PERFORMANCE EVALUATION OF RC FRAMED STRUCTURES WITH AND WITHOUT SHEAR WALL USING STAAD PRO

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Abstract
Engineering structures are very difficult to analyze for their dynamic or vibration behavior since they are very complex. In the last couple of decades alone in India, with the incidental loss of life and property witnessed due to failure of structures caused by earthquakes, now attention is given to neglect the adequacy of strength in RC framed structures to resist strong ground motions. As we know that in the present scenario, buildings with shear walls are gaining more popularity than buildings without the shear wall in earthquake-prone areas mainly under zones III, IV and V due to their capability to the resistance during earthquake. In this paper, 7 storey's RCC framed structure is considered for the seismic analysis which is located in zone III is considered the analysis using equivalent static analysis method. Six models have considered for the analysis out of which one is bare frame model i.e without shear wall and remaining five models are structures with column support shear wall at various positions is considered. Initially, shear walls are used in reinforced concrete buildings to resist wind force. Since building with shear wall gives excellent performance even under seismic force, shear walls are extensively used for all earthquake resistance design. The shear wall imparts lateral stiffness to the system and also carries the gravity load. When design for wind loading, the location of shear wall in building plan does not play important role. In case of Seismic loading, location of shear walls plays a critical role. Under wind loading, a fully elastic response is expected, while during strong earthquake significant inelastic deformations are anticipated. Hence, in this paper, Column support shear walls are placed at different locations in RC frames of G+6 Storey building and analyzed for seismic action and also subjected to static pushover analysis. The modeling and analysis are done using Staad Pro. An attempt is made to study and compare the seismic parameters such as storey displacement, storey drift, storey shear and story stiffness by equivalent static analysis method. This paper aims to find the optimum location of shear walls which can be determined with the help of seismic performance parameters. The torsional effects in a building can be minimized by proper location of vertical resisting elements and mass distribution. Multi-storied RCC building with shear walls is now becoming popular as an alternative structural form for resisting the earthquake force.

Keywords: Shear walls, Static pushover analysis, Storey displacement, Storey drift, Storey shear & storey stiffness

1. Introduction

The major criteria nowadays in designing RCC structures in seismic zones are control of lateral displacement resulting from lateral forces originated by earthquake. Shear walls are one of the excellent means of providing earthquake resistance to multistoried reinforced concrete buildings [1,2]. The behavior of structure during earthquake motion depends on distribution of weight, stiffness and strength in both horizontal and planes of building. To reduce the effect of earthquake on RC framed structures, shear walls are used in the building [3,4]. These can be used for improving seismic response of buildings. In this paper, effort has been made to investigate the effect of shear wall position on lateral displacement, storey drift, storey shear and storey stiffness in RC Frames. Six types of G+6 structures are considered, out of which one is bare frame model i.e. without shear wall and for remaining five models, column supported shear wall is considered at various locations. All six models are analyzed by equivalent static method. After the analysis, obtained results are compared for lateral displacement, storey drift, storey shear and storey stiffness for 6 models and then by comparing the results to determine an optimum location of shear wall.

1.1.Objectives

- To perform seismic analysis and investigate the seismic performance of G+6 storey RC frame structure without and with the shear wall using STAAD PRO.
- To study and compare the seismic parameters such as storey displacement, storey drifts storey shear, and storey stiffness.

2. Materials and Methods

2.1. Methodology

- Modeling and analysis of multistoried buildings without and with shear walls at various locations by ESA for seismic loads.
- Comparison of results and graph of all models for the seismic parameters such as storey displacement, storey drift, storey shear, and storey stiffness.

2.2.Modeling and Analysis

For this study, a 7-storey building with each storey height of 3.2 meters is considered and modeled in Staad Pro. These buildings were designed in compliance with the Indian Code of Practice for Seismic Resistant Design of Buildings. The buildings are assumed to be fixed at the base and the floors act as rigid diaphragms. The sections of structural elements are rectangular. In this project, storey heights of buildings are assumed to be constant including the ground storey. A symmetrical building of plan area 30x20 m located in seismic zone III i.e. Chennai area is considered for analysis. Six bays of length 5 m along X direction and five bays of length 4 m along Z direction are provided. The buildings are modeled using software Staad Pro. Six different models (shown in Fig.1 to 6 below) are considered, out of which one is bare frame model i.e. without shear wall and other five models with shear wall at various positions of RC framed structure. Models are studied in zone III and comparing seismic parameters such as lateral displacement, storey drift, storey shear and storey stiffness for seismic performance evaluation of all models listed in Table 1.

