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Seismic Performance of a Tall Multi Storey Tower Connected by a large Podium

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Abstract**:** ***The present work focus on the effect of podium structure of single tower structure connected by a common podium at the interface level under seismic load. For this purpose, the simulation model with varying tower height and podium height is created in the ETABs and it is analyzed for the equivalent static and response spectrum method. In this study, the effect on the top displacement of the tower connected with podium structure under equivalent static and response spectrum method of analysis is observed. The backstay forces that are developed to resist the lateral overturning actions at the interface when the lateral horizontal forces are transferred from the tower to the podium are studied. The unfavorable effect of podium on the shear force distribution at and above the interface level of the structural wall is observed. The positioning of the tower on the podium structure is found to be the reason for the differential displacement between the structural walls.***

Key words**:** ***backstay effect, equivalent static method, podium structure, response spectrum method, strutting force.***

I. INTRODUCTION

Any bottom portion of a tall structure that is larger in the floor plan and contains a significantly increased seismic force resistance when compared to the portion of the tower above can be considered as a podium structure. Many tall structures have an arrangement in which the below few storeys have a larger floor plan than the towers above, this type of construction is common in multi-storey buildings where the lower part of storeys often used for retail stores, parking lot, meeting rooms etc. The recent studies focused on the effects of the podium on the distribution of shear forces in tower structure and focused on the backstay effects due to the podium structure. A depth discussion of the backstay effects and modelling procedure is in IS 16700:2017 and PEER/ATC 72-1. Yacoubian et al. (2017a) investigated the adverse effect on the twin shear wall structure due to the interference of the podium structures. It was concluded that the magnitude of strutting action and incompatible displacements are highest when the twin tower walls are offset from the center [3,4]. Babak et al. (2009) has found that when an immense portion of the overturning moment in structural walls are transferred to the basement wall through one or more diaphragms the maximum bending moment tends to occur above the diaphragm and the shear force changes its direction below this level [5]. Moehle et al. (1990) the study includes experimental and analytical studies on the behavior of the setback structure under the earthquake load. They focused on the effects of a setback on the dynamic response of the structure and design criteria to improve the response of setback building for lateral forces [6]. Tocci et al. (2012) discussed the backstay effect which is most perceptible in buildings with a distinct lateral system (ex: shear wall, core wall) which are connected with the base structure [7]. It has been found that ample amount of study has been carried out on the displacement parameter for single tower connected by a podium structure in which the number of storeys in the podium structure is varied. Lacks detailed study on backstay, strutting action and differential displacement occurring at the podium tower interface level. To encounter this limitation the present study has been carried out. In this present investigation the top displacement behavior of the single tower structure with increasing the number of stories in the podium structure is carried out. To determine the optimum placement of the tower on the podium structure the strutting action and the differential displacement developed at the interface level of the tower positioned centrally and the tower which is offset from the center of the podium are studied. The amount of backstay forces developed at the podium tower interface level are also presented in this paper.

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II. METHODOLOGY

A 15 to 40 storey RCC lateral load resisting structures with and without podiums are modelled using the extended 3D analysis of building system (ETABS) software. Each floor is taken as 3m height. The number of storeys in the podium structure is also varied from one to five storeys. The two cases which are considered in this study are as follows,Case 1: The tower structure without a podium structure, where the base dimension of the architectural plan is 36m×36m.

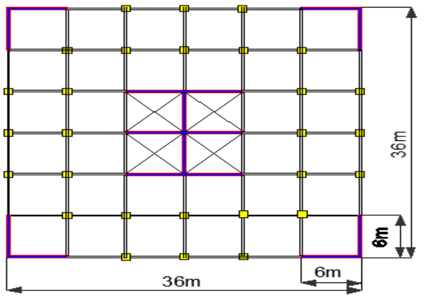

Fig1.1: Plan view of the tower

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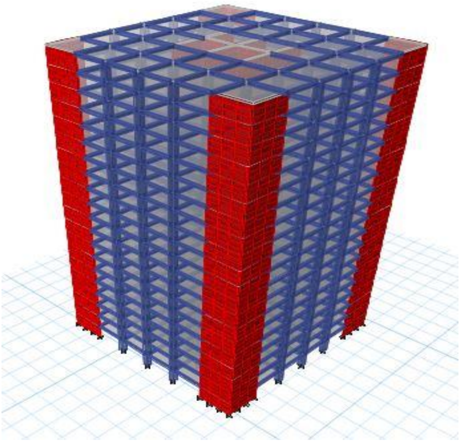


Fig1.2: Isometric view of the tower

Case 2: The tower structure with podium structure, where the architectural plan area for tower structure is 36m×36m and plan area of podium structure is 108m×108m.

