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Backstay Effect of Diaphragm in Tall Building

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Abstract: - Seismic analysis of structural systems with floor diaphragms has been a requisite in the recent past. The duty of a structural engineer is to be prudent about the behavior of every structural system adopted. Amongst the structural systems that are adopted world over, diaphragm with rigid and semi-rigid floor plate are adopted widely in the analysis. This research focuses on the backstay effect i.e. podium structural interaction with the tower area and consideration of retaining wall as increment of lateral stiffness as specified in latest tall building code IS6700:2016 for low and high rise structures. In the current study models were prepared with low to high rise storeys with rigid and flexible diaphragms considering backstay diaphragm placing tower at center and corner. The models were subjected to seismic forces; response spectrum along with the combination of the gravity loads. The structural responses like natural periods, base shear, displacement and inter storey drift were also studied.

Keywords : Podium tower, Backstay effects, Rigid and Semi-rigid diaphragm. Seismic Analysis.

I. INTRODUCTION

One of the least understood aspects of modelling building structures is dealing with at and below-grade components. This includes soil structure interaction, but also the question of which below-grade structural elements should be included in a lateral model and what is an accurate representation of the base conditions. The focus of this research is what is most commonly referred to as the backstay effect. Traditionally, lateral systems have been viewed as simple cantilever beams fixed at the base. While this analogy is reasonable for the above-grade structure, a more accurate analogy would also include the effects of the below-grade structure, which behaves like a back span to the cantilever. In this analogy, the lateral system is viewed as a beam overhanging one support, where that support is created by the at-grade diaphragm and foundation walls. The backstay effect is not limited to restraint at the grade level. Backstay effects are also seen at setbacks with changes to the lateral system, the most common example being lower level podiums. They are often very large in plan and introduce new lateral elements, and are therefore significantly stiffer than the set-back structure above. Backstay effects are also impacted by multiple basement levels. For simplicity of explanation, this article will focus on the most common example which is the effect of the ground floor diaphragm in contributing to backstay effects. The concepts can be extended to all conditions where backstay effects occur. effectively larger beam section below grade.

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A rigid diaphragm transfer load to frames or shear walls depending on their flexibility and their location in the structure.

A diaphragm may be considered rigid when its midpoint displacement, under lateral load, is less than twice the average displacements at its ends. Flexible diaphragms resist lateral forces depending on the tributary area, irrespective of the flexibility of the members that they are transferring force to. A diaphragm is considered flexible, when the midpoint displacement, under lateral load, exceeds twice the average displacement of the end supports.

R.Khajehdehi et. al (2018) the main objective is flexible floor diaphragm along with opening. They had done different models for their research work to analyze the behaviour of floors which are solid as well as with floor openings up to 25%. Parameters studied are base shear, displacement, deflection. It is concluded that opening in the floor with increased flexibility diaphragm results in breaking of floor panels, load carrying capacity is reduced floors will fail. Mehair Yacoubian et al. (2017), worked on podium interference and finite element 3D analysis using etabs. The purpose of the 3D analysis was to find the horizontal response on the structure. In this analysis they have researched on three models Tower with- out podium interference, Tower with podium interference placed at the center of plot area. Tower placed at one corner of the plot area. Analyzed the structure using static analysis. Parameters studied are difference of displacement between walls, story drift and shear force, wall bending moment and base shear. It can be known that the conditions which are not in favour of the podium and the tower.Mohammad et al., (2013) work on the behavior of the tall structure which have soft and hard diaphragm. In this paper they mainly examined concrete is fully hardened, loss in concrete (1/3). The analysis was done by using equivalent static and dynamic method. Parameter studied displacement, modal time period, time history. It can be known that the structure with flexible diaphragm have large displacement, momentum while for rigid structure time period is larger. Dhiman Basu and Sudhir. K. Jain (2004) worked on both flexible and rigid floors diaphragm along with the centre of rigidity of individual floors. The analysis was done by using static method. Parameters are static, accidental eccentricities, response due to torsion, accidental torsion and shear force. From this paper it can be known that the both flexible and rigid diaphragm can be used depending on structure's position and effect of torsion.

II. OBJECTIVE

The objective of present study is comparison of diaphragm effect for rigid and semi rigid flexibility effect of the floor slab of frame building with shear wall at the core, comparison of diaphragm effect with the effect of backstay for rigid and semi rigid flexibility effect of the floor slab framed building with shear wall at the core, comparative study of rigid and flexible diaphragms for twenty and fourty stories framed building, to study of parameters like time period, base shear, storey displacement and storey drifts, in this study slabs are considered as rigid and semi rigid floor systems.

III. METHODS

A. Description of Specimen

RC Structure with, twenty and fourty storey are taken into consideration. The RC frames are designed as per Bureau of Indian Standards codes, IS 456-2000, "Plain and Reinforced Concrete-code of practice", IS 1893-2002 (Part1), "Criteria for earthquake resistant design of structures".

B. Analysis Type

Etabs, finite element based software used for analysis and design of structures. Analysis was done by using etabs 2016.

C. Design

The RC frames comprises of columns, beams and slabs. concrete frame. Table 1 represents the various loads and earthquake factors assigned for the frames as per IS codes.

Table 1: Applied Loads and Seismic-Factors

Type of Load	Members	Applied Loads and Factors	Codes
Dead load	Unit weight of concrete	25 kN/m^3	1S 875:1987 Part-I
	Floor finish	1.5kN/m^3	
	Roof finish	3.0kN/m^3	
Imposed Load	Slabs	2.0kN/m^2	1S 875:1987 Part-II
Earthquake Load	Zone factors	0.36	IS 1893:200 2 Part-I
	Importance factor	1.5	
	Response reduction factor	5	
	Soil condition	Medium	
	Damping	5%	

D. Details of RC Frame

Different types concrete used for the analysis of the two type of structures like twenty and fourty storey with type of concrete M30, M 35, M40, M50 and Tor steel such as Fe 415 and Fe500 are used for reinforcement. Dimensions of external and internal beams are (300 x 600 , 250 x 600) mm .Dimensions for columns for stories are from plinth to ten ,eleventh to twenty, twenty-first to thirtieth, thirty-first to fortieth floors are (1050 x 1050, 900x 900, 750x750, 650x650) mm with change in grade of concrete M50, M40,M35,M30 gradually.

E. Parametric Studies

Following seismic analysis of three dimensional buildings of twenty and fourty storey with shear wall at center done. Building frames with fixed base without considering sub soil. For each stories discussed above there are ten different types of models were done in this thesis to investigate the seismic behavior of each buildings. Here, M20.1, and M40.1 etc. indicates model with no. of individual building for twenty and fourty storey.

