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Effective Location of Shear Walls in High-Rise RCC Buildings Subjected to Lateral Loads

1	K, Nallasivam	nallasivam_iit_nit@yahoo.co.in	Ph.D.	Assistant Professor	India	Assistant Professor, Corresponding author, Department of Civil Engineering, National Institute of Technology (NIT) Hamirpur -177001, Himachal Pradesh, India

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Abstract

The main objective of this research is to identify buildings with and without shear walls that adequately resist lateral load by utilizing finite element-based ETABS software that can minimize the displacement and drift of buildings induced by the earthquake and wind load. The equivalent static approach based on the IS Code was used to compute seismic loads. The results of story displacements and drifts were obtained using four load combinations from the IS Code. It has been observed that shear walls located in the center, in the shape of a core, perform well against lateral loads. The displacement at the top of such a building is around 2.5 times less than the displacement at the top of a building without a shear wall. Shear walls near corners have the lowest effectiveness.

Keywords: High-Rise building; Shear wall; ETABS models; Seismic &Wind load; Equivalent static method.

1. Introduction

The attraction of mankind towards high-rise structures has started since ancient times. However, it becomes necessary as the urban population increases rapidly. Globally, more people live in urban areas than in rural areas(U.N organization,2018). This fact leads us to the wide scope available for research and development in the field of high-rise buildings. From a structural engineer's perspective, a high-rise building is defined as a building that is affected by lateral loads due to wind or earthquake actions to such an extent that they play an important role in the structural design(Bryan and Alex,1991). Lateral load effects on buildings increase rapidly with an increase in height. In such a situation, the provision of lateral stiffness becomes the most important building component(Bungale,1988). Between two primary types of vertical load-resisting elements, columns, and shear walls, the latter provides more stiffness. A vertical plate like a reinforced concrete wall starting from the foundation level and extending up to the full height of the building to form a vertical cantilever is called a shear wall (Pankaj and Manish,2007). It is subjected to in-plane shear forces due to lateral loads. Due to higher in-plane stiffness, shear walls are suitable to use in buildings up to 35 stories(Bryan and Alex,1991). For effective load resistance, the location and arrangement of shear walls are important factors. Although lateral loads due to earthquakes and wind are dynamic, codes permit the use of quasi-static analysis methods because of difficulties associated with dynamic analysis(Menon,2008). The objective of the quasi-static analysis is to find an equivalent static load that results in maximum response. This study deals with multi-story rectangular buildings with different arrangements of shear walls, modeled using ETABS software. The equivalent static method according to (IS Code 1893, Part-1,2016) has been adopted to find out earthquake loads, and wind loads have been applied according to(IS Code 875, Part 3,2015). (Akhil and Pradeep,2020) have studied the effects of the location of shear walls in a twenty-story residential building by adopting response spectrum analysis. Three models have been made using ETABS; one without a shear wall, one with a shear wall at two corners on the same side of the building, and the last with shear walls at all four corners of the building. It has been concluded that buildings with shear walls on all four corners perform better than others as they show lower displacement, drift, and base shear. (Lingeshwaran et al.,2021) have examined the usage of shear walls in building with floating columns. Building without a floating column, building with a floating column, and building with a floating column and shear wall- such three G+9 story models were made in ETABS software and analyzed using response spectrum and time history method. It has been proven that using the shear wall in a building with a floating column provides much better stiffness. (Dodiya et al.,2018) have researched the positioning of shear walls in 20-story buildings considering these three models: shear walls at corners, shear walls at opposite directions and shape shear walls. It has been seen from the results that when shear walls are located in opposite directions show minimum displacement.(Meena and Ramana,2021) have designed G+3 R.C.C. framed Structure with a shear wall perpendicular and parallel to the blast load, and a shear wall at all the faces in ETABS. The conclusion was made that building with a shear wall perpendicular to the blast load and shear wall at all the faces performs almost with similar efficiency and is more effective than building with walls parallel to the load. (Sylviya and Eswaramoorthi, 2018) have proposed that the most effective building for resisting earthquake load is a building with shear walls located at the edges. To arrive at this conclusion, four models had been made and results for story drift, displacement, and story shear have been shown in all the zones i.e., Zone II, III, IV, and (Khadri et al., 2021) have explained about the effectiveness of shear wall in resisting seismic load when the building is situated on sloping ground. Various models with different shear wall arrangements had been prepared with the building located both on a plane and sloped ground for their study. (Al Agha and Umamaheshwari,2020) have presented the study of irregular RCC buildings with only shear walls, and dual framed - shear wall systems subjected to seismic loads calculated using both equivalent static method and response spectrum method. (Wang et al.,2001) have studied the effect of shear wall height on the earthquake response of frame–shear wall structures. It has been derived that the influence of the height of shear walls on the effective stiffness of the buildings is marginal for some buildings. (Tuppad and Fernandas,2015) have researched about optimum positioning of shear walls in G+10 story buildings when the seismic load is applied. A total of six models, one without a shear wall and the other five with a shear wall at different locations had been prepared using ETABS and seismic loads applied using an equivalent static method. A genetic algorithm was also used for optimization and it has been concluded that the shear wall at the center gives better results. (Titiksh and Bhatt,2017) prepared four different buildings in ETABS to give an idea about the effectiveness of shear wall positioning against lateral loads.(Sherkhane and Manjunath,2020) have replaced all the columns in the G+20 story building with shear walls. Four buildings have been made providing shear walls as the only lateral load-resisting element and analyzed using an equivalent static method. (Abd-el-Rahim and Farghaly,2010) studied the effect of edge shear walls in slender buildings resting on a raft foundation. Various models have been prepared for this study considering different subgrade moduli and analyzed after applying seismic load using the time history method in SAP2000 software. (Bongilwar et al.,2018) have checked the vulnerability of irregular G+8 story building models using two models, one with shear walls and one without shear walls. The fundamental objective of the research is to identify buildings with various arrangements of shear walls and without shear walls that effectively resist lateral load by using finite element-based ETABS software and can minimize to a minimum the displacement and drift of buildings caused by the earthquake and wind load. (Tavakoli et al., 2022) performed to examine the influence of outrigger-braced system location optimization on the seismic response of a 50-story structure. The seismic responses are investigated using IDA curves. The energy balance in the structures is evaluated, and the strain energy parameter is chosen as EDP, from which the damage level is computed. The plastic strain energy is used to examine the outcomes of plotting fragility curves. The results reveal that optimizing the location of an outrigger-braced system improves all structural characteristics while decreasing the likelihood of collapse.Yusef and Farhad(2023) investigated the maximum practical values of the eccentricity of torsionally-coupled structures, followed by an evaluation of the safety margin against the seismic collapse of such buildings. Different levels of mass eccentricity in a stiffness-eccentric plan are explored in nonlinear analysis. The eccentricity ratio, building height, and soil type all influence the collapse safety margin and median spectral acceleration.