Table 1 Details of the Building

Building Parameters	Details
Type of frame	Moment Resisting Frame with shear walls
No. of Stories	Seven (G+6)
Building Plan Size	30 x 20 M (6 X 5 Bays)
Bay Size	5 M (X direction) X 4 M (Z direction)

Floor to Floor Height	3.2 M
Column details	400 mm x 750 mm, steel - 14 Nos. of 20mm dia main bar
Beam details	230 mm x 500 mm steel 3 Nos. of 25mm dia straight throughout, extra 2Nos. of 25mm dia Curtail @450, 4 Nos. of 16 midspans extra.
Slab details	150mm, steel - 10mm dia @ 150mm c/c spacing in both direction
Shear wall details	230mm thick, 10mm dia @ 150mm c/c spacing in both direction (Horizontal & vertical) – double mesh
Building Location	Chennai
Seismic Zone	Zone III
Zone Factor	0.16
Importance Factor	1
Response Reduction Factor	5
Boundary Condition	Fixed
Type of Soil	Hard Strata
LL on floors	4 KN/m2
LL on Roof	1.5 KN/ m2
Grade of Concrete	M25
Grade of Steel bars	Fe500D

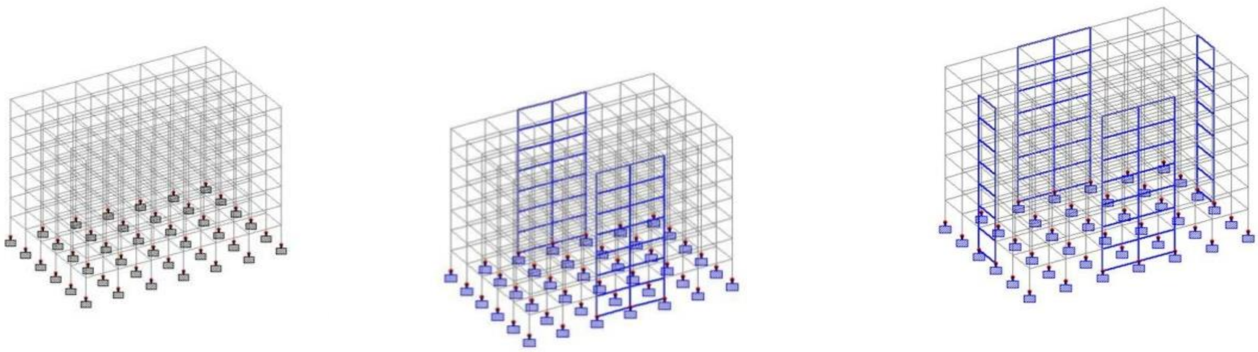

Fig 1,2,3 - Model of G+6 building without a shear wall - M0, M1, M2

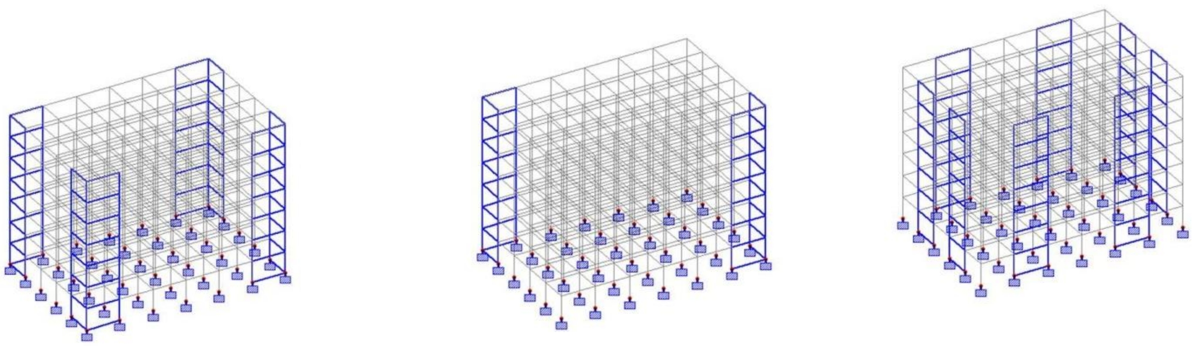

Fig 4,5,6 - Model of G+6 building without a shear wall – M3, M4, M5

3. Results and Discussion

3.1. Storey Displacement

It is the absolute value of displacement of the storey under the action of the lateral forces. It is an important factor in the seismic analysis when the structure is affected by seismic forces. It mainly depends on the height of the structure, tall structures are more flexible for lateral loads.

In comparison of the obtained results (Tables 2,3 and graphs/charts 7,8) because of storey displacement along X and Z direction, model M1 has exhibited least displacement compared to other four models (with shear wall) along X direction and model M3 has exhibited the least displacement compared to other four models (with shear wall) along Z direction.