F. Twenty Storey

In this storey ten different types of models were done discussed below:

- M 20.1 Rigid diaphragm with bare frame.
- M 20.2 Rigid diaphragm with backstay tower at center.
- M20.3 Rigid diaphragm with backstay and retaining wall tower at centre.
- M 20.4 Rigid diaphragm with backstay tower at corner.
- M20.5 Rigid diaphragm with backstay and retaining wall tower at corner.
- M 20.6 Semi-rigid diaphragm with bare frame.
- M 20.7 Semi-rigid diaphragm with tower at center.
- M 20.8 Semi-rigid diaphragm backstay and retaining wall tower at corner.
- M 20.9 Semi-rigid diaphragm with backstay tower at corner.
- M 21 Semi-rigid diaphragm with backstay and retaining wall tower at corner.

Two structures such as bare frame with diaphragms, backstay with diaphragm and retaining wall tower at corner of area, their floor plan and three dimensional view shown bellow in fig 1and 2.

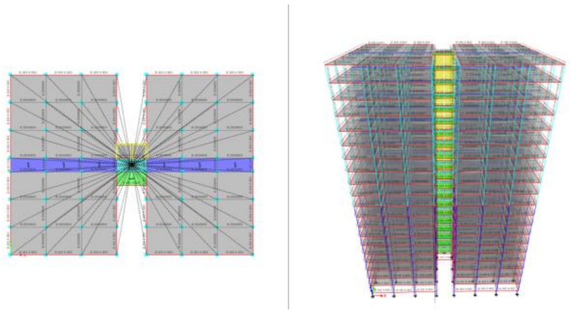

Fig 1: Plan and 3D view of twenty storey bare frame diaphragm.

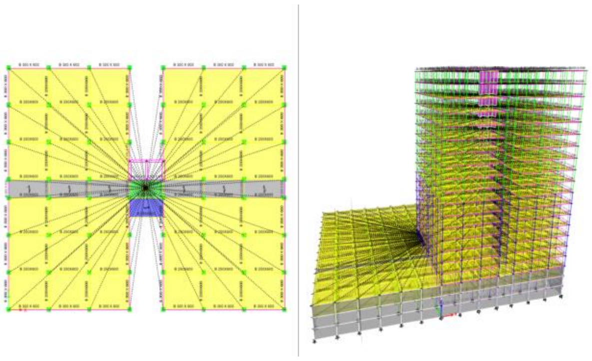

Fig 2: Plan and 3D view of twenty storey backstay with retaining wall diaphragm tower at corner.

A. Fourty Storey

In this storey ten different types of models were done discussed below:

- M 40.1 Rigid diaphragm with bare frame.
- M 40.2 Rigid diaphragm with backstay tower at center.
- M40.3 Rigid diaphragm with backstay and retaining wall tower at centre.

- M 40.4 Rigid diaphragm with backstay tower at corner.
- M40.5 Rigid diaphragm with backstay and retaining wall tower at corner.
- M 40.6 Semi-rigid diaphragm with bare frame.
- M 40.7 Semi-rigid diaphragm with tower at center.
- M 40.8 Semi-rigid diaphragm backstay and retaining wall tower at corner.
- M 40.9 Semi-rigid diaphragm with backstay tower at corner.
- M41 Semi-rigid diaphragm with backstay and retaining wall tower at corner.

Two structures such as bare frame with diaphragms, backstay with diaphragm and retaining wall tower at corner of area, their floor plan and three dimensional view shown bellow in fig 3and 4

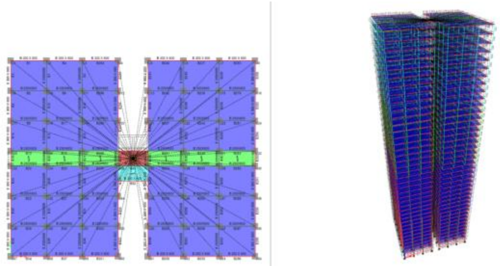

Fig 3: Plan and 3D view of fourty storey bare frame diaphragm.

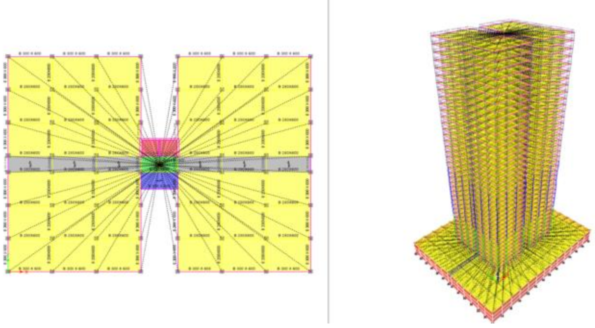

Fig 4: Plan and 3D view of fourty storey backstay with retaining wall diaphragm tower at center.

IV. RESULTS AND DISCUSSIONS

a) Natural Time Period

A graph is prepared bellow to understand the each time period of building when subjected to earth quake. From graph it is observed that first mode time period is more than other two modes. (Refer fig 5).

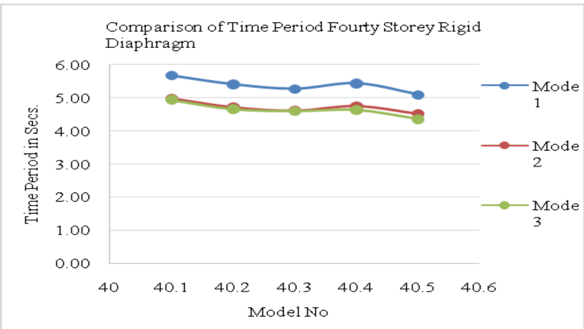

Fig 5: Comparison of Time Period for Fourty Storey Rigid Diaphragm

A graph is prepared bellow to understand the each time period of building when subjected to earth quake. From graph it is observed that first mode time period is more than other two modes.(Refer fig 6).

