MODAL ANALYSIS OF TALL BUILDING WITH AND WITHOUT SHEAR WALL

Razesh Kanti Sarkar[1], Mahruha Farzana Alam[2] , Adittya Dey[3], Fatema Tuz Zahura*[4], Aseaya Khanom Mim[5], Fowzia Mahbub[6] and Hameem Al Hussain[7]

[1] *Lecturer, Uttara University, Bangladesh, e-mail :rksarkar@uttarauniversity.edu.bd*
[2] *Graduate Student, Ahsanullah University of Science and Technology, Bangladesh, e-mail: avaalam252@gmail.com*
[3] *Graduate Student, Ahsanullah University of Science and Technology, Bangladesh, e-mail: adittya099@yahoo.com*
[4] *Associate Professor, Ahsanullah University of Science and Technology, Bangladesh, e-mail: fatema.ce@aust.edu*
[5] *Lecturer, Uttara University, Bangladesh, e-mail: aseayakhanom.akm@gmail.com*
[6] *Graduate Student, Ahsanullah University of Student, Ahsanullah University of Science and Technology, Bangladesh, e-mail: fowzia.mahbub@gmail.com*
[7] *Lecturer, Uttara University, Bangladesh, e-mail: hahussain @uttarauniversity.edu.bd*

***Corresponding Author**

ABSTRACT

Due to land scarcity in densely populated modern cities and capitals, highrise buildings are growing fast worldwide. Bangladesh currently has a thriving economy and population, which is driving up demand for land to accommodate the expanding population. As a result, building high-rise structures has become urgently necessary. High-rise structures necessitate a high level of structural stability in order to ensure safety and meet design requirements, owing to their extensive array of structural components and features. In this present research modal analysis on two high rise buildings with and without edge shear walls has been simulated using finite element model (FEM) to find out which one is better and effective under the given conditions. This study started with two high-rise concrete buildings (one with an edge shear wall and another without a shear wall). For modeling and analyzing the structures, finite element software has been used. All the loads, load patterns, load combinations, and loading conditions are selected following BNBC 2020 ASD load combination. After the modal analysis of the two 20-story buildings, modal period and frequency, displacement, story drift, base reaction, and bending moment of columns and typical story beams are observed and analyzed. The analysis and comparison results showed that the edge shear walls can effectively reduce the time period. The building with an edge shear wall has a lower frequency. Also, the building with an edge shear wall shows less story displacement, story drift, and bending moment but a high base reaction. Finally, it has been found that among the systems under consideration, building with an edge shear wall is best effective under similar considerations. This method of analysis can be used for a quick evaluation of the existing structures or for the early design of new ones.

Keywords: *Model, High-rise Building, Displacement, Structure, Shear Wall*

1. INTRODUCTION

Every object has an inherent period during which they will oscillate if given a horizontal push. The frequency or period of an earthquake is a significant feature. If a structure's natural period and the period of an earthquake wave coincide, the structure can be severely damaged or destroyed. For the structure's protection, it is important to determine its natural period of vibration as well as complex characteristics. This may also be useful in the future in the event of an earthquake. Wind load is sometimes more dangerous than an earthquake for tall buildings. As a result, systems must take into account wind loads. The method of determining a system's inherent dynamic characteristics, such as natural frequencies, damping factors, and mode shapes, and using them to formulate a mathematical model for its dynamic behaviour is known as modal analysis. Modal analysis is used in structural engineering to assess the natural frequency, natural time, and mode shapes of a structure. It is the most basic of all dynamic analysis types and serves as the foundation for more comprehensive dynamic analysis. It's a non-destructive research technique for locating critical defects and the dynamic behaviour of civil structures when subjected to real-life forces such as earthquake waves, wind, ambient vibration, traffic loading, and so on.

The performance of shear walls based on their location, orientation, and building materials was discussed in relation to several research. Thilakarathna et al., (2018) examined the seismic performance of a 40-story high-rise RC building intended to withstand various amounts of lateral wind loads. This highlights how the seismic performance of high-rise dual-system structures can be impacted by the design wind load level. In order to ensure overall structural safety and integrity, a comprehensive performance-based seismic evaluation should be carried out even when wind must be a deciding factor in the design of a lateral load-resisting system.

Banerjee et al., (2022) have shown that shear walls are one of the most effective building features in resisting lateral stresses during earthquakes. By creating shear barriers, damage from lateral forces brought on by earthquakes and strong winds can be minimized. Shear wall construction will increase the rigidity of the buildings, reducing damage to the structure and its contents. Rakshit Patil and Avinash S Deshpande constructed the models with shear walls in various positions (for example, at the centre of the building and at the building's corner). Based on this research, they determined if a shear wall given at the building's core is more effective in reducing displacement than the shear wall provided in the building's corner. The reduced story drifts as a result of the addition of a shear wall at the building's core sections, allowing the structure to perform virtually optimally stiff.

