Scientific Journal of Impact Factor(SJIF): 3.134

e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 8, August -2015

Dynamic Analysis of High Rise RC Structure with Shear Walls and Coupled Shear Walls

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Abstract — *Among the dangerous natural hazards earthquake is the one which, cause great damage of life and livelihood. The ground motion and the structure itself are the characteristics on which the response of the structure depends during an earthquake. The high in plane stiffness and strength of the shear wall systems helps to resist both large horizontal load and gravity load. Now a days in order to resist lateral loads in the high rise buildings, the shear wall systems are commonly used. The present study carried out helps in determining the response of a high rise RC Frame structure with shear walls, coupled shear walls and equivalent coupled shear wall systems. To study the behavior of the system, parameters such as base shear, storey shear, storey drift, displacements and member forces are considered. The above systems with shear wall are compared with the bare frame without any shear wall and coupled shear wall. The effect on the high rise building systems, built in the very sever seismic zones will be studied and compared. For the present study 30, 40 and 50 storied RC Frame structures are considered and analyzed with and without shear wall system, and effectiveness of bare frame with only shear walls, coupled shear walls and combination of both i.e., equivalent coupled walls are found out and best of the three systems for particular height of the building is suggested*

Keywords- Seismic response; shear wall; coupled shear wall; RC bare frame; high rise building.

I. INTRODUCTION

In the structural planning of the high rise building the use of shear walls has been found long back. Walls are very efficient in resisting lateral loads (earthquake or wind) when placed in proper position of the building [10]. Shear walls are the structural elements of the building which carries large amount of lateral loads and horizontal shear forces which are generated from the loads. Now a days multi-storey building are built taller and less thinner, for this reason the analysis of the shear walls have become most important and critical part of the design. By using the shear walls, the inter storey deflections caused when subjected to lateral loads are controlled in the multi-storey building. Great structural safety and protection can be achieved by providing well designed shear wall in the multi-storey building under moderate seismic zones. The material used, wall thickness, wall length, wall positioning in building frame are taken into consideration for judging the behaviour of shear walls [4]. By the provision of the shear walls the designer aim in achieving basic criteria such as, ductility, strength and stiffness [5]. During large earthquake, the structures base will experience substantial cyclic deformations in the inelastic range so it is important to study the base shear force of shear walls [5]. "Shear walls are particularly suited for ductile response with very good energy dissipation characteristics when regular patterns of openings (e.g., doors, windows, and/or mechanical penetrations) are arranged in rational pattern" [9].

A coupled shear wall is a shear wall that has one or more vertical rows of openings. The surrounded openings are doors and windows. A coupled shear wall is one in which walls piers are interconnected to each other by coupling beams which forms composite action between separate sub cores. Coupled shear walls and shear walls are together called 'equivalent coupled shear walls'. Generally, moment resisting frames and equivalent coupled shear walls together forms the RC high rise building.

II. THE MODEL CASES

ETABS Software is used for the modeling and analysis of high rise buildings. Following Cases are taken for analyzing in ETABS Software varying the storeys, i.e. 30, 40 and 50. Plan is selected as Simple and Regular geometry from Clause 7.1 of IS: 1893-2002 part-1 with floor height 3.5m and with spacing of columns 5m in both directions. (8x8 Bays). M-40 and Fe-415 material is used. The columns are economized by changing the sizes at every ten storey levels. For 30 storey models: 800×800mm, 600×600mm and 500×500mm. For 40 storey models: 1250×1250mm, 1000×1000mm, 800×800mm and 500×500mm. For 50 storey models: 1100×1100mm, 1000×1000mm, 800×800mm, 650×650mm and 500×500mm. Beams: For 30 and 40 storey models: 300×600mm. For 50 storey models: 450×750mm. Slab thickness= 200mm. Shear wall and coupled shear wall thickness=300mm. Opening= 25.71% (3×1.5m). Live load= 4 kN/m^2. Super Dead load= 1.5 kN/m^2 . Live load on roof= 1.5 kN/m^2. For Earthquake analysis the following are considered based on the code provision IS 1893:2002 (Part 1): very severe seismic zone-5: z=0.36 with medium soil (type 2) condition, Importance factor: I= 1.5 (Public building), Reduction factor: R=5 (SMRF) and Natural period: $T=0.075h^{0.75}$.

