Parametric Study of Dual Structural System using NLTH Analysis

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Abstract— The dual structural system consisting of ordinary moment resisting frame (OMRF) and concrete shear wall has better seismic performance due to improved lateral stiffness and strength. It is obvious that a well-designed system of shear walls (non-planar c shape or core type) in a building frame improves its seismic performance, but in this paper, study is carried out on planar shear walls. For the research purpose the time history function (BHUJ) is applied in the direction orthogonal to the planar shear wall towards which the seismic performance is inferior compared to its application along the shear wall direction. An in-elastic (nonlinear) analysis is carried out for the evaluation of seismic performance. The configurations of symmetric RC moment resisting framed building structure with five different arrangements of planar shear walls are considered for evaluation using nonlinear time history analysis, so as to arrive at the best suited pattern of shear wall in the structural framing system. A comparison of structural behavior in terms of strength, stiffness and damping characteristics is done by studying the parameters like time period, base shear, overturning moments, storey displacements and drifts by arranging shear walls at five different patterns in the structural framing system.

Key words: NLTH, OMRF, Non-Linear Time History Analysis

I. INTRODUCTION

An earthquake is a sudden tremor or movement of the earth's crust, which originates naturally at or below the surface. Earthquake doesn't kill humans, but the buildings do. The behavior of a building during an earthquake depends on several factors, stiffness, and adequate lateral strength, and ductility, simple and regular configurations. Hence the research in these fields has become an important aspect. With the objective of improvement in the performance of structures subjected to earthquakes, structural engineers have developed methods through the Finite element computer technology/software which efficiently model, analyze and display the results in a meticulous manner.There are many available techniques for the analysis of the structures and to evaluate their performance under the given loading, the most accurate among them being the Non-Linear Time History analysis.

The control of structural vibrations produced by earthquake or wind loads can be done by various fundamental means. These conceptual approaches include modifying rigidities, masses, damping, or shape, and by providing passive or active counter forces. In present contest many buildings are provided with more than one type of seismic resisting systems. Usually these days structures are designed in such a way that the lateral force resistance is provided by frames and shear walls, frames and infill or frames and bracings. This combined system can be said as dual structural system. Dual structural system may combine the advantage of constituent elements.

The structural model in early research was considered to remain perfectly elastic. However, large magnitude earthquakes cause inelastic behavior in nonlinear responses. The Kutch Earthquake of January 26, 2001 in Gujarat, India, caused the destruction of a large number of modern 4 to 10-storied buildings. After this earthquake, doubts arose about our professional practices, building by-laws, construction materials, building codes and education for civil engineers and architects. It was found that Most of the Buildings that were analyzed for lateral Seismic Analysis were observed to ignore the Post-Yield Response (Non-linear Response) subjected to Dynamic Loading. Therefore, the pursuit of nonlinear analysis for the seismically excited building has been as both the structural damage and large motion hysteretic structural damping processes are inherently nonlinear. A nonlinear evaluation models can portray the salient structural dynamics for which appropriate evaluation criteria and control constraints can be presented for design problems.

II. OBJECTIVES OF THE STUDY

The present work aims at the following objectives:

- To perform Non Linear Time History Analysis on a regular symmetric Reinforced buildings using Bhuj time history function.
- To study the seismic response of the structures by inducing the time history function or the accelerogram in the axis perpendicular to the planar shear wall.
- To study the various parameters of the building like time period, base shear, overturning moments, storey displacements, storey drifts etc which are obtained by the analysis results.
- To perform a comparative study of the parameters between the bare frame structure and dual frame system structures incorporated by the planar shear walls involving different patterns of their location and configuration.
- To illustrate the seismic capacity variation in the results and to illustrate the effects of best performing patterns of planar Shear Walls on the response of the Low-rise to High-rise Symmetric Buildings

III. CASE STUDY

The Layout of plan has 5X5 bays of equal length of 4m. The storey height is kept uniform of 3m for all kind of building models. Stiffness of the infill is neglected in order to account the Nonlinear Behavior of Seismic demands. The beam sections are taken as 0.45 x 0.3 m and the column sections are taken as 0.45 x 0.45 m. Two nonlinear hinges are provided at each column and each beam of the structure. The buildings considered are Reinforced concrete ordinary moment resisting bare frames and dual structural system consisting of nonlinear layered type shear wall of 5, 10 & 20 storey symmetric buildings.

