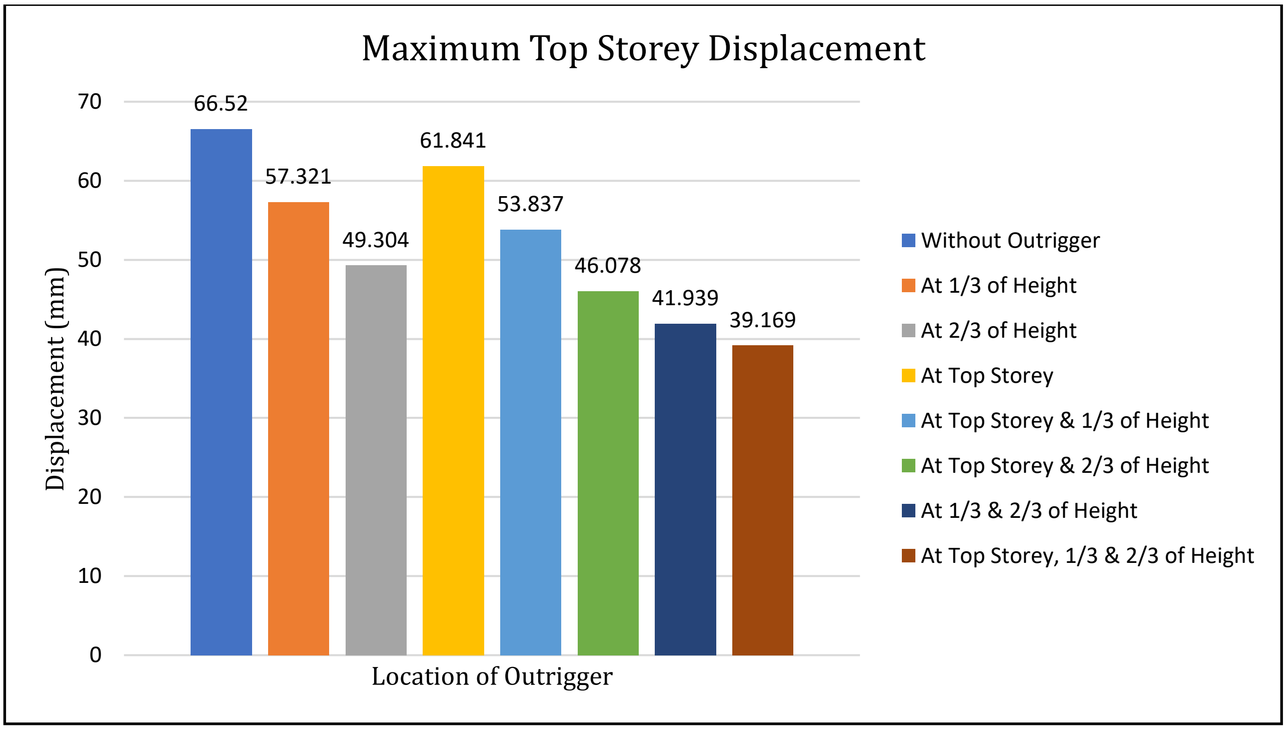

Figure 39 Maximum Top Story Displacement in RS-X & Y Direction (Response Spectrum)

The above figure 39 provides information on maximum story displacement for outriggers provided at different floors