2. Materials and Methods

To establish identical circumstances throughout all nine models, the following assumptions were established before the commencement of the modeling procedure:

- ✓ Just the main block of the building is taken into account. The staircases are not taken into account in the design process.
- ✓ The building will be employed for residential purposes, but no walls will be built since the research will simply look at the reaction of the Frame configuration.
- ✓ No slabs are placed on the bottom floor.
- ✓ The beams are resting centrally on the columns to prevent eccentric circumstances. In ETABS, this is done automatically.
- ✓ The footings have not been designed. Fixed supports are used to assign supports.
- ✓ Seismic loads are only examined in the horizontal direction (X & Y), with vertical loads (Z) presumed to be minor.

A total of nine G+30-story buildings have been modeled using finite element-based ETABS software. Details about the arrangement of shear walls in all the models are listed below as model-1 to model-9:

Model-1:Rectangular building without any shear wall
Model-2:Buildings with shear walls located at all four corners-1
Model-3:Buildings with shear walls located at all four corners-2
Model-4:Buildings with shear walls located at only two opposite corners
Model-5:Buildings with shear walls located at all four edges
Model-6:Buildings with shear wall located at the center as core
Model-7:Buildings with shear walls located at two opposite edges and center
Model-8:Buildings with shear wall located at the center in E-shape
Model-9:Building with a shear wall located at the center in I-shape

The Floor plan and 3D view of the above models are shown in **Error! Reference source not found.**-Fig.9 respectively. The fixed supports have been provided at the base of each building making it a vertical cantilever.