In order to establish the precise location of a shear wall in a multi-story building, Mr. K. LovaRaju et al., (2015) undertook a non-linear analysis of frames. An eight-story structure made up of four models with shear walls at various positions throughout all seismic zones was subjected to an earthquake load using ETABS. Push-over curves were created, and it was demonstrated that, when displacement and base shear are taken into consideration, a construction with a shear wall at the proper location is more significant.

Eshan et al., (2013) investigated how the placement of shear walls affected a building's seismic performance. SAP 2000 was used to calculate the top-story displacements for various configurations. According to the findings of the study, the top story drift can be minimized by modifying the placement of the shear wall, and the quantity of the shear wall has no effect on the seismic behaviour of buildings.

Our goal is to compare 20 stories and a 20-story building having shear walls by examining natural frequency, mode shapes, and other characteristics.

2. METHODOLOGY

2.1 Information of analysed building

Two 20 storied buildings models, Model-A & Model-B have been considered for this study. Each model is square building which is 90ft in long and wide. Total height of the building is 212 ft where the ground floor height is 12ft and rest floors are 10ft. The bottom story height is 15ft. All of the geometrical properties, reinforced concrete properties, load combination of building and seismic loading condition are given this following table:

Table 01: Details of Geometrical Properties

S. No	Description Parameter	Value			
1	Depth of Foundation	25 ft			
2	Floor to Floor height	10 ft			
3	Ground Floor height	12 ft			
4	Compressive Strength of Concrete	4000 psi			
5	Column Size	Floors	C_1 (in^2)	C_2 (in^2)	C_3 (in^2)
		1 to 11	36*24	30*24	24*20
		12 to 20	32*22	28*22	24*20
		Stair Column, C_4 (in^2)		20*18	
6	Beam Size	Floors	B_1 (in^2)	B_2 (in^2)	B_3 (in^2)
		1 to 11	32*20	28*20	24*18
		12 to 20	24*20	26*20	22*18
		Great Beam, GB (in^2)		26*20	
		Stair Beam, SB (in^2)		24*20	
7	Slab Thickness	Floor Slab		8 in	
		Stair Slab		10 in	
8	Shear Wall Thickness	12 in			

Table 02: Reinforced concrete properties

Item	Description	Unit	Value
f_c'	Compressive strength of concrete	ksi	4
f_y	Yield stress of steel reinforcement	psi	72,500
E_c	Modulus of elasticity of concrete	lb/in^2	3604996.5
ς_c	Density	lb/in^2	150
U	Poisson's ratio		0.2
G	Shear Modulus	lb/in^2	1502081.88

Table 03: Load combination of the building

Live load (floor slab):	40 psf
Live load (roof slab):	60 psf
Live load (stairs):	100 psf
Floor finish (floor):	16 psf
Floor finish (roof):	22 psf

Partition wall loads on beams	0.5 k/ft
Load for overhead water tank	As per BNBC 2020

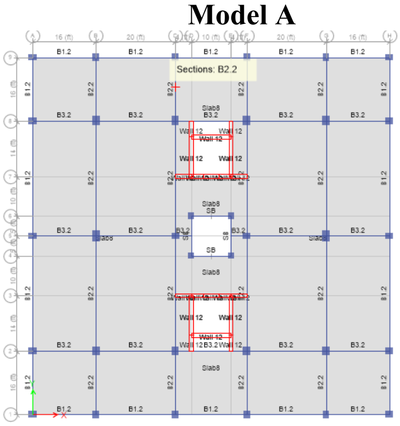
Table 04: Seismic loading parameters

Location:	Dhaka (Zone 2)
Zone coefficient, *Z* :	0.2
Structural Importance factor, *I*:	1
Building height in meters, h_n:	64.62
Building framing system:	Concrete moment resisting frame
Coefficient C_t:	0.0466
Time period, *T:*	1.59 s
Building design category:	C
S_S:	0.5

2.2 Building layout

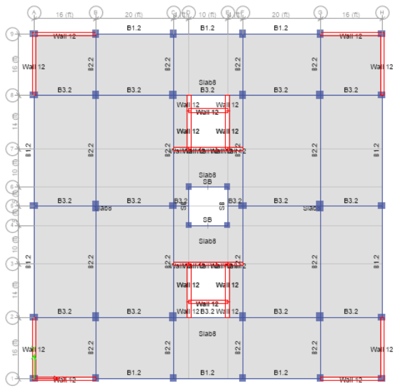
In this project the behaviour of a 20 storied RCC building under seismic analysis has been observed. Finite element software has been used for modelling of those buildings. In this paper, two types of buildings are compared: one without shear walls on four edges of the building which is Model-A and the other with shear walls on four edges which is Model-B.