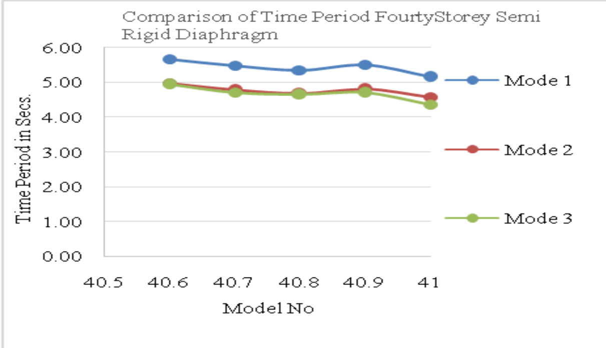

Fig 6: Comparison of Time Period for Fourty Storey Semi-rigid Diaphragm

The model with bare frame for fourty storey has maximum time period, when compared to models with effect of backstay diaphragms. Bare Frame is more flexible when compared to other models. If the structure is flexible time period is more. If the structure is stiffer there will be reduced time period. It is seen that when the diaphragm effect is considered with the tower accounting back stay time period is less. Also, with the consideration of retaining wall of the structure there will be reduced time period which is increasing the lateral stiffness of the structure. As observed in the tables time period is directly proportional to stiffness of the structure. Hence increase in stiffness there will be reduced time period for the structure with rigid diaphragm (Refer fig 5). When the structure with flexible diaphragm is considered in the analysis there will be marginal increase in the time period. Hence resulting in increased time period .Structure with flexible diaphragm is flexible and vurnable to earth quake as when compared to rigid diaphragms (Refer fig 6). It is seen that model without effect of back stay diaphragm has translation (x) in 1st mode, torsion is in 2nd mode and translation (y) is in 3rd mode which is non-compliant as per codal requirement. It is seen that with the effect of backstay diaphragm the modes of oscillation were regular namely translation in both principal directions. Hence it can be also observed that analysis can be compliant with the introduction of back stay diaphragm effect. Hence added stiffness to the structure as compared to bare frame performed better. Further when the effect of retaining wall with the effect of backstay diaphragm is considered alteration in the stiffness of the structure resulting disparior of the IS code. The analysis model can be altered with increasing stiffness by adding shear wall at podium area which will improve the results by implementing torsion in the 1st two modes. Further when the tower placed at corner the results perform better than the model tower placed at the center.

Analysis results of twenty storey rigid diaphragm structure is shown figure bellow. It is seen from graph that the each time period of building when subjected to earth quake,that first mode time period is more than other two modes. (Refer fig 7).

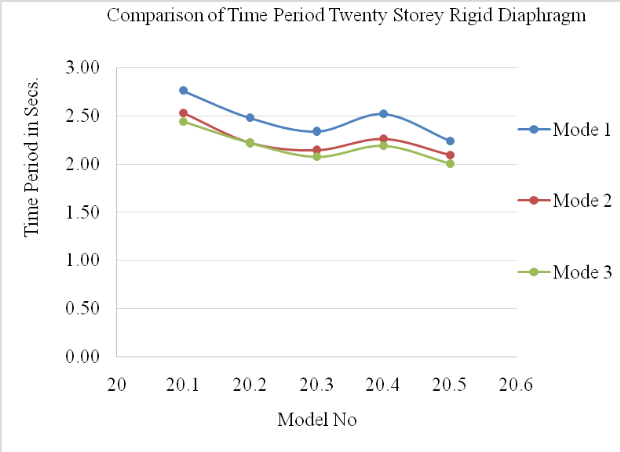

Fig 7: Comparison of Time Period for Twenty Storey Rigid Diaphragm

Analysis results of twenty storey semi-rigid diaphragm structure is shown figure bellow. It is seen from graph that the each time period of building when subjected to earth quake, that first mode time period is more than other two modes.(Refer fig 8).

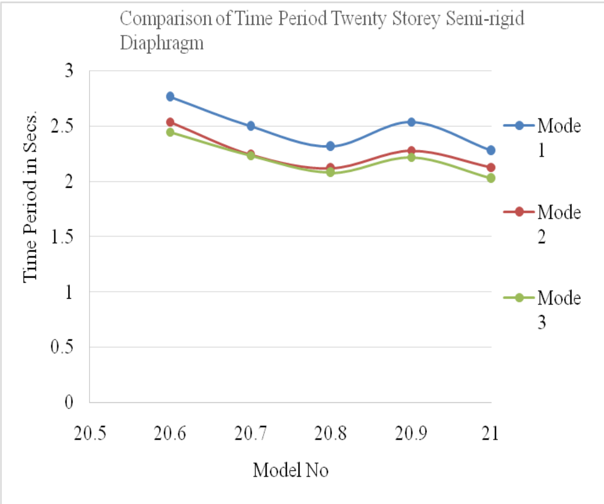

Fig 8: Comparison of Time Period for Twenty Storey Semi-rigid Diaphragm

It is observed that models with bare frame have 1st, 3rd mode is in translation and 2nd mode is in torsion which is not relevant to code. With the consideration of backstay diaphragm the oscillation of directions of 1st two modes are in translation while the other is in torsion which is safe for structure and follow the IS code. With retaining wall and back stay diaphragm there are change is oscillation which is not as per codal requirement. Stiffness can be added by placing shear wall all round thus eliminate torsion in 1st two modes.

b) Base Shear in Both Static and Dynamic Analysis.

It is the expected maximum lateral force induced at the base of the structure during earth quake shaking. For fourty storey rigid diaphragm base shear for each model in this storey is shown in figure. We can notice base shear for individual building and how they behave in static and dynamic case with rigid diaphragms. From the graph we can observe variation in base shear. For all models in EQX and EQY directions capacity of taking base is more. But for dynamic base shear is less because of considering ground parameters. (Refer fig 9)

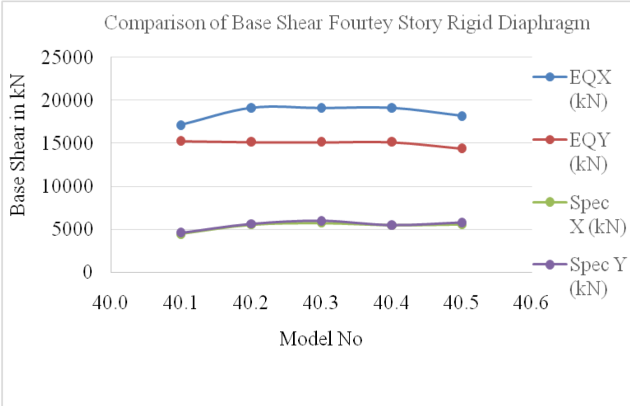

Fig 9: Comparison of Base shear Fourty Storey Rigid Diaphragm

Base shear for semi-rigid models in discussed here. Similar patterns are seen with decrease in base for Spec X and Spec Y, because of considering ground parameters. We can see base shear is more for models for static case but for dynamic case models have similar base shear as we can watch from graph. (Refer fig 10)

