Seismic Performance of Tall Building Using Transfer Plate System Method

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***Abstract—*The evolution of high-rise construction has necessitated structural systems that can accommodate architectural demands such as vertical irregularities. Transfer plate systems are increasingly employed to bridge structural discontinuities where vertical elements like columns and shear walls do not align. This study evaluates the seismic performance of tall buildings using a transfer plate system through nonlinear static pushover analysis in SAP2000.**

I. INTRODUCTION

Two primary structural configurations are investigated:
(1) A moment-resisting frame (MRF) system and
(2) A box-type reinforced concrete shear wall system, both incorporating a 2-meter thick transfer slab. Multiple models with varying heights (62 m, 77 m, and 78 m) and transfer plate positions are analyzed. Key seismic parameters such as base shear, story drift, roof displacement, time period, and performance point are assessed.

Results reveal that shear wall systems significantly outperform MRF systems in terms of seismic behavior. The shear wall model exhibits 15–30% higher base shear capacity and up to 300% reduction in story drift and roof displacement, attributed to the enhanced stiffness and box effect of the walls. The study also finds that the location of the transfer plate influences seismic response, with optimal positioning around 30% of the total height yielding better results.

This research confirms that shear wall systems combined with transfer plates offer superior seismic performance in tall buildings and recommends their use in seismic-prone regions. It also emphasizes the importance of integrated structural modeling over segmented design approaches for accurate seismic evaluation.

II. LITERATURE REVIEW

A. Osman and M. Abdel Azim (2015) studied the structural analysis and behavior of high-rise buildings utilizing thick transfer plate slabs between their tower and podium floors. Importance is placed on evaluating the significance of the different analysis approaches traditionally followed by the designers in consulting offices to analyze these structures and on the necessity of considering the interaction between the transfer plate slabs and the supporting tower during analysis process. The effects of different design aspects such as transfer slabs span to thickness ratio and stiffness on the structural behavior of such structures are investigated. It was concluded that interaction between the transfer plate slabs and supporting tower can significantly affect the calculated straining actions within tower structural elements and consequently should be accounted for during analyzing the structure. This requires that the transfer plate slabs modeled accurately during developing the structural numerical model to simulate the real structural behavior of the high-rise building and to capture the interaction between them and the vertical structural elements of the tower. The two stage analysis technique should not be used in analysing high-rise buildings with transfer slab in spite it is allowed by codes, since it neglects the interaction between the transfer floor and the structural elements for the tower leading to estimating the straining actions incorrectly. In addition, the study showed that, transfer slab should be accurately modelled in any global model to structures in order to simulate the real behaviour of this thick slab that can significantly affect the analysis results.

Ezzeldin Sayed Ahmed, Amal Elawady, Amr Abdelrahman (2014) made a comparative investigative study for the seismic response of high-rise buildings with transfer floors. The prototype models were analyzed using elastic linear response spectrum and inelastic nonlinear time history techniques using three-dimensional finite element models. The analyzed models had different transfer floor system: transfer slabs and transfer girders. The vertical position of the transfer system with respect to the building height was investigated. Global seismic response of the buildings such as storey shear and bending moment distribution, and inter-storey drift were numerically evaluated. The results showed the localization of damage in the vicinity of the transfer floor in addition to the first floor; the location of the transfer floor influenced the global seismic response of the structure.

Hasan and Mehdi (2012) investigated the high-rise buildings with transfer floor under progressive destruction in nonlinear formulation. Influenced by the ratio of the transverse rigidity of transitional floors and upper floor in seismic resistance structures. Buildings with these floors and shear walls having transfer floors located in lower region it is possible to limit the variation of drift angle between the floors above and below. Buildings with shear wall and transfer floor should be designed such that the ratio if equivalent rigidity ye should be close to 1 and not more than 1. The core rigidity and transitional floors of has no abrupt change when the building us designed having moment resisting frame, but it shown that there is steep change in shear force on the height of the structure.

III. METHODOLOGY

Need for Pushover analysis

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The evaluation is based on an assessment of important performance parameters, including global drift, interstory drift, inelastic element deformations (either absolute or normalized with respect to a yield value), deformations between elements, and element connection forces (for elements and connections that cannot sustain inelastic deformations), The inelastic static pushover analysis can be viewed as a method for predicting seismic force and deformation demands, which accounts in an approximate manner for the redistribution of internal forces that no longer can be resisted within the elastic range of structural behavior. The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are the examples of such response.

Force deformation behavior of nonlinear Hinges

- Point A which is located at the origin represents the unloaded condition of the structure.
- AB represents the linear range of yielding of member without deformation, from unloaded state at A to maximum or effective yielding at B.
- BC corresponds to plastic deformation and the linear response is reduced.

Where C is being as the ultimate load carrying capacity of the member.