Model A

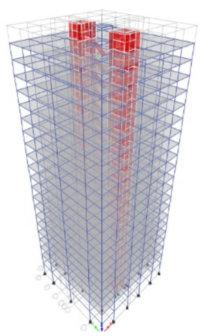


Plan View

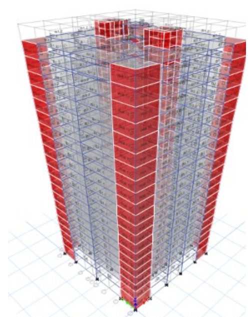
Model B



Plan View



3D View



3D View

Figure 1: Building Layout of Model, A & B

3. RESULT AND DISCUSSION

3.1 Modal Period and Frequency of 20 storied Building

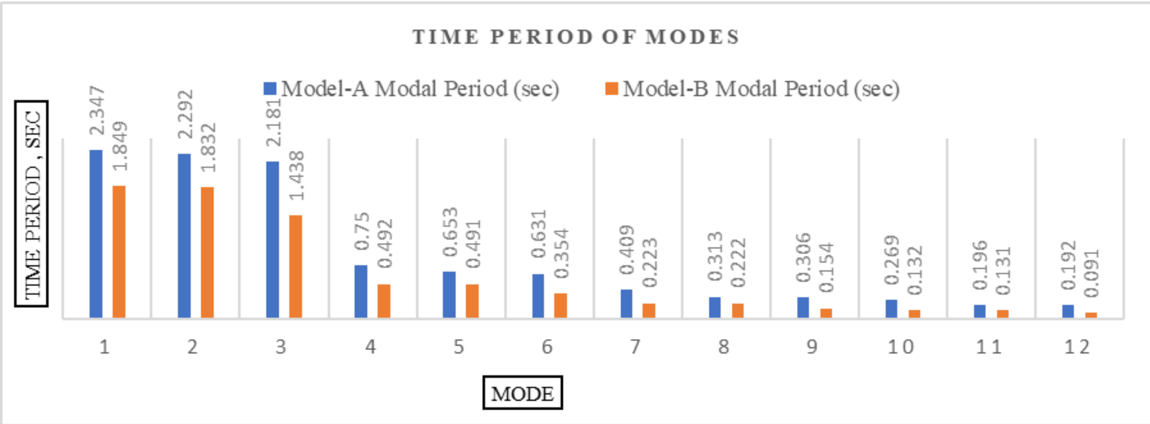


Figure 2: Time period of modes of model A and model B

Figure 2 illustrates information about the period of modes of model A and model B. By comparing the given data, it can be observed that model B gives the lowest value of period T for all of the modes compared to model A. In mode 2, model a give the maximum value of 2.292 sec, higher than the others. Overall, the values of the period T, decrease for all models with the increase of the number of modes.