A. **Case-1:** Base Model (Bare frame)

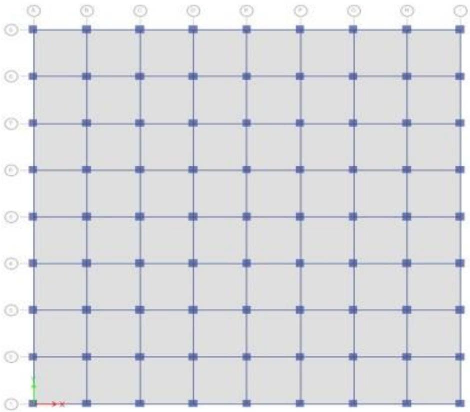

Figure 1. Plan of 30, 40 and 50 storey case-1 models

B. **Case-2:** Base Model with shear wall

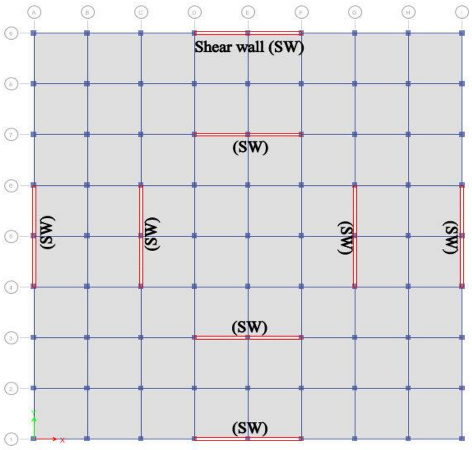

Figure 2. Plan of 30, 40 and 50 storey case-2 models

Case-3: **Base Model with coupled shear wall**

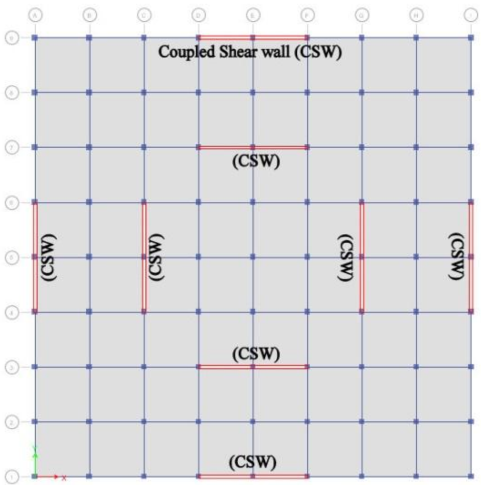

Figure 3. Plan of 30, 40 and 50 storey case-3 models

C. **Case-4:** Base Model with shear walls and coupled shear wall i.e., equivalent coupled walls.

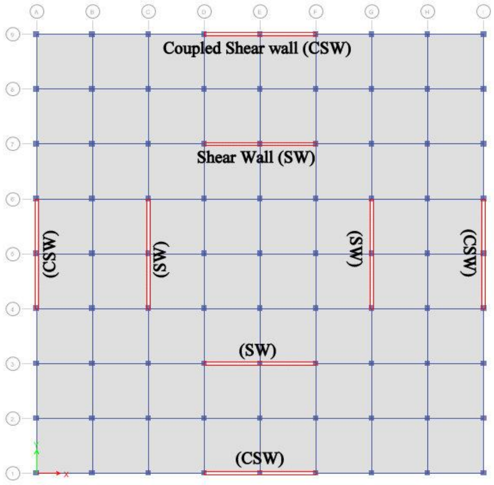

Figure 4. Plan of 30, 40 and 50 storey case-4 models

III. RESULTS AND DISCUSSION

This research work is carried out to compare the dynamic response of RC bare frame with shear wall, coupled shear wall and equivalent coupled shear wall to suggest suitable combinations of wall system for different heights of high rise buildings i.e., 30, 40 and 50 storey buildings. Totally twelve models are considered for the dynamic analysis which includes modal analysis, equivalent static and response spectrum analysis. From the modal analysis using response spectrum analysis base shear, storey shear, storey drift, displacement, time period and member forces results for zone V as per IS 1893 (Part 1) 2002 are obtained.

