

Study on Analysis of Fiber-Reinforced Concrete Shear Walls with Openings

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Abstract

High-rise buildings employ shear walls as structural elements to withstand lateral forces brought on by earthquakes and wind. According to number of studies, shear walls function effectively when devoid of openings, although openings are essential to meet diverse functional needs such as doors, windows, staircases, and service ducts. Therefore, the presence of openings impacts the structural strength. 11 multi story buildings with 12 story with symmetric plan of 25mX25m are analyzed in this study in ETABS to compare its story displacement, storey drift, storey shear and storey stiffness between without and with vertical or regular as well as staggered openings in the shear walls placing shear wall at corner and center of the structure. Furthermore, the model with effective strength is analyzed by changing the size of openings in the shear wall. This study focuses on replacing the shear wall's concrete with fiber-reinforced concrete in order to strengthen the larger openings in the wall.

Keywords: Shear wall, Regular and staggered openings, Response spectrum method, Size of opening, Fiber reinforced concrete, ETABS.

1.Introduction

Superfast urbanization has led to the rise in no of buildings in the most of the cities. A high- rise building is typically one that has 12 or more stories and is used for the commercial and residential purpose. In this high rise buildings, beam and column dimensions work out large and reinforcement at the beam-column joints are often heavy, so that there is a blocking at beam column joints and it is difficult to position the concrete and vibrate the concrete, this leads to unsafety of the building ,to address these concerns and enhance building safety, shear walls are introduced in high rise structures[1]. These walls typically extending from the foundation level to the building's full height and play a crucial role in mitigating lateral forces induced by factors such as wind and seismic activity. As a result, these buildings exhibit improved effectiveness in resisting external forces and minimizing structural deformations[12]. Shear walls are typically constructed from materials such as concrete or masonry and also steel braced frames. Shear walls should be positioned along the perimeter of buildings or they may be a shear core. The placement of shear wall significantly influences its ability to resist lateral loads.

Shear walls necessitate openings to meet various functional needs, such as accommodating windows, doors, service ducts, and staircases[5]. However, the existence of openings significantly influences the building's performance. They diminish the building's strength and compromise its lateral stiffness. The placement, size and shape of these shear wall openings significantly influence the structure's stiffness and strength[6]. Openings are generally provided in the regular or staggered pattern. Bush et al.,(2022) [12] studied on shear walls with uniform and staggered openings in ETABS software. They proved that staggered openings perform better against lateral loads than do normal openings. Hui Wu and Bing Li (2003) [7] studied on shear walls with openings along with flanges. Their findings indicated that shear walls featuring small openings exhibit superior performance when contrasted with those incorporating large openings. Hence smaller openings have a relatively limited effect on stiffness and strength, larger openings can exert a more pronounced influence.

Therefore, it is crucial to implement appropriate measures to counteract these reductions and maintain the structural integrity of the building.

2.Methods And Modeling

The analysis of buildings was carried out using the methods mentioned below

- Equivalent static method
- Dynamic analysis method

In turn, dynamic analysis can be performed by

Response spectrum method

According to the Indian code (IS 1893-2016), if a building exceeds a height of 15 meters and is located in Zone IV, it is mandatory to conduct dynamic analysis. The analysis can be carried out using either the response spectrum method or the time history method. In this investigation, 12-story building models were developed and subjected to analysis using the response spectrum method in ETABS software. This method involves determining the displacements and member forces for each vibration mode. A response spectrum is a set of curves drawn between the maximal response of the SDOF system and the time interval. In order to compute the lateral forces an earthquake induces in a structure; response spectra help identify the largest structural responses within the linear range.

Modeling

A 12storey building with a 3 m story and bottom height with shear walls is used in this. This structure has five bays that span five meters in X and Y direction. Fig 1 shows the plan of the building. All the model buildings are fixed at base and location selected as Zone IV. Table 1 shows the geometrical and sectional properties of the building. Table 2 and Table 3 shows the applied loads on building and seismic data. 11 models were analyzed in this study.