The Plan configuration consists of the below cases for five, ten and twenty storey buildings.

- CASE 1 - Bare frame - Building in square shape- symmetry in both X & Y axes, consists of only columns and beams, Number of bays in x-direction=5 , Number of bays in y-direction=5.
- CASE 2 – Shear wall pattern P1- Building of CASE 1 with beams and columns replaced with nonlinear planar shear wall at extreme ends of grid line “A” and “E”.
- CASE 3 - Shear wall pattern P2- Building of CASE 1 with beams and columns replaced with nonlinear planar shear wall between grid “2” & “4” at each horizontal grids of Y axis.
- CASE 4 - Shear wall pattern P3- Building of CASE 1 with beams and columns replaced with nonlinear planar shear wall at the grid line “C”
- CASE 5 - Shear wall pattern P4- Building of CASE 1 with beams and columns replaced with nonlinear planar shear wall at the grid lines “A” , “C” , “E”
- CASE 6 - Shear wall pattern P3- Building of CASE 1 with beams and columns replaced with nonlinear planar shear wall at the grid line “B” & “D”

Sl.no	Variable	Data
1	Type of structure	Moment Resisting Frame and dual structural frame system
2	Number of Stories	5 , 10 & 20
3	Floor height	3m
4	Live Load	3.0 kN/m^2
5	Dead load	1.0 kN/m^2 and wall load of 15KN/m
6	Materials	Concrete (M30) and Reinforced with HYSD bars (Fe415)
7	Size of Columns	450X450 mm
8	Size of Beams	300x450 mm in longitudinal direction 300x450 mm in transverse direction
9	Depth of slab	150mm thick (only load is considered)
10	Specific weight of RCC	25 kN/m^3
11	Zone	V
12	Importance Factor	1
13	Response Reduction Factor	3
14	Type of soil	Medium i.e. type 2
15	Software used	ETABS 13.1.3

Table 4.1 Assumed Preliminary data required for the Analysis of the frame

Below are the plan configuration of the models that were considered in the study.