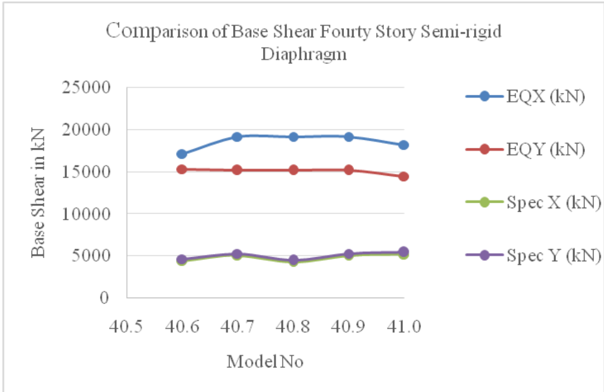

Fig 10: Comparison of Base shear Fourty Storey Semi-rigid Diaphragm

From figure 9 for rigid diaphragm of fourty storey structure without back stay diaphragm base shear was found to be 17139 kN in EQX direction and 15281 kN in EQY direction for static analysis. The base shear in response spectrum dynamics analysis was almost 3.5 to 4 times lesser than static forces because of ground motion parameters given in IS Codes. There was a marginal difference in the forces base shear when semi-rigid diaphragm was assigned as observed in figure 10. When effect of back stay diaphragm was considered there was increase in forces in base shear values, this is because when there is increase in mass there will be proportional increase on base shear for tower at center. When back stay diaphragm for tower placed at corner of plot their slight decrease in base shear as the tower is placed unsymmetrically at corner when compared to tower placed at center. When twenty storey with rigid diaphragm is considered decrease in height base shear is notice to be less in both cases . In dynamic cases it is always lesser than static case due to ground motion parameters given in IS code. For models in static with tower at center and bare frame base shear capacity taking is more in x and y direction but for models with corner base shear is less.

But for model 20.2 base shear capacities is more in y direction in dynamic. Refer fig 11

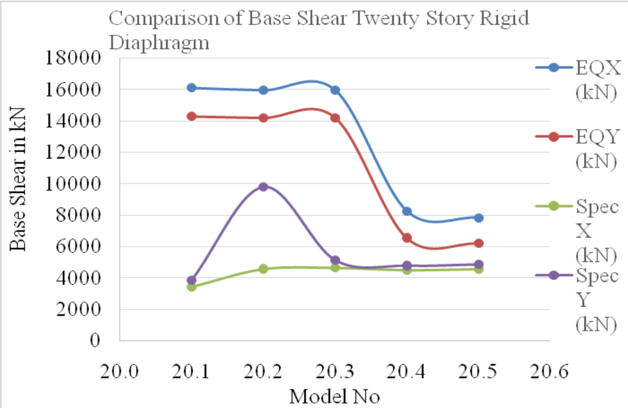

Fig 11: Comparison of Base shear Twenty Storey Rigid Diaphragm

When twenty storey with semi-rigid diaphragm is considered decrease in height base shear is notice to be less in both cases . In dynamic cases it is always lesser than static case due to ground motion parameters given in IS code. For models in static with tower at center and bare frame base shear capacity taking is more but for models with corner base shear is less in x and y direction..(Refer fig 12)

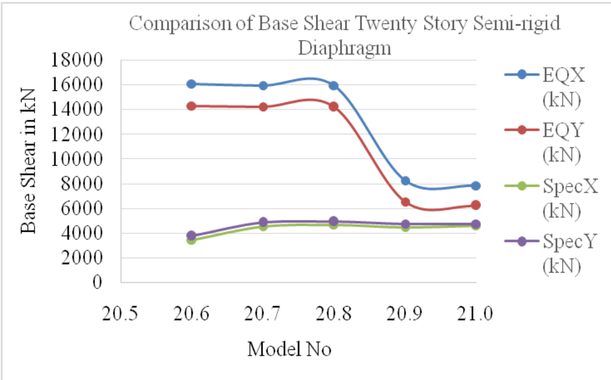

Fig 12: Comparison of Base shear Twenty Storey Semi-rigid Diaphragm

Base shear for twenty storey similar patterns were observed in twenty storey structure whereas analytical models with back stay diaphragm placed at corner observed nearly 50% reduction in base shear when compared to the models placed at center as seen in figure 11 and 12.

d) Lateral Displacement

As per tall building code clause 5.4 for lateral drift for factored earth quake load factored combination the drift is limited to h_i / 250.For dynamic analysis displacement for scaled factor of base shear for bare frame h_i/250 theoretical limit was calculated to be 512 mm. It was found that bare frame displacement was found to be within the limits for dynamic analysis. The top storey displacements for rigid decreased about 10 to 15 % when back stay diaphragm effect was considered. This is because increase in stiffness and mass due to backstay diaphragm. As seen the graph for average displacement at terrace for model 40.3 is more with the consideration of retaining wall and backstay with rigid diaphragm for spec y direction for rigid diaphragm. (Refer fig 13)

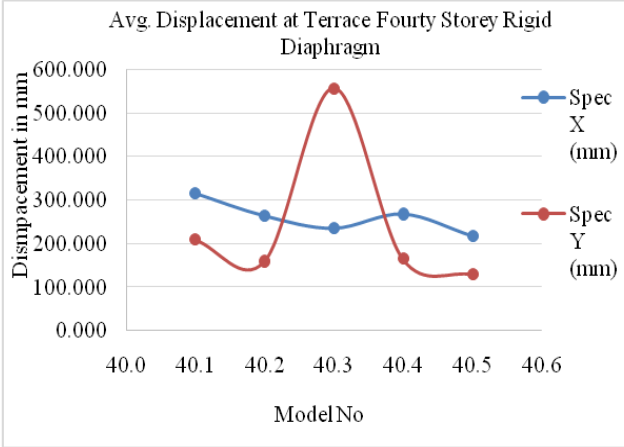

Fig 13: Comparison of Lateral Displacement Fourty Storey Rrigid Diaphragm

For dynamic analysis displacement for scaled factor of base shear for bare frame h_i/250 theoretical limit was calculated to be 512 mm. It was found that bare frame displacement was found to be within the limits for dynamic analysis in semi-rigid. The top storey displacements for rigid decreased about 10 to 15 % when back stay diaphragm effect was considered. This is because increase in stiffness and mass due to backstay diaphragm From graph we can observed for spec x direction average displacement is more as compared to spec y directions but with in limit 512 mm. In corner model in spec x direction displacement very less as compared to other models. For spec y there is slight variation in terrace displacement. (Refer fig 14)