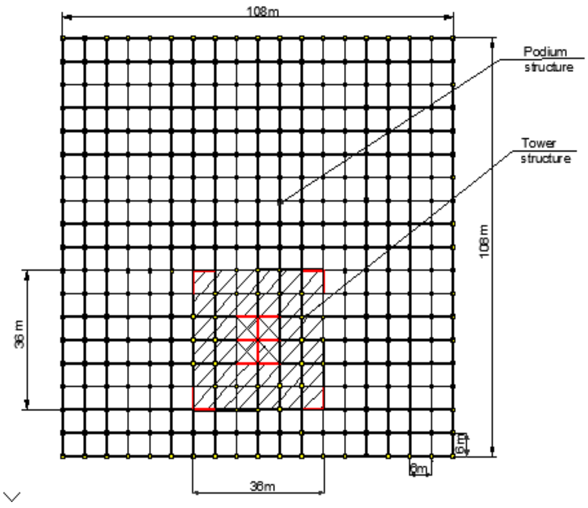
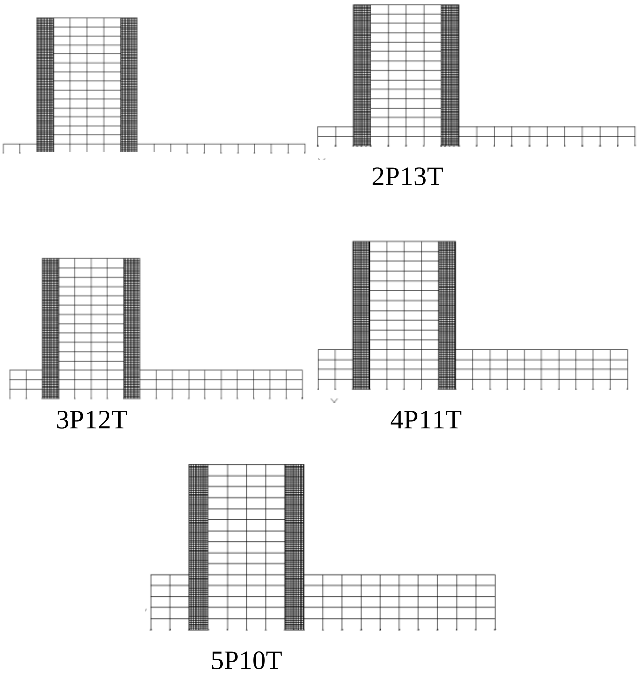


Figure 1.3: Plan view of the podium-tower



2P13T

3P12T

4P11T

5P10T

Fig1.4: Analysed tower connected by podium sub-assemblages along Y direction.

Table 1: Data used for Analysis

Building Type	RCC
Column size	900mm×900mm
Beam size	300mm×600mm
Shear-wall	350mm thick
Core-wall	400mm thick
Slab	200mm thick
Grade	M50, M60
Seismic zone	III as per IS1893:2016 (Part 1)
Response reduction factor	3
Importance factor	1.2

A live load of 3 kN/m2 is taken as per IS 875 (PART 2), a wall load of 12.42 kN/m and parapet wall load of 3.726 kN/m considering masonry wall is applied to the model. The unit weight of the bricks used for the masonry wall is taken as per IS 875(Part 1).

The structure is analysed for seismic loading conforming to IS1893:2016(Part 1).