Models are arranged in a seismic performance manner based on the storey displacement value (i.e. from low to high- ascending order) which is as follows: Along X direction: M1 > M3 > M2 > M4 > M5 > M0 Along Z direction: M3 > M4 > M5 > M2 > M1 > M0

From the above comparison, it is clearly understood that RC frame structure with shear wall exhibit lesser displacement compared to RC frame structure without a shear wall, and also it is evident that lateral displacement values are maximum at top storey of the structure [5-7]. In the present study, it is noticed that there is a reduction of 68% and 59 % in the top storey displacement of best model with shear wall compare to model without shear wall along X and Z direction respectively.

Table 2. Storey Displacement Along X Direction

STOREY	STOREY LEVEL IN M	LOAD CASE	DISPLACEMENT ALONG X DIRECTION (mm)					
			M0	M1	M2	M3	M4	M5
Storey 7	22.40	EQX	13.92	4.36	5.61	4.89	7.11	7.72
Storey 6	19.20	EQX	12.79	3.91	5.06	4.31	6.30	6.93
Storey 5	16.00	EQX	11.08	3.30	4.31	3.59	5.27	5.89
Storey 4	12.80	EQX	8.84	2.58	3.39	2.78	4.08	4.61
Storey 3	9.60	EQX	6.24	1.81	2.37	1.92	2.82	3.20
Storey 2	6.40	EQX	3.56	1.04	1.36	1.09	1.60	1.81
Storey 1	3.20	EQX	1.19	0.37	0.48	0.39	0.56	0.63
Storey 0	0.00	EQX	0.00	0.01	0.00	-0.01	-0.01	-0.02

Table3-Storey Displacement Along Z Direction

STOREY	STOREY LEVEL IN M	LOAD CASE	DISPLACEMENT ALONG Z DIRECTION(mm)					
			M0	M1	M2	M3	M4	M5
Storey 7	22.40	EQZ	16.93	16.70	12.76	6.84	9.51	10.56
Storey 6	19.20	EQZ	15.88	15.47	11.71	6.15	8.58	9.70
Storey 5	16.00	EQZ	13.99	13.53	10.15	5.21	7.30	8.40
Storey 4	12.80	EQZ	11.42	10.99	8.16	4.10	5.77	6.73
Storey 3	9.60	EQZ	8.41	8.06	5.92	2.92	4.12	4.86
Storey 2	6.40	EQZ	5.17	4.94	3.59	1.74	2.47	2.94
Storey 1	3.20	EQZ	2.00	1.94	1.41	0.68	0.96	1.15
Storey 0	0.00	EQZ	0.00	-0.06	-0.05	-0.02	-0.02	-0.04

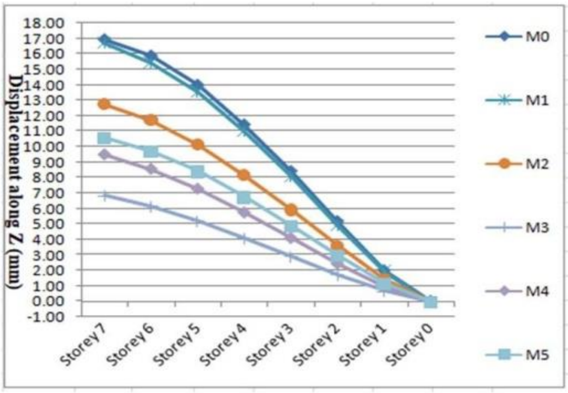

Fig7- Graph of storey displacement along the X direction

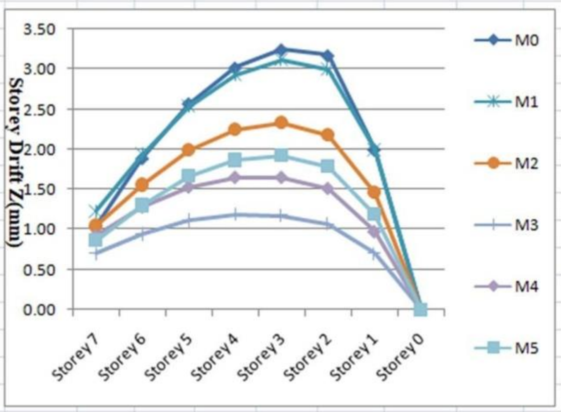

Fig. 8. Graph of storey displacement along the Z direction

3.2. Storey Drift

Storey drift is the relative displacement between the floors above and/or below the storey under consideration. It is also an important factor in the seismic analysis when the structure is affected by seismic forces.

In a comparison of the obtained results (Tables 4,5 and graphs/charts 9,10) because of storey drift along X and Z direction, model M1 has exhibited least storey drift compared to the other four models (with shear wall) along the X direction, and model M3 has exhibited least storey drift compared to other four models (with shear wall) along Z direction.

