EFFECT OF CORE WALL ON SEISMIC RESPONSE OF SOFT STORY RC BUILDING

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Abstract – *During an earthquake, the main cause of collapse of a structure is vertical irregularities such as stiffness irregularity, mass irregularity etc. The buildings with soft stories have less stiffness, low strength and are very much vulnerable to resist lateral loads. Hence, to resist these lateral loads and safe design of a building special investigation is required. Many lateral loads resisting systems are developed and their stiffness is considered during analysis and design of a building. The most commonly used lateral load resisting system is building with Shear wall system. It can be used to resist large lateral forces and to take gravity loads. RC shear wall gives massive strength and rigidity to the structures. In present study, the effect of RC core type shear wall on seismic performance of soft story buildings is determined. In addition to that, the study considers a different height of soft story in building with and without RC core wall using the approach proposed by IS: 1893 - Part1 (2002/2016) for the comparison purpose. A (G+11) RC residential building situated in Zone V is analyzed by Response spectrum method using ETABS v16, 2016 software. The study shows that the core wall significantly increases the base shear capacity and decreases the story drifts and story displacement of soft story buildings.*

Key Words: **Soft Story Building, RC core wall, Response Spectrum Analysis, ETABS, Story Shear, Story drift etc.**

1. INTRODUCTION

Buildings with soft story are inherently defective structure as it alters rigidity and strength of the building. The difficulty appeared because of neglecting the masonry infill wall. In general, only bare frame elements are taken while designing buildings and the inverted pendulum effect has not considered in analysis and design. If the effect of infill is considered in the design and analysis of frame, the results may be significantly different. The presence of masonry infill and soft story in a building changes the behaviour of frame action because of relative changes of stiffness. In many earthquakes, the buildings with sufficient shear walls that were not specially detailed but properly distributed reinforcement were prevented from collapse. Shear walls are easy to built, because reinforcement detailing of the walls is relatively straight-forward and therefore easily constructed at site. The ability of the structure totally depends on the interaction between frame and shear wall. The RC frame is used to resist shear while the shear wall is used to resist bending, similar to a cantilever. Hence the stiffness of the building is improved significantly because their combined action is based on the relative stiffness of both and their modes of deflection. Thus, the shear walls are significantly increases the stiffness and shear capacity of the building. Following are the major classification of the shear wall:

i. Rectangular or Flanged cantilever shear wall
ii. Coupled shear wall
iii. Shear wall with openings
iv. Core type shear wall or Core Wall

In the present work, an E-shaped RC core wall has been considered throughout height of the building.

2. LITERATURE REVIEW

Several investigators performed the various types of studies considering the effect of shear wall on frame building. The various parameters that have to be considered for the analysis of the soft story building and shear wall building are discussed below. The investigations of such researchers are discussed as follows:

C.V.R. Murty and Sudhir Jain (2000) conducted experiments on RC frames with masonry infill based on cyclic tests. It was observed that masonry infill provides significant lateral stiffness, energy dissipation capacity and ductility. With the help of some arrangement by providing reinforcement in the masonry infill, it was anchored into the column of the frame to improve effectively the out of plane response of masonry infill.

G.V. Mulgund et al. (2011) designed five RC frame buildings with masonry infill walls as per IS code in order to consider the effect of masonry infill under same seismic condition because while designing of RC frame buildings usually do not consider the effect of masonry infill. The present work deals with a study of RC frames subjected to dynamic loading with different arrangement of masonry infill walls. The results were extracted and compared for both bare frame and bare frame with infill walls. Finally, conclusion were derived and put forward in accordance of with IS code.

N. Sivakumar et al. (2013) studied behavior of the ground story columns of multi-story building subjected to dynamic earthquake loading. An equivalent strut method had been used for modeling of upper story masonry infill wall panel to account the structural effect of masonry infill. Various models of finite element consisting of six and nine story buildings were subjected to seismic loading by performing equivalent static analysis and response spectrum analysis as per IS code. By incorporating masonry infill in the model, model analysis predicted the dynamic behavior of the structure. A significant increase in column shear and moment was experienced in the presence of infill panel. In addition to that, study suggested that design the columns of ground story twice the magnitude of shear and moment calculated from linear static analysis.