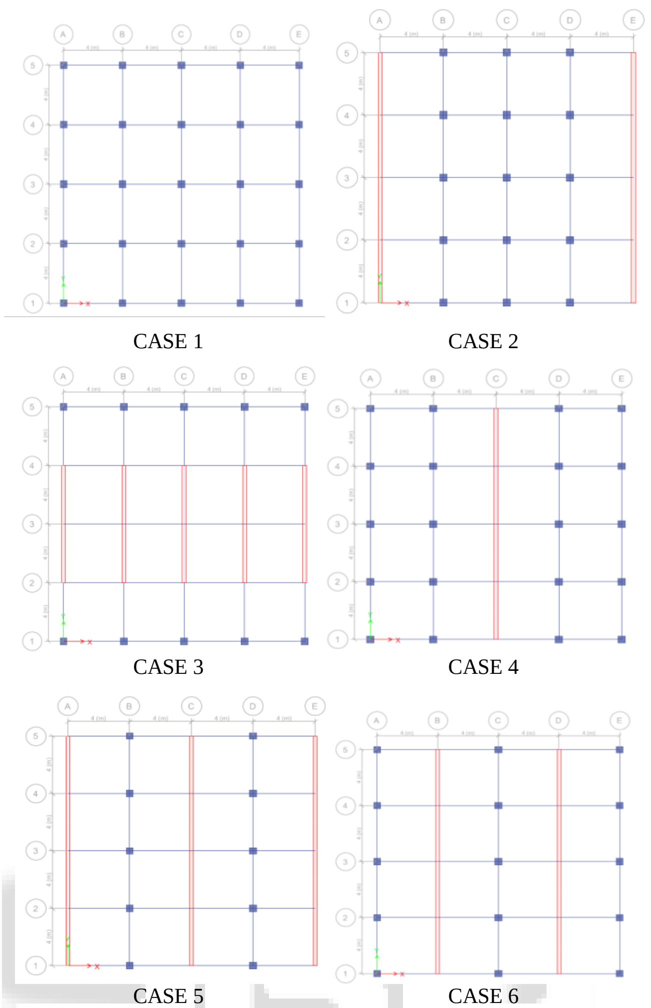

Fig. 4.1: Plan view of all the models categorized under the storey cases

IV. Method Of Analysis - Non-Linear Time History Analysis

NLTHA is the most accurate method available to understand the behavior of structures subjected to earthquake forces. As the name implies, it is the process of finding out the history of responses throughout the life span of the dynamic loading like an earthquake ground acceleration record until the structure reaches a limit state. Two earth-quake ground acceleration records namely N-E Bhuj and components of the Bhuj Earthquake record have been selected. In this work, only one component of N-E bhuj is induced to the models in the orthogonal direction. Bhuj is a place located in the state of Gujarat which is a high intensity earthquake zone of zone factor 0.36 which comes under the Zone-V according to the classification of seismic zones by IS 1893-2002 part-1.The records are defined for the acceleration points with respect to a time-interval of 0.005 second. The acceleration record has units of m/sec^2 and has a total number of 26,706 acceleration data coordinates out of which the most critical data points which are of the highest intensity are the first 10,000 acceleration data coordinates have been considered.

In this the Non-Linear time history analysis is carried out through the Direct-Integration methods by defining the Non-Linear time history direct integration load cases. The acceleration data points are converted to loading by multiplying the acceleration data points with the mass matrix of the structure. The time history load case is continued from state end of a non-linear load case known as a non-linear static load case.