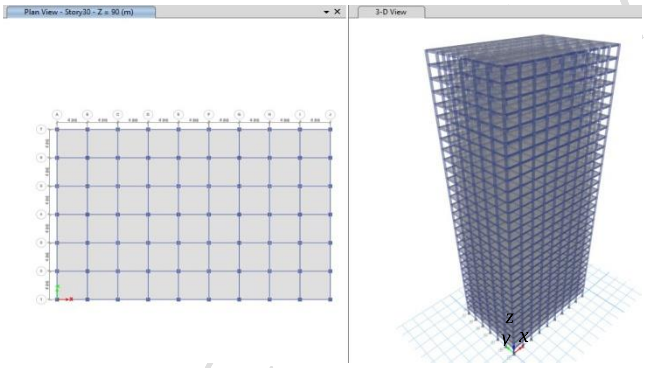

Fig 1. Model 1-building without any shear wall

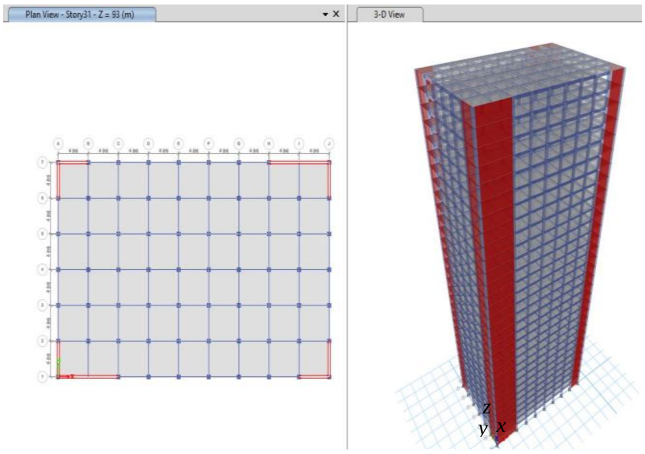

Fig. 2. Model 2- Buildings with shear walls located at all four corners-1

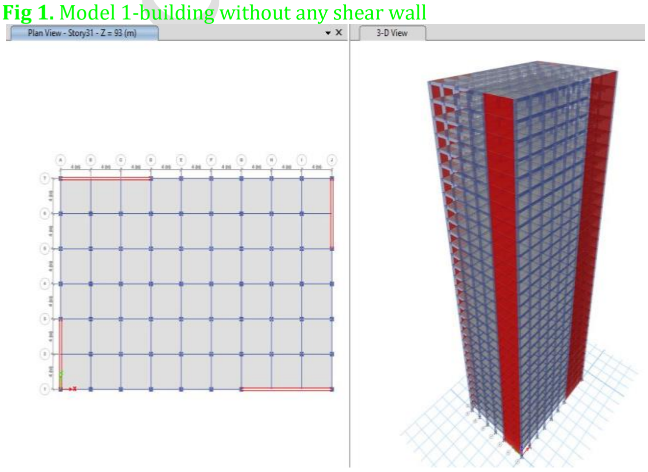

Fig. 3. Model 3- Buildings with shear walls located at all four corners-2

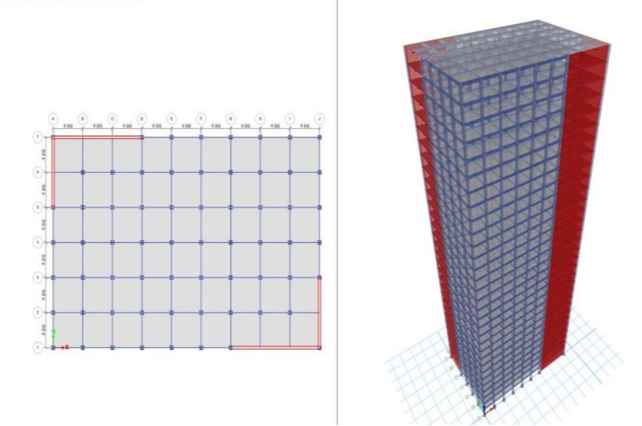

Fig.4. Model 4- Buildings with shear walls located at only two opposite corners

z
y x

z
y x

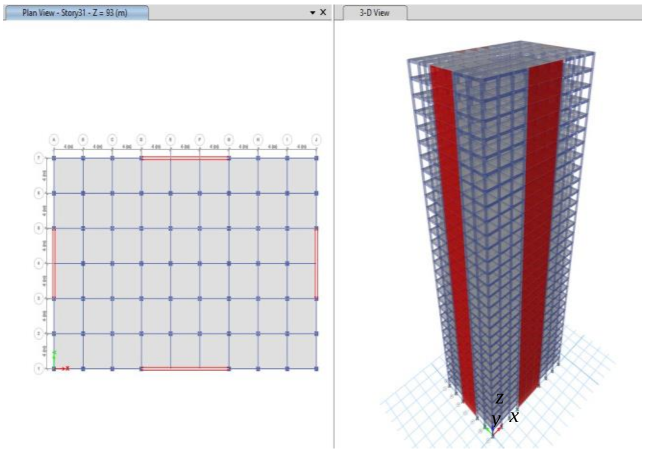

Fig. 5. Model 5-Buildings with shear wall located at all four edges

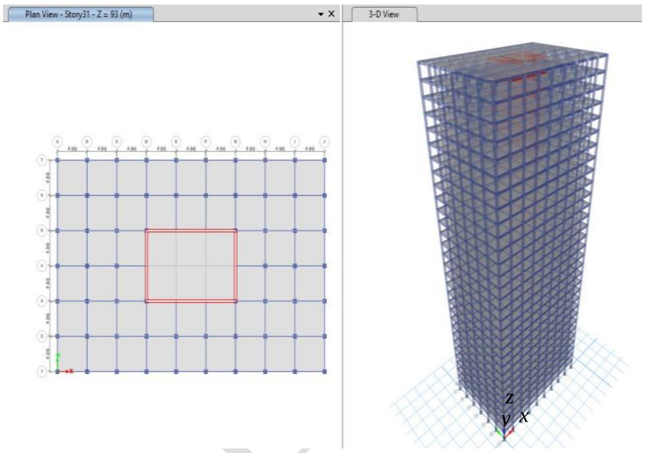

Fig. 6. Model 6-Buildings with shear wall located at the center as core

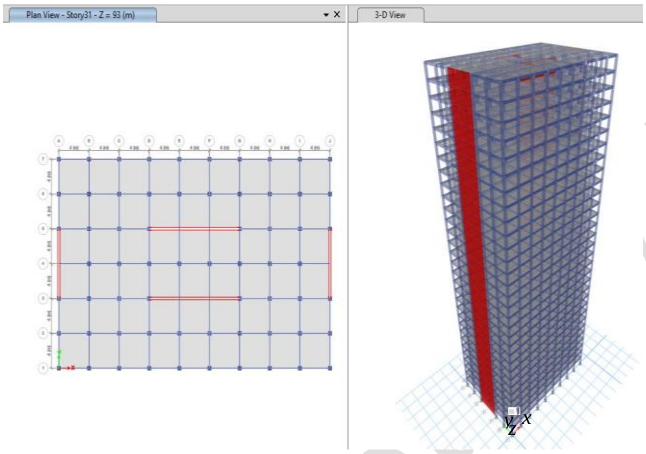

Fig. 7. Model 7-Buildings with shear wall located at two opposite edges and center

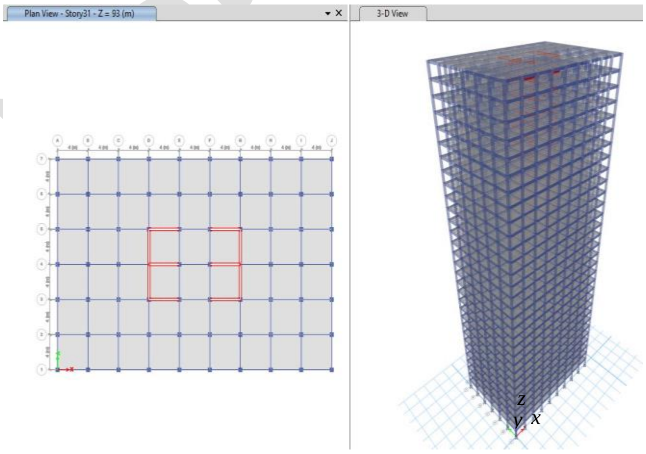

Fig.8. Model 8-Buildings with shear wall located at the center in E-shape

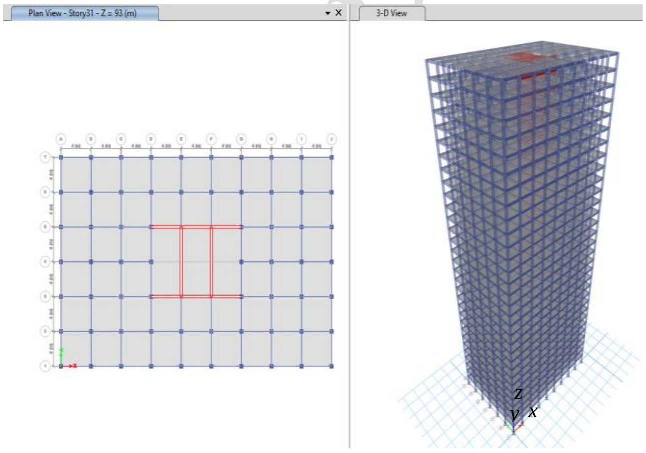

Fig.9. Model 9-Building with shear wall located at the center in I-shape

Dimensional Configurations

The plane grid has been defined with ten gridlines parallel to the Y-direction and seven gridlines parallel to the X-

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No. of bays along the X-direction	9