C. Todut et al. (2014) presented the results of an experimental program developed to study the seismic performance of precast reinforced concrete wall panels with and without openings. The specimen characteristics and reinforcement configuration were taken from a typical Romanian project used widely since 1981 and scaled 1:1.2 due to the constraints imposed by the laboratory facilities. This type of precast wall panels was used mostly for residential buildings with multiple flats built from 1981 to 1989. The performance and failure mode of all of the panels tested revealed a shear type of failure that is influenced by the opening type, and critical areas and lack of reinforcement were observed in certain regions. A numerical analysis was performed to create a model that could predict the behavior of the precast reinforced concrete shear walls of different parameters.

Ashwani Singh (2015) has studied the seismic performance of typical open ground story buildings strengthened with shear walls and compared to that of OGS buildings by applying various multiplication factors using pushover analysis. The comparative cost analysis is carried out between shear walls models and models with increasing the cross section of ground story columns applying multiplication factors. It is observed that the shear walls considerably increases the base shear capacities of soft story buildings but also increases the cost of construction.

K.O. Lakshmi et al. (2014) presented the effect of location of shear wall in buildings subjected to seismic loads by pushover analysis using ETABS 9.5 and SAP 2000.V.14.1 software. The capacity spectrum method is used to evaluate the overall performance level of a building. They concluded that the maximum reduction in storey drift values is obtained when shear walls are provided at corners of the building. The reinforcement requirement in column is affected by the location and orientation of adjacent shear walls and columns. It could be seen that the columns situated near to core area show a reduction in steel requirement up to 44.6% when shear wall is provided at the core and 34.7% when shear wall is located at core and corner of the structure.

P. Mary Williams et al. (2016) studied the effect of shear wall and its location on the linear and nonlinear behaviour of irregular buildings with different eccentric loads by linear static, linear dynamic and nonlinear static analysis using FEM based software. A G+14 story symmetric RC frame building is considered for the analysis. The various parameters taken are story drift, reinforcement in columns, base shear, torsion and hinge formation in the structure. It observed that the lateral stability of the building especially in case of asymmetrical structures is reduces after provision of shear wall. When shear wall is constructed at the core as a box, the drift, torsion and displacement reduces by a larger value.

3. PROPOSED WORK

In present study, a twelve stories RC special moment resisting frame (SMRF) building with soft story at ground floor has been taken in order to evaluate the seismic behavior of building and an importance of reinforced concrete core wall. The building model also analyzed by changing soft story height, as per Indian Standard Code IS: 1893(Part 1) 2002/2016 (The Indian Code of Practice for Seismic Resistant Design of Buildings) under gravity and seismic loading. The building considered for analysis is to be asymmetrical about X-axis and symmetrical about Y-axis in plan. The models are considered to be fixed at the base. The story heights of models are considered to be constant excluding the ground story. Six different models are studied in which three models are without core wall and another three are with core wall. Models are studied in zone V to check the exact behavior of all models. The analyses of the models are done by using ETABS v16, 2016. Following are the models to be considered for the analysis –

Model-1: (G+11) RC building with soft story of 3.5m at the ground floor.
Model-2: Model 1 reanalyzed with providing RC core wall.
Model-3: (G+11) RC building with soft story of 4.5m at the ground floor.
Model-4: Model 3 reanalyzed with providing RC core wall.
Model-5: (G+11) RC building with soft story of 5.5m at the ground floor.
Model-6: Model 5 reanalyzed with providing RC core wall.

As all the models looks similar except ground story height and provision of core wall; only plan view are shown in fig. 1 and 2 for models with and without core wall.