V. RESULTS AND DISCUSSIONS

A. *Modal time period*

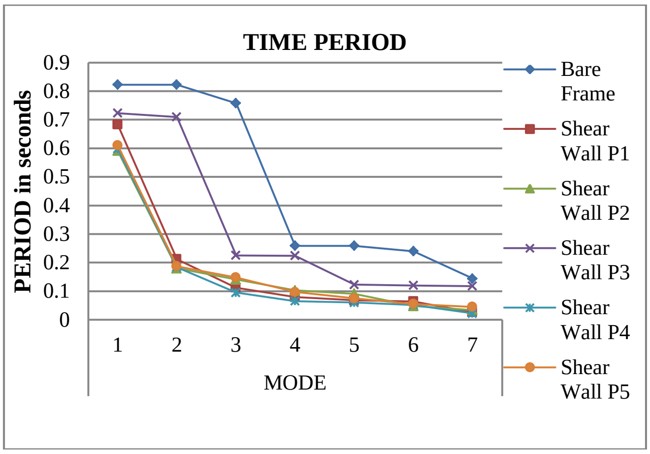

Fig. 5.1: Mode vs. Time Period for 5 storey models

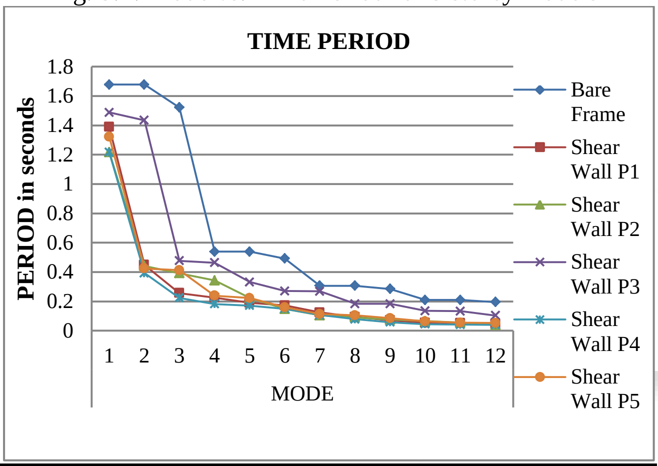

Fig. 5.2: Mode vs. Time Period for 10 storey models

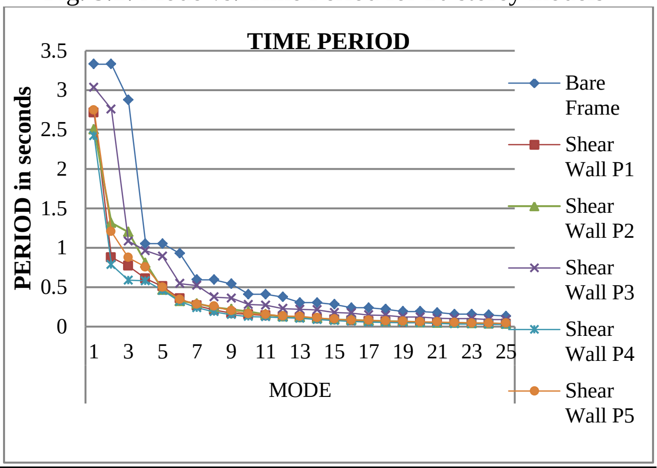

Fig. 5.3: Mode vs. Time Period for 20 storey models

– It is observed that the variation in the time period for the five – ten – twenty storey models remains identical; however the time period increases in each storey case. It is observed to have 50 -55 % increase in ten the storey and a 73 – 78 % in the twenty storey models when compared them with the models of 5 storey.
– It is observed that time period shows a steep curve between the mode 2-4 for all building modals. Initial Damping of structure reduces time period considerably.
– According to the observation drawn from the chart, bare frame possesses maximum time period at all modes and for all storey cases when compared to the dual structural system for the obvious reason.
– When comparing among the different shear wall patterns, the pattern P3 has distinctly larger time periods in all the three storey cases. This is due to the uni-planar shear wall arrangement at the centre.
– The dual structural system with shear wall pattern P4 for all the three storey cases possesses least time period due to large number and proper position of the shear wall.
– On comparison between the bare frame and dual frame system with shear wall pattern P4, the time period at the 1st mode reduces to about 28 % , 77% for the 2nd mode, approx 80 – 88% in the 3rd mode. In further higher modes the percentage reduction in the time period is less.