III. RESULTS AND DISCUSSION

The results obtained from the current study are presented in this paper. The interpretation of the results for different parameters under equivalent static method (EQ) and response spectrum method (RSM) are represented graphically. First, the Top Displacement graphs are plotted for the Equivalent Static and Response spectrum method of analysis along X and Y direction. Fig 4.01 to 4.02 shows the Top displacement of a single tower without a podium and with a podium with varying number of storeys in the podium structure (Hp) for a considered tower height (Ht). From Fig 4.01 to 4.02 the increase in lateral top displacement of the tower with increase in number storeys in the podium structure can be observed under static load. The Fig 4.03 demonstrated that with an increase in podium storeys the shear forces at the top of the structure under equivalent static method of analysis increases, lateral top displacement increases. In the case of RSM Fig 4.02, it is observed that the top displacement decreases after increment at certain point and then remains independent to the height of the podium. Comparatively the top displacement observed under response spectrum analysis is lesser than equivalent static method. This difference is observed due to the decrease in the shear force at the top of the tower in the case of response spectrum analysis compared to the results obtained from equivalent static method of analysis which is shown in the Fig 4.04.

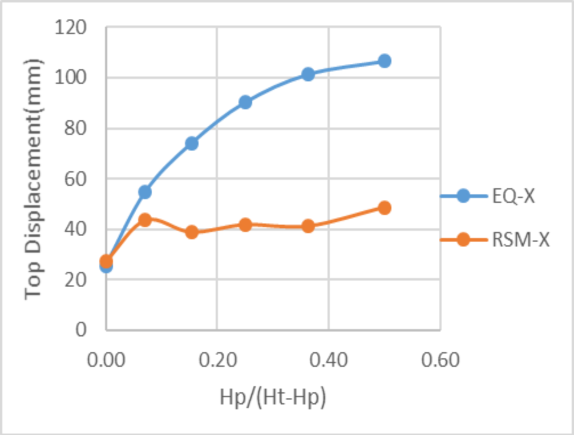


Fig 4.01: Top displacement of 15 storey tower with podium for different podium height along X direction

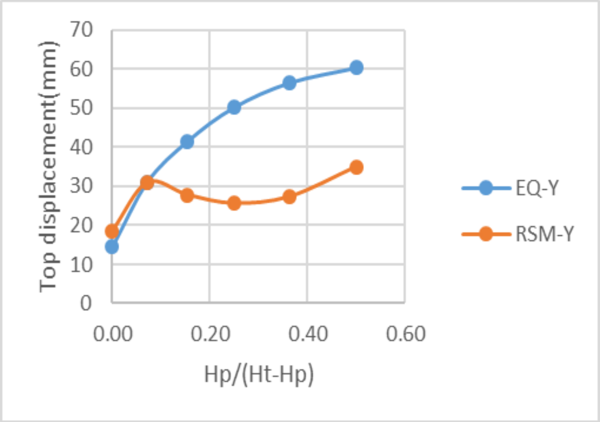


Fig 4.02: Top displacement of 15 storey tower with podium for different podium height along Y direction

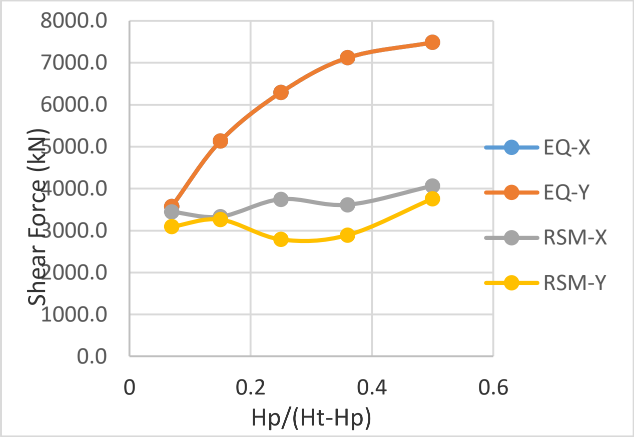


Fig 4.03: shear force at the top of a single tower structure with podium under Equivalent static method (EQ) and response spectrum method (RSM).