- CD shows the steep decrease in load carrying capacity and initial failure of the element which is taken as unreliable.
- DE represents that residual resistance of the member before failing.
- E is signifying the complete failure of the member.

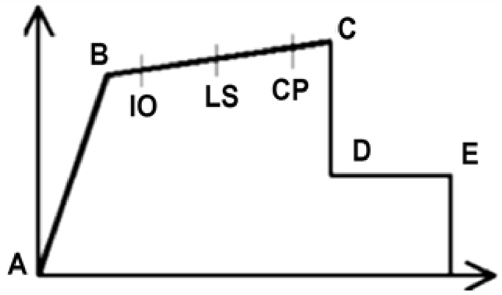

Fig 3.2 Force Vs Deformation, curve showing the nonlinear hinges in pushover analysis

Assumptions of plastic theory are used to plot the behavior of nonlinear pushover hinges which has the concentration of deformations on the plastic hinges and the residual are shown on according to their elastic behavior. Location for various nonlinear elastic and plastic hinges are can be studied on the pushover curve as, AB show the elastic nature, B-IO is the immediate occupancy range, IO-LS shows the life safety limits, LS-CP is the range for collapse prevention. The hinges falling between IO-CP are taken to be safe and could be retrofitted based upon the importance factor and the age of the structure.

Pushover Analysis Procedure in SAP 2000

Pre processing

• A three dimensional model representing the geometric figure; the required sectional and material properties is created using the structural wizard.
• Material properties such as the grade of concrete and rebar materials for reinforced concrete structures; and steel for steel structures are defined.
• Section properties such as beams, columns, slab, reinforced concrete walls, are the defined using the materials which are defined earlier.
• Now defining the load patterns viz., Dead, Live, Super imposed, Seismic and the load combinations are established using the load patterns. Now assign the loads at appropriate sections.
• Assigning the restrains to the columns as fixed or hinged or pinned accordingly.
And run the preliminary analysis. The model is linearly designed according to the guidelines of the relevant codes.
• Once the structural members are passed the design then proceeded to the nonlinear static analysis.
• POA starts with assigning the nonlinear hinges conforming the acceptance criteria of the FEMA 356 guidelines.
• Defining the nonlinear static load cases generally three cases viz., i. Modal, ii.
Acceleration (UX), iii. Acceleration (UY) are sufficient for the analysis. Then run the analysis.

Post processing
• Display the static pushover curve and the table
• Review the curve and study the various parameters, derive the numerical and tables and their conclusions which are the objectives of the dissertation.

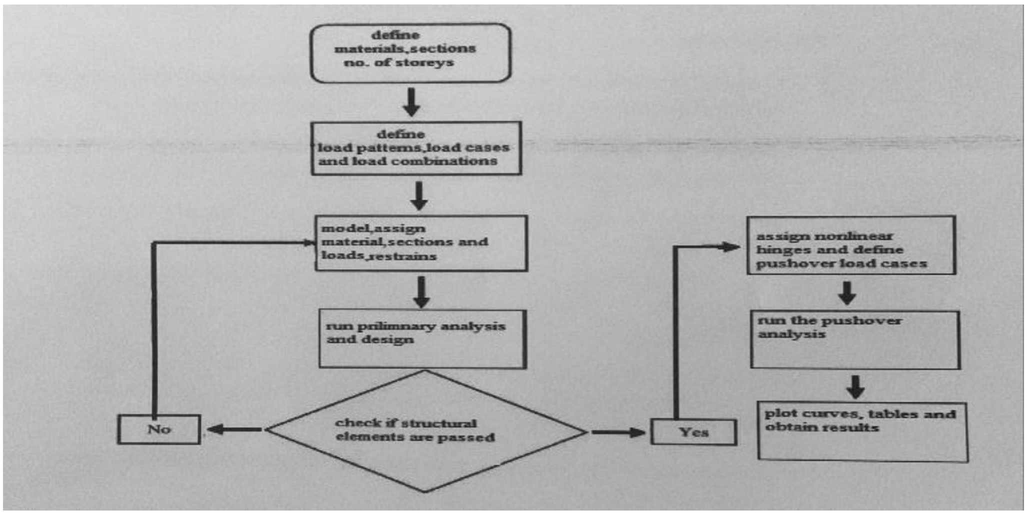

Fig 3.4 Flow chart of pushover analysis procedure in SAP 2000.

IV. MODELS USED IN PRESENT STUDY

CASE-1
i. The configuration is taken as G+4+transfer slab (5m storey height) + 15 storeys. ii. A model replacing the beams and columns with reinforced concrete walls (all exterior, and partition walls), with 62m height from ground to roof of the structure. iii. A model with beam and column frame with coupled shear wall for basic lateral resistance with the total height of 62m.