D. Time Period

The time period for the models with shear wall systems is less than as it is for the bare frame. And on comparing with the bare frame model, the time period of 30 storey models is reducing by 31.56%, 27.55% and 29.47% for SW, CSW and MSW models respectively. For 40 storey models it is reducing by 28.67%, 20.85% and 27.14% for SW, CSW and MSW models respectively and. For 50 storey models it is reducing by 19.32%, 16.42% and 17.87% for SW, CSW and MSW models respectively. The frequency of structure depends on stiffness and mass, from figures 5, 6 and 7 the time periods for models with SW, CSW and MSW are decreasing when compared to bare frame. The stiffness increases in the model with shear wall systems for the constant mass, which shows increments in linear frequency and it is inversely proportional to the time period.

Table 1. Time Period of first mode shapes for 30 storey models.

Models	Time period(seconds)
Case-1 (Base Model)	4.0852
Case-2 (SW Model)	2.7957
Case-3 (C SW Model)	2.9594
Case-4 (MSW Model)	2.8811

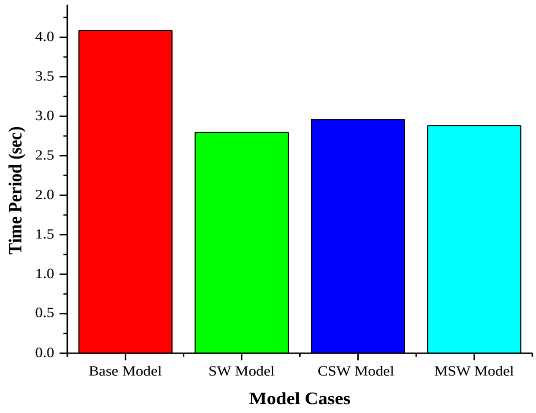

Figure 5. Comparisons of Time Period for Different Model Cases

Table 2. Time Period of first mode shapes for 40 storey models.

Models	Time period(seconds)
Case-1 (Base Model)	5.0639
Case-2 (SW Model)	3.6119
Case-3 (C SW Model)	4.0079
Case-4 (MSW Model)	3.6893

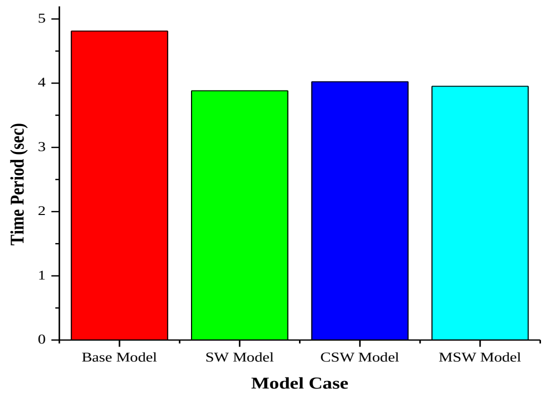

Figure 6. Comparisons of Time Period for Different Model Cases

Table 3. Time Period of first mode shapes for 50 storey models.

Models	Time period(seconds)
Case-1 (Base Model)	4.8110
Case-2 (SW Model)	3.8811
Case-3 (C SW Model)	4.0210

Case-4 (MSW Model)	3.9509

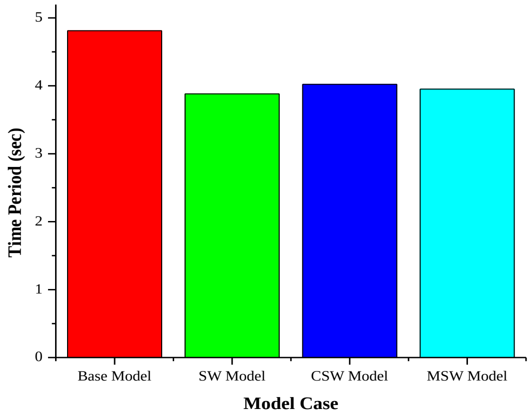

Figure 7. Comparisons of Time Period for Different Model Cases

E. Scale Factor (Initial scale factor taken for response spectrum = Ig/2R=1.4715)

Table 4. Scale factors for 30 storey models

Model Cases	Case-1	Case-2	Case-3	Case-4
Static V_b (kN-m)	10932.01	19899.13	19450.38	19734.71
Dynamic V_b (kN-m)	10218.7	16544.78	15128.12	15942.49
Scale factor	1.57	1.77	1.89	1.82