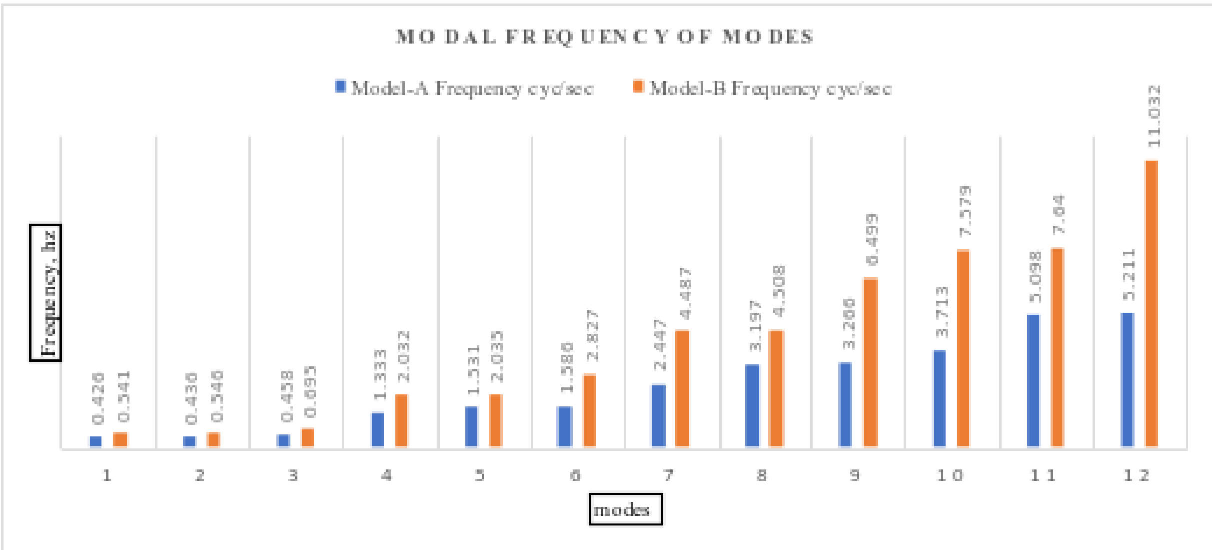


Figure 3: Frequency of modes of model A and model B

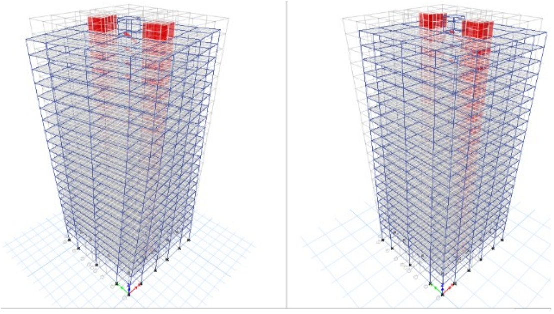
The frequency of modes is inversely proportional to the time period. All modes of both model buildings are shown in figure 3. Model-B gives the maximum values for frequency, f than Model-A. The frequency value, f, increases with the increase in number of modes.

3.2 Mode Shapes of Model-A and Model-B

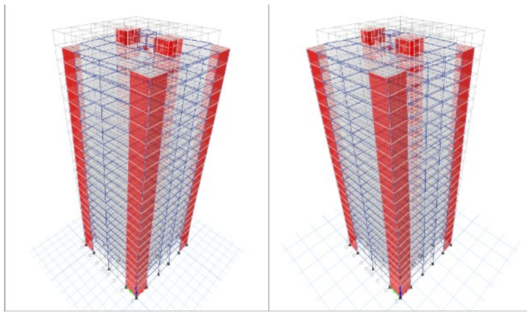
The mode shapes of Model-A and Model-B are given below:

