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Research Article

Effect of Location of Shear Walls on Seismic Performance of Buildings

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Abstract

Shear walls are one of the most commonly used lateral load resisting systems in high rise buildings. Shear walls are high in plane stiffness and strength, which can simultaneously be used to resist lateral loads and support gravity loads. Incorporation of shear walls has become inevitable in multi-storey buildings to resist lateral forces. It is very necessary to determine effective, efficient and ideal location of a shear wall. In the present study investigation are carried out by varying percentage length of a shear wall with aspect ratio (L/B) 1 for seismicity. The seismic parameters are considered as storey shear, displacement, drift, base shear, stiffness and natural period. The seismic analysis is performed by a Response spectrum method using an application software ETABS.

Keywords: *Shear wall, Location, Aspect ratio, Displacement, Drift, Natural period, Response spectrum method, ETAB.*

1. Introduction

Reinforced concrete (RC) buildings often have vertical plate-like RC walls called 'Shear Walls' in addition to slabs, beams and columns. These walls generally start at foundation level and are continuous throughout the building height. Their thickness can be as low as 150 mm, or as high as 400 mm in high rise buildings. Shear walls are usually provided along both length and width of buildings. Shear walls are like vertically-oriented wide beams that carry earthquake loads and distribute them to the foundation. Properly designed and detailed buildings with shear walls have shown very good performance in the past for several earthquakes. Shear walls in high seismic regions require special detailing. However, in past earthquakes, even buildings with sufficient amount of walls that were not specially detailed for seismic performance (but had enough well-distributed reinforcement) were saved from collapse. Shear wall buildings are a popular choice in many earthquake prone countries, like Chile, New-Zealand and USA. Shear walls are easy to construct, because reinforcement detailing of walls is relatively straight-forward and therefore easily implemented at site. Shear walls are efficient, both in terms of construction cost and minimizing earthquake damage in structural and nonstructural elements like glass windows and building contents. Shear walls also have following advantages

1) Large strength
2) High stiffness and
3) Ductility

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Fig. 1.1 shows that, when buildings have shear walls they deform largely and give the desired strength with height.

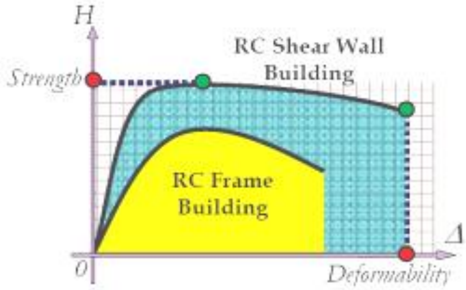


Fig. 1.1 Shear wall can be detailed to have large ductility

Research has been carried out on the seismic response of irregular shaped (in plan) structures and reduction of displacements, bending moments, column moments, storey drifts and torsion by providing shear walls. Different source, which contribute to the torsion like mass irregularity, stiffness irregularity, effect of configuration of structure are studied in detail. [Halkude S A, *et al*, 2014]. A 25 storey building situated in zone V is analyzed with changing the position of shear wall in plan. The parameters are studied such as storey drift, storey shear and displacement using an application software ETABS [Agrawal A S, *et al*, 2012]. Study has been carried out to determine the optimum configuration of a multistory building by changing the shear wall location, which is very effective against seismic induced torsion. Four different cases of shear wall positions for a 25-storey building has been analyzed as a space frame system using the application software ETABS [Ashraf *et al*, 2008]. The study has been carried out on the torsion response of ductile structure indicating the need for improvements in current seismic design provisions. This is because most of the structures dealing with the torsion problems were based on the concept of elastic response. This provision may be satisfactory at the serviceability limit state but are generally irrelevant for ductile structure. This paper evaluates the rotation of asymmetric structures and its effect on the displacement ductility demand using a displacement approach based on a realistic element modeling [Castillo *et al*, 2001].