No. of bays along the Y-direction	6
Length of each bay (Meter)	4
Height of each floor (Meter)	3
Total height of buildings (Meters)	93
Size of the beam (mm x mm)	300 x 450
Size of column (mm x mm)	500 x 500
The thickness of the slab (mm)	150
The thickness of the shear wall (mm)	300

Material	**Concrete**	**Steel**
Grade	M30	Fe415
Specific weightγ (kN/m³)	25	76.97
Density ρ (kg/m³)	2549.29	7849.05
Modulus of Elasticity E (MPa)	27386.13	200000
Poisson's ratio μ	0.2	----------
Coefficient of Thermal Expansion (1/°C)	$10x10^{-6}$	$12x10^{-6}$
Shear ModulusG (MPa)	11410.89	----------

Material Properties

The properties of the two materials used in RCC building modeling are given in Table **1.** Dimension Configurations **Table 2.**

Loading Details

Dead loads are automatically calculated in the software. The floor finish load on each floor, as well as the roof, is taken as 1 kN/m^2. Live Loads on floors and roofs are taken as (IS Code 875, Part 2, 1987), which are 2 kN/m^2 and 1.5 kN/m^2 respectively. Wall loads on floors and roofs are 11.26 kN/m and 6.28 kN/m respectively, which are applied on the four outer edges of the buildings. Earthquake load data are taken from (IS Code 1893, Part 1,2016) and shown in Table 3. Wind load data shown in Table 4 are according to (IS Code 875, Part-3,2015).