CASE-2
i. The configuration is taken as G+4+transfer slab (5m storey height) + 20storeys. ii. A model replacing the beams and columns with reinforced concrete walls (all exterior, and partition walls), with 78m height of the building.
ili. A model with beam and column frame with coupled shear wall for basic lateral resistance with 78m height of the building.

CASE-3
i. The configuration is taken as G+6+transfer slab (5m storey height) + 18storeys. ii. A model replacing the beams and columns with reinforced concrete walls (all exterior, and partition walls), with 77m height of the building.
ili. A model with beam and column frame with coupled shear wall for basic lateral resistance with 77m height of the building.
iv. In this model the location of the transfer slab is changed to 3m in height while keeping the height of the structure as 78m.

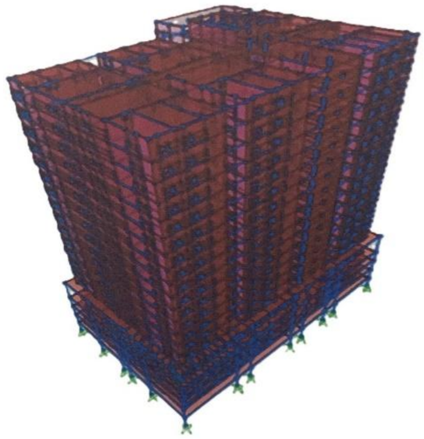

Fig 4.5 3-D View of shear wall model

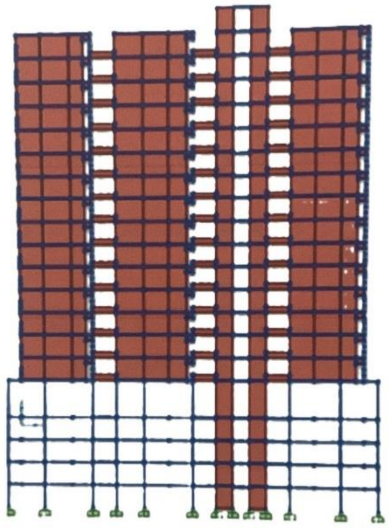

Fig 4.6 Elevation of Shear wall model

Table 4.1 Preliminary data assumed for the analysis for the structure.

S.No	Variables	Data
1	Types of structure	Moment Resisting Frame with box type reinforced concrete wall
2	Number stories	20
3	Floor height	3m typical,5m for transfer floor
4	Live load	2.0kN/m^2 and 3.0kN/m^2
5	Materials	Concrete (M30) Reinforced with HYSD Fe500 bars
6	Specific weight of RCC	25kN/m^2
7	Zone	V
8	Importance factor	1
9	Response Reduction Factor	5

Table 4.2 Sizes of beams, columns and slab in the structure, in the model with moment resisting frame.

G+4TP+15 MOR Frame	Storey 15-10	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m
Top Beam	0.23mX0.6m	0.23mX0.6m	0.23mX0.6m	0.45mX1m
Column	0.3mX0.75m	0.3mX0.9m	0.6mX0.9m	0.75mX1.5m
Slab	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-	-
Shear wall	0.3m	0.3m	0.3m	0.3m

Table 4.3 Sizes of beams, columns and slab in the structure, in the model with box shear wall.

G+4TP+15 Box Shear Wall	Storey 15-10	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m
Beam	-	-	-	0.45mX1m

Column	-	-	-	0.75mX1.5m
Slab	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-	-
Shear wall	0.3m	0.3m	0.3m	0.3m

Table 4.4 Sizes of beams, columns and slab in the structure, in the model with moment resisting frame.

G+4TP+20 MOR Frame	Storey 20-16	Storey 15-11	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m
Beam	0.23mX0.6m	0.23mX0.6m	0.23mX0.6m	0.23mX0.6m	0.45mX1m
Column	0.3mX0.75m	0.45mX0.9m	0.6mX0.9m	0.75mX1.5m	0.75mX2m
Slab	0.12m	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-		-
Shear wall	0.3m	0.3m	0.3m		0.3m

Table 4.5 Sizes of beams, columns and slab in the structure, in the model with box shear wall.

G+4TP+20 Box Shear Wall	Storey 20-16	Storey 15-11	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m
Beam	-	-	-	-	0.45mX1m
Column	-	-	-	-	0.75mX1.5m
Slab	0.12m	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-	-	-
Shear wall	0.25m	0.25m	0.25m	0.25m	0.25m

Table 4.6 Sizes of beams, columns and slab in the structure, in the model with moment resisting frame.

G+4TP+18 MOR Frame	Storey 18-16	Storey 15-11	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m
Top Beam	0.23mX0.6m	0.23mX0.6m	0.23mX0.6m	0.23mX0.6m	0.45mX1m
Column	0.3mX0.75m	0.45mX0.9m	0.6mX0.9m	0.75X1.5m	0.75mX1.5m
Slab	0.12m	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-	-	-
Shear wall	0.3m	0.3m	0.3m	0.3m	0.3m

Table 4.7 Sizes of beams, columns and slab in the structure, in the model with box shear wall.