The objective of the paper is to study the behavior of RC shear walls located at different positions in the building with increasing the percentage length of shear wall in plan configuration; comparing the results of frames with a shear wall along X and Y direction. Finally an attempt is made to equalize all the parameter in both axis and identifying which case will provide the good results for the structure. The parameters considering as story shear, displacement, drift, base shear, stiffness and time period of the structure.

2. Methods of Analysis

There are two commonly used methods for determining seismic design lateral forces:

- Equivalent static force analysis
- Response spectrum method

In this present study the Response Spectrum Method is employed for determination of seismic parameters of the building.

2.2.1 Response Spectrum Method

Response spectrum method of analysis shall be performed using the design spectrum specified in Clause 6.4.2 or by a site specific design, spectrum mentioned in Clause 6.4.6 of IS 1893 (2002). Following are steps to perform the analysis:

Step 1 Compute the seismic weight of the building (*W*)

Step 2 Establish mass *[M]* and stiffness *[K]* matrices of the building using system of masses lumped at the floor levels with each mass having one degree of freedom.

Step 3 Using *[M]* and *[K]* of previous step and employing the principles of dynamics compute the modal frequencies, {ω} and corresponding mode shapes, [φ].

Step 4 Compute modal mass M_k of mode *k* using the following relationship with *n* being number of modes considered.

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \phi_{ik}\right]^2}{g\sum_{i=1}^{n} W_i {\phi^2}_{ik}} \tag{2}$$

Step 5 Compute modal participation factors P_k of mode *k* using the following relationship with *n* being number of modes considered

$$P_k = \frac{\sum_{i=1}^{n} W_i \phi_{ik}}{\sum_{i=1}^{n} W_i {\phi^2}_{ik}} \tag{3}$$

Step 6 Compute design lateral force (Q_{ik}) at each floor in each mode (i.e., for i^{th} floor in mode *k*) using the following relationship,

$$Q_{ik} = A_{h(k)} \phi_{ik} P_k W_i \tag{4}$$

Step 7 Compute storey shear forces in each mode (Vik) acting in storey *i* in mode *k* as given by,

$$V_{ik} = \sum_{i+1}^{n} Q_{ik} \tag{5}$$

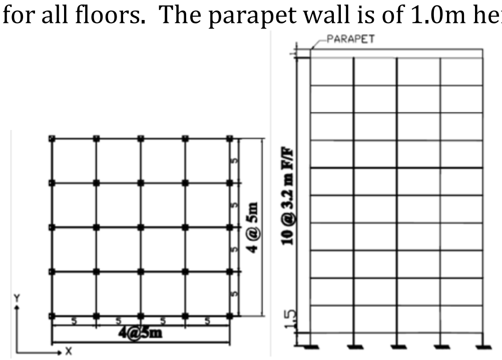
Step 8 Compute storey shear forces due to all modes considered, *Vi* in storey *i,* by combining shear forces due to each mode in accordance with Clause 7.8.4.4 of IS 1893 (2002). i.e., either CQC or SRSS modal combination methods are used

Step 9 Finally compute design lateral forces at each storey as,

$$F_i = V_i - V_{i+1} \tag{6}$$

3. Problem Statement

The plan of the building is shown in the Fig 3.1a. In the present study bay width is taken as 5m along both the directions i.e. X and Y direction. The breadth (B) of the building is kept constant and length (L) of building is varying i.e. L/B should vary with a constant increment of 0.25. Fig.3.1b shows the sectional elevation of the structure. The storey height consider in this study is 3.2m for all floors. The parapet wall is of 1.0m height.