Table 5. Scale factors for 40 storey models

Model Cases	Case-1	Case-2	Case-3	Case-4
Static V_b (kN-m)	23165.88	24070.025	21785.45	23876.52
Dynamic V_b (kN-m)	14572	20321.05	16092.25	19404.82
Scale factor	2.339	1.7429	1.992	1.810

Table 6. Scale factors for 50 storey models

Model Cases	Case-1	Case-2	Case-3	Case-4
Static V_b (kN-m)	25755.51	26506.5	25993.63	26250.06
Dynamic V_b (kN-m)	19599.1	23556.47	21915.34	22750.54
Scale factor	1.934	1.656	1.745	1.698

F. Base Shear

Table 7. Base shear contribution percentage of the shear wall systems in X direction for 30 storey models

Model Cases	Base shear contribution percentage
Case-2	81.36%
Case-3	69.06%
Case-4	63.34%

Table 8. Base shear contribution percentage of the shear wall systems in X direction for 40 storey models

Model Cases	Base shear contribution percentage
Case-2	68.69%
Case-3	64%
Case-4	61.84%

Table 9. Base shear contribution percentage of the shear wall systems in X direction for 50 storey models

Model Cases	Base shear contribution percentage
Case-2	79.18%
Case-3	48%
Case-4	59.29%

G. Displacements

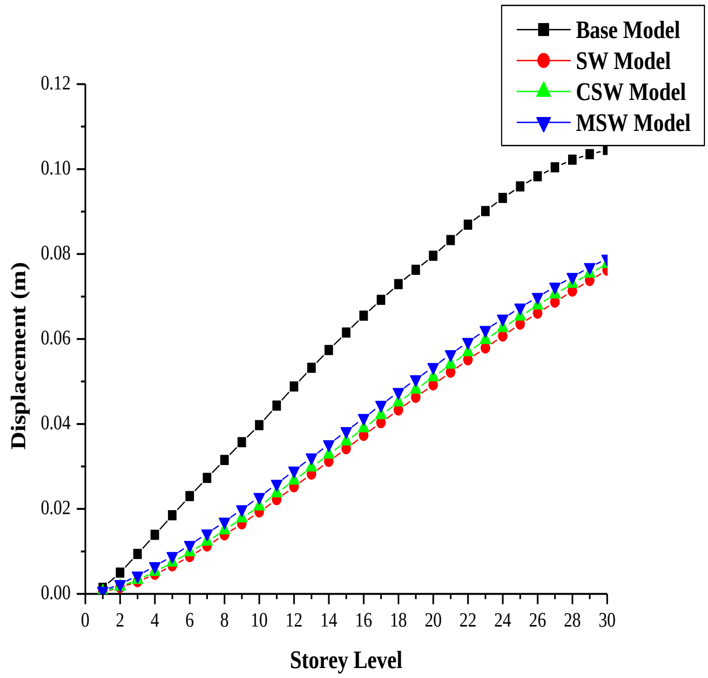

Figure 8. Comparisons of Displacements along X Direction for 30 storey models

The displacements compared to base model (bare frame) at 30th storey decreased by 27.08%, 25.64% and 24.49% for SW, MSW and CSW respectively. This can be observed from fig 8 above