Models are arranged in a seismic performance manner based on the storey drift value (i.e. from low to high-ascending order) which is as follows: Along X direction: M1 > M3 > M2 > M4 > M5 > M0 Along Z direction: M3 > M4 > M5 > M2 > M1 > M0

From the above comparison, it is clearly understood that RC frame structure with shear wall exhibit lower storey drift compared to RC frame structure without a shear wall, and also it is evident that storey drift values are maximum at mid stories of the structure [8,9].

As per Indian standard, Criteria for earthquake resistant design of structures, IS 1893 (Part 1): 2002, the story drift in any story due to service load shall not exceed 0.004 times the story height. The height of each storey is 3.2 m. So, the storey drift limitation as per IS 1893 (part 1): 2002 is 0.004 X 3.2 m = 12.8 mm. The maximum drift in the model is 2.69 mm along X direction and 3.24 mm along Z direction which is well within the limits.

Table 4 -Storey Drift Along Z Direction

STOREY	STOREY LEVEL IN M	LOAD CASE	STOREY DRIFT ALONG Z DIRECTION(mm)					
			M0	M1	M2	M3	M4	M5
Storey 7	22.40	EQZ	1.05	1.23	1.04	0.70	0.93	0.86
Storey 6	19.20	EQZ	1.89	1.94	1.56	0.94	1.28	1.30
Storey 5	16.00	EQZ	2.57	2.54	1.99	1.11	1.53	1.67
Storey 4	12.80	EQZ	3.02	2.93	2.25	1.18	1.65	1.87
Storey 3	9.60	EQZ	3.24	3.12	2.33	1.17	1.65	1.93
Storey 2	6.40	EQZ	3.17	3.00	2.18	1.07	1.51	1.79
Storey 1	3.20	EQZ	2.00	2.00	1.46	0.70	0.97	1.19
Storey 0	0.00	EQZ	0.00	0.00	0.00	0.00	0.00	0.00

Table 5-Storey Drift Along X Direction

STOREY	STOREY LEVEL IN M	LOAD CASE	STOREY DRIFT ALONG X DIRECTION(mm)					
			M0	M1	M2	M3	M4	M5
Storey 7	22.40	EQX	1.13	0.45	0.55	0.58	0.81	0.78
Storey 6	19.20	EQX	1.71	0.60	0.75	0.72	1.03	1.05
Storey 5	16.00	EQX	2.24	0.72	0.92	0.82	1.19	1.28
Storey 4	12.80	EQX	2.59	0.78	1.02	0.86	1.26	1.40
Storey 3	9.60	EQX	2.69	0.77	1.02	0.83	1.22	1.39
Storey 2	6.40	EQX	2.37	0.67	0.88	0.70	1.04	1.19
Storey 1	3.20	EQX	1.19	0.36	0.48	0.39	0.57	0.65
Storey 0	0.00	EQX	0.00	0.00	0.00	0.00	0.00	0.00

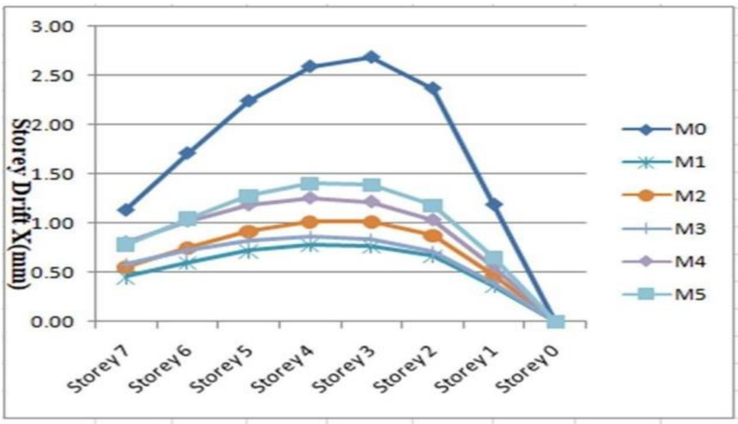

Fig 9- Graph of storey drift along the X direction

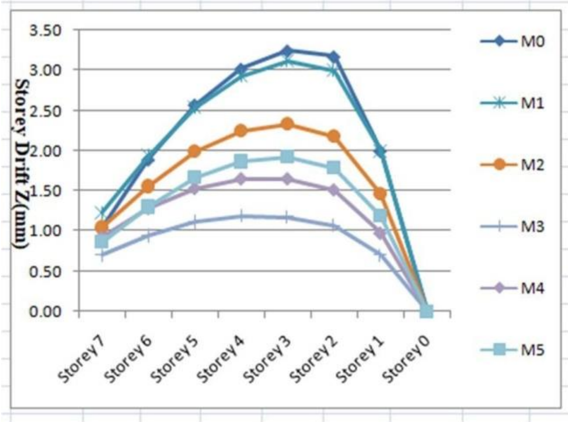

Fig10- Graph of storey drift along the Z direction

3.3. Storey Shear

Storey shear is the sum of design lateral forces at all levels above the storey under consideration.