Table 3. Earthquake load data

Zone Factor (Z)	0.16
Importance factor (I)	1
Response reduction Factor (R)	5
Site type	2 (Medium soil)
Time period (T)	2.25 seconds
Damping ratio (ξ)	5%

Table 4. Wind load data

Basic wind speed (v_b)	39 m/s
Terrain Category	3
Risk Coefficient (k_1)	1
Topography Factor (k_3)	1
Importance factor (k_4)	1
Windward coefficient(X-dir.)	1.2
Leeward coefficient(X-dir.)	0.9
Windward coefficient(Y-dir.)	1.3
Leeward coefficient(Y-dir.)	0.6

The following four load combinations are considered as per (IS Code 456,2000).

L.C.1:1.2(DL+LL+EQX)
L.C.2:1.2(DL+LL+EQY)
L.C.3:1.2(DL+LL+WX)
L.C.4:1.2(DL+LL+WY)

2. Results and Discussion

Validation of the method

Two models were created for this validation. The following are the descriptions:

Model:1 Conventional Frame(Building without shearwall) (Figure.10)

Model:2 Building with Box-type Shear Wall at the center of the geometry(Building with shearwall inform of core) (Figure.11)

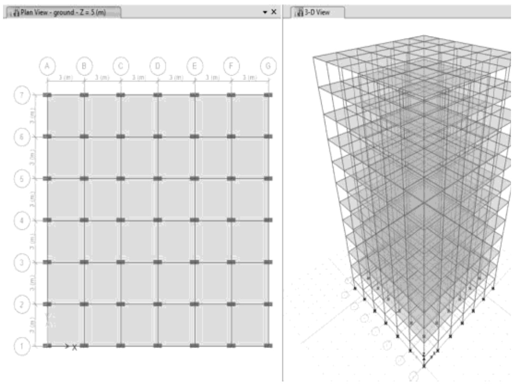

Fig. 10. Model:1 Conventional Frame(Building without shearwall)

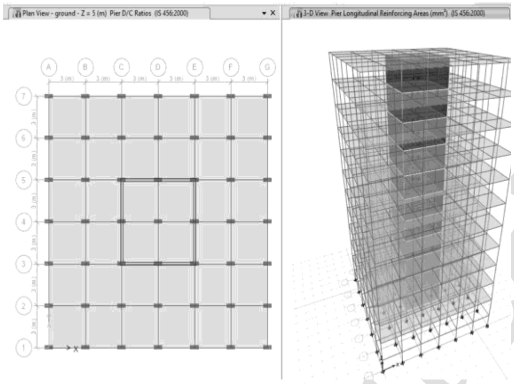

Fig. 11. Model:2 Building with Box-type Shear Wall at the centre of the geometry (Building with shear wall inform of core)

Table 5 summarizes the Model Descriptions, material properties, and the load applied and load combinations. The structures with different framing systems have been modeled using ETABS with the above-mentioned load conditions and combinations.

Table 5. Model Descriptions

SN	Specifications			Size
1	Plan dimensions			18m x 18m (X*Y)
2	Length in X- direction			18 m (6 Bays)
3	Length in Z- direction			18 m (6 Bays)
4	Floor-to-floor height			3.0 m
5	Plinth Level			2 m
6	Total height of Building (G+10)			35 m
7	Slab Thickness			200 mm
8	Type of Structure			OMRF has Shear Walls
9	Soil Type (as per IS:1893-2002)			Medium
10	Response Reduction Factor			5
11	Importance Factor			1
12	Seismic Zone Factor			0.36 (Zone V)
13	Time Factor			0.963
14	Grade of concrete			M25
15	Grade of Steel			Fe 415
16	Plinth Beam Size			0.23 m x 0.23 m
17	Floor Beam Size			0.23 m x 0.48 m
18	Column Size			0.30 m x 0.70 m
19	Loads Applied	DL	Dead Load	Calculated as per Self Weight
			Floor Finish	1 kN/m^2
		LL	Live Load	2.5 kN/m^2
		EQX	Seismic Load (X direction)	Calculated as per IS:1893-2002
20	Load Combination			1.2 DL + 1.2 LL + 1.2 EQX

The results of parameters like maximum story drifts have been carried out using the ETABS software. The results of story drift have been validated with the work of (Titiksh and Bhatt, 2017) for two models: A building without shear walls and a Building with shear walls at the center in the form of a core. It has been compared in Figure.12, in which current results show good agreement with the results of the previous paper. The data presented in Figure.12 for model-

1 and model-2 confirms the accuracy and applicability of the finite element method. Thus, the current modeling is correct and can be used to fulfill the objective of the study.