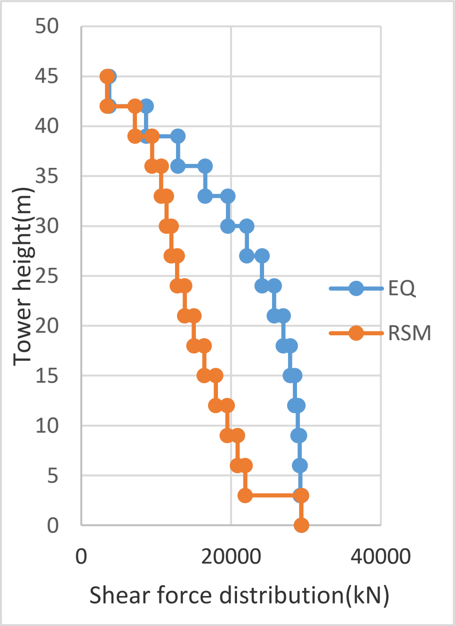


Fig 4.04: shear force distribution of a single tower structure with podium.

To study the influence of podium on the tower the backstay forces developed at the podium tower interface are plotted. The shear force of the lateral load resisting system of a tower at the level of podium-tower interface is calculated and then it is deducted from the storey shear at the interface level. From Figure 4.05 it is observed that with the increase in podium storeys the backstay forces at top of the podium-tower interface increases.

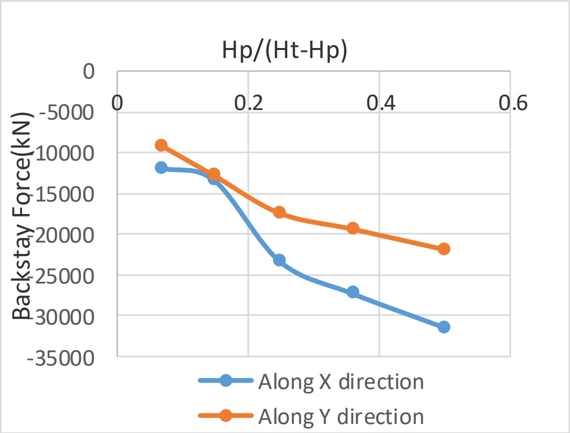


Fig 4.05: Backstay force along X and Y direction of 15 storey building varying number of storeys in the podium structure.

Further, the study on the in-plane strutting force developed in the beam connected to structural walls to maintain the compatibility between the shear wall due to the differential restrains occurred at the interface zone imposed by the podium is observed in Figure 4.06 to 4.07. To understand the effect of the geometric configuration on strutting action the tower which is offset from the center of the podium and also tower centrally positioned have been analyzed and results are plotted.

As the tower is offset from the center of the podium it is observed that strutting force generated in the beam connected to the exterior wall is highest than the beam connected to the interior wall within the podium tower interface level. In the case of tower positioned at a center of the podium the amount of strutting force developed in a beam connected to exterior and interior wall at the interface level is same.

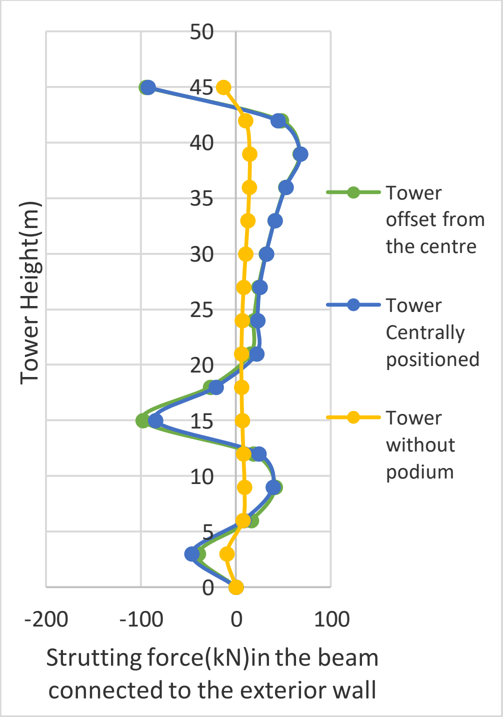


Fig 4.06: Strutting in-plane force in the beam connected to exterior wall for 5P10T podium-tower structure (equivalent static method).