G+6+TP+20 Box Shear Wall	Storey 18-16	Storey 15-11	Storey 10-06	Storey 05-01	Storey TP-G
Plan Dimension	30mX51.6m	30mX51.6m	30mX51.6m	30mX51.6m	34mX55.6m

Beam	-	-	-	-	0.45mX1m
Column	-	-	-	-	0.75mX1.5m
Slab	0.12m	0.12m	0.12m	0.12m	0.18m
Transfer slab	2m	-	-	-	-
Shear wall	0.25m	0.25m	0.25m	0.25m	0.25m

4.3.1 Loads considered

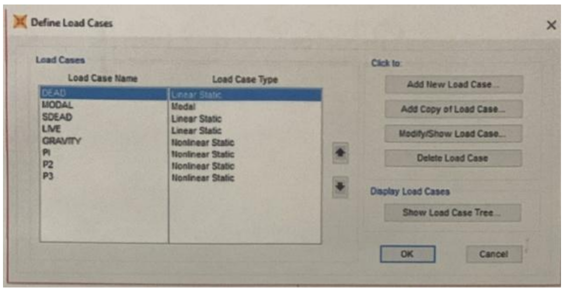

Fig 4.9 Load cases considered in the case study.

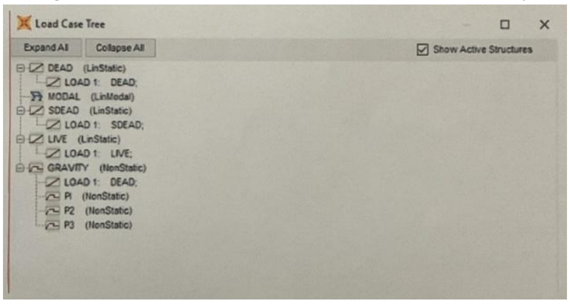

Fig 4.10 Load cases tree which has both linear and nonlinear load cases.