B. *Base Reaction - Base Shear*

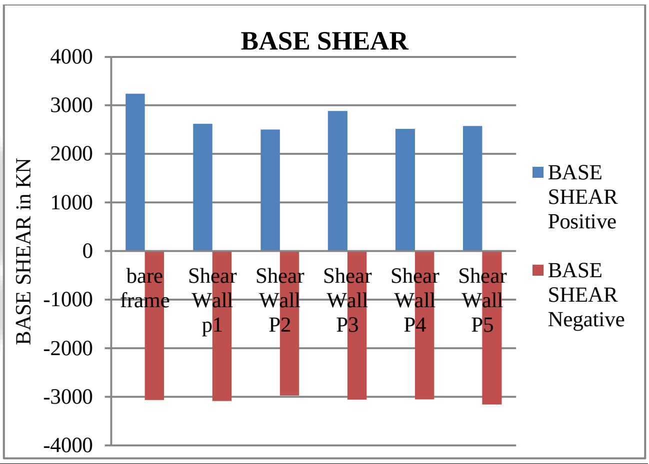

Fig. 5.4: Base Shear of Different Models of 5 Storey Buildings

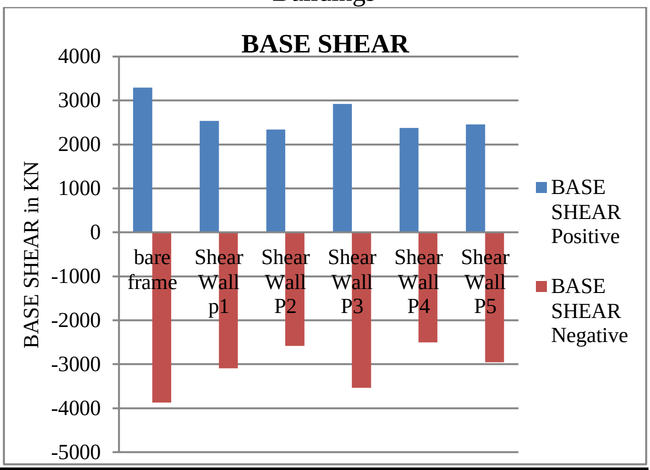

Fig. 5.5: Base Shear of Different Models of 10 Storey Buildings

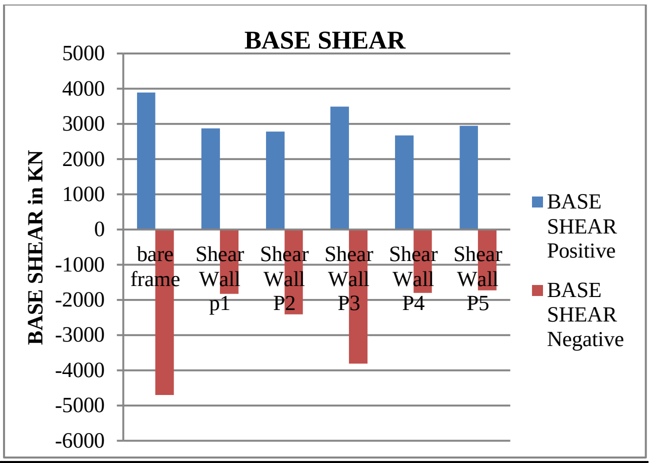

Fig. 5.6: Base Shear of Different Models of 20 Storey Buildings

- The variations of the positive base shear are very much similar to the variations of negative base shear for 10 and 20 storey cases.
- The base shear increases to about 2% – 7% for the 10 storey models and about 6% - 18% for 20 storey models when compared it with 5 storey models.
- It can be observed from the charts that the bare frame has the largest base shear for all the three storey cases when comparing it with their respective dual system structures.
- When comparing among the dual structural systems, the models with the shear wall pattern P3 has the largest base shear. The reduction in base shear from the bare frame in these models is 11.05 % for 5 storey, 11.23 % for 10 storey, 10.17% for 20 storey.
- The dual system structure with the shear wall pattern P4 & P2 perform almost same and possesses the least base shear among all. The reduction in base shear from the bare frame is about 23 % for 5 storey, 29% for 10 storey and 32% for 20 storeys.