Model A

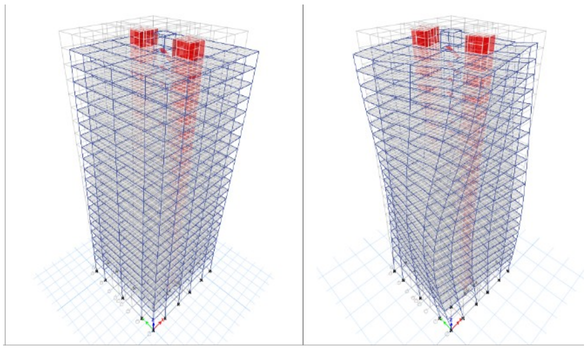
Model B



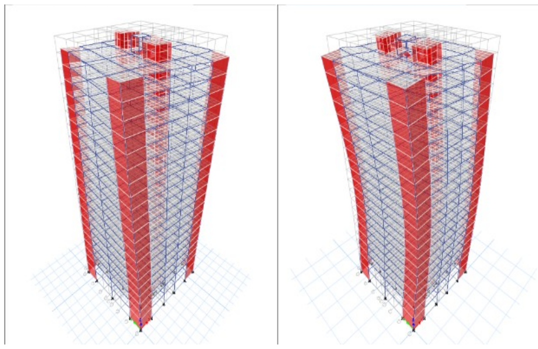
Mode Shape 1&2



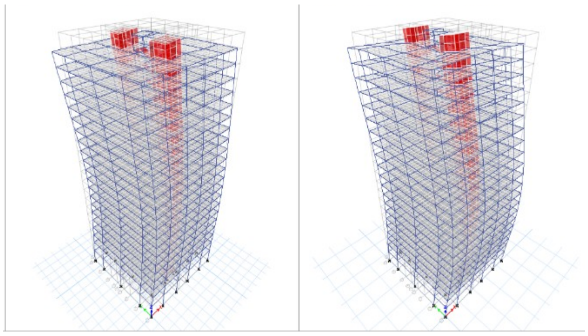
Mode Shape 1&2



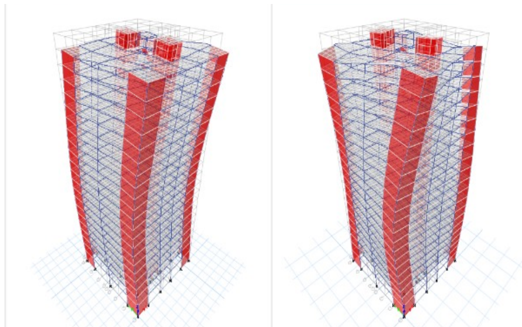
Mode shape 3&4



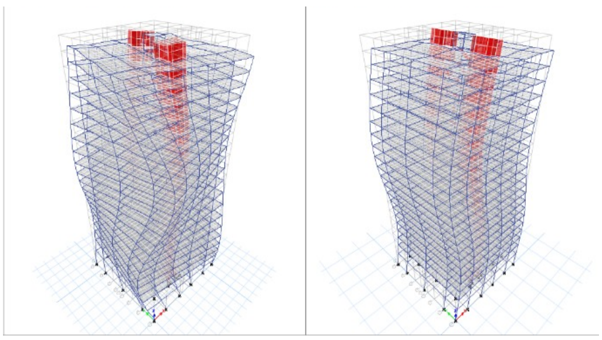
Mode shape 3&4



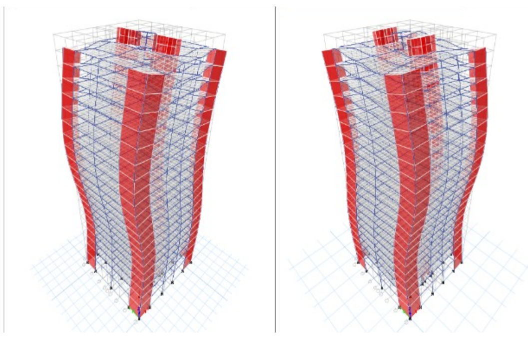
Mode shape 5&6



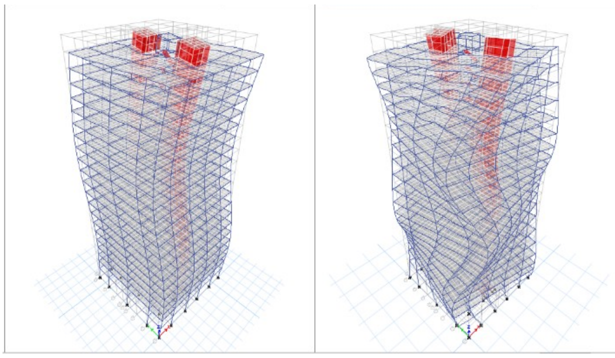
Mode shape 5&6



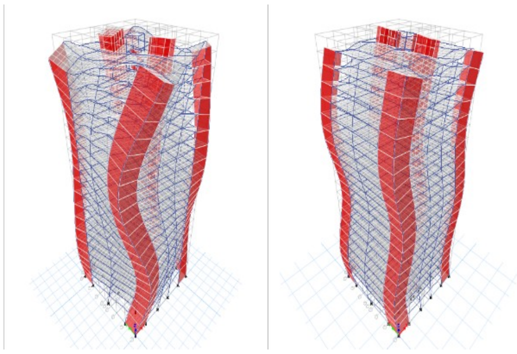
Mode shape 7&8



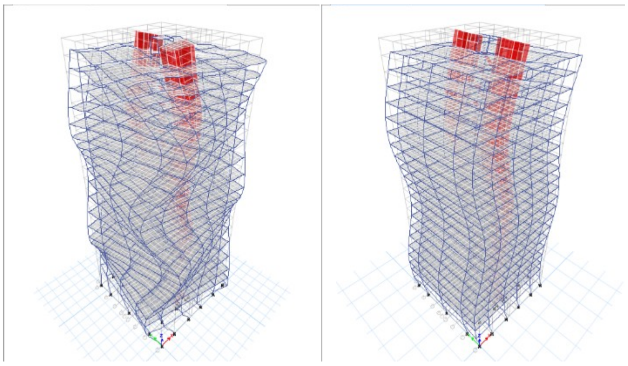
Mode shape 7&8



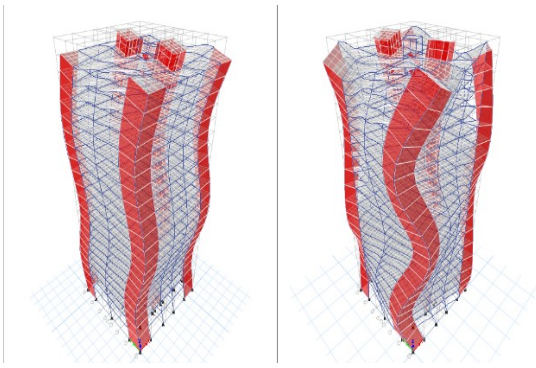
Mode shape 9&10



Mode shape 9&10



Mode shape 11&12