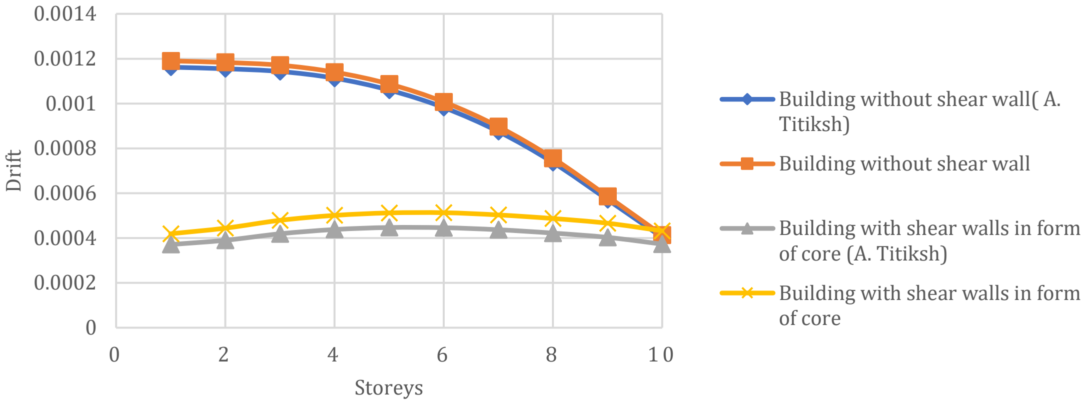

Fig 12. Max. Story drift of the First 10th story compared with the results of A. Titiksh *and G.Bhatt*

Present study

The results of parameters like maximum story displacements and maximum story drifts have been carried out using the Etabs software. For each parameter, comparison charts have been developed to get an idea about how the height of a building has affected the variation in parameters for each model. The top displacement of model-2 to model-9 has been compared with the top displacement of model-1. The results are discussed in the following four sections, categorized according to the load combination mentioned before.

Earthquake load considering load combination 1.2(DL+LL+EQX)

Maximum story displacements are shown in Figure 13. The displacement increases non-linearly with the height of the building. When a shear wall is introduced in the building, it increases the rigidity of the building and displacements are less. Shear walls also decrease the rate of increment of displacement. Among the models with various arrangements of shear walls, models 8 and 6 show maximum and minimum displacement at the top. Compared to model-1, the top-story displacement of other models is less by: 2.63 times for model-6, 2.12 times for model-7, 2.06 for model-9, 1.97 for model-5, 1.76 for model-4, 1.6 for model-3, 1.54 for model-2, and 1.49 for model-8. Story drift is the relative displacement of one-story relative to another story. The introduction of shear walls also decreases drift in buildings because of an increment in stiffness (Figure 14). There has been an increment in drift up to the 10th–15th story depending upon the arrangement of walls, followed by a decrement at a much slower rate for models with shear walls than model-1. So, Model-1 has experienced less drift at the top story. In addition, in all models with the shear wall, there is less difference between the drifts of two adjacent stories. Model-6 shows the minimum drift value compared to others. When compared to other models with shear walls, Model-8 drifts more at lower stories.

Earthquake load considering load combination 1.2(DL+LL+EQY)

When earthquake forces were applied in the Y-direction, models-6, and model-3 experienced minimum and maximum displacement (1.98 and 1.27 times less than model-1), respectively(Figure 15). Among the other models, model-2 was displaced 1.29 times, model-4 by 1.32 times, model-7 by 1.38 times, model-5 by 1.48 times, model-8 by 1.83 times, and model-9 by 1.91 times less than model-1 at the top story. Buildings have drifted in the Y-direction in the same way that they have drifted in the X-direction(Figure 16). Here, Models 6 and 9 show almost similar drift values, which are the minimum among all models. At lower levels, model-2 and model-3 have greater drift values; however, model-4 has the most drift on the top floor.