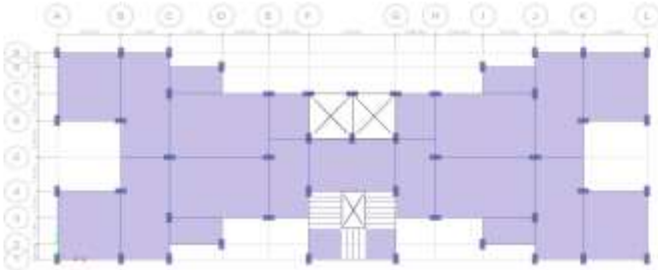

Fig. 1: Plan of the building model without core wall

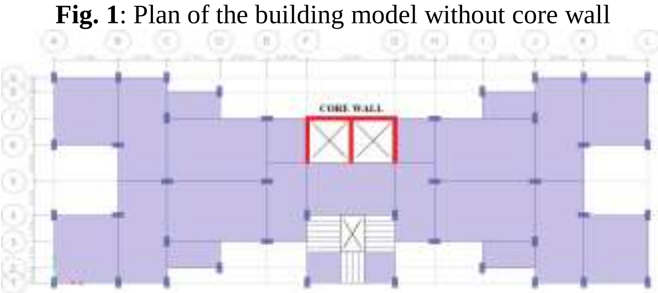

Fig. 2: Plan of the building model with core wall

The properties and parameters considered for modeling and analysis of building models are shown in the tables 1.

Table 1: Geometric properties and parameters considered

Parameter	Values
No. of stories	12 (G+11)
Floor to floor height	3.5m
Ground story height	3.5m, 4.5m, 5.5m
Thickness of Slabs	150mm
Thickness of Shear Wall	200mm
Size of Beams	250mm X 450mm
Size of Columns	300mm X 600mm
Thickness of outer wall	200mm
Thickness of inner wall	100mm
Thickness of parapet wall	200mm
Concrete grade	M 25
Density of reinforced concrete	25 kN/m3
Young's modulus of concrete	25000 N/mm2
Poisson ratio of concrete, μ	0.2
Density of brick masonry	20 kN/m3
Seismic Zone , Z	V, 0.36
Response reduction factor, R	5
Importance factor, I	1
Damping ratio	0.05

In present work, dead loads, live loads and seismic loads for analysis of the building models is taken as per IS: 875 (Part 1)-1987, IS: 875 (Part 2)-1987 and IS: 1893 (Part 1)-2002/2016 respectively.

4. RESULTS AND DISCUSSION

As mentioned earlier the selected building is analyzed by Response spectrum method for two different cases:

1. Without core wall models.
2. With core wall models.

Six models are considered for the analysis and the effect of core wall on soft story building is studied under gravity and seismic loads. The results obtained for all models in terms of various parameters, such as story drift, story displacement and story shear are tabulated and discussed along with graphs.

4.1 Story Shear

4.1.1 Comparison of Story Shear (kN) between model 1 and model 2

Comparison of maximum story shear at different floor level between model 1 and model 2 i.e. for models have soft story of 3.5m, in X and Y direction are shown in table 2 & 3 and figure 3 & 4.

Table 2: Comparison of maximum story shear (kN) at different floor level between model 1 and model 2 in X direction

Floor Level i	Without Core (kN)	With Core (kN)	Increase in %
Base	1866.82	2520.94	35.04
1	1866.82	2520.94	35.04
2	1771.11	2456.57	38.70
3	1658.91	2335.18	40.77
4	1549.32	2181.19	40.78
5	1439.89	2016.24	40.03
6	1327.25	1849.85	39.37
7	1205.99	1682.29	39.49
8	1067.96	1516.99	42.05
9	904.38	1350.27	49.30
10	705.84	1143.52	62.01
11	461.62	831.96	80.23
12	181.18	367.71	102.96

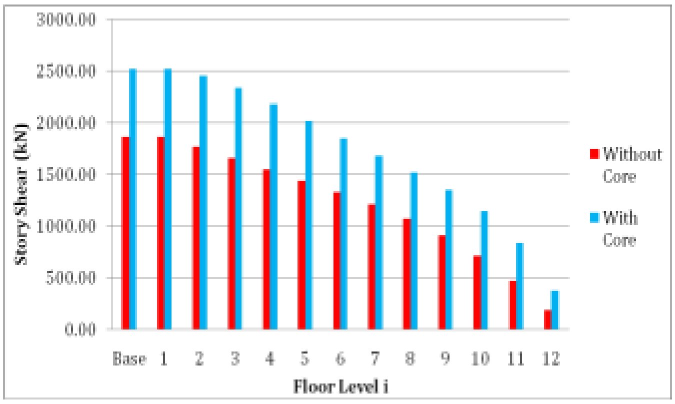

Fig. 3: Story shear (kN) for soft story of 3.5m at different floor level in X direction

Table 3: Comparison of maximum story shear (kN) at different floor level between model 1 and model 2 in Y direction