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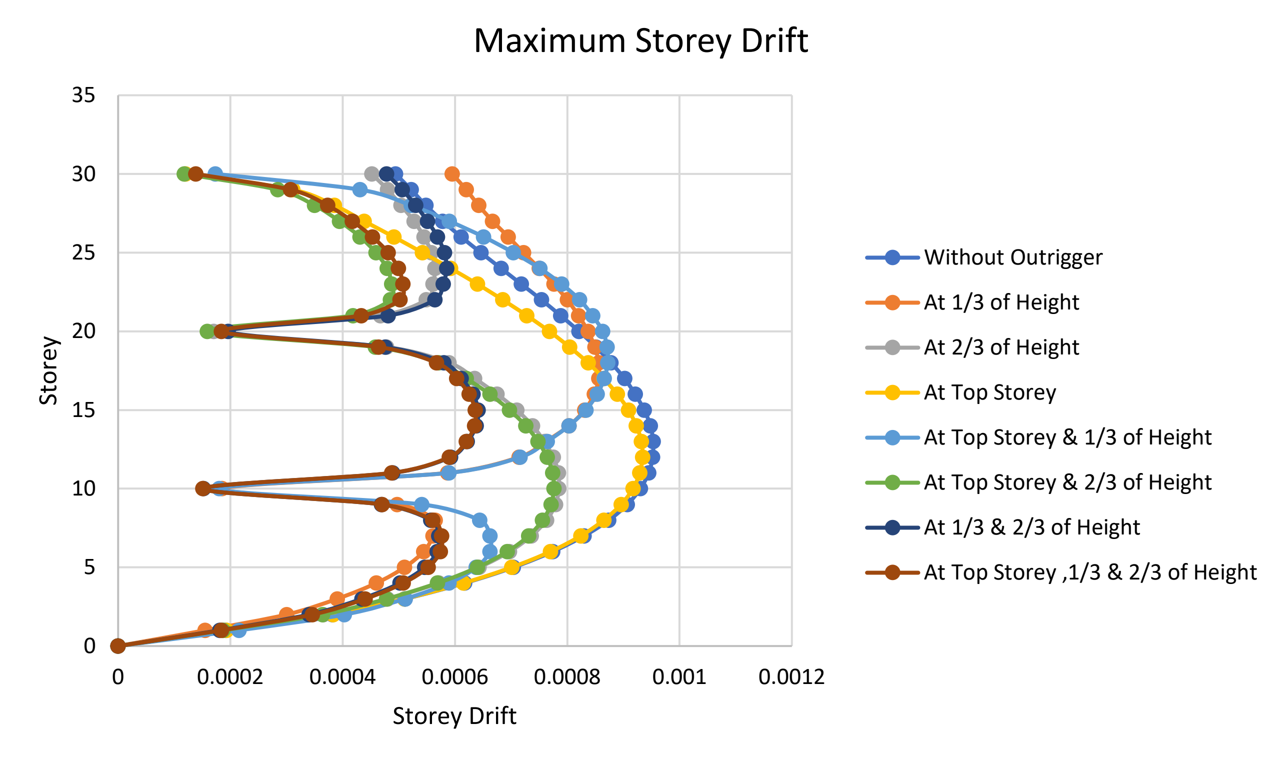

Figure 40 Maximum Story Drift in RS-X & Y Direction (Response Spectrum)

Figure 40 above illustrates the maximum story drift at the top story of the building in both X and Y directions under dynamic earthquake conditions The drift is decreasing at the outrigger location due to an increase in stiffness at that specific point.