(a) Plan (b) Elevation

Table 3.1 Structural Data of Building

Geometry of Building	
Height of storey	3.2m
Number of storey	10.
Column size	600 x 600 mm.
Beam size	300 x 600 mm.
Slab thickness	150 mm.
Wall thickness	230 mm.
Parapet wall height	1 m.
RC shear wall thickness	230 mm.
Grade of concrete	M25.
Grade of steel	Fe 500 .
Seismic zone (Z)	V
Soil type	Medium

Table 3.2 Various cases considered for study

Sr.No	Case No.	L/B ratio	No. of Models	No. of shear walls	% Length of S.W.
1	1	1	6	4	10
2	2	1	6	8	20

Table 4.1

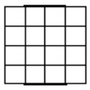
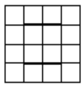
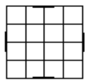
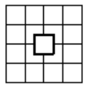
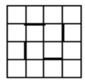
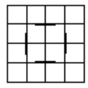
M1	M2	M3	M4	M5	M6
					
X=100%, Y= 0%	X=100 Y =0%	X= 50%, Y=50%	X= 50%, Y= 50%	X= 50%, Y= 50%	X= 50%, Y= 50%

Table 4.2 Seismic parameters along X-dir (Case I)

Parameter	M1	M2	M3	M4	M5	M6
Storey Shear (kN)	672.11	668.00	462.08	486.32	493.06	465.57
Displacement (m)	0.0108	0.0105	0.0162	0.0153	0.0165	0.0158
Drift (m)	0.000375	0.000361	0.000391	0.000487	0.000508	0.000361
Base Shear (kN)	4253.14	4303.78	2797.93	3058.83	2826.22	2851.09
Stiffness	1.79E+06	1.85E+06	1.18E+06	0.99E+06	0.97E+06	1.29E+06
Time Period (sec)	0.571	0.562	0.924	0.833	0.937	0.904

Table 4.3 seismic parameter along Y-dir (Case I)

Parameter	M1	M2	M3	M4	M5	M6
Storey Shear (kN)	322.77	324.39	461.48	486.32	493.06	465.58
Displacement (m)	0.0237	0.0238	0.0163	0.0153	0.0165	0.0158
Drift (m)	0.000269	0.000286	0.000391	0.000487	0.000508	0.000361
Base Shear (kN)	1921.80	1919.62	2797.53	3058.85	2826.22	2287.95
Stiffness	1.20E+06	1.13E+06	1.18E+06	0.99E+06	0.97E+06	1.29E+06
Time Period ((sec)	1.464	1.466	0.924	0.833	0.901	0.904

3.1 Cases considered for the study

The following Table 3.2 shows that the models are arranged in various cases according to L/B ratio and percentage length of shear wall used in the plan of building.

4. Parametric Investigation

There are all together two cases leading to 12 models which are considered for parametric study. The results obtained are tabulated below

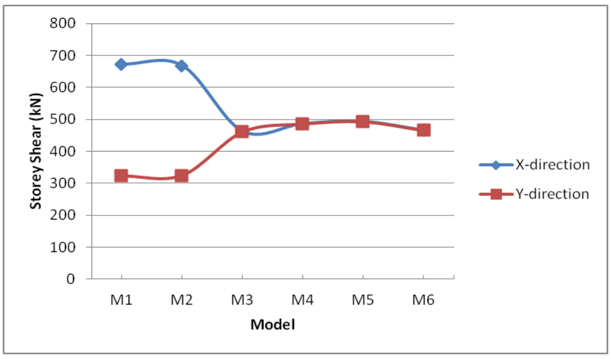
4.1 Case I- Models having L/B=1 with 10% length of shear walls used.

See Table 4.1

From above table 4.2 and 4.3 following graph has been plotted to study the variation of seismic parameters along both the directions for models having L/B =1.

Storey Shear

From the above graph it is observed that, when all shear walls are placed only in X direction, then the storey shear is maximum in that direction; at the same time the storey shear is minimum in Y direction.