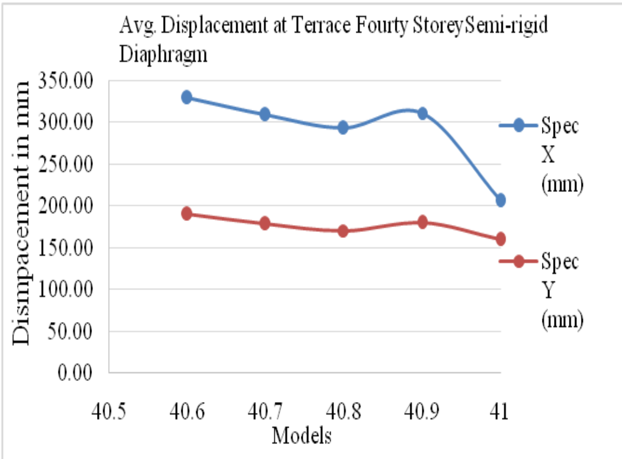

Fig 14: Comparison of Lateral Displacement Fourty Storey Semi-rigid Diaphragm

The patterns were observed in twenty storey structure is that with change in building height and reduced displacement values with limits for rigid. Bare frame displacement is more as compared to other buildings. But for model with retaining wall back stay average terrace displacement is more in spec y direction as compared to backstay models. But in spec y direction lateral displacement is more than y direction but within the calculated limit (Refer fig 15)

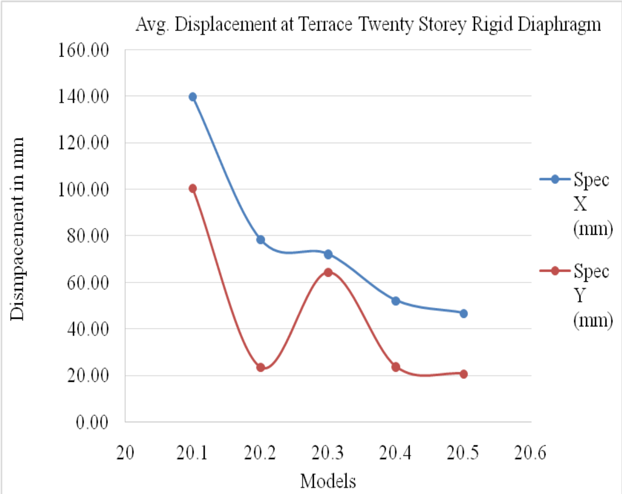

Fig 15: Comparison of Lateral Displacement Twenty Storey Rrigid Diaphragm

The patterns were observed in twenty storey structure is that with change in building height and reduced displacement values with limits. Bare frame displacement is more as compared to other buildings. Corner models have less displacement due to stiffness as shown in fig 16 for semi rigid diaphragm .

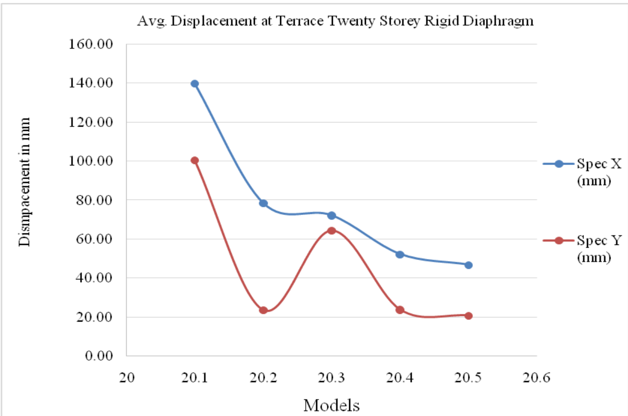

Fig 16: Comparison of Lateral Displacement Twenty Storey Semi-rrigid Diaphragm

e) Inter-story Drift

Inter storey drift = 0.004 x H (Floor height 3200 mm). Storey drift limitation as per IS 1893-2016 clause 7.11.1 shall not exceed 0.004 times the storey height under the action of design base shear V_b. As per IS 16700- 2017 the storey tall building code the drift is taken as limited as h_i/400. Drift limit 0.004 x 3200 = 12.8 mm.

It is seen that bare frame analytical model had the storey drift within the limit following model analysis shape in EQX direction for rigid diaphragm. Further when the back-stay diaphragm effect was considered there was increased in inter-story drift limit in the form 19-33 storey indicating higher second order moment in structure bringing in notice to the engineer to counter act or to take remedial measure to keep the structure safe with in permissible limit. Similar trends were observed on all the remaining models where drift limit exceeds in EQX direction (limit exceeds 12.8 mm). It also indicates that stiffness is to be increased in X direction of rigid diaphragm building direction. (Refer fig 17)

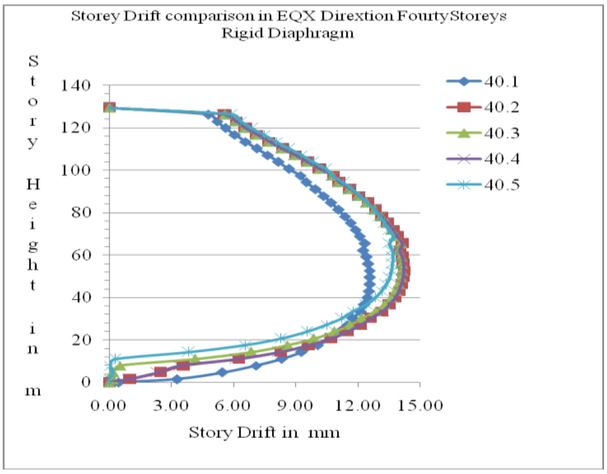

Fig 17: Comparison of Inter-storey Drift in EQX Direction Fourty Storey Rigid Diaphragm

Drift limit in EQY direction were within the limits following proper mode shape curve from fig 18

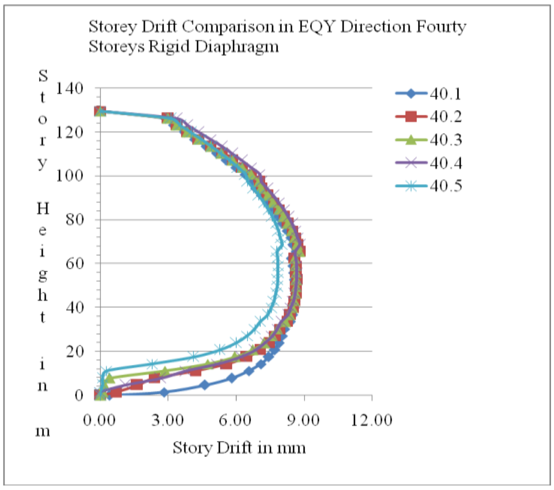

Fig 18: Comparison of Inter-storey Drift in EQY Direction Fourty Storey Rigid Diaphragm

For spec x directions for dynamic analysis drift for the storey is very less within the limits and safe for all models in figure 19