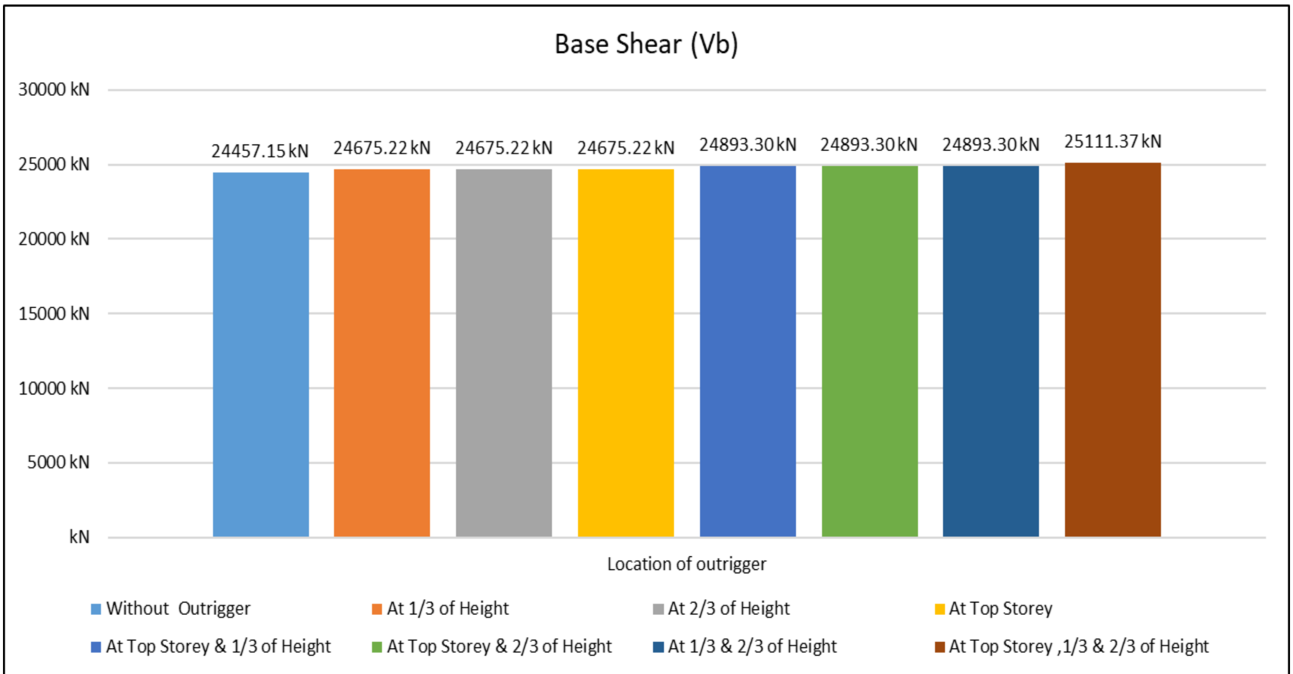

Figure 41 Base Shear

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Figure 41 illustrates the base shear in both the X and Y directions under static earthquake conditions. As depicted in the figure, as the number of outriggers increases, the base shear also increases. This is because an increase in the mass leads to an increase in the base shear

Discussion of Results

- According to figures 12 and 14, one outrigger system in a G+19 belt-truss structure reduces the maximum top story displacement by 19.83% and 19.846%, respectively, with the highest reduction occurring at 2H/3. H stands for the building height.
- According to figures 17 and 19, a single outrigger system at 2H/3 reduces the maximum story displacement by 13.86% and 14.928%, respectively. The maximum top-story displacement decrease for two outrigger systems has been determined to be 17.30% and 18.34% when the outrigger is used at H/3 and 2H/3, respectively
- The ideal location of outrigger system in G+19 and G+24 belt-truss structure is at 2H/3 for one outrigger and for two outrigger the optimum position is H/3 and H/3.
- As shown in figure 32, the conventional outrigger system provides greater reduction than the virtual outrigger system. For one outrigger at 2H/3, the conventional outrigger reduces story displacement by up to 22.41%. The maximum reduction in maximum top story displacement for three outrigger systems used in bundled tall buildings is 35.83%.
- The figures 16, 21, 26, 31, 36 and 41 demonstrate that as the number of outrigger systems increases, the base shear also increases, and this trend is observed due to an increase in seismic weight of the building

V. CONCLUSION

The G+19, G+24 and G+29 Bundled tall buildings were Subjected to both Static and Dynamic analysis using various lateral load resisting systems, such as belt-truss outrigger, deep beam outrigger, conventional outrigger and virtual outrigger system

- For a G+19 and G+24 Bundle tall building with Belt-truss outrigger system, the ideal position for one outrigger system is 2H/3 of the building. H stands for the building's height.
- For a G+19 Bundle tall building with Belt-truss outrigger system, the ideal position for two outrigger system is H/3 and H/3 of the building.
- The G+19 Bundle tall building with Belt-truss outrigger system, for three outrigger system is provided at top story, H/3 and 2H/3 of the building.
- For a G+24 and G+29 Bundle tall building with deep beam outrigger system, for conventional outrigger system the displacement reduced more as compare to virtual outrigger and the ideal position for one outrigger system is 2H/3, for two outrigger system H/3 and 2H/3 of building.

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