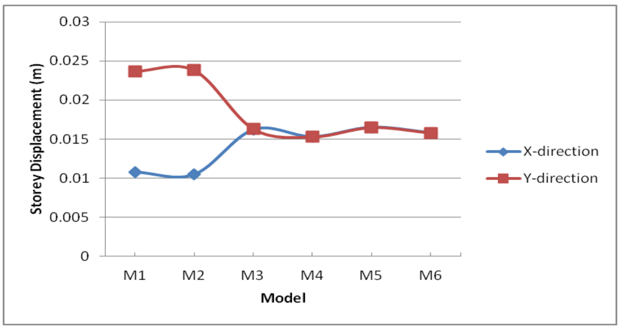


Graph 4.1 Variation of storey shear force (kN) in either direction v/s various models having L/B=1 with 10% length of shear wall

Initially, as all the shear walls are placed only in X direction the storey shear is 50% more than Y direction. However, it is observed that, storey shear is dependent upon placement of shear wall in plan, when shear walls are equally placed (i.e. 50-50%) in both the directions, the storey shear is nearly same in both directions. If shear walls are placed very close to the

C.G. of the structure; then the storey shear increases slightly and vice-versa when shear walls are placed away from the C.G of the structure, then the storey shear decreases in both the directions.

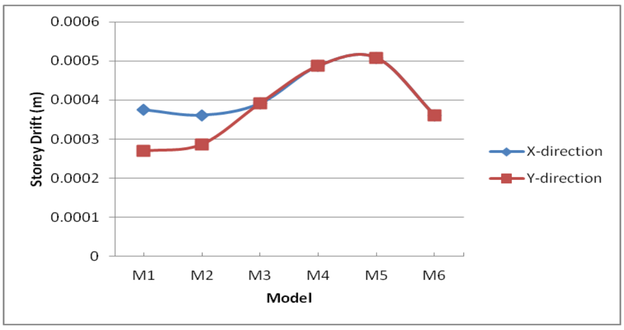
Storey Displacement



Graph 4.2 Variation of storey displacement (m) in either direction v/s various models having L/B=1 with 10% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the storey displacement is minimum in that direction; at the same time, the storey displacement is maximum in Y direction. Initially, when shear walls are placed only in X direction, then the storey displacement is 54.43% less than the Y direction. However, it has been observed that, the storey displacement is dependent upon the placement of shear wall, when shear walls are equally (i.e. 50-50%) placed in both direction, then storey displacements are less and nearly same in both directions. If shear walls are placed very close to the C.G of the structure then displacements are minimum and vice-versa when shear walls are placed away from the C.G of the structure, then displacements are observed maximum in both directions.

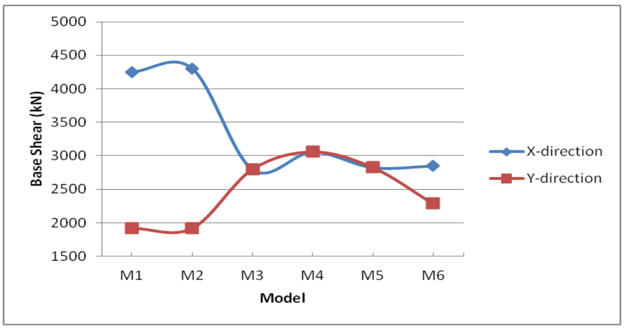
Storey Drift



Graph 4.3 Variation of storey drift (m) in either direction v/s various models having L/B=1 with 10% length of shear wall.

From the above graph it is observed that, when all shear walls are placed only in X direction, then the storey drift is maximum in that direction; at the same time storey drift is minimum in Y direction. Initially, when shear walls are placed only in X direction, then the storey drift is 28.26% more than the Y direction. However, it is observed that, the storey drift is dependent upon the placement of shear wall, when the shear walls are equally placed (i.e. 50-50%) in both X and Y directions at periphery, then the storey drift is found slightly maximum and nearly same. When shear walls are placed very close to C.G, then the storey drift is maximum and vice-versa the drift is minimum, when shear walls are placed away from the C.G of structure.