C. Base Reaction- Moments

Fig. 5.7: Graphical representations of the moments for 5 storey building

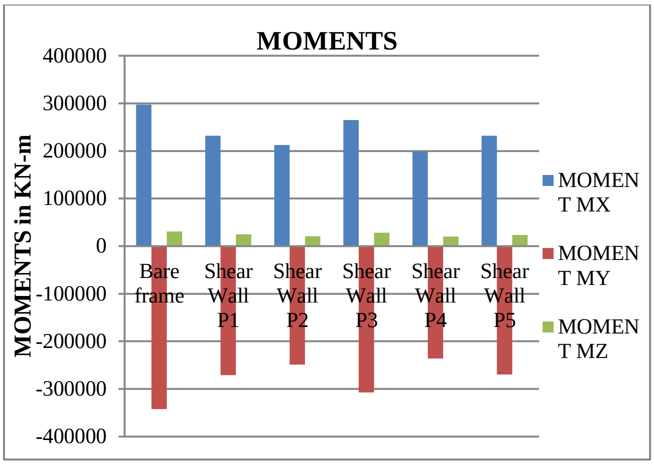

Fig. 5.8: Graphical representations of the moments for 10 storey building

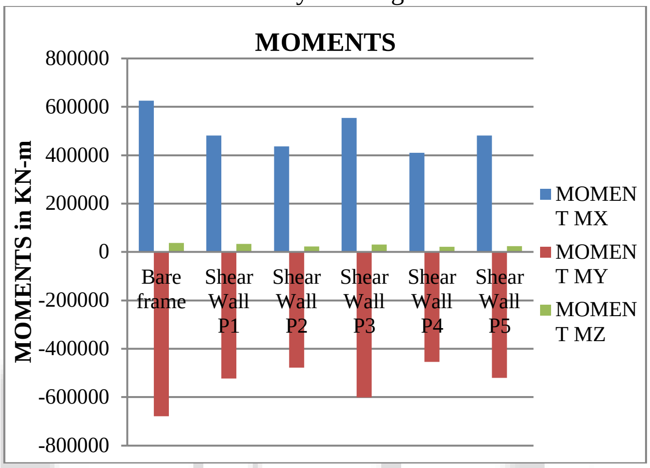

Fig. 5.9: Graphical representations of the moments for 20 storey building

- The positive and the negative signs in the moments are only the representation of the direction of the moments. The moment exists in both the positive and negative direction however for the comparison purpose only the moments with greater magnitude is considered.
- The twisting moments i.e. Mz is less in magnitude due to the symmetric configuration of the structure. Comparing the Moments My & Mx, we observe that the moments My is greater than Mx by 14% -19% for 5 storey models, 19% -15% for 10 storey models and 7% -10% for 20 storey models. The reason being the presence of the shear wall in the orthogonal direction to the induced earthquake.
- It can be observed from the charts that the bare frame has the largest overturning moments for all the three storey-cases when comparing it with their respective dual system structures.
- When comparing among the dual structural systems, the models with the shear wall pattern P3 has the largest overturning moment. The reduction in the overturning moments from the bare frame in these models is 11% -12% for Mx, 9% -12% % for My for all the three storey-cases.
- The dual structural system with the shear wall pattern P4 possesses the least overturning moments among all. The reduction in overturning moments

from the bare frame is about 32 % - 34 % for Mx, 29% -33 % for My for all the three storey-cases.

D. Storey Displacements

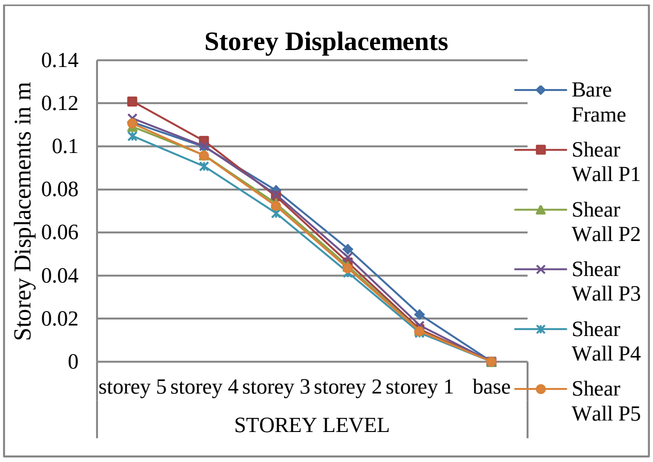

Fig. 5.10: Graphical representation of maximum storey displacements for 5 storey models

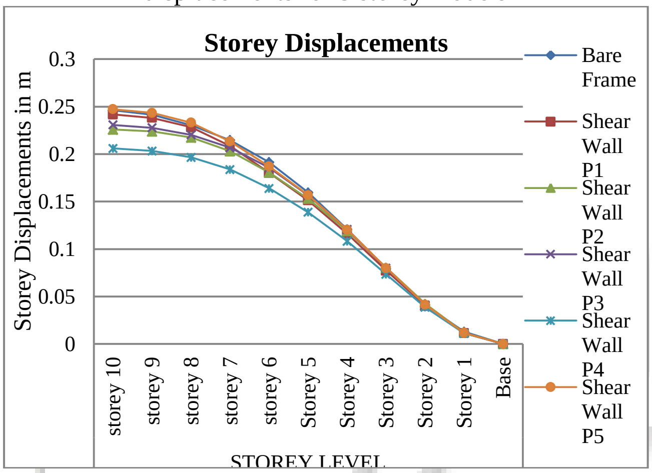

Fig. 5.11: Graphical representation of maximum storey displacements for 10 storey models

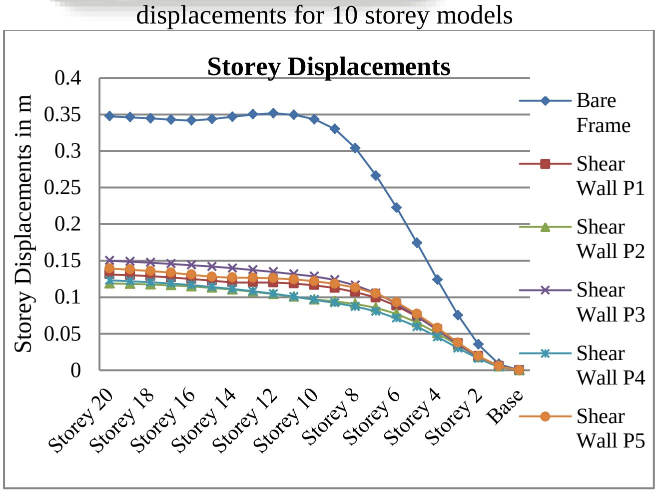

Fig. 5.12: Graphical representation of maximum storey displacements for 20 storey models

– According to the graphical representations, the difference in the displacements of bare frame and dual structural system is more in twenty storey building models when compared with five storey models and ten storey models.