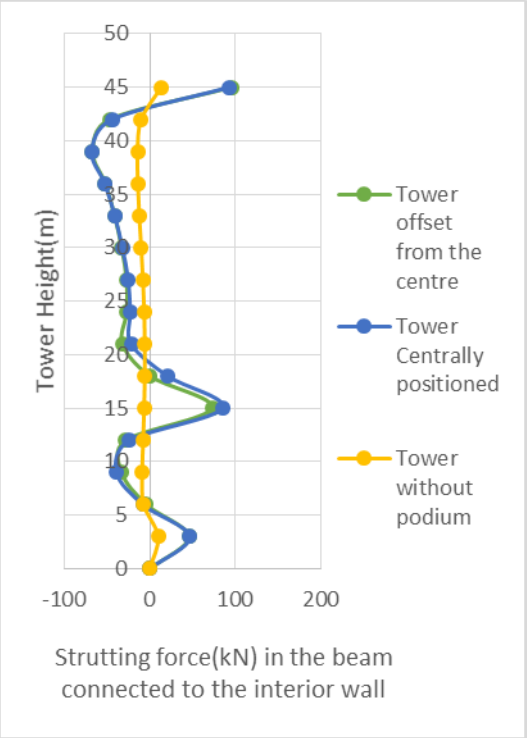
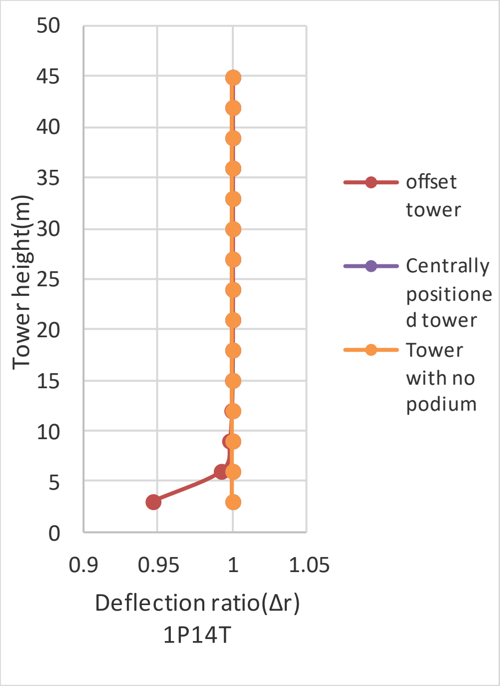
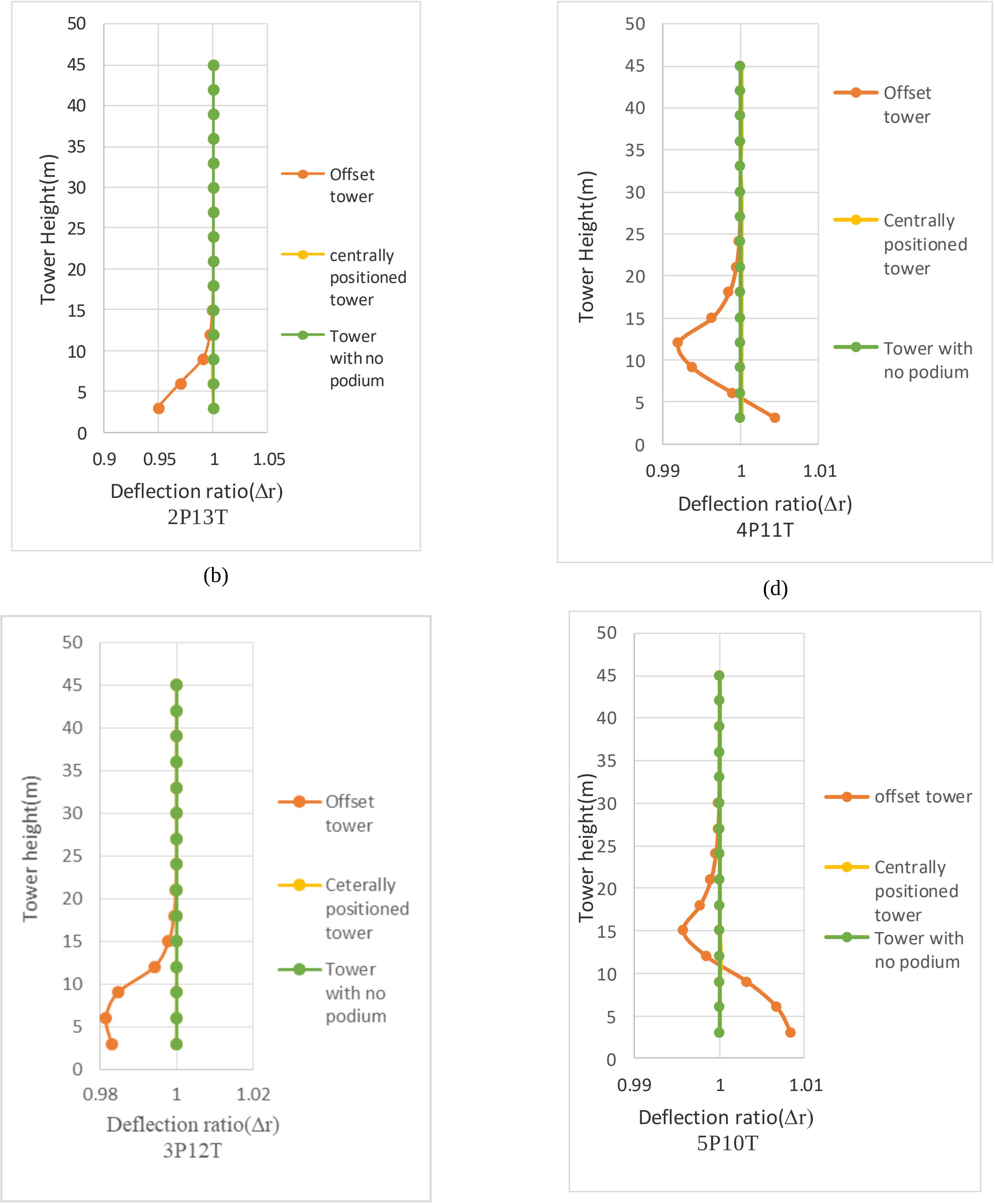