In comparison of the obtained results (Tables 6,7 and graphs/charts 11,12) because of storey shear, model M5 has exhibited maximum base shear compared to other four models (with shear wall) along X & Z direction.

Models are arranged in a seismic performance manner based on the storey shear value (i.e. from high to low - descending order) which is as follows: Along X & Z direction: M5 > M3 > M2 > M1 > M4 > M0

From the above comparison, it is clearly understood that RC frame structure with shear wall exhibit higher base shear compared to RC frame structure without a shear wall, and also it is evident that storey shear values are maximum at bottom/base storey of structure [10-12]. In the present study, it is noticed that there is an increase of 20% in the base storey shear of best model with shear wall compare to model without shear wall along X and Z direction.

Table 6 -Storey Shear Along X Direction

STOREY	STOREY LEVEL IN M	STOREY SHEAR ALONG X DIRECTION(KN)					
		M0	M1	M2	M3	M4	M5
Storey 7	22.40	318.02	335.35	342.29	349.24	333.62	355.26
Storey 6	19.20	676.79	707.83	720.25	732.67	704.72	795.35
Storey 5	16.00	925.93	966.23	982.35	998.48	962.20	1100.49
Storey 4	12.80	1085.39	1131.36	1149.76	1168.15	1126.77	1295.33
Storey 3	9.60	1175.08	1224.03	1243.62	1263.20	1219.14	1404.53
Storey 2	6.40	1214.94	1265.05	1285.09	1305.13	1260.04	1452.74
Storey 1	3.20	1224.91	1275.21	1295.33	1315.45	1270.18	1464.63

Table 7- Storey Shear Along Z Direction

STOREY	STOREY LEVEL IN M	STOREY SHEAR ALONG Z DIRECTION(KN)					
		M0	M1	M2	M3	M4	M5
Storey 7	22.40	318.02	335.35	342.29	349.24	333.62	355.26
Storey 6	19.20	676.79	707.83	720.25	732.67	704.72	795.35
Storey 5	16.00	925.93	966.23	982.35	998.48	962.20	1100.49
Storey 4	12.80	1085.39	1131.36	1149.76	1168.15	1126.77	1295.33
Storey 3	9.60	1175.08	1224.03	1243.62	1263.20	1219.14	1404.53
Storey 2	6.40	1214.94	1265.05	1285.09	1305.13	1260.04	1452.74
Storey 1	3.20	1224.91	1275.21	1295.33	1315.45	1270.18	1464.63

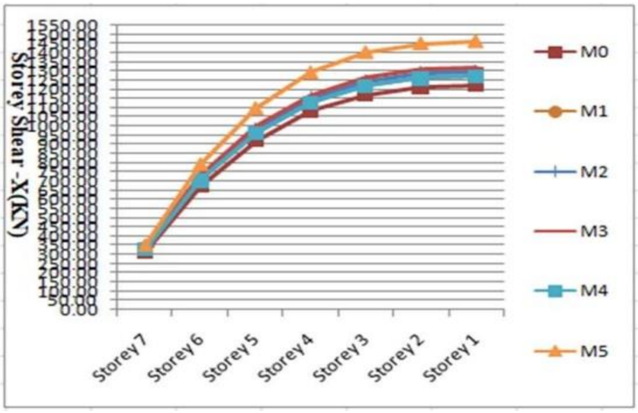

Fig11-Graph of storey shear along the X direction

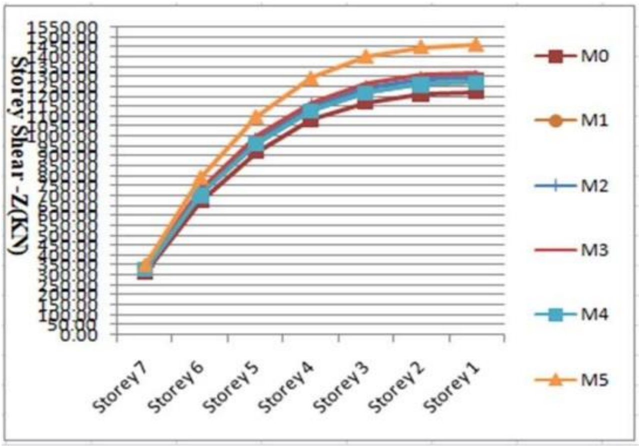

Fig12- Graph of storey shear along the X direction

3.4 Storey Stiffness

The lateral stiffness of a storey is generally defined as the ratio of storey shear to storey drift.

In comparison of the obtained results (Tables 8,9 and graphs/charts 13,14) because of storey stiffness, model M1 has exhibited maximum storey stiffness compared to other four models (with shear wall) along X and model M3 has exhibited maximum storey stiffness compared to other four models (with shear wall) along Z direction.