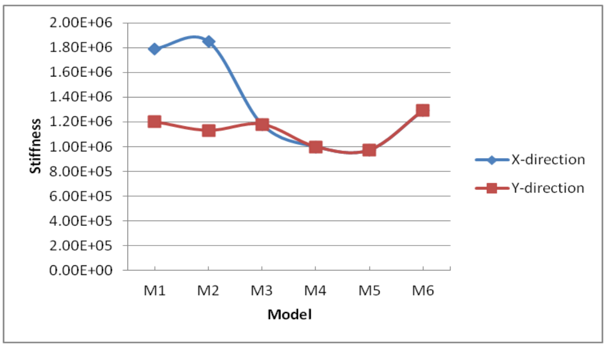
Base Shear



Graph 4.4 Variation of base shear (kN) in either direction v/s various models having L/B=1 with 10% length of shear wall.

From the above graph it is observed that, when all shear walls are placed only in X direction, then the base shear is maximum in that direction; at the same time the base shear is minimum in Y direction. . Initially, as shear walls are placed only in X direction, the base shear is 54.81% maximum than the Y direction. However, it is observed that, the base shear is also dependent upon the placement of shear wall, when shear walls are equally placed (i.e. 50-50%) in both the directions, the base shear is nearly same in X and Y direction. If shear walls are placed very close to C.G. of the structure then base is observed maximum and vice-versa when shear walls are placed away from the C.G, then the base shear is maximum in that direction.

Stiffness



Graph 4.5 Variation of stiffness in either direction v/s various models having L/B=1 with 10% length of shear wall

Table 4.4

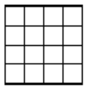
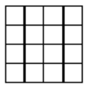
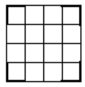
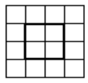
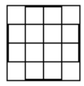
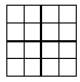
M1	M2	M3	M4	M5	M6
					
X=100%, Y= 0%	X=100 Y =0%	X= 50%, Y=50%	X= 50%, Y= 50%	X= 50%, Y= 50%	X= 50%, Y= 50%

Table 4.5 Seismic parameters along X-dir (Case II)

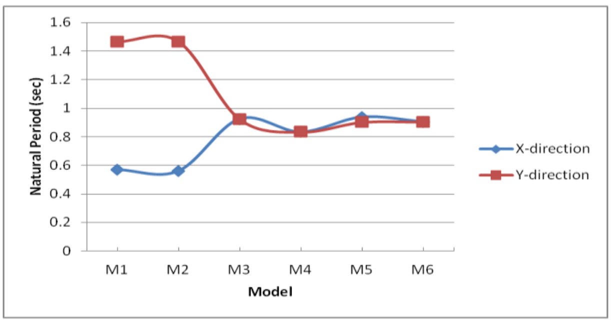
Parameter	M1	M2	M3	M4	M5	M6
Storey Shear (kN)	677.85	337.98	632.27	692.80	704.86	682.28
Displacement (m)	0.0032	0.0237	0.0129	0.0063	0.0108	0.0058
Drift (m)	0.000098	0.000292	0.000457	0.000191	0.000375	0.000174
Base Shear (kN)	4536.98	1944.58	3679.72	4567.93	4286.69	4583.63
Stiffness	6.92E+06	1.16E+06	1.38E+06	3.63E+06	1.88E+06	3.92E+06
Time Period (sec)	0.308	1.458	0.672	0.435	0.573	0.419

Table 4.6 Seismic parameters along Y-dir (Case II)

Parameter	M1	M2	M3	M4	M5	M6
Storey Shear (kN)	335.30	675.78	632.87	692.80	705.18	682.28
Displacement (m)	0.0235	0.0031	0.0130	0.0063	0.0108	0.0058
Drift (m)	0.000265	0.000094	0.000461	0.000191	0.000375	0.000174
Base Shear (kN)	1946.06	4549.11	3679.95	4567.92	4287.06	4583.63
Stiffness	1.27E+06	7.19E+06	1.37E+06	3.63E+06	1.88E+06	3.92E+06
Time Period (sec)	1.458	0.304	0.672	0.435	0.573	0.419