Fig 4.07: Strutting in-plane force in the beam connected to interior wall for 5P10T podium-tower structure (equivalent static method). The effect of the podium-tower interface will also results in incompatible displacements of the shear wall. These activities must be accounted for if the in plane flexibility of floor has been incorporated into the model. Thus, analyzing through rigid floor diaphragm assumption such actions are misrepresented. The incompatible displacement under static lateral load in the tower wall (deflection ratio Δr=Δint/Δext) till the height of the tower is plotted Fig 4.08. Results obtained from the analysis of a tower connected to podium structure in which the tower is offset from the podium are compared with the centrally positioned tower-podium Fig 4.08. The incompatible displacement occurs at the podium-tower interface level i.e., Δr < 1 is shown in Fig 4.08. The trend extends one to two storeys above the interface level beyond this level the compatible displacement is achieved i.e., Δr=1. These incompatible displacements are not obtained in the case where the tower is centrally positioned and the tower without connecting podium Fig 4.08.



(a)



(b) (d)

(c) (e)

Fig 4.08: (a), (b), (c), (d), (e) Differential displacement of the tower wall for the tower connected by a podium with varying podium height (Equivalent static method of analysis). In the case of response spectrum analysis Fig 4.09 to Fig 4.10 as the tower positioned offset from the center of the podium it is observed that the force generated in the beam connected to the exterior wall will be highest than the force in the beam connected to the interior wall but will remain in the same direction.

The similar trend cannot be observed in the case where the tower is placed at the center of the podium Fig 4.11. Under the response spectrum analysis Fig 4.12 the internal wall undergoes higher displacement than the exterior wall with increase in the number of story in the podium i.e. Δr>1. In the case of tower placed at the center of the podium Fig 4.13 the compatible displacement can be observed i.e. Δr=1.