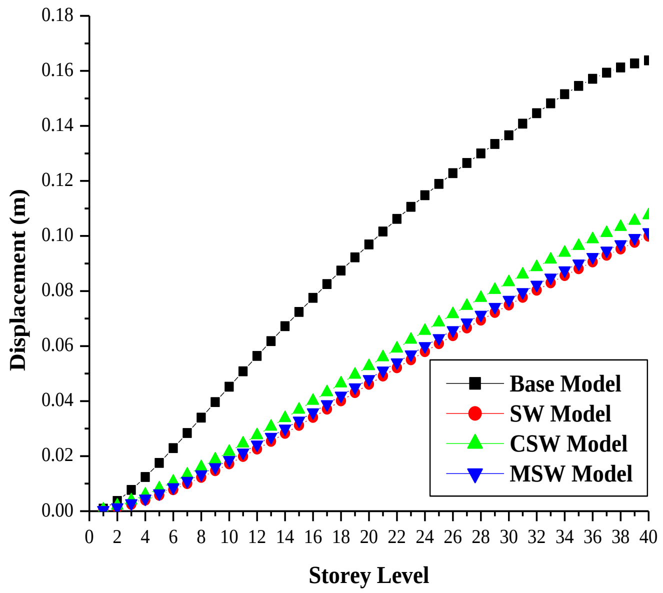

Figure 9. Comparisons of Displacements along X Direction for 40 storey models

The displacements compared to base model (bare frame) at 40th storey decreased by 39.01%, 34.37% and 38.10% for SW, MSW and CSW respectively. This can be observed from fig 9 above.

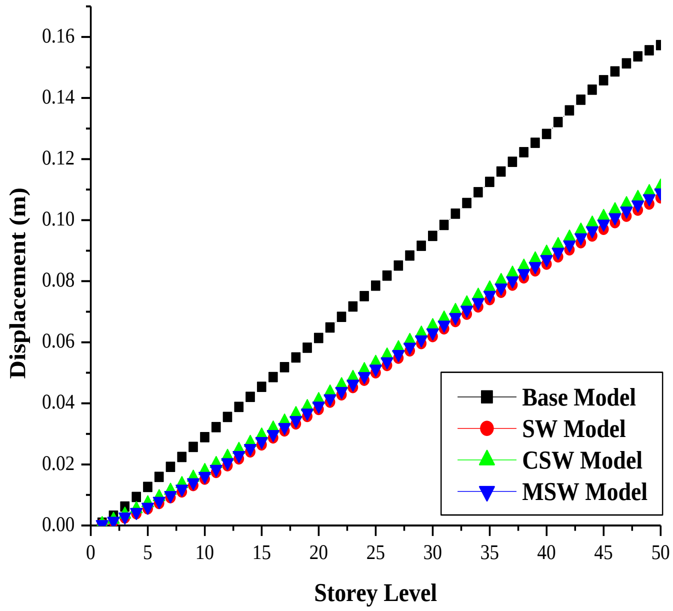

Figure 10. Comparisons of Displacements along X Direction for 50 storey models

The displacements compared to base model (bare frame) at 50th storey decreased by 31.79%, 29.43% and 30.71% for SW, MSW and CSW respectively. This can be observed from fig 10 above. RC bare frame is having Maximum value of displacement because of variation in stiffness after the provision of shear wall systems i,e shear wall, coupled shear wall and equivalent coupled shear wall the displacements were completely reduced. The models with the shear wall is having minimum displacement, compared to coupled shear wall and then mixed shear wall.