4.3.2 Pushover Parameters

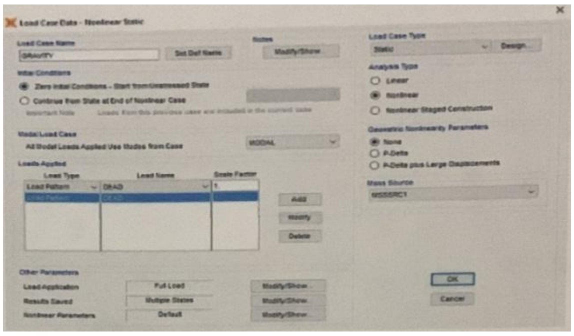

Fig 4.11 Non-linear static gravity (G) load case

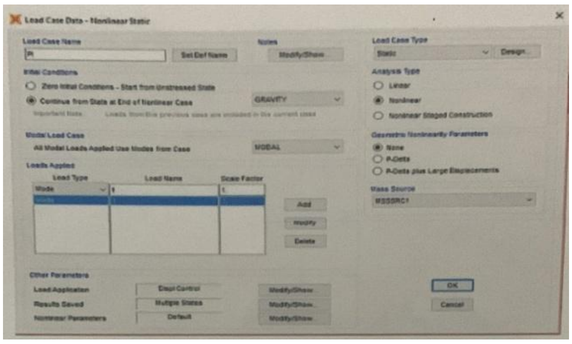

Fig 4.12 Non-linear static modal (P1) load case

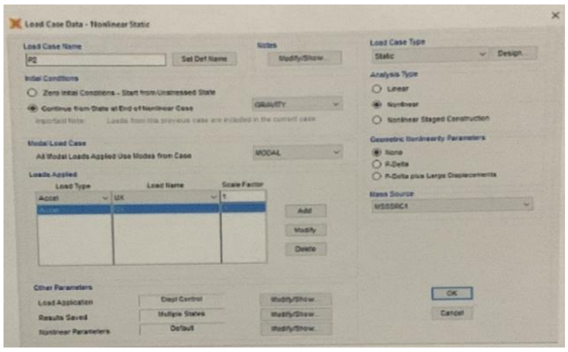

Fig 4.13 Non-linear static acceleration inX-direction (P2) load case

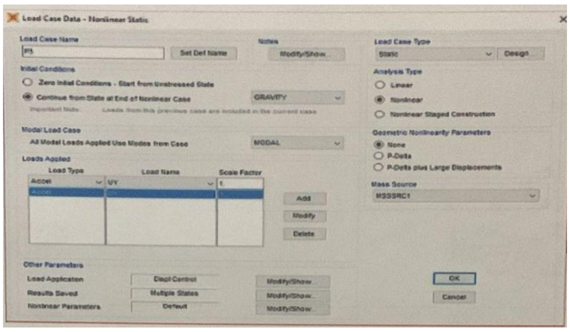

Fig 4.14 Non-linear static acceleration in Y-direction (P3) load case

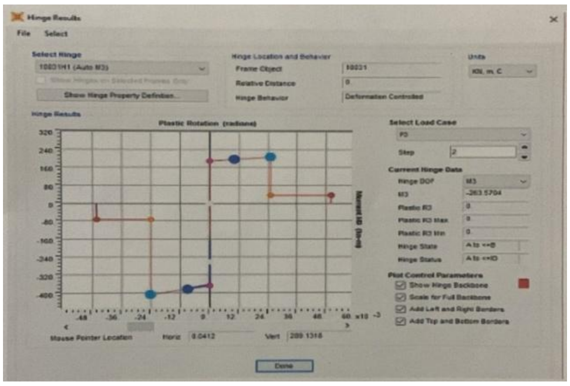

Fig 4.15 Non-linear pushover hinges to the element conforming to ATC-40 acceptance criteria

V. RESULTS AND DISCUSSIONS

This chapter deals with the results obtained from the building models and their variations in their structural configuration such as box type shear wall building, moment resisting frame along with the effects of change in overall height (G+4+TP+15), (G+4+TP+20), (G+6+TP+18) of the building and the variation of the location of transfer slab i.e., (from 17m to 23m) in vertical direction. Using SAP 2000 and performing pushover analysis.

5.2.1 Pushover Curves

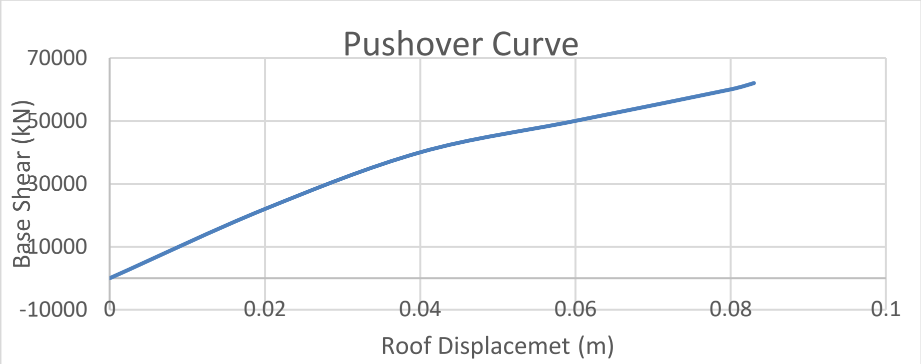

Fig 5.1 Pushover curve V v/s D for MOR Frame structure with (G+4+TP+15)

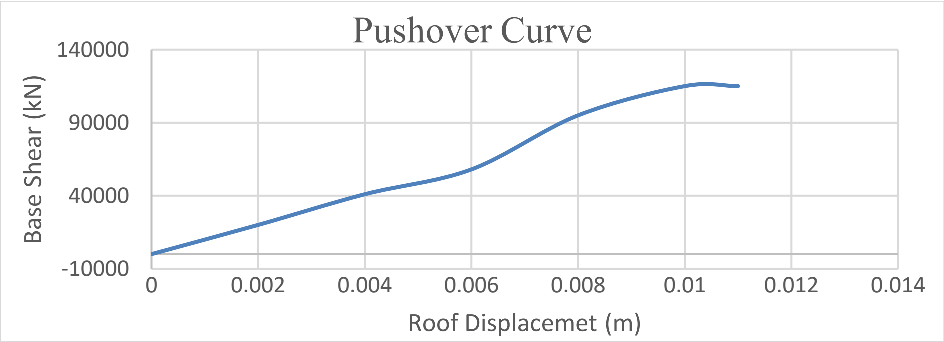

Fig 5.2 Pushover curve V v/s D for box shear wall type structure with (G+4+TP+15)

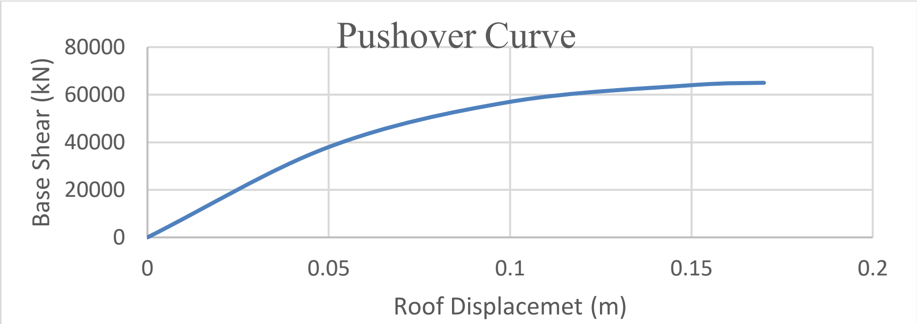

Fig 5.3 Pushover curve V v/s D for MOR Frame structure with (G+4+P+20)

5.2.2 Storey Drifts

Storey drift is the result of difference of the displacement of successive of storey, which is again restricted as in any case the difference should not be more than 0.004 times the height of building at any level.