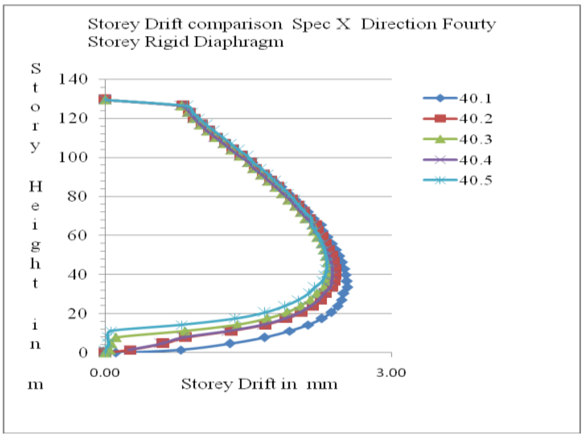

Fig 19: Comparison of Inter-storey Drift in Spec X Direction Fourty Storey Rigid Diaphragm

For spec y directions i.e. for dynamic analysis drift for the storey is very less and safe for all models in fig 20

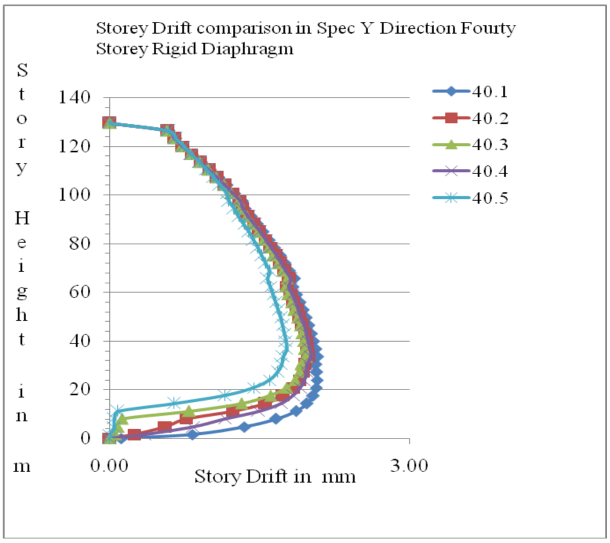

Fig 20: Comparison of Inter-storey Drift in Spec Y Direction Fourty Storey Rigid Diaphragm

It is observed that bare frame analytical model had the storey drift within the limit following model analysis shape in EQX direction for semi-rigid diaphragm. Further when the back-stay diaphragm effect was considered there was increased in inter-story drift limit in the form 19-33 storey indicating higher second order moment in structure bringing in notice to the engineer to counter act or to take remedial measure to keep the structure safe with in permissible limit. Similar trends were observed on all the remaining models where drift limit exceeds in EQX direction (limit exceeds 12.8 mm). It also indicates that stiffness is to be increased in X direction of semi-rigid diaphragm building direction.(Refer fig 21)

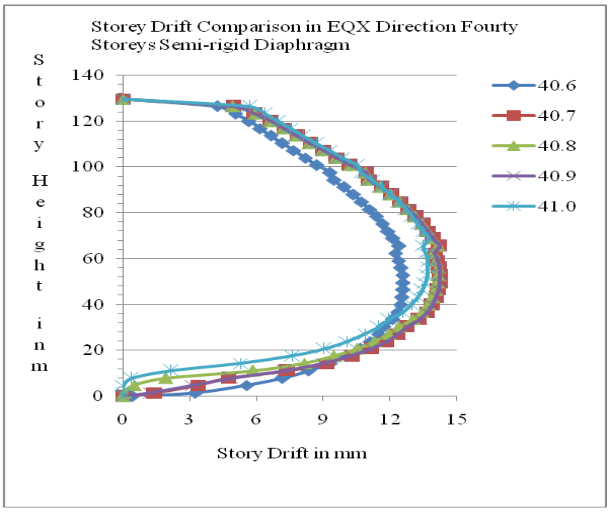

Fig 21: Comparison of Inter-storey Drift in EQX Direction Fourty Storey Semi-rigid Diaphragm

From the graph we can see the models with and without podium interference drift limit is within proper mode shape curve figure 22

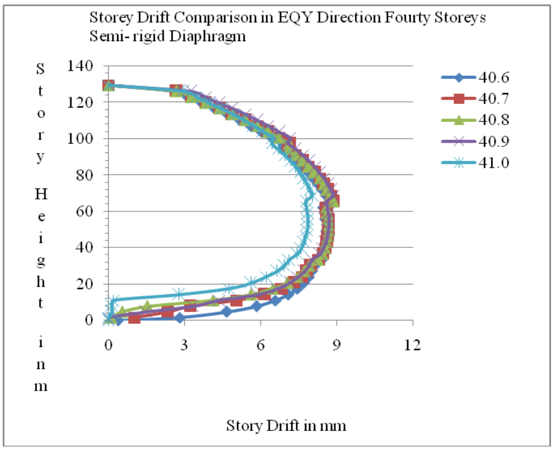

Fig 22: Comparison of Inter-storey Drift in EQY Direction Fourty Storey Semi-rigid Diaphragm

For spec x directions i.e. for dynamic analysis drift for the storey is very less and safe for all models in fig 23

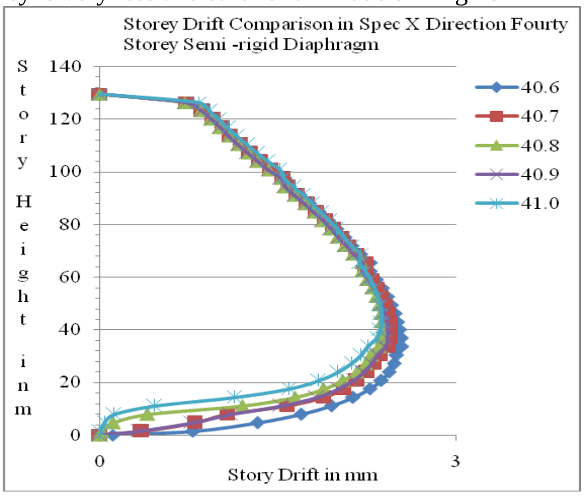

Fig 23: Comparison of Inter-storey Drift in Spec X Direction Fourty Storey Semi-rigid Diaphragm

For spec y directions for dynamic analysis drift for the storey is very less and safe for all models in graph. (Refer fig 24)