From the above graph it is observed that, when all shear walls are placed only in X direction, then the stiffness is maximum in that direction; at the same time the stiffness is minimum in Y direction. Initially, as shear walls are placed only in X direction, the stiffness is 36.96 % more than the Y direction. However, it is observed that, the stiffness is inversely proportional to mass, also it is depends on the load and displacement. There is little change in the displacement makes more difference in the stiffness. However, it is observed that, when shear walls are equally placed (i.e. 50-50%) in both the directions, the stiffness is found nearly same in X and Y direction. The stiffness is observed maximum; when the shear walls are placed very close to C.G of the structure; vice versa the stiffness is observed minimum, when the shear walls are placed away from the C.G.

Natural Period



Graph 4.6 Variation of natural period (sec) in either direction v/s various models having L/B=1 with 10% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the natural period is minimum in that direction; at the same time, the natural period is maximum in Y direction. Initially, as shear walls are placed only in X direction, then the natural period is 61% more than the Y direction. However, it is observed that, the natural period is proportional to 1/ (Stiffness) $^{1/2}$. As we notice that there is change in results in both X and Y direction depending upon the stiffness of the model in both direction. When shear walls are equally placed (i.e. 50-50%) in both the direction, then the natural period is nearly same in X and Y direction. If shear walls are placed very close to the C.G of the structure then natural period is found very less; and vice-versa when shear walls are placed away from the C.G of the structure then the natural period is observed maximum.

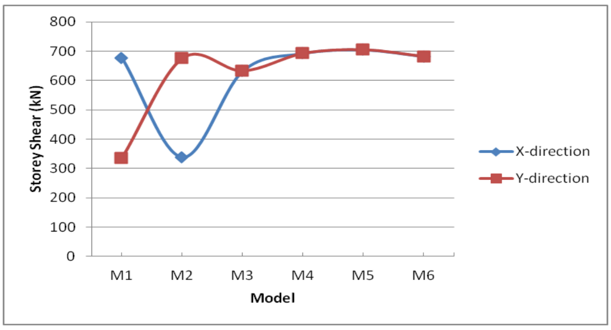
4.2 Case 2- Models having L/B=1 with 20% length of shear walls used.

See Fig 4.4

From the table 4.5, 4.6 following graph has been plotted to study the variation of seismic parameters along both the directions for models having L/B =1.

Storey Shear

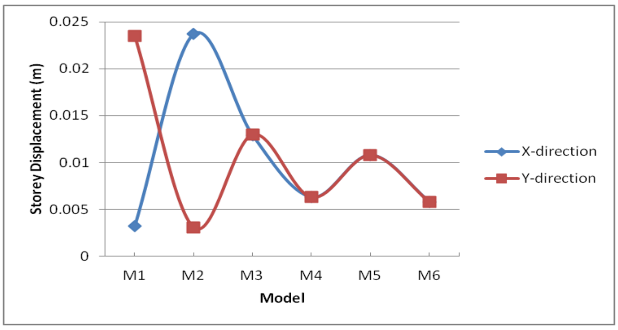
From the below graph it is observed that, when all shear walls are placed only in X direction, then the storey shear is maximum in that direction; at the same time the storey shear is minimum in Y direction.



Graph 4.7 Variation of storey shear force (kN) in either direction v/s various models having L/B=1 with 20% length of shear wall

If all the shear walls are placed only in X direction then the storey shear is 50% maximum than Y direction. However, it is observed that, shear force is dependent upon placement of shear wall in plan, when shear walls are equally placed (i.e. 50-50%) in both the directions, the storey shear is getting nearly same in X and Y direction. When shear walls are placed very close to the C.G. of the structure; then the storey shear is increasing slightly and vice-versa when shear walls are placed away from the C.G of the structure, the storey shear is decreasing in both directions.