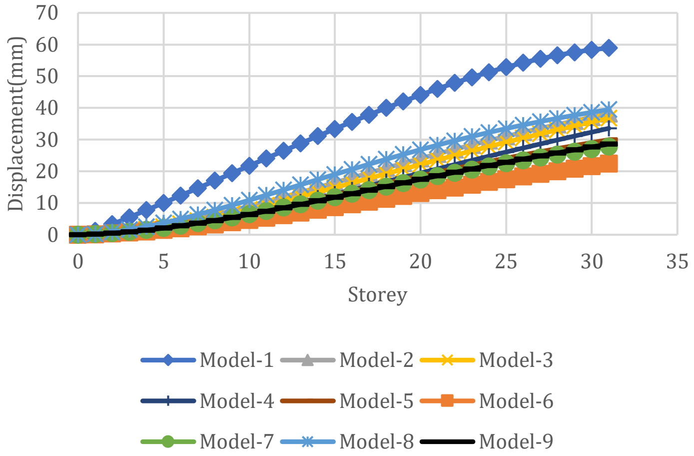

Fig.13. Storey displacement in X-direction due to L.C.1

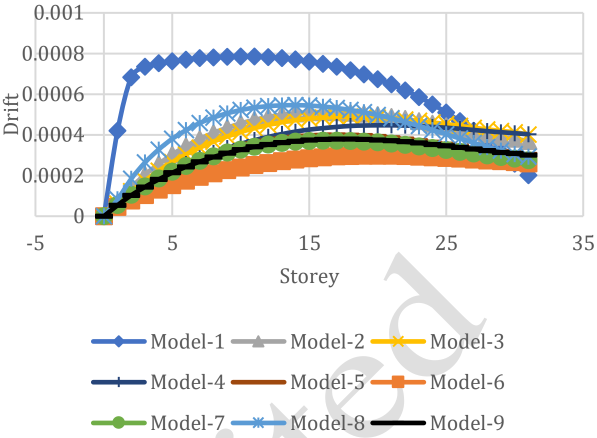

Fig.*14*. Storey drift in X-direction due to L.C.1

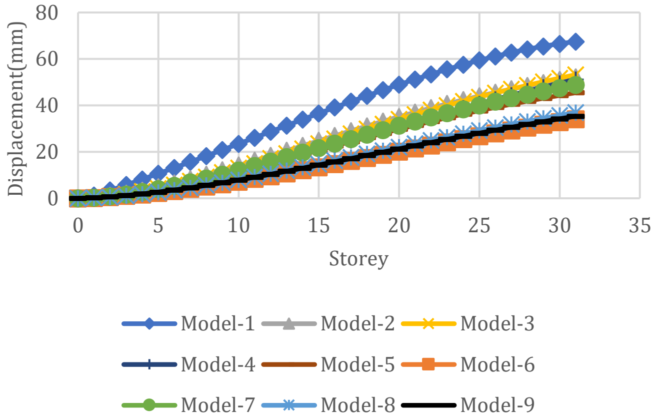

Fig.15. Storey displacement in Y-direction due to L.C.2

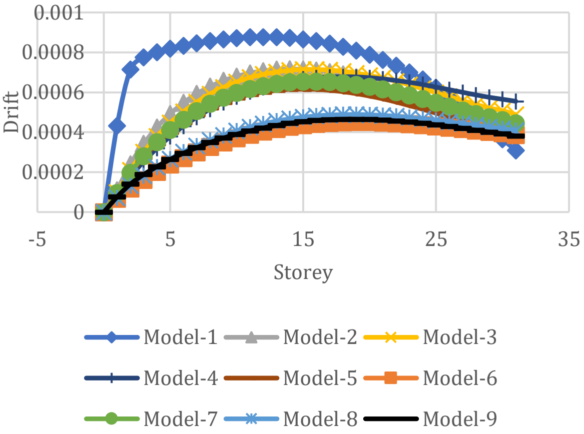

Fig 16. Story drift in Y-direction due to L.C.2

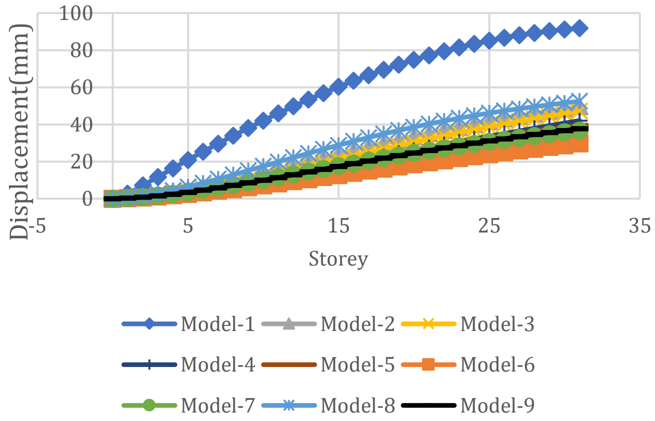

Fig 17. Story displacement in X-direction due to L.C.3

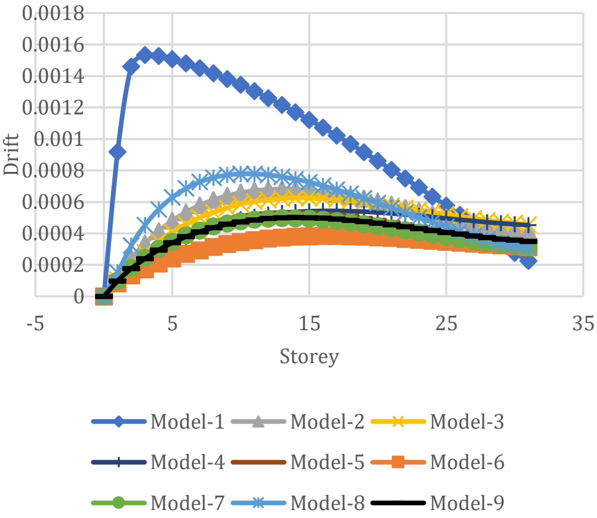

Fig 18. Story drift in X-direction due to L.C.3

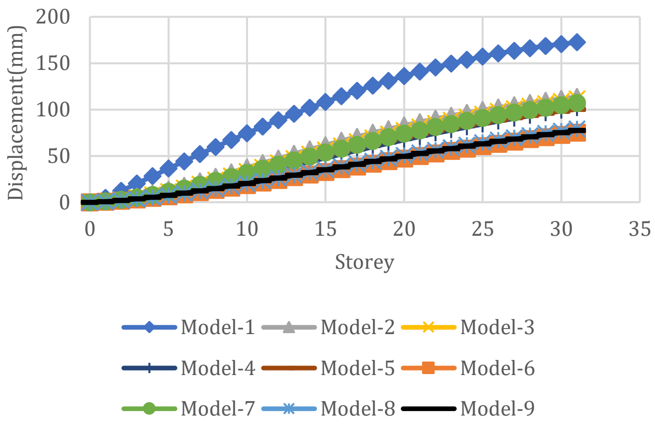

Fig. 19. Storey displacement in Y-direction due to L.C.4

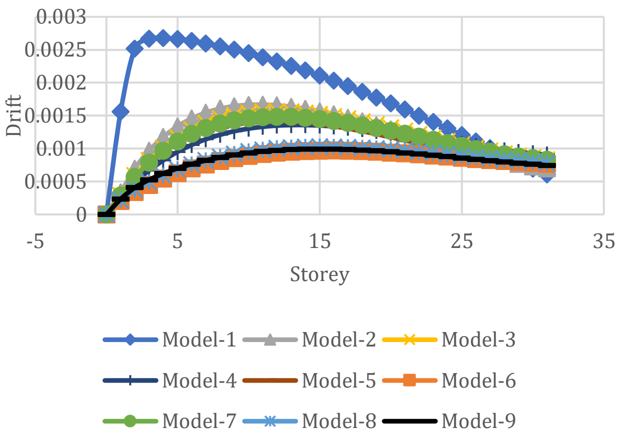

Fig 20. Story displacement in Y-direction due to L.C.4

Wind load considering load combination 1.2(DL+LL+WX)

The maximum story displacement chart for a given load combination is shown in Figure 17. Model-8 has a maximum displacement of the displaced top story, which is 1.75 times less than model-1. Model-6 has experienced a minimum displacement at the top (3 times less than model-1). The top displacements of other models compared to model-1 are 1.85, 1.94, 2.18, 2.33, and 2.5 times less for models-2, model-3, model-4, model-5, model-9, and model-7, respectively. The placement of shear walls serves to minimize the amount of drift that buildings experience when they are exposed to wind forces in the X-direction (Figure 18). The drift has increased up to 7th–12th stories depending upon the arrangement of walls, followed by decrement at a much slower rate than model-1. So, model-1 has less drift at the top story. Similar to earthquake loads in the X-direction, Model-6 drifts less than other buildings with shear walls, and Model-8 drifts more at lower stories.

Wind load considering load combination 1.2(DL+LL+WY)

When wind forces have been applied to models in the Y-direction, model-2 displaced its maximum, but its top displacement is still 1.52 times less than model-1(Figure 19). Model-6 has experienced a minimum displacement at the top (2.3 times less than model-1). The top displacements of other models compared to model-1 are 1.55, 1.61, 1.70, 1.72, 2.18, and 2.23 times less for models-3, model-7, model-4, model-5, model-8, and model-9, respectively. The drift of the buildings on the application of Y-direction wind forces has been shown to have a similar pattern to that of what we get on the application of X-direction wind forces(Figure 20).