Floor Level i	Without Core (kN)	With Core (kN)	Increase in %
Base	2601.67	3032.77	16.57
1	2601.67	3032.77	16.57
2	2465.21	2985.45	21.10
3	2302.30	2872.56	24.77
4	2141.54	2714.64	26.76
5	1980.91	2534.32	27.94
6	1813.41	2338.68	28.97
7	1630.47	2122.85	30.20
8	1422.73	1880.59	32.18
9	1181.02	1604.17	35.83
10	899.17	1276.37	41.95
11	576.71	870.57	50.96
12	219.49	363.68	65.69

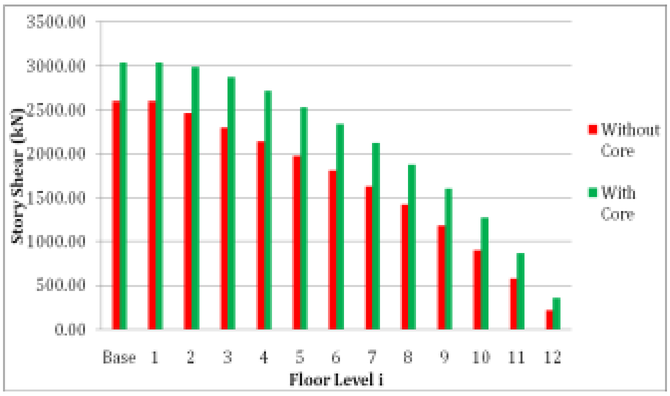

Fig. 4: Story shear (kN) for soft story of 3.5m at different floor level in Y direction

The table 2 & 3 and fig. 3 & 4 shows that, the story shear have increased for models with core wall as compared to models without core wall in present analysis. The increase in story shear has obtained 35.04 to 102.96% and 16.57 to 65.69% from base to top floor for soft story of 3.5m in X and Y directions respectively. Similarly 52.73 to 160.80% and 36.12 to 111.36% for soft story of 4.5m and 72.54 to 230.52% and 59.38 to 166.73% for soft story of 5.5m has increased in X and Y direction respectively.

4.1.2 Comparison of Base Shear

Comparison of maximum base shear with increasing soft story height in X and Y direction are shown in table 4 and fig.5

Table 4: Comparison of maximum base shear (kN) with increasing soft story height in X and Y direction

Direction	Soft Story Height	Without Core	With Core	Increase in %
X	3.5m	1866.82	2520.94	35.04
	4.5m	1592.42	2432.18	52.73
	5.5m	1361.06	2348.32	72.54
Y	3.5m	2601.67	3032.77	16.57
	4.5m	2175.27	2961.08	36.12
	5.5m	1813.77	2890.85	59.38

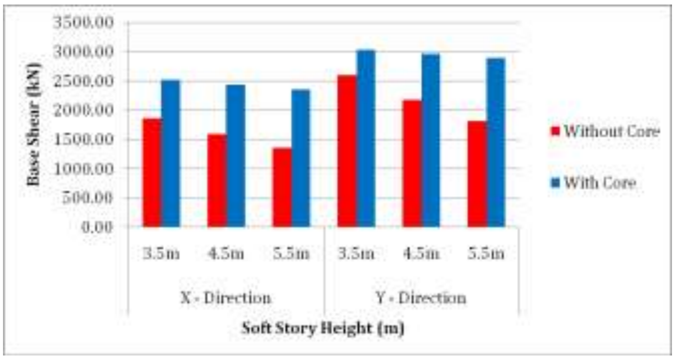

Fig. 5: Comparison of Base shear (kN) with increasing soft story height in X and Y direction

The table 4 and fig.5 shows that, the base shear values of all models in X and Y directions. It is clearly seen that, the base shear values are decreases with increase in the height of a soft story. If we increases the height of a soft story from 3.5m to 4.5m and 5.5m the base shear has decreased 14.7% and 27.09% for without core wall models while 3.52% and 6.85% for core wall models in X direction and 16.39% and 30.28% for without core wall models while 2.36% and 4.68% for core wall models in Y direction respectively.