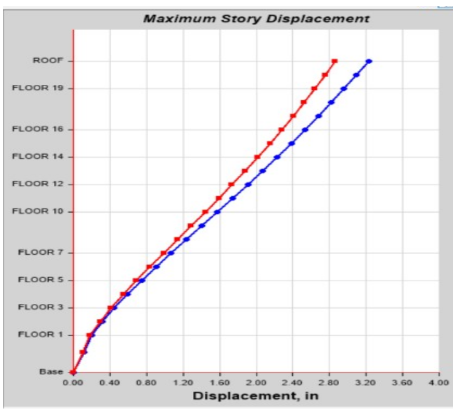


Mode shape 11&12

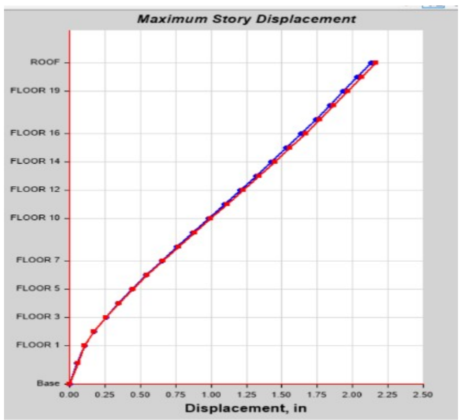
Figure 4: The mode shapes of Model-A and Model-B

3.3 Displacement of Structure

Displacement is an important parameter to determine the lateral movement of a structure. Although a building is designed to bear all lateral loads, an excessive displacement hampers people's comfort, and sometimes it causes damage to the beam column. Displacement graph for 20 stories for both models are shown in figure 5.



Model A



Model B

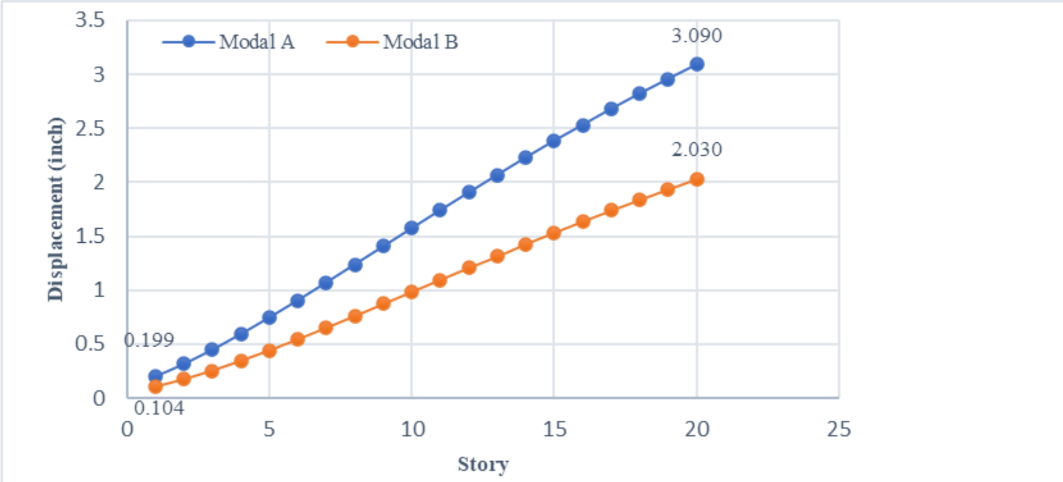
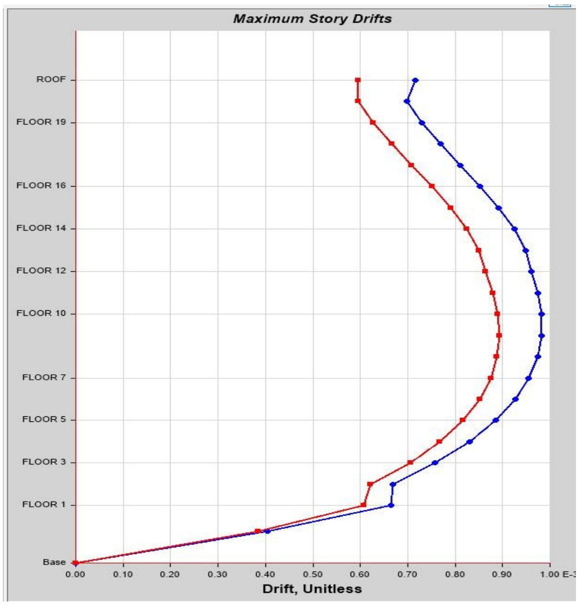