H. Storey Drift

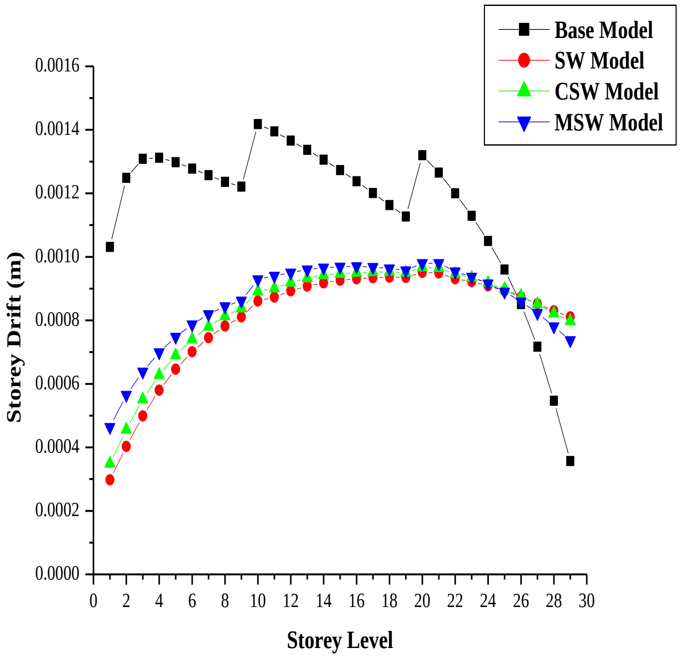

Figure 11. Comparison of Storey Drift along X Direction for 30 storey models

At 10th and 20th storey level there is sudden increase in drift of the base model. On comparison with base model the decrease in the drift was about 33.58%, 31.37% and 29.40% for SW, MSW and CSW models respectively at 10th storey level. Similarly at 20th storey level it is decreased by 17.04%, 15.71% and 15.08%. Fig 11 shows the comparison of Storey Drift for the different model cases.

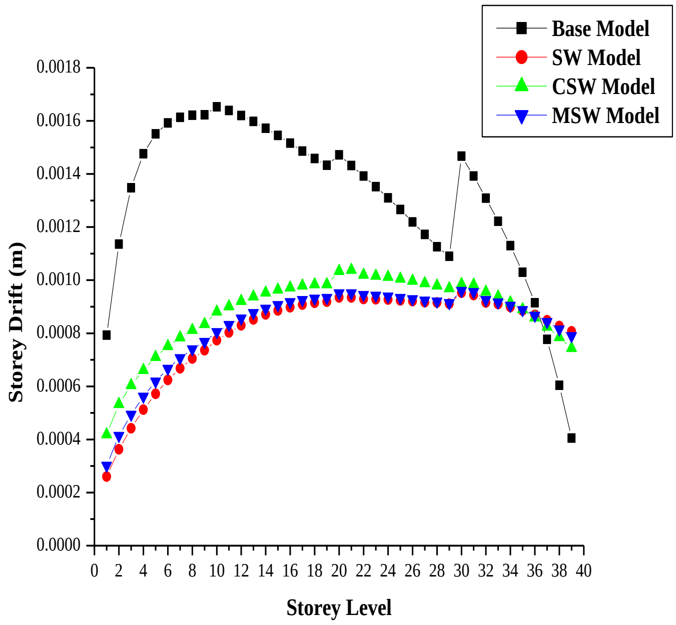

Figure 12. Comparison of Storey Drift along X Direction for 40 storey models

At 10th, 20th and 30th storey level there is sudden increase in drift of the base model. On comparison with base model the decrease in the drift was about 54.65%, 48.61% and 52.68% for SW, CSW and MSW models respectively at 10th storey level. At 20th storey level it is decreased by 35.87%, 31.33% and 34.82%. Similarly At 30th storey level it is decreased by 16.42%, 11.10% and 16.15%. Fig 12 shows the Comparison of Storey Drift for the different model cases.

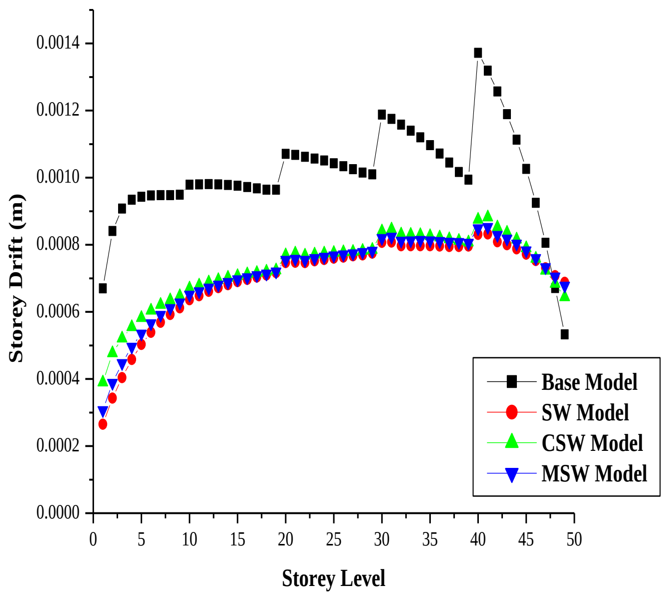

Figure 13. Comparison of Storey Drift along X Direction for 50 storey models

At 10th, 20th, 30th and 40th storey level there is sudden increase in drift of the base model. On comparison with base model the decrease in the drift was about 35.51%, 31.82% and 33.83% for SW, CSW and MSW models respectively at 10th storey level. At 20th storey level it is decreased by 25.62%, 24.90% and 25.31%. At 30th storey level it is decreased by 23.27%, 22.28% and 22.57%. Similarly At 40th storey level it is decreased by 19.92%, 18.81% and 18.91%. Fig 13 shows the Comparison of Storey Drift for the different model cases.