4.2 Story Displacement

4.2.1 Comparison of Story Displacement (mm) between model 1 and model 2

Comparison of maximum story displacement at different floor level between model 1 and model 2 i.e. for models have soft story of 3.5m, in X and Y direction are shown in table 5 & 6 and fig. 6 & 7.

Table 5: Comparison of maximum story displacement (mm) at different floor level between model 1 and model 2 in X direction

Floor Level	Without Core (mm)	With Core (mm)	Decrease in %
Base	0	0	0
1	35.04	7.28	79.22
2	47.00	11.68	75.15
3	54.48	16.18	70.30
4	62.01	20.78	66.49
5	69.14	25.43	63.22
6	75.85	30.00	60.46
7	82.03	34.39	58.07
8	87.59	39.98	54.36
9	92.44	46.48	49.72
10	96.53	52.80	45.30
11	99.80	58.91	40.97
12	102.31	64.74	36.72

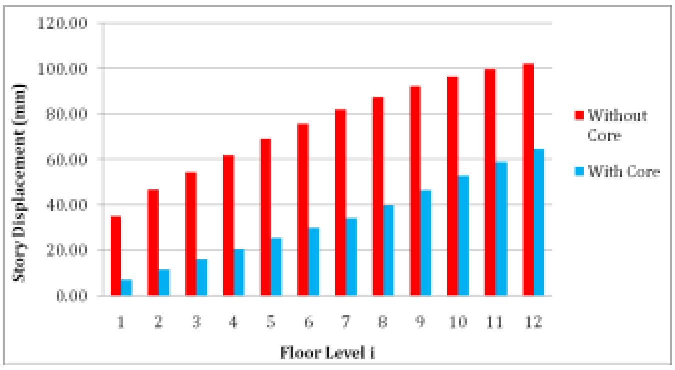

Fig. 6: Story displacement (mm) for soft story of 3.5m at different floor level in X direction

Table 6: Comparison of maximum story displacement (mm) at different floor level between model 1 and model 2 in Y direction

Floor Level i	Without Core (mm)	With Core (mm)	Decrease in %
Base	0	0	0
1	31.40	6.42	79.55
2	41.20	11.56	71.96
3	47.86	17.11	64.25
4	54.60	23.33	57.28
5	61.20	29.89	51.16
6	67.50	36.54	45.86
7	73.37	43.07	41.29
8	78.73	49.34	37.33
9	83.49	55.24	33.84
10	87.60	60.71	30.70
11	91.04	65.73	27.80
12	93.88	70.29	25.13

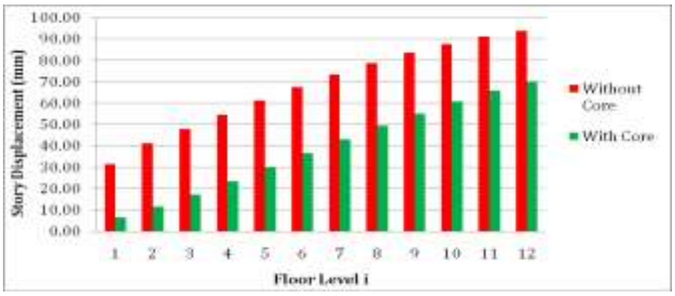

Fig. 7: Story displacement (mm) for soft story of 3.5m at different floor level in Y direction

The table 5 & 6 and fig. 6 & 7 shows that, the story displacement for models with core wall have considerably reduced as compared to models without core wall. The story displacement has reduced 79.22 to 36.72% and 79.55 to 25.13% from 1st floor to 12th floor for soft story of 3.5m in X and Y directions respectively. Similarly 80.98 to 39.90% and 80.39 to 30.24% for soft story of 4.5m and 81.81 to 42.98% and 80.50 to 35.65% for soft story of 5.5m has deceased in X and Y direction respectively.

4.2.2 Comparison of top floor displacement

Comparison of top floor displacement with increasing soft story height in X and Y direction are shown in table 7 and fig.8.