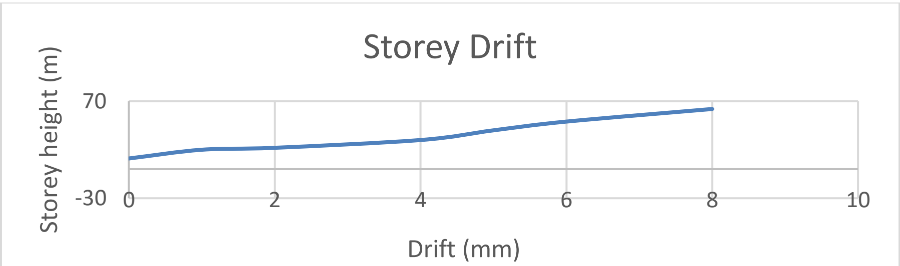

Fig 5.7 Storey drift for MOR frame (G+4+TP+15)

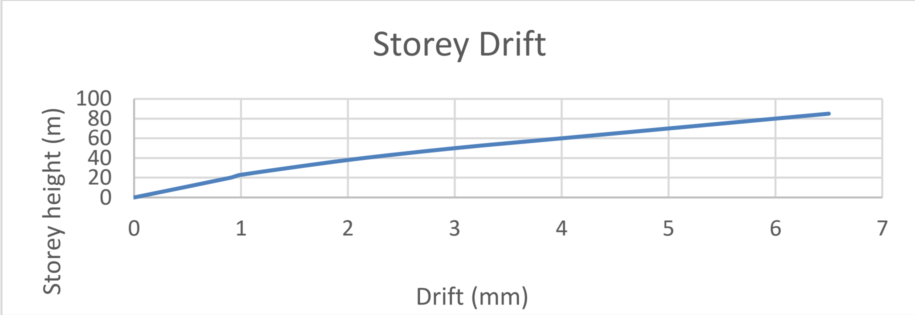

Fig 5.9 Storey drift for MOR frame builidng with (G+4+TP+20

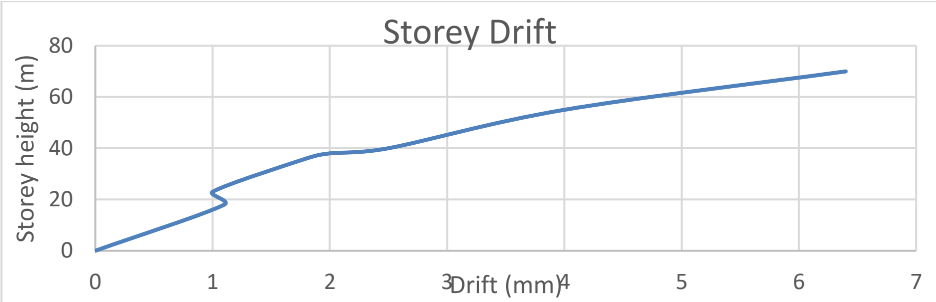

Fig 5.11 Storey drift for MOR frame builidng with (G+6+TP+ 18)

• The above curves plotted for Storey height v/s Storey Drift for models and their variations. Fig 5.7, 5.9,5.11 are the curves for moment resisiting frame building model and the Fig 5.8,5.10,5.12 are plots for shear wall building model with box effect.

• Fig 5.7 and 5.8 are compared for both models, we can observe that the MOR frame building showing a regular curve with no steep changes in drifts compared to storey height and has more drift upon reaching the highest point on the building. Whereas the other model has regular drift upto the location of transfer slab reaching the maximum drift for sub strucutre and suddenly changes to minimum and follows a regural pattern with height and reaching the highest point.

Storey drift is 150% less in current model when compared the MOR frame building

5.2.3 Base Shear

Base shear is one of the most important factor in determining the performance of the structure in analysis. It is defined as the sum of lateral forces acting on the structure from top to bottom or along the height of the structure. Nonlinear static analysis is performed for all the building models with various configurations their results are represented below.