Models are arranged in a seismic performance manner based on the storey stiffness value (i.e. from high to low - descending order) which is as follows: Along X direction: M1 > M3 > M2 > M5 > M4 > M0 Along Z direction: M3 > M4 > M5 > M2 > M1 > M0

From the above comparison, it is clearly understood that RC frame structure with shear wall exhibit higher storey stiffness compared to RC frame structure without shear wall, and also it is evident that storey stiffness values are maximum at bottom/base storey of structure [13-15]. In the present study, it is noticed that the base storey stiffness of model M1 is nearly 3.5 times more than the model M0 along X direction and the base storey stiffness of model M3 is nearly 3 times more than the model M0 along Z direction.

Table 8-Storey Stiffness Along X Direction

STOREY	STOREY LEVEL IN M	STOREY STIFFNESS ALONG X DIRECTION(KN/mm)					
		M0	M1	M2	M3	M4	M5
Storey 7	22.40	280.44	741.92	620.09	601.10	411.36	453.13
Storey 6	19.20	395.55	1175.79	959.05	1024.72	686.86	758.92
Storey 5	16.00	413.18	1343.85	1065.46	1219.14	808.57	859.75
Storey 4	12.80	418.91	1454.19	1131.65	1359.90	893.55	923.26
Storey 3	9.60	437.65	1591.72	1224.04	1523.77	996.84	1009.73
Storey 2	6.40	512.85	1899.47	1465.33	1864.47	1213.91	1224.91
Storey 1	3.20	1029.33	3522.68	2698.61	3338.70	2240.18	2260.23

Table 9- Storey Stiffness Along Z Direction

STOREY	STOREY LEVEL IN M	STOREY STIFFNESS ALONG Z DIRECTION(KN/mm)					
		M0	M1	M2	M3	M4	M5
Storey 7	22.40	303.45	273.09	328.18	500.34	360.66	411.65
Storey 6	19.20	358.66	364.86	461.99	781.94	549.71	610.40
Storey 5	16.00	360.57	380.40	493.15	901.97	628.48	660.56
Storey 4	12.80	360.00	386.13	511.91	987.45	682.47	693.06
Storey 3	9.60	362.45	392.32	533.74	1075.98	738.42	729.63
Storey 2	6.40	383.38	421.82	589.76	1223.18	832.81	812.95
Storey 1	3.20	613.68	637.60	887.82	1887.30	1304.09	1231.81