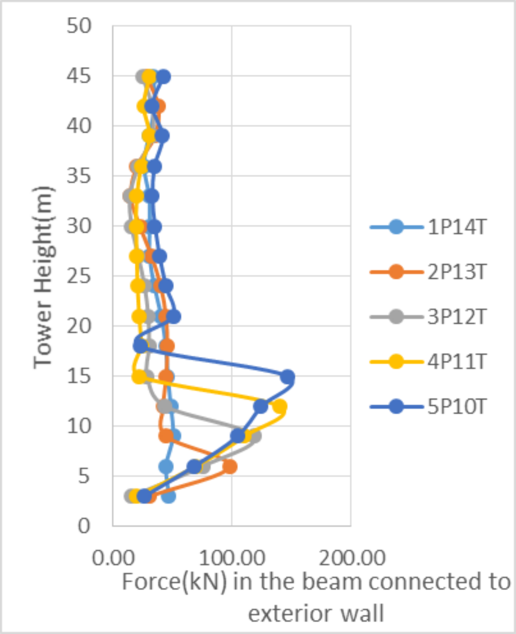


Fig 4.09: Force in the beam connected to exterior wall for podium-tower sub-assemblages with varying podium height (Response spectrum method).

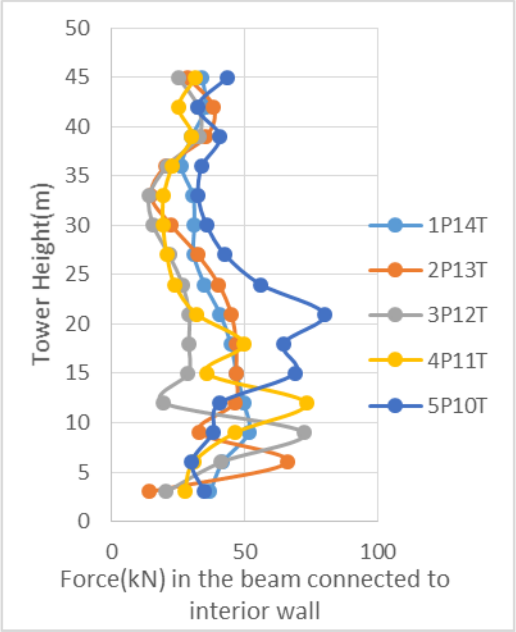
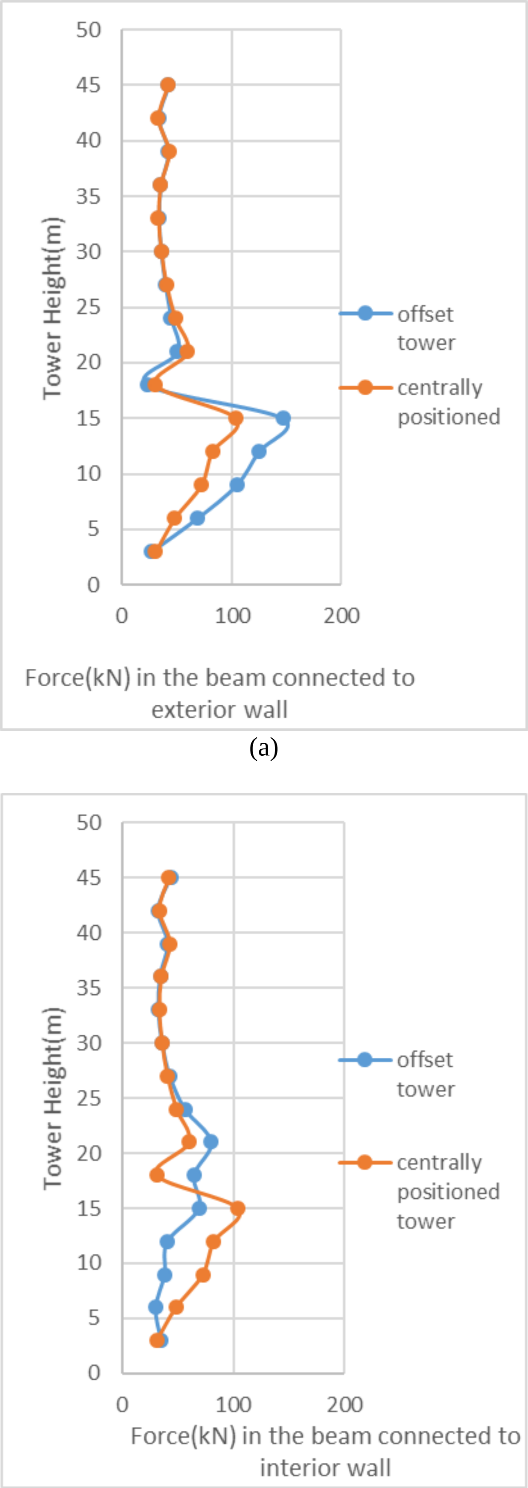


Fig 4.10: Force in the beam connected to interior wall for podium-tower sub-assemblages with varying podium height (Response spectrum method).