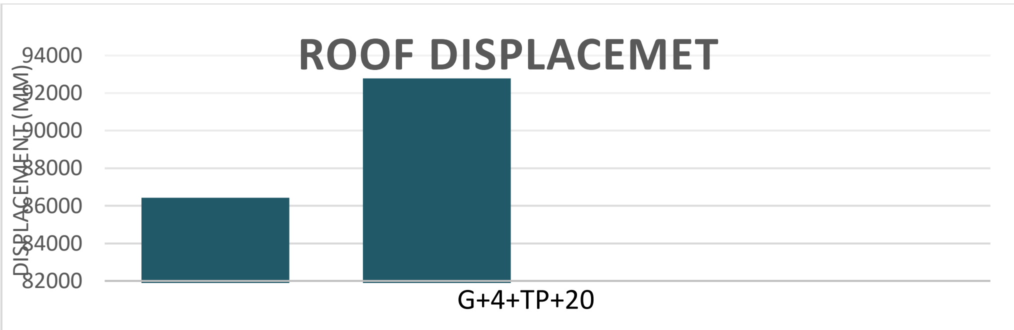

Fig 5.13 Base shear for MOR frame V/S Box effect shear wall building with (G+4+TP+15)

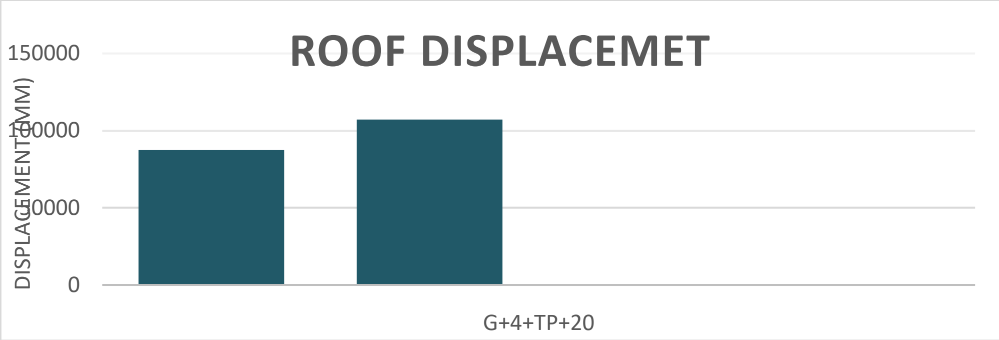

Fig 5.14 Base shear for MOR frame V/S Box effect shear wall building with (G+4+TP+20)

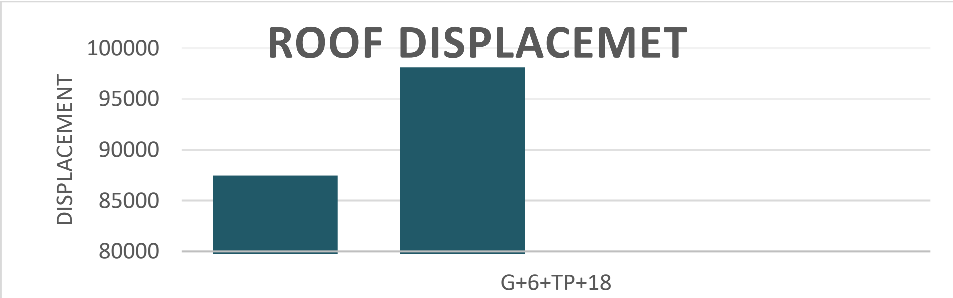

Fig 5.15 Base shear for MOR frame V/S Box effect shear wall building with (G+6+TP+18)

Fig 5.13, 5.14, 5.15 showing the base shear of the different models used in the present study and they are compared with buildings with varying parameters.

Roof Displacement

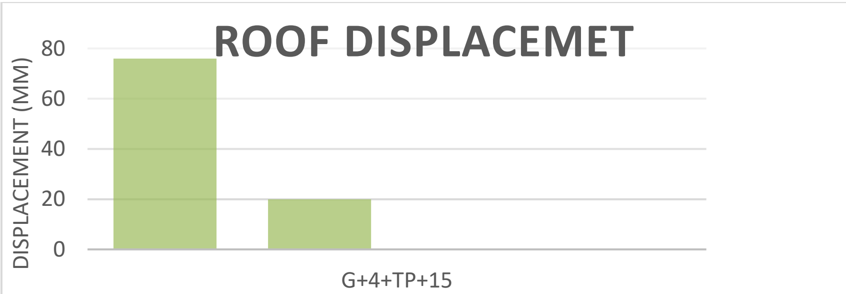

Fig 5.16 Comparision in roof displacement of MOR frame and shear wall model with G+4+TP+15 configuration

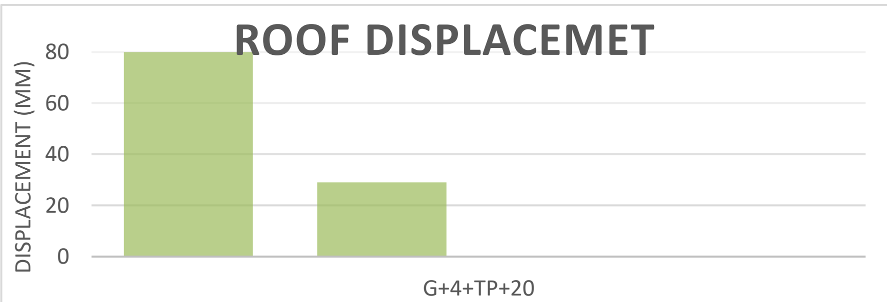

Fig 5.17 Comparision in roof displacement of MOR frame and shear wall model with G+4+TP+20 configuration