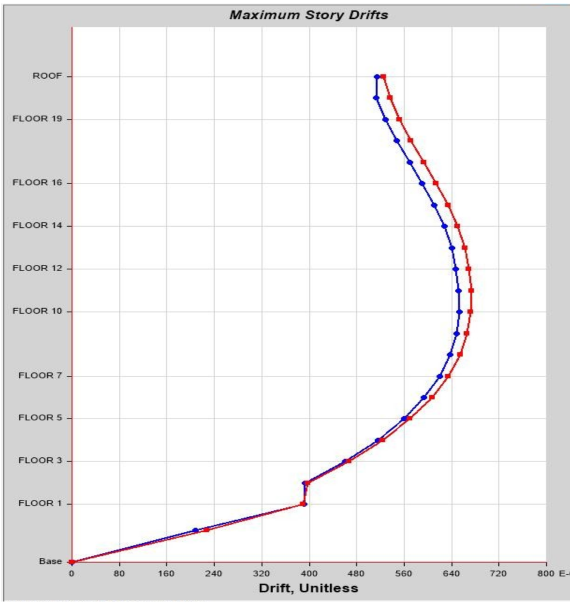
Figure 5: Displacement of 20 stories for the Model A & B

The line graphs represent the change in deflection concerning story level for both structures, including the building with no edge shear wall (Model-A) only and the building with edge shear walls (Model-B). In Model A, displacement varies from 0.199 inch to 3.090 inch. In Model B, displacement varies from 0.104 inch to 2.030 inch. For both models, story 1 shows the most minor displacement, and Story 20 shows the maximum displacement.

3.4 Story Drift



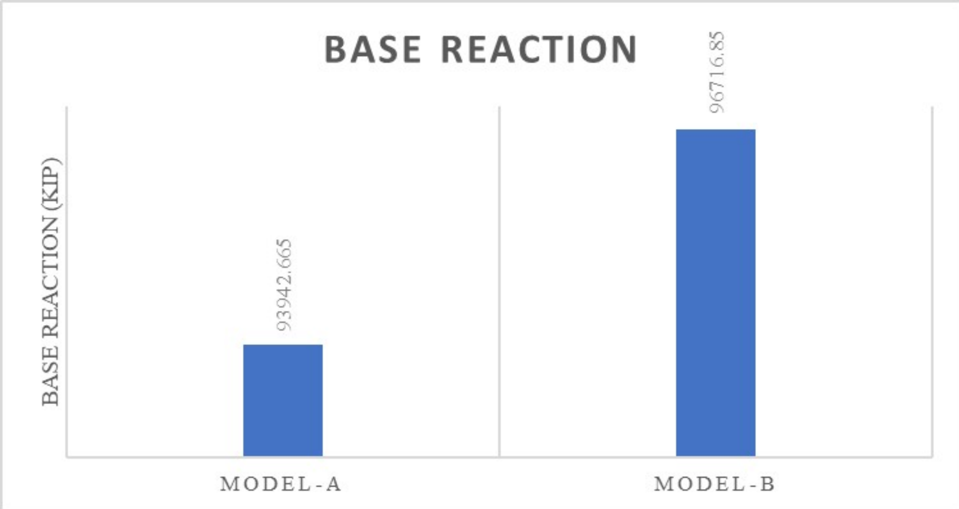
Model A



Model B

Figure 6: Story drift for Model A & B

From the above figure 6, it can be seen that in both direction for both models Story 7 to 10 shows the maximum drift and Ground Floor (GF) shows the minimum drift. It also can be seen that story drift is less when there are shear walls in four edges.