Table 7: Comparison of top floor displacement (mm) with increasing soft story height in X and Y direction

Direction	Soft Story Height	Without Core	With Core
X - Direction	3.5m	102.31	64.74
	4.5m	110.26	66.27
	5.5m	119.07	67.90
Y - Direction	3.5m	93.88	70.29
	4.5m	102.58	71.56
	5.5m	114.00	73.36

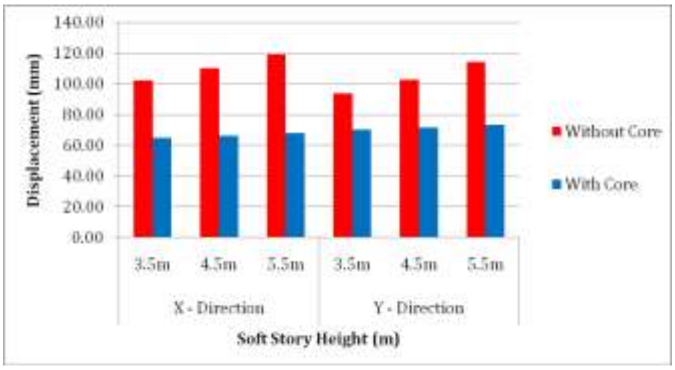

Fig. 8: Top floor displacement (mm) with increasing soft story height in X and Y direction

The table 7 and fig. 8 shows that, the top floor displacement of all models in X and Y directions. It is clearly seen that, the floor displacements are increases with increase in the height of a soft story. If we increase the height of a soft story from 3.5m to 4.5m and 5.5m the increase in displacement has 7.77% and 16.38% for without core wall models while 2.36% and 4.88% for core wall models in X direction and 9.27% and 21.43% for without core wall models while 1.81% and 4.37% for core wall models in Y direction respectively.

4.3 Story Drift

4.2.1 Comparison of Story Drift between model 1 and model 2

Comparison of maximum story drift at different floor level between model 1 and model 2 i.e. for models have soft story of 3.5m, in X and Y direction are shown in table 8 & 9 and fig. 9 & 10.

Table 8: Comparison of maximum story drift at different floor level between model 1 and model 2 in X direction

Floor Level i	Without Core	With Core	Permissible Limit
Base	0	0	0
1	0.0100	0.0021	0.004
2	0.0036	0.0013	0.004
3	0.0024	0.0013	0.004
4	0.0022	0.0015	0.004
5	0.0022	0.0017	0.004
6	0.0021	0.0018	0.004
7	0.0020	0.0019	0.004
8	0.0019	0.0019	0.004
9	0.0017	0.0019	0.004
10	0.0014	0.0019	0.004
11	0.0012	0.0018	0.004
12	0.0009	0.0017	0.004

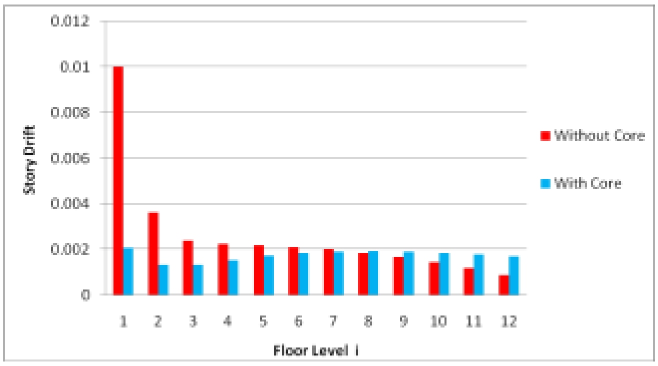

Fig. 9: Story drift for soft story of 3.5m at different floor level in X direction

Table 9: Comparison of maximum story drift at different floor level between model 1 and model 2 in Y direction

Floor Level i	Without Core	With Core	Permissible Limit
Base	0	0	0
1	0.0090	0.0018	0.004
2	0.0029	0.0015	0.004
3	0.0021	0.0015	0.004
4	0.0020	0.0014	0.004
5	0.0020	0.0014	0.004
6	0.0019	0.0014	0.004
7	0.0018	0.0014	0.004
8	0.0017	0.0014	0.004
9	0.0015	0.0013	0.004
10	0.0013	0.0013	0.004
11	0.0011	0.0012	0.004
12	0.0009	0.0011	0.004