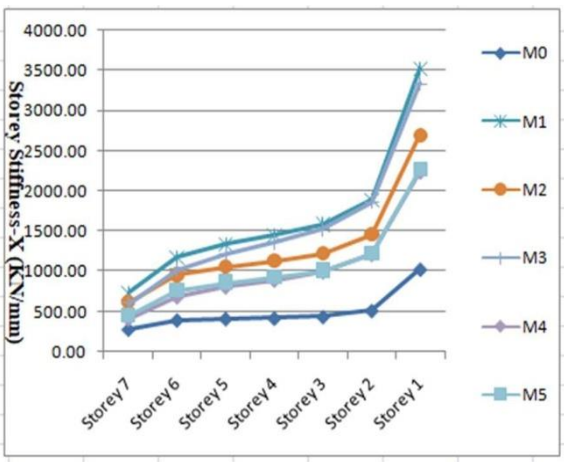

Fig13- Graph of storey stiffness along the X direction

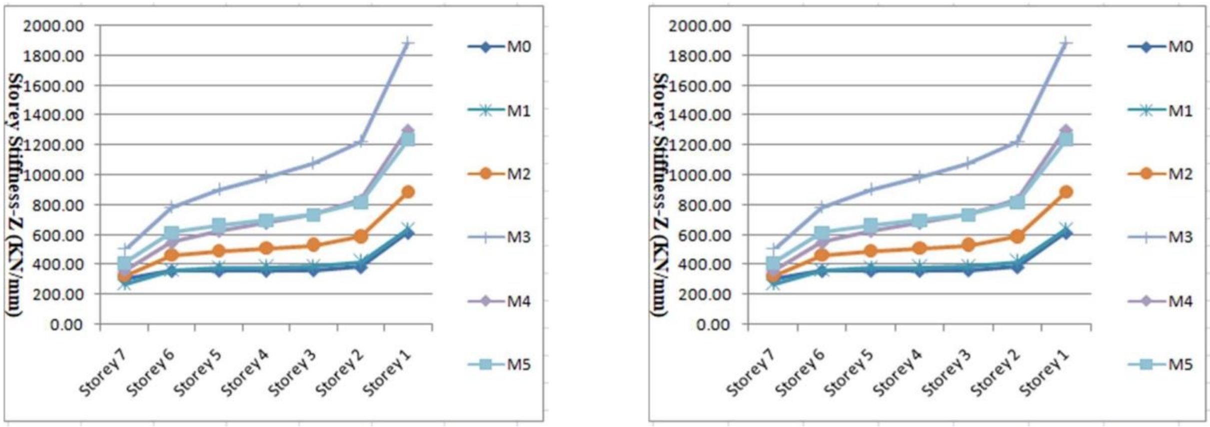

Fig14-Graph of storey stiffness along the Z direction

3.5.Displacement versus base shear

Based on the obtained values of lateral displacement and base shear as shown in Table 10 & 11 for all six models, graphs/charts are plotted for all six models by assuming displacement in X-axis and base shear in Y-axis as shown in Fig 15 & 16 for ease of comparison

In comparison of the obtained results (tables and graphs/charts) because of lateral displacement and base shear, model M1 has exhibited least displacement and highest base shear as compared to other four models (with shear wall) along X direction and model M3 has exhibited least displacement and highest base shear as compared to other four models (with shear wall) along Z direction [16-18].

Models are arranged in a seismic performance manner based on the minimum displacement with maximum base shear which is as follows: Along X direction: M1 > M3 > M2 > M5 > M4 > M0
Along Z direction: M3 > M4 > M5 > M2 > M1 > M0

From the above comparison, it is clearly understood that RC frame structures with shear walls exhibit higher storey stiffness compared to RC frame structures without shear walls.

Table 10.-Displacement X Vs Base Shear X

STOREY	STOREY LEVEL IN M	Base SHEAR ALONG X DIRECTION (KN)						DISPLACEMENT ALONG X DIRECTION (mm)					
		M0	M1	M2	M3	M4	M5	M0	M1	M2	M3	M4	M5
Storey 0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	-0.01	-0.01	-0.02
Storey1	3.20	9.97	10.16	10.24	10.32	10.14	11.88	1.19	0.37	0.48	0.39	0.56	0.63
Storey 2	6.40	39.86	41.02	41.47	41.93	40.90	48.21	3.56	1.04	1.36	1.09	1.60	1.81
Storey3	9.60	89.69	92.67	93.86	95.05	92.37	109.20	6.24	1.81	2.37	1.92	2.82	3.20
Storey 4	12.80	159.45	165.14	167.41	169.67	164.57	194.84	8.84	2.58	3.39	2.78	4.08	4.61
Storey 5	16.00	249.15	258.40	262.11	265.80	257.48	305.14	11.08	3.30	4.31	3.59	5.27	5.89
Storey 6	19.20	358.77	372.48	377.96	383.44	371.11	440.09	12.79	3.91	5.06	4.31	6.30	6.93
Storey 7	22.40	318.02	335.35	342.29	349.24	333.62	355.26	13.92	4.36	5.61	4.89	7.11	7.72

Table 11-Displacement Z Vs Base Shear Z

STOREY	STOREY LEVEL IN M	Base SHEAR ALONG Z DIRECTION (KN)						DISPLACEMENT ALONG Z DIRECTION (mm)					
		M0	M1	M2	M3	M4	M5	M0	M1	M2	M3	M4	M5
Storey 0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06	-0.05	-0.02	-0.02	-0.04
Storey1	3.20	9.97	10.16	10.24	10.32	10.14	11.88	2.00	1.94	1.41	0.68	0.96	1.15
Storey 2	6.40	39.86	41.02	41.47	41.93	40.90	48.21	5.17	4.94	3.59	1.74	2.47	2.94
Storey3	9.60	89.69	92.67	93.86	95.05	92.37	109.20	8.41	8.06	5.92	2.92	4.12	4.86
Storey 4	12.80	159.45	165.14	167.41	169.67	164.57	194.84	11.42	10.99	8.16	4.10	5.77	6.73
Storey 5	16.00	249.15	258.40	262.11	265.80	257.48	305.14	13.99	13.53	10.15	5.21	7.30	8.40
Storey 6	19.20	358.77	372.48	377.96	383.44	371.11	440.09	15.88	15.47	11.71	6.15	8.58	9.70
Storey 7	22.40	318.02	335.35	342.29	349.24	333.62	355.26	16.93	16.70	12.76	6.84	9.51	10.56