(a)

(b)

Fig 4.11: Strutting in-plane force in the beam connected to (a) exterior wall (b) interior wall for 5P10T podium-tower structure (Response spectrum method).

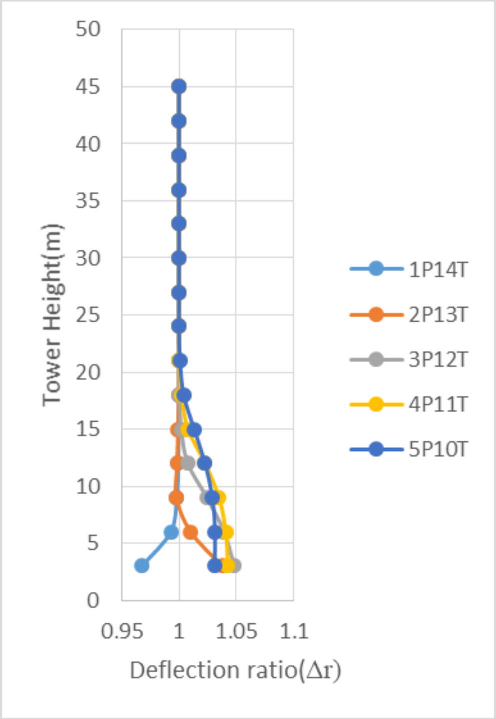


Fig 4.12: deflection ratio of the tower offset from the podium with varying number of storeys in the podium for response spectrum method.

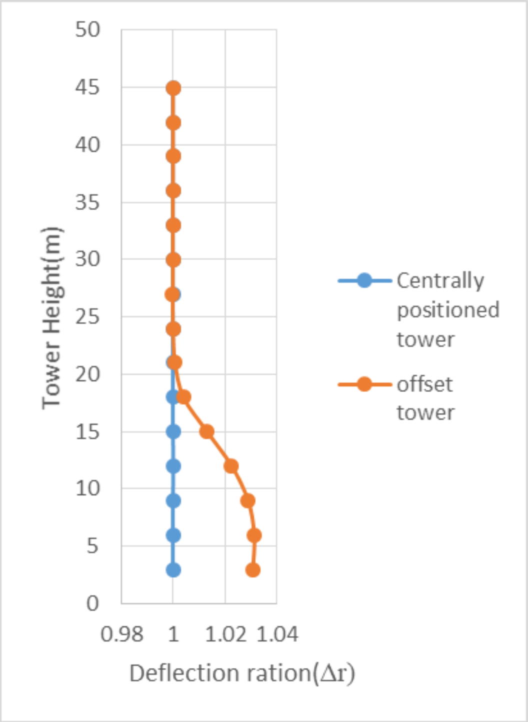


Fig 4.13: deflection ratio of the tower offset from the podium and centrally position tower for response spectrum method.

IV. CONCLUSION

To evaluate the performance of a single tower building with a large podium for varying number of storeys in the podium and to study the effect of the podium on the tower at the interface level of the structure under seismic loading,the modal is created in the ETABs and it is analyzed for the equivalent static method and response spectrum method. From the results obtained the following conclusions can be drawn:

- The increase in the podium height of single tower- podium configuration the top displacement of the structure increases. In the case of response spectrum analysis the top displacement decreases after increment at certain point and then remains independent to the height of the podium.
- The podium imposes the backstay effect at the podium –tower interface level. It is observed that with the increase in podium storeys the backstay forces at podium-tower interface increases.
- In the case of single tower -podium structure, the podium imposes differential restraints at the interface level based on the tower position with respect to the center of the podium.
- The incompatible displacement of tower wall is observed for single tower podium connected structure at the interface level.
- From the study it is concluded that the structure must be designed for the results obtained from the response spectrum analysis than the results obtained by the equivalent static method of analysis which overestimates the results.

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