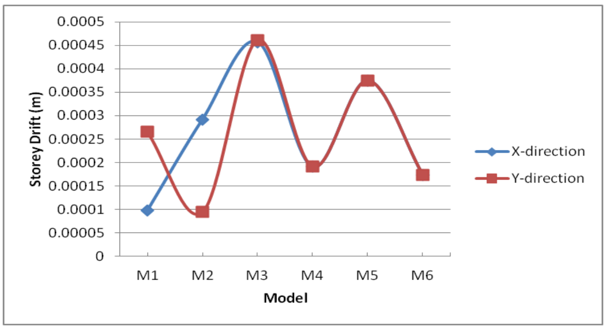
Storey Displacement



Graph 4.8 Variation of storey displacement (m) in either direction v/s various models having L/B=1 with 20% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the storey displacement is minimum in that direction; at the same time, the storey displacement is maximum in Y direction. However, it has been observed that, the storey displacement is dependent upon the placement of shear wall because when shear walls are equally (i.e. 50-50%) placed in both direction, the storey displacements are less and nearly same in X and Y directions. If the shear walls are placed very close to the C.G of the structure then the storey displacements are observed minimum, and vice-versa when shear walls are placed away from the C.G of the structure, the displacements are observed maximum in both directions.

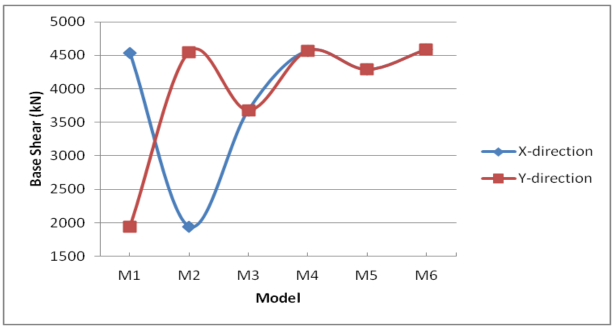
Storey Drift



Graph 4.9 Variation of storey drift (m) in either direction v/s various models having L/B=1 with 20% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the storey drift is maximum in that direction; at the same time storey drift is minimum in Y direction. However, it is observed that, the storey drift is dependent upon the placement of shear wall, when the shear walls are equally placed (i.e. 50-50%) in both X and Y directions at periphery, then the storey drift is found slightly maximum and nearly the same. When shear walls are placed very close to C.G, then the storey drift is maximum and vice-versa the drift is minimum when shear walls are placed away from the C.G of structure.

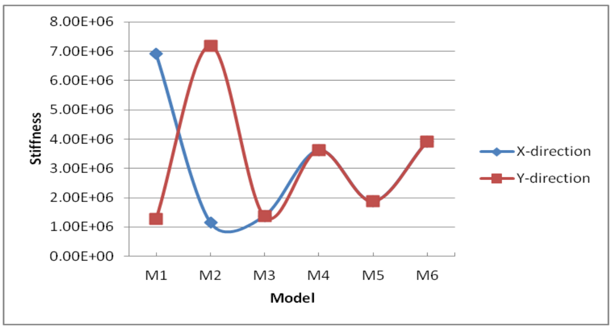
Base Shear



Graph 4.10 Variation of base shear (kN) in either direction v/s various models having L/B=1 with 20% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the base shear is maximum in that direction; at same time the base shear is minimum in Y direction. However, it is observed that, the base shear is also dependent upon the placement of shear wall, when shear walls are equally placed (i.e. 50-50%) in both the directions, the base shear is nearly same in X and Y direction. If shear walls are placed very close to C.G. the base shear is observed maximum,; vice-versa when shear walls are placed away from the C.G, then the base shear is maximum in that direction.