4. Conclusions

The present study has presented the responses of various models subjected to seismic and wind loads. The findings of the study are concisely concluded here:

1. Model-6, in which shear walls have been arranged at the center in the form of a core, has performed most effectively against lateral loads in both directions.
2. It can't be stated from the study that walls at the center location always perform better, as model-8 has shown comparatively poor performance against lateral loads in the X-direction, leading to the conclusion that the direction in which walls have been arranged also plays an important role.
3. It has been seen that buildings with walls located at the corners are more vulnerable to both earthquake and wind load compared to buildings with properly arranged walls at the center and buildings with shear walls located at the edges.
4. Buildings with walls located at the edges and center are more effective than buildings with walls located only at the edge.
5. Because the T-shape building lacks symmetry in the y-direction, it is not very good at withstanding lateral loads that come from the y-direction. While x-directional symmetry makes it effective at withstanding earthquakes that come from the x-direction.

6. When compared to other shapes, regular shapes like rectangles and squares have done better than others when it comes to efficiently resisting the pressure of the wind.
7. As a result of its form, the C-shape has a greater degree of stiffness in the y-direction than it does in the x-direction.

Research limitations/implications- The study focused only on symmetrical building shapes, and lateral loads were calculated using the equivalent static method.

This investigation may be improved in the following ways.

1) Model analysis and forced vibration analysis of multi-story buildings subject to seismic or wind forces may be emphasized in the study.
2) The research may emphasize asymmetric building shapes, with the results applicable to real-world circumstances

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Ethics approval and consent to participate

Not applicable

Competing interests

The authors declare that they have no competing interests.

Further reading

Not applicable.

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