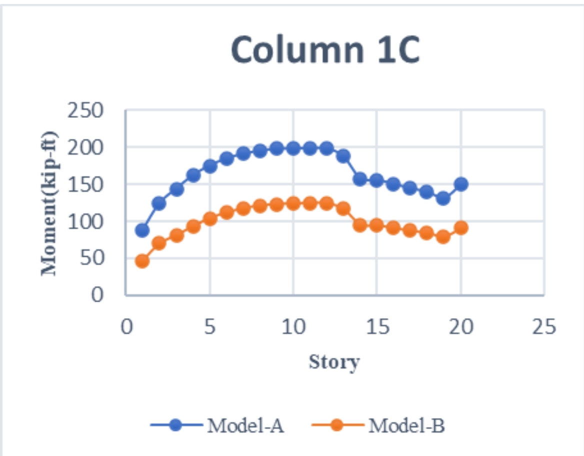
3.5 Base Reaction of 20 Story Building

Figure 7: Base reaction for Model A & B

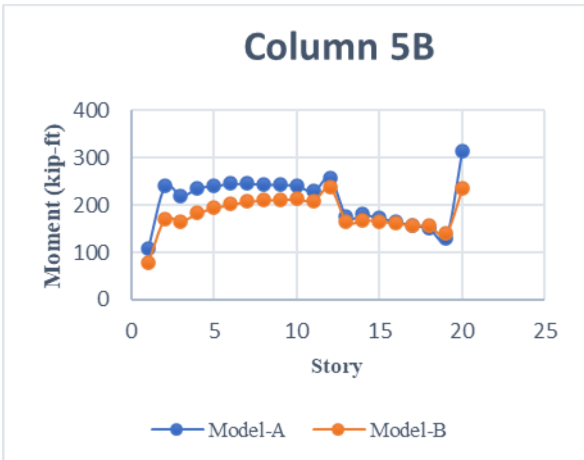
From figure 7, it has been seen that the base reaction shows higher values in the building with edge shear walls than the building with no edge shear wall.

3.6 Moment Distribution in Columns

The moment distribution in the exterior column 1C and the interior column 5B has been shown for 20 storied building for both models. The plan view, elevation view and bending moment with respect to story level for the aforesaid columns are shown in the following figures.



Moment Distribution of Exterior Column 1C



Moment distribution of interior column 5B

Figure 8: Moment distribution in Column 1C and 5B for Model A & B

Figure 8 represents the moment distribution of exterior column 1C that clearly shows the moment is maximum in mid height which is in 9th ,10th floor for both the models. It is also seen that moment is less when shear wall is placed in four corners. Furthermore, moment gradually increases up to mid height and then starts to decline. The curve shape of moment distribution for both models are same. However, the moment distribution of interior column 5B indicates that the maximum moment occurs in 20th story for both models. The value is less in the one with edge shear walls for this case also.

4. CONCLUSION

Under modal analysis, the behaviors of the two 20-story buildings with and without edge shear walls are closely observed, and the results are compared.

01. As the period T decreases, the frequency f increases. By providing a shear wall in four corners, the modal period decreases nearly 0.78 times in Model-B related to Model-A.
02. The building with edge shear walls shows less displacement and reduces story drift from the building without edge shear walls. The average displacement for Model A is 1.656 inches, and for Model B is 1.0441 inches. So, the edge shear wall has reduced by 36.95% displacement. The average drift reduced from 0.001022 inches to 0.000651 inches in Model-B, meaning edge shear walls have reduced by 36.30%.
03. Values of base reaction are higher in Model-B (96716.85 kips) than in Model-A (93942.665 kips). The edge shear wall has increased by 2.95% base reaction.
04. The bending moment in the exterior and interior columns has decreased in Model B from Model A. In both models, the exterior column 1C on floor 11 shows the maximum bending moment. (Model A-198.9kip and Model B- 124.13kip). The interior column 5B shows similar behavior. In the interior column 5B, Story 20 shows the maximum values (Model A-315.26k-ft, Model B-235.03k-ft). So, the edge shear wall decreases by 37.6% bending moment in exterior column 1C and 25.45% bending moment in interior column 5B.

5. RECOMMENDATION

From this study it is observed that building with edge shear walls (Model-B) is most effective under the given load and modal conditions. So, it is recommended that, in future construction, under such loading conditions edge shear walls should be used for better effective design for higher safety margins.

Following recommendations may be taken into consideration for further development in this kind of study and for another research works-

- Edge shear walls have proven effective. So further work can be done on shear walls placed in different locations of the building.
- Shear walls help to get better modal data.
- Time history analysis with different earthquake data P-delta effect and other analysis may be give the best result.
- This study plays a vital role in future modal analysis of high-rise buildings.

REFERENCES

Banerjee, R. and Srivas, J.B. (2022) Optimization of shear wall location in C shaped reinforced concrete framed building subjected to earthquake loading [Preprint]. doi:10.21203/rs.3.rs-1926210/v1.

Ehsan, S.F., Rao, K.R. and Bahador, B. (2013) 'Determination of time period of vibration effect on seismic performance of building', Applied Mechanics and Materials, 330, pp. 878–883. doi:10.4028/www.scientific.net/amm.330.878.

LovaRaju, Mr.K. and Balaji, Dr.K.V.G.D. (2015) 'Effective location of shear wall on performance of building frame subjected to earthquake load', IARJSET, pp. 33–36. doi:10.17148/iarjset.2015.2105.

Reeba Mary Cherian and Aswathy S Kumar (2017) 'Seismic analysis of multistoried symmetrical building based on shear wall positions', International Journal of Engineering Research and, V6(06). doi:10.17577/ijertv6is060258.

Thilakarathna, S.N. et al. (2018) 'The effect of wind loads on the seismic performance of Tall Buildings', Athens Journal of Technology & Engineering, 5(3), pp. 251–276. doi:10.30958/ajte.5-3-3.