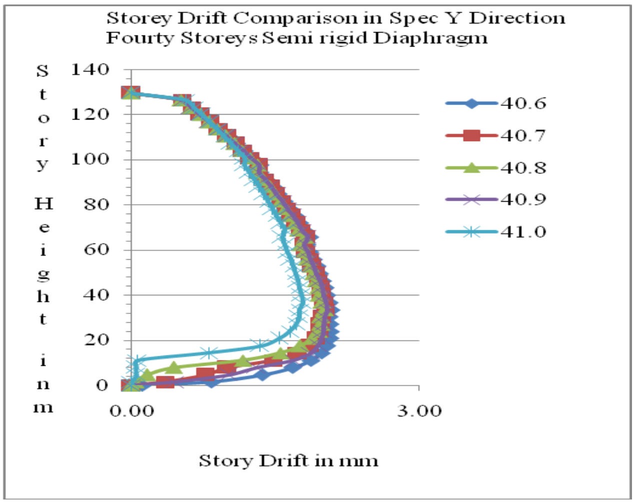

Fig 24:Comparison of Inter-storey Drift Spec Y Direction Fourty Storey Semi-rigid Diaphragm

Models with bare frame and placed at center with back stay diaphragm effect had all the drift within the limit making the analytical model code compliant as observed from table for rigid diaphragm. Models placed at corner there was reduced storey drift because low storey height and stiffness of retaining wall accounted in figure 25 for twenty storey rigid diaphragm.

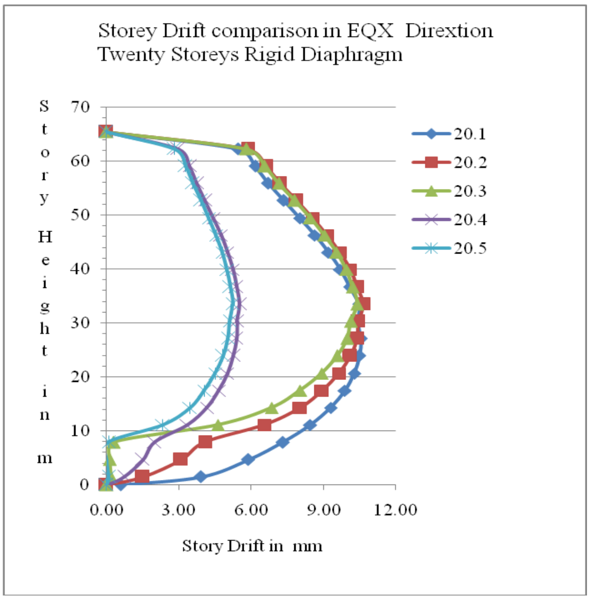

Fig 25 Comparison of Inter-storey Drift in EQX Direction Twenty Storey Rigid Diaphragm

Models with bare frame and placed at center with back stay diaphragm effect had all the drift within the limit making the analytical model code compliant as observed from table for rigid diaphragm. Models placed at corner there was reduced storey drift because low storey height and stiffness of retaining wall accounted in figure26

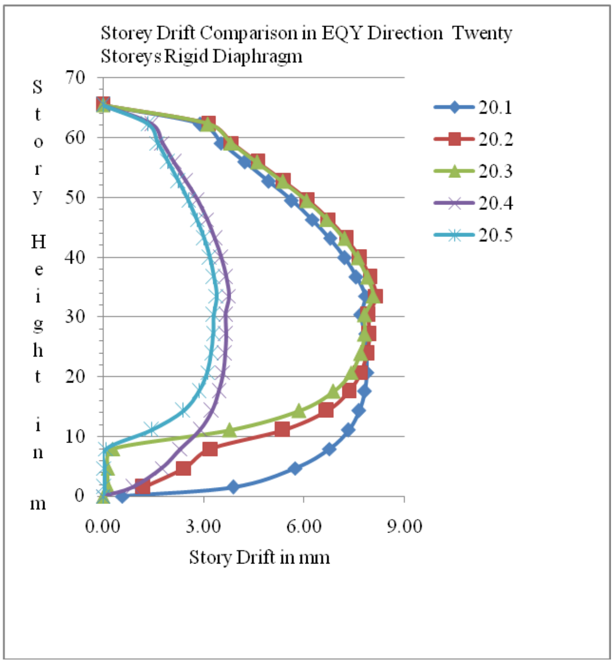

Fig 26 Comparison of Inter-storey Drift in EQY Direction Twenty Storey Rigid Diaphragm

Models with bare frame and placed at center with back stay diaphragm effect had all the drift within the limit making the analytical model code compliant as observed from table for rigid diaphragm. Models placed at corner there was reduced storey drift because low storey height and stiffness of retaining wall accounted (Refer fig 27).

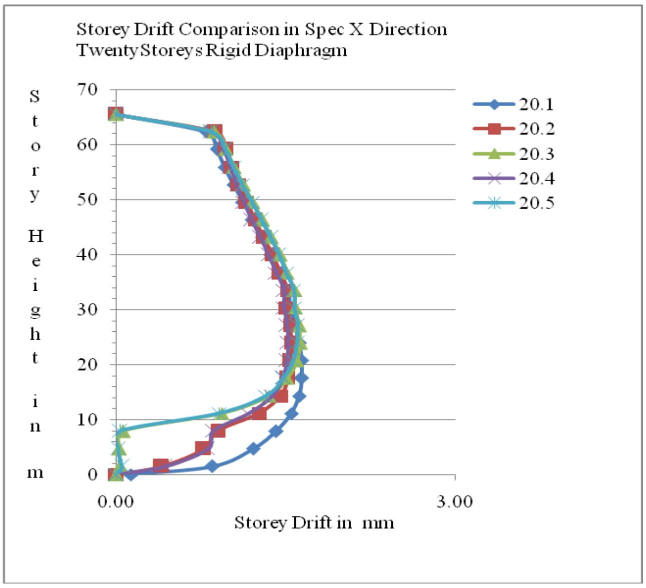

Fig 27 Comparison of Inter-storey Drift in Spec X Direction Twenty Storey Rigid Diaphragm

Similar patterns were observed in spec y directions like spec x as gien in fig 28

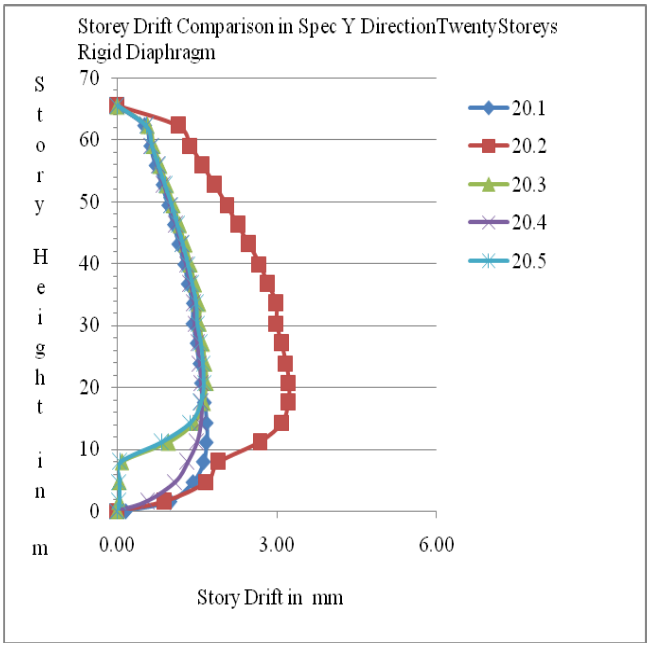

Fig 28 Comparison of Inter-storey Drift in Spec Y Direction Twenty Storey Rigid Diaphragm