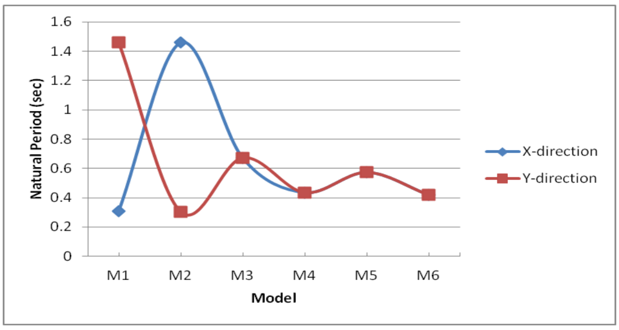
Stiffness



Graph 4.11 Variation of stiffness in either direction v/s various models having L/B=1 with 20% length of shear wall.

From the above graph it is observed that, when all shear walls are placed only in X direction, then the stiffness is maximum in that direction; at same time the stiffness is minimum in Y direction. However, it is observed that, the stiffness is inversely proportional to mass and it is also depends on the load and the displacement. There is little change in the displacement which makes more difference in the stiffness. However, it is observed that, when shear walls are equally placed (i.e. 50-50%) in both the directions, the stiffness is found nearly same in X and Y direction. If shear walls are placed very close to C.G then the stiffness is observed maximum and vice versa when the shear walls are placed away from the C.G. then the stiffness is observed minimum.

Natural Period



Graph 4.12 Variation of natural period (sec) in either direction v/s various models having L/B=1 with 20% length of shear wall

From the above graph it is observed that, when all shear walls are placed only in X direction, then the natural period is minimum in that direction; at the same time, the natural period is maximum in Y direction. However, it is observed that, the natural period is proportional to 1/ (Stiffness) $^{1/2}$. It is noticed that there is a change in the results in both X and Y directions depending upon the stiffness of the model in both the directions. When shear walls are equally placed (i.e. 50-50%) in both the direction, then the natural period is nearly same in X and Y direction.

The natural period is observed minimum, when shear walls are placed very close to the C.G of the structure; and vice-versa when shear walls are placed away from the C.G of the structure then natural period is observed maximum.

5. Conclusion

The present work is carried out with the objective of evaluating the seismic behavior of various buildings having square shape in plan with ten storey considered for all cases. The parametric study is carried out for various percentage lengths of shear wall and their location in the plan configuration. In all taken together 2 cases are considered, leading to 12 model formulations which are studied. The seismic behavior of these various cases are assessed in the form of seismic parameters such as storey shear, displacement, drift, base shear, stiffness and natural period etc. On the basis of this parametric study certain conclusions are drawn as follows:

5.1 Location and Orientation of Shear Wall

1) Building having the shear wall at the central part of the structure is much effective in resisting the seismicity. However, present study shows that when shear walls are placed away from the C.G. then, the seismic parameters such as storey displacements, drift, and natural period are found more; but other parameters such as storey shear, base shear and stiffness of structure become less.
2) The shear wall shall not be placed in only one direction, because behavior of the structure is good in that direction, but the stability of structure in other direction becomes weak.
3) The placement of shear wall in both longer and shorter directions should be maintained. Symmetry of placement of shear wall shall be provided in both directions preferably with same thickness.
4) Shear wall at the periphery of the structure takes the same amount of lateral force as core type shear wall, but shear wall placed at the periphery shows relatively more displacement, drift and natural period as compared to shear wall placed near core.
5) The shear wall should be provided equally (i.e. 50-50%) in both directions for buildings having square shape in plan configuration.
6) For square type of building having length of shear wall 10 to 20% of plan dimension shows efficient seismic performance.
7) With increasing length of shear wall, the stiffness of the structure also increases.

5.1 Suggestive Optimum Combinations

From the above conclusions, the most optimum combinations suggested for structural frame with shear walls are as follows:

For square type building with core wall at centre 20% length of shear wall of plan dimension shall be provided. The shear wall distribution shall be @ 50-50 % in either direction in the plan. However, if any functional difficulties occur, then it is preferable to go for periphery placed shear wall with 20% length and same distribution.

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