– The displacements of all the building models increases up to a certain storey level linearly and then attain a saturation level.

– In case of five storey models, the displacements of the bare frame is maximum up till the 3rd storey after which the dual structural system with shear wall pattern P1 crosses it and becomes maximum.

– When comparing among the dual structural systems, the models with the shear wall pattern P3 has the overall largest storey displacements. Anyhow the reduction in the displacements is prominent only in twenty storey models.

– The dual structural system with the shear wall pattern P4 possesses the least overall storey displacements among all. As above discussed, the reduction in storey displacements is again prominent in twenty storey models.

– All the other dual structural systems P1, P5 & P4 have more or less same results and thus trace the curve identically.

E. Storey Drifts.

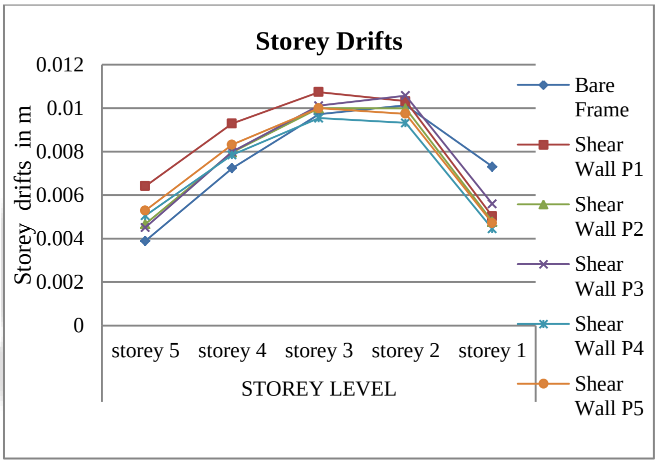

Fig. 5.13: Graphical representation of storey drift for 5 storey models

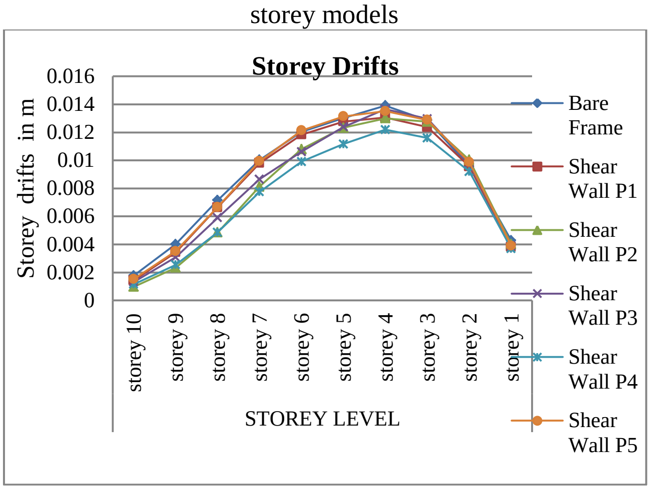

Fig. 5.14: Graphical representation of storey drift for 10 storey models

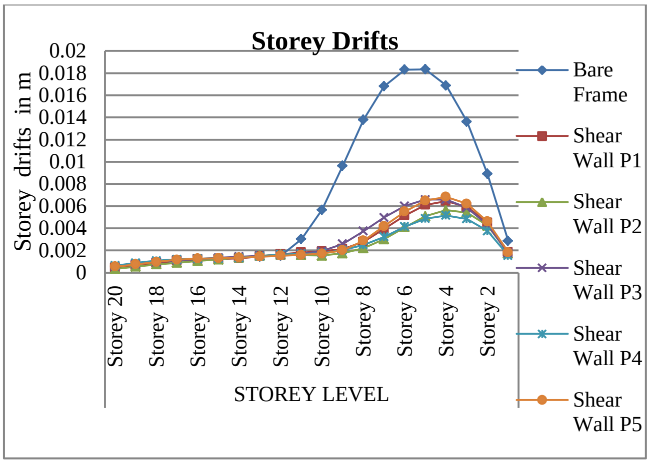

Fig. 5.15: Graphical representation of storey drift for 20 storey models

- A clear pattern of the storey displacements can be studied through the charts of storey drifts.
- In all the storey cases, it is observed that the drift increases with the storey level then becomes maximum at a certain storey level and then further drops down decreasing.
- The maximum allowable drift in this research would be 0.004*h =0.004*3 =0.012m. or it can be said as 12 mm
- Studying the figure 5.13, the maximum drift occurs at the storey level 3. The dual system of structure with the shear wall pattern P3 has the maximum drift at the stated level with the drift of 10.74 mm, whereas the dual structural system with shear wall pattern P4 has the least drift at this maximum level with the drift of 9.54 mm.
- Observing the figure 5.14, the maximum drift occurs at the storey level 4. In this case the bare frame yields the maximum drift at the storey level 4 with the drift of 13.9mm which is above the allowable limit. This is followed by the dual system of structure with shear wall pattern P3 with 13.65mm which is again above the allowable limit. The dual structural system with shear wall pattern P4 has the least drift at the above stated storey level with the drift of 12.01mm which may be allowed.
- For the twenty storey models, the maximum drift occurs at the storey 4 in the figure 5.15. Here again the bare frame yields the maximum drift of 18.34 mm (above the allowable limit) followed by the dual structural system with shear wall pattern P3 with the drift of 6.58 mm. The least drift is shown by the dual structural system with shear wall pattern P4 with the drift of 5.164mm at the stated storey level.

VI. CONCLUSION

- Shear wall arranged along the direction of earthquake may have significant effect in the performance. Anyhow the arrangement of the shear wall orthogonally with the earthquake cannot be under determined as it gives satisfactory results considering the performance of high rise structures.