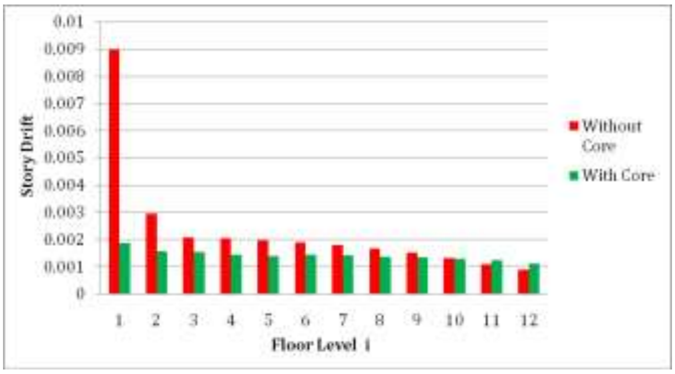

Fig. 10: Story drift for soft story of 3.5m at different floor level in Y direction

The table 8 & 9 and fig. 9 & 10 shows that, the story drift has decreased in models with core wall as compared to models without core wall in lower floors while in upper floors it is increases. The permissible limit of the story drift is 0.004 times the story height as per clause of IS: 1893(Part1)–2002/2016. In case of models with core wall the drift values didn't crosses the permissible limit in all the floors but in case of without core wall this limit have crossed at the 1st floor level only which is due to the low stiffness at the bottom story. After providing the core wall the story drift at the 1st floor level has decreased 79.21% and 79.39% for soft story of 3.5m in X and Y directions respectively. Similarly 80.98% and 80.36% for soft story of 4.5m and 80.50% and 81.81% for soft story of 5.5m has decreased in X and Y direction respectively.

4.3.2 Comparison of Drift at Ground Story

Comparison of ground floor story drifts with increasing soft story height in X and Y direction are shown in table 10 and fig. 11.

Table 10: Comparison of ground floor story drift with increasing soft story height in X and Y direction

Direction	Soft Story Height	Without Core	With Core
X - Direction	3.5m	0.010012	0.002081
	4.5m	0.010714	0.002179
	5.5m	0.012526	0.002279
Y - Direction	3.5m	0.008971	0.001849
	4.5m	0.010714	0.002104
	5.5m	0.012055	0.002351

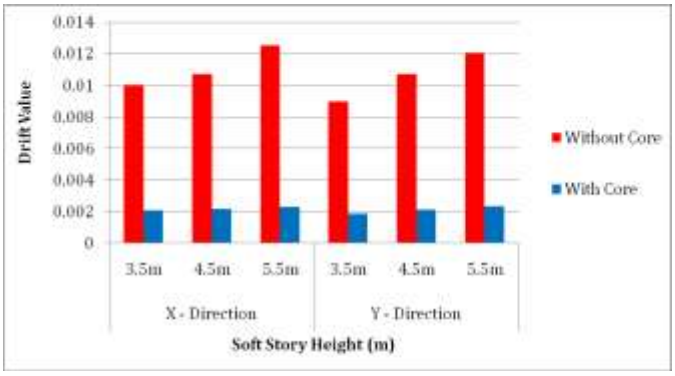

Fig. 11: Story drift comparison with increasing soft story height in X and Y direction

The table 10 and fig. 11 shows that, the story drifts at bottom floor of all models in X and Y directions. It is clearly seen that, the story drifts are increases with increase in the height of a soft story. If we increase the height of a soft story from 3.5m to 4.5m and 5.5m the increase in drift has 7.01% and 25.11% for without core wall models while 4.71% and 9.51% for core wall models in X direction and 19.43% and 34.38% for without core wall models while 13.79% and 27.15% for core wall models in Y direction respectively. The permissible limit of the story drift is 0.004 times story height as per clause of IS: 1893(Part1)–2002/2016. In core wall models, the drift value does not exceed the permissible limit but in case of without core wall models this value crosses the permissible limit and also increases with increasing in soft story height.

5. CONCLUSIONS

In present work, the effect of core wall is studied on (G+11) stories RC building. Results are compared in terms of Story drift, Floor displacement and Story shear between models with and without core wall for different height of the soft story. The conclusions drawn from the present study are as follows:

- The story shear on all the floors has increased for core wall models as compared to without core wall models. It means the core wall attracts larger lateral forces on the building but also increases the strength and stiffness of the building.

- The story drift and story displacement has decreased for core wall models as compared to without core wall models in all comparisons. The story drift and story displacement also increases with increase in height of a soft story.

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