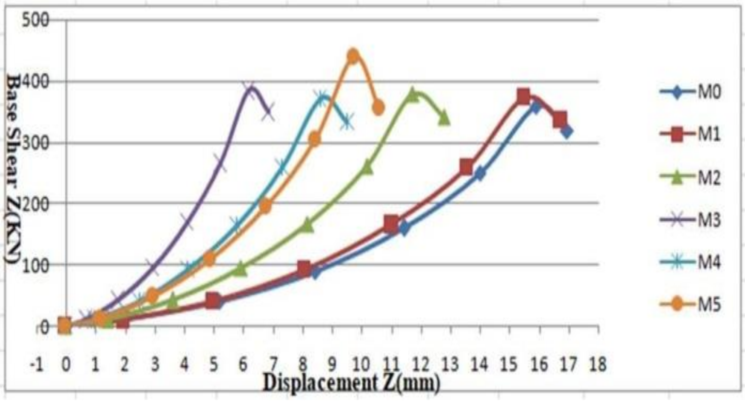

Fig15- Graph of displacement X Vs base shear X

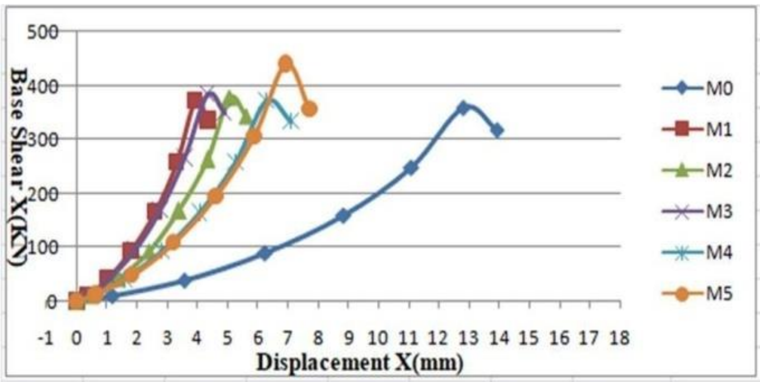

Fig16- Graph of displacement Z Vs base shear Z

4. Conclusion and Recommendations

4.1. Conclusions

In this paper, reinforced concrete buildings without and with shear walls were analyzed with the procedures laid out in IS codes. Seismic performances of building models are evaluated.

From the above results and discussions, the following conclusions can be drawn:

- Model without shear wall has more displacement, more storey drift, less base shear, and less stiffness when compared to other 5 models with shear wall.
- Based on the analysis and discussion, shear walls are very much suitable for resisting earthquake-induced lateral forces in multistoried framed structural systems as compared to multistoried framed structural systems without shear walls. They can be made to behave in a ductile manner by adopting proper detailing techniques.
- Shear walls must provide the necessary lateral strength to resist horizontal earthquakes and

they will transfer these horizontal forces to the next element in the load path below them such as other shear walls, floors, foundation walls, slabs or beams or footings.
- Shear walls also provide lateral stiffness to prevent the roof or floor above from excessive side-sway.
- From the results, it is confirmed that lateral displacement values are maximum at the top storey. In the present study, it is noticed that there is a reduction of 68% and 59 % in the top storey displacement of best model with shear wall compare to model without shear wall along X and Z direction respectively.
- Initially, storey drift values go on increases with increase in height of storey till the maximum value is reached and then drift value starts to fall even though there is an increase in the storey height. The maximum drift in the model is 2.69 mm along X direction and 3.24 mm along Z direction which is well within the limits.
- The Storey stiffness of a structure is high at the bottom/base storey as compared with top storey. The base storey stiffness of model M1 is nearly 3.5 times more than the model M0 along X direction and the base storey stiffness of model M3 is nearly 3 times more than the model M0 along Z direction.
- The Storey shear of a structure is high at the bottom/base storey as compared with the top storey. In the present study, it is noticed that there is an increase of 20% in the base storey shear of model M5 compare to model M0 along X and Z direction.
- Building with shear walls provided at all corners of the external perimeter showed better performance in terms of maximum storey displacements and storey drifts comparatively. Also, the base shear and storey stiffness was found to be higher for this case when compared with other models. Comparing all models, model M1 i.e. location of shear wall at centre of external perimeter of the building along X direction has less storey drift, less lateral displacement, high base shear and high storey stiffness value when compared to other five models along X direction and model M3 i.e. location of shear wall at corners of external perimeter of the building has less storey drift, less displacement, high base shear and high storey stiffness value when compared to other five models along Z direction.
- Changing the shear wall position will affect the attraction of forces, so that wall must be in the proper position.
- Providing shear walls at adequate locations substantially reduces the displacements due to earthquakes.

4.2.Recommendations

Different assumptions and limitations have been adopted for simplicity in modeling the proposed structures. In reality, it might affect results. Thus, all factors which may influence the behavior of the structures should be considered in the modeling. For further study, to obtain the real responses of the structures, the following recommendations are made:
- Since the study was performed for only one type of shear wall, further investigations should be made for different types of shear walls.
- A flexible foundation will affect the overall stability of the structure by reducing the effective lateral stiffness. So, the soil-structure interaction should be considered in further study.
- The study was performed for a damping ratio of 5% for all models. Further studies should be carried out for damping ratios of 10%, 15%, and so on.

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