- Dual type structural system with proper location and sufficient number of shear walls is more effective in resisting earthquake forces than the moment resisting frame system.
- The influence of the shear wall is significant in terms of damping characteristics which can be easily observed by the sudden fall of time period after the first two modes.
- It is evident that as the storey increases, the time period of the structure also increases due to the increased height that acts as a cantilever.
- The torsion or the twisting moment is very less when compared with their respective overturning moments because of the symmetric configuration of the building plan and also due to the shear wall being arranged in the way that the centre of stiffness of the structure coincides with the centre of mass of the structure.
- The presence of the shear wall at the orthogonal direction to the earthquake reduces the overturning moment in the same direction.
- It is evident that as the storey increases, the base shear, moments and displacements of the structure also increases due to the increase in the bulk mass of the structure.
- If the dimensions of shear wall are large then major amount of horizontal forces are taken by shear wall.
- Dual structural system with the shear wall arranged as pattern P3 has large time period, base shear, moments, displacements, drifts. This because the shear walls in such arrangements is less in number and has a uni planar in nature.
- Dual structural system with the shear wall arranged as pattern P4 has the least time period, base shear, moments, displacements, drifts. This implies that as we increase the number of shear wall, the stiffness increases and so do the performance.
- Shear wall with pattern P1 and P5 has the same number of shear walls but arranged in different way. The dual structure with shear wall pattern P5 has the shear wall close to the center of the structure whereas the dual structure with shear wall pattern P1 are at outer face of the structure. The study shows that the pattern with the shear wall close to the centre of structure performed a little better than the one arranged at outer face.
- Based upon the results of the storey displacements, we can conclude that the shear wall is not efficient in 10 storey or below 10 storey. The shear wall is effective in only high rise structures.
- For high rise building, the shear wall is efficient only upto the mid height of the structure. After which the dual frame structure acts as an ordinary bare frame structure.
- The presence of shear wall can affect the seismic behavior of frame structure to large extent, and the shear wall increases the strength and stiffness of the structure. In general, the provision of shear wall has significant influence on lateral strength in taller buildings while it has less influence on lateral

stiffness in taller buildings. The provision of shear wall has significant influence on lateral stiffness in buildings of shorter height while it has less influence on lateral strength.

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