Models with bare frame and placed at center with back stay diaphragm effect had all the drift within the limit making the analytical model code compliant as observed from table for semi- rigid diaphragm. Models placed at corner there was reduced storey drift because low storey height and stiffness of retaining wall accounted in fig 29

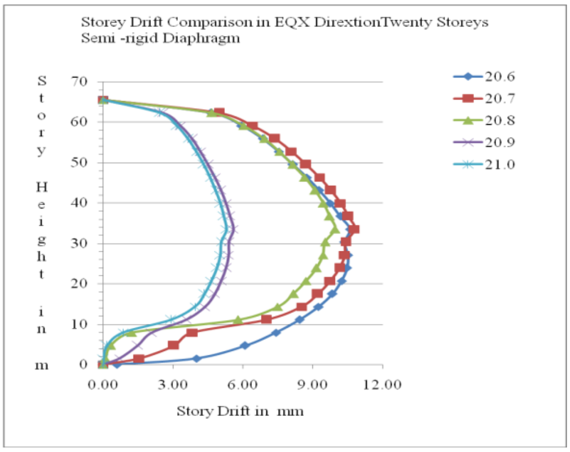

Fig 29 Comparison of Inter-storey Drift in EQX Direction Twenty Storey Semi-rigid Diaphragm

Similar patterns were observed in EQY directions like EQX as gien in fig 30

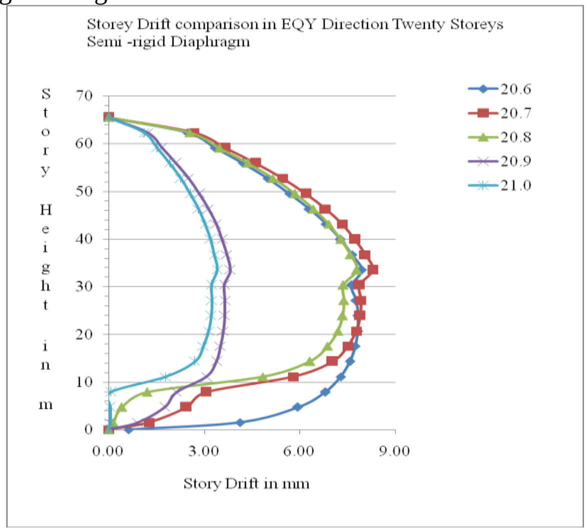

Fig 30 Comparison of Inter-storey Drift in EQY Direction Twenty Storey Semi-rigid Diaphragm

Similar patterns were observed in Spec x directions as shown in fig 31

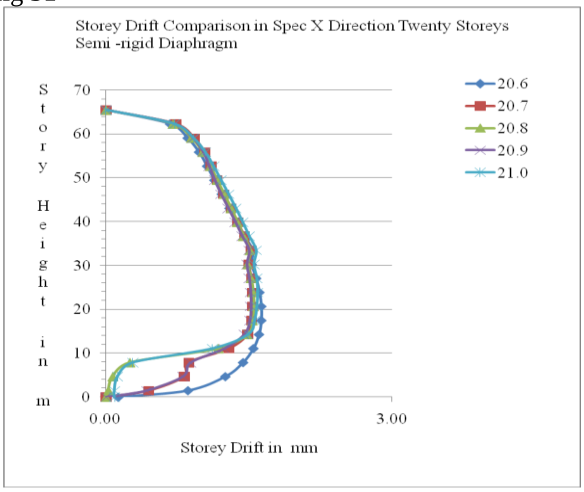

Fig 31 Comparison of Inter-storey Drift in Spec X Direction Twenty Storey Semi-rigid Diaphragm

Similar patterns were observed in Spec y directions as shown in fig 32

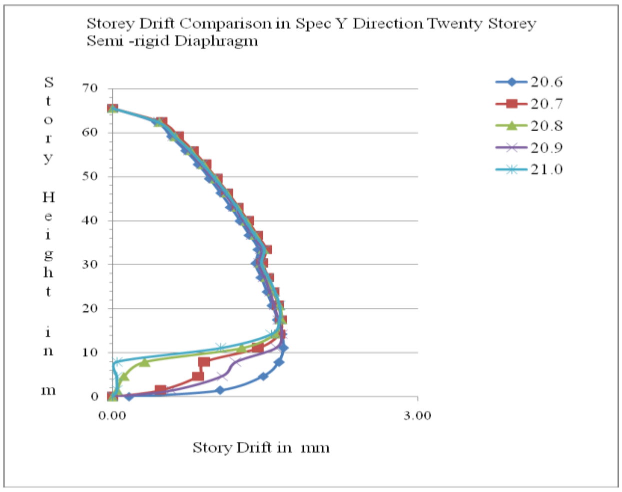

Fig 32 Comparison of Inter-storey Drift in Spec Y Direction Twenty Storey Semi-rigid Diaphragm

V. CONCLUSION

Two types of stories like twenty story and fourty storey were analysed to know their seismic behaviour and parameter like time period, base shear, lateral displacement and inter-storey drift.

1) A tall building structure free standing had maximum time period which indicates the building is flexible in nature. Consideration of backstay effect in tall storey structure increases lateral stiffness resulting in reduced time period. With consideration of backstay diaphragm the structure can be made has an code compliant with respect to direction.

2) The effect of backstay diaphragm results in increased mass therefore resulting in proportional increase in base shear. For low rise structure the stiffness of building the benefit of backstay diaphragm were not much when compared to high structure.

3) There was 35% of reduction in displacement with consideration of backstay effect with backstay diaphragm effect in twenty and fourty stories when compared to bare frame

4) Displacement gradually reduces more with effect of backstay and retaining wall.

5) Bare frame tall building model had more second order moment which is a result of drift with exceeds permissible drift.

6) The effect of backstay diaphragm had the drift with in permissible limit (0.004 times floor height).

7) Rigid diaphragm is stiffer than flexible diaphragm structure.

8) Structure behaved in favorable results when tower was placed at the centre of the plot area when compared to corner tower.

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