From the above storey drift figures 11, 12 and 13. It is observed that, due to the change in the column sizes at each and every 10 storey levels, the stiffness reduces, reduced stiffness increases the deflection at that level. For this purpose the peak drift is observed at 10th, 20th, 30th and 40th storey levels.

I. Storey Shear

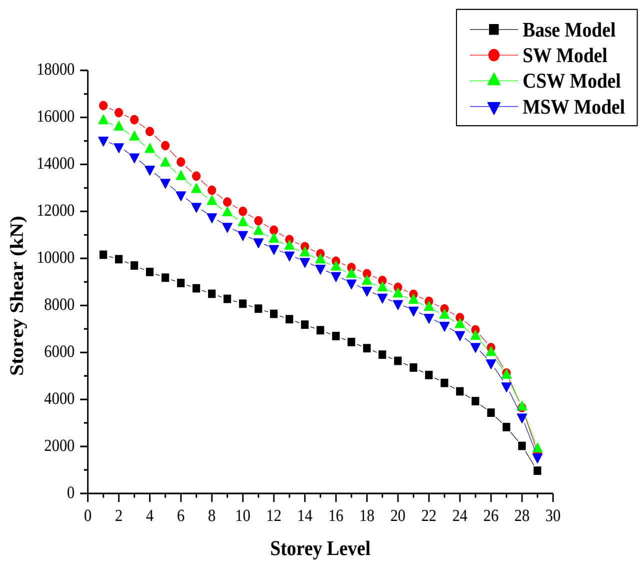

Figure 14. Comparison of Storey Shear along X Direction for 30 storey models

By comparing the storey shear at base of the 30 storey base model (bare frame) it is evident to see that storey shear has increased by 61.90%, 56.01% and 48.04% for SW, MSW and CSW.

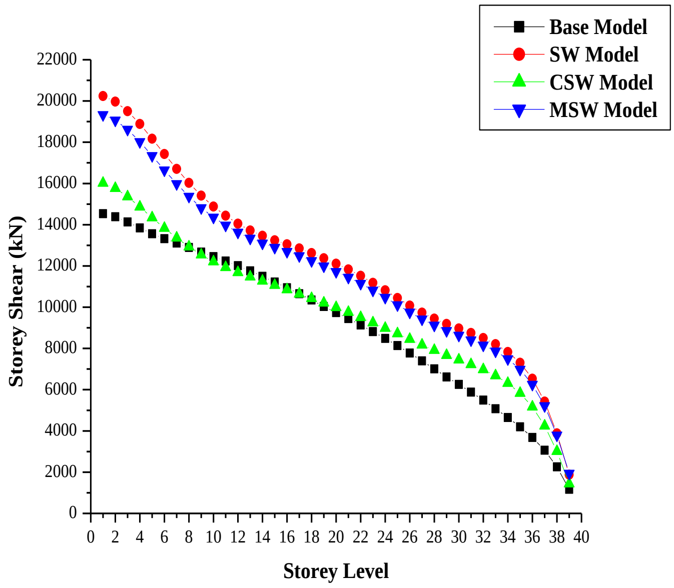

Figure 15. Comparison of Storey Shear along X Direction for 40 storey models

By comparing the storey shear at base of the 40 storey base model (bare frame) it is evident to see that storey shear has increased by 39.45%, 10.43% and 33.17% for SW, CSW and MSW.