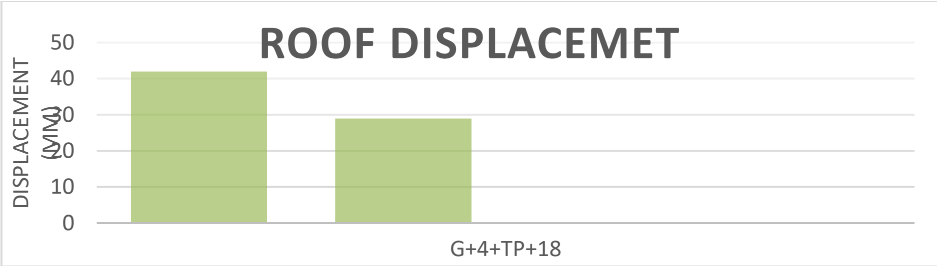

Fig 5.18 Comparision in roof displacement of MOR frame and shear wall model with G+4+TP+18 configuration

VI. RESULTS

• Base shear observed for the structures i.e., moment resisting frame model and the shear wall model showing in the Fig 5.13 to 5.15. Figure 5.13 is the comparitive graph showing the base shear of the model with moment resisting frame and the shear wall model with same number of storeys. It is evident that box effect of the shear wall model has good lateral resistance with 15% more base shear than the other model.
• Fig 5.14 we can observe that there is 25% more base shear developed in shear wall model when compared with other model. So we can note that the performance of box shear wall model is reliable when the structure is considered for greater heights.
• Fig 5.15 is the plot for the change in location of the transfer slab and is evident that the effect of change in location of transfer slab has no effect on the performance of the building and the amount of the base shear developed is good with 15% more base shear.
• Roof displacements of the structures shown in figures 5.16, 5.17, 5.18 it is evident that the displacement in the shear wall building is 250%-350% less when compared with the MOR frame. This proof that the roof displacement is very much controlled or regulated in shear wall building model due to the overall box effect of the structure.
• Storey drifts showing in Plots 5.7 to 5.12 we can state that the storey drifts in MOR frame model is regular in pattern without steep variations when compared to the shear wall model with overall box effect but has vary steep deviations in the pattern and shows very much less when compared to the former with values ranging 150%-300% increased when compared. All the values for the storey drifts are within the allowable limits i.e., 3000/250 equals 12mm (storey heigth/250). Permissible as mentioned in IS 1893:2002 Part-1.
• It can be observed that the time period of the shear wall model with box effect is having typically more time period varying from increase of 18% in Fig 5.31 and further increased to 30% for model with increased height and 38% for the model with altered location of the transfer slab.

VII. CONCLUSIONS

Based on the observations in the present study following conclusions are drawn:
• The lateral load resistance is more in shear wall model with base shear values ranging from 15%-25% more than moment resisting frame building. Hence we can state that shear wall building has good seismic performance.
• Roof displacement is also well controlled in shear wall model is 250% less when compared with the MOR frame. This proof that the roof displacement is very much controlled or regulated in shear wall building model due to the overall box effect of the structure.
• Roof displacement for the G+4+TP+20 model is 280% less compared to the later one and when the location of transfer plate is the changed i.e., G+6+TP+18 the roof displacement is very much regulated up to 350% hence we can conclude that the box effect has good performance characteristics for high rise buildings.
• Storey drift is better control in the shear wall model for all the models compared to the moment resisting frame building with values ranging 150% for G+4+P+15; 200% for G+4+TP+20; and 300% for G+4+TP+18. When the structure is to be designed as a tall building the overall box effect building may be chosen as a best alternative as the lateral storey displacement is controlled by shear wall building is dependable.
• The performance of the structures shown from the performance points in Fig 5.18 to 5.28 we can state that the building with shear wall has more base shear and controls better roof displacement compared to moment resisting frame building.

• Hinge formation in MOR frame building can be seen in almost 71% of the building height and mostly concentrated in the substructure, reason for the concentration is due to the load of the superstructure along with the dead load of the transfer slab is subjected to the lower storey columns. Whereas in the shear wall model there are no hinge formation is concentrated along the height of the building as there are no frame is available and the only area where hinges are formed is dust eight frame elements with elements id (12012,11879,11226,9494,9455,11220,11873,12006). All the hinge formations in both conbinations fall in immediate occupancy which is considered to be safe for the performance of the structure.

• On comparision of all the models we can state that the shear wall building along with transfer plate performs well and gives better results for base shear, storey drift, roof displacement and hence we can state that the shear wall model to be safe in seismic performance.

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