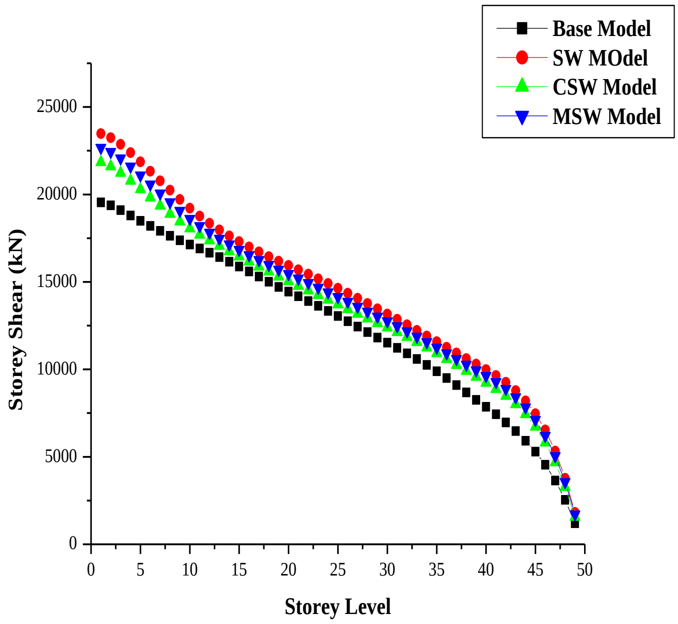

Figure 16. Comparison of Storey Shear along X Direction for 50 storey models

By comparing the storey shear at base of the 50 storey base model (bare frame) it is evident to see that storey shear has increased by 20.19%, 11.82% and 16.08% for SW, CSW and MSW.

Storey shear is the distribution of design base shear along height of the structure. Similar to base shear, it is observed from Figures 14, 15 and 16. Storey shear varies parabolically with respect to storey level. The storey shear of the shear wall system model has increased due to the increase in stiffness because of the shear walls provided.

IV. CONCLUSION

For the present study 30, 40 and 50 storied RC Frame structures were considered and analyzed with and without shear wall system, and effectiveness of bare frame with only shear wall, coupled shear wall and combination of both i.e., equivalent coupled walls are found out. The responses such as, time period, displacements, storey drift, storey shear, and member forces are obtained for each case and observations are made based on the results obtained. Finally conclusions are drawn based on the results obtained.

- The time period for the models with shear wall systems is less than that for the bare frame. And on comparing with the bare frame model, the time period is reducing by 31.56%, 28.67% and 19.32% for SW models of 30, 40 and 50 storey respectively.
- It is seen that the base shear contribution percentage of the shear wall systems (case-2) in X direction is maximum when compared to other shear wall systems.
- The displacement is maximum for the bare frame and minimum for the model with the shear walls (case-2) as compared to other shear wall models (case-3 and case-4). RC bare frame undergoes maximum displacement compared to other models because of less inplane stiffness as compared to other models. The models with the shear wall are having minimum displacement compared to coupled shear wall and then mixed shear wall. The percentage reduction in the displacement as compared to bare frame by provision of shear wall (case-1) for 30th, 40th and 50th storey models was found to be 27.08%, 39.01% and 31.79%.
- Drift is found to be decreasing significantly for models with shear wall, coupled shear wall and mixed shear wall and among which shear wall model has the least drift. For 30th storey model the drift obtained at 10th and 20th storey decreased by 33.58% and 17.04% as compared to bare frame model. For 40th storey model the drift obtained at 10th, 20th and 30th storey decreased by 54.65%, 35.87% and 16.42% as compared to bare frame model. For 50th storey model the drift obtained at 10th, 20th, 30th and 40th storey decreased by 35.51%, 25.62%, 23.27% and 19.92% as compared to bare frame model.
- From the observations, the storey shear is found minimum in the bare frame as considered with the other models analyzed for different shear walls (SW, CSW and MSW) and stories (30, 40 and 50 storey). The storey shear of the shear wall system models is increased due to the increase in stiffness because of the shear wall provided. By comparing the storey shear at base of the 30, 40 and 50 storey base model (bare frame) it is evident to see that storey shear has increased by 61.90%, 39.45% and 20.19% for Shear wall model.
- Hence it is concluded that the shear wall systems provided in all models for different stories was effective as compared to bare frame model. The shear wall (case-2) model was more effective than other two shear wall systems (cases-3 and 4).

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