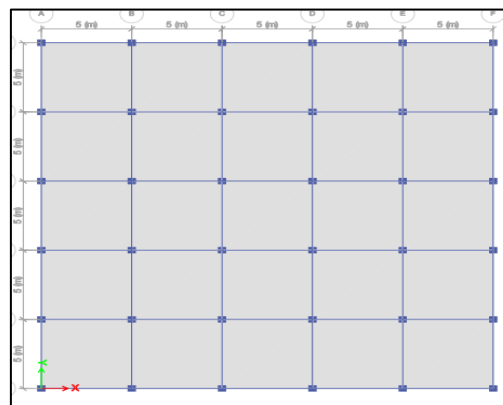


Figure 1. plan of structure

Table 1: Sectional properties

Plan	25x25 m
Height of building	36m
No. of stories	12
Height of each storey	3m
Beam dimensions	300 X 450 mm
Column dimensions	450 X 450 mm
Slab thickness	125 mm

Shear wall thickness 200 mm

Table 2: Loads

Dead load (As per IS 875 Part 1)	1.5 kN/m ² and 1kN/m ² on roof
Live load (As per IS 875 Part 2)	2 kN/m ² and 1.5 kN/m ² on roof
Wall load on slab	2.346 kN/m ²
Wall load on beam	11.73 kN/m
Earthquake load	As per IS 1893-2016

Table 3: Seismic data

Zone	IV
Zone factor(Z)	0.24
Importance factor	1
Response reduction factor	3
Soil type	Type 2

Table 4: Properties of fiber reinforced concrete [13]

Properties	Steel fiber	Glass fiber
Specific mass density	2640 kg/m ³	2407 kg/m ³
Modulus of elasticity	25100 MPa	22200 MPa
Poisson ratio	0.3	0.23
Coefficient of thermal expansion	0.0000008	0.0000059
Shear modulus	9653.85 MPa	9024.39 MPa
Compressive strength	52.5 MPa	47.5 MPa

Table 5: Models data

Model	Description
Model 1	Shear walls at centre of structure without openings
Model 2	Shear walls at corners of structure in X direction without openings
Model 3	Shear walls at corners of structure without openings
Model 4	Shear walls at corner of structure with regular openings
Model 5	Shear walls at corner of structure with staggered openings
Model 6	Shear walls at centre of structure with regular openings

Model 7	Shear walls at centre of structure with staggered openings
Model 8	Shear walls with the size of opening 1200mmx1500mm at corners of structure
Model 9	Shear walls with the size of opening 1500mmx2000mm at corners of structure
Model 10	Shear walls with openings of 1500mmx2000mm made of concrete reinforced with steel fiber
Model 11	Shear walls with openings of 1500mmx2000mm made of concrete reinforced with glass fiber

3. Results And Discussion

3.1 Analysis of shear walls

A 12storey building with five bays in each direction is considered for the analysis as shown in table 5. The shear walls at the corners as shown in figure 2 and figure 4 and at the center bay as shown in figure 3 are considered in the first stage and analyzed.

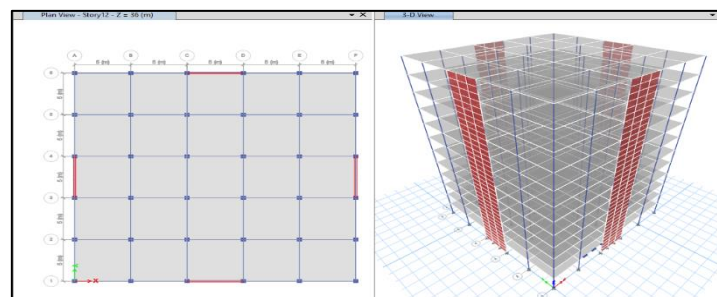


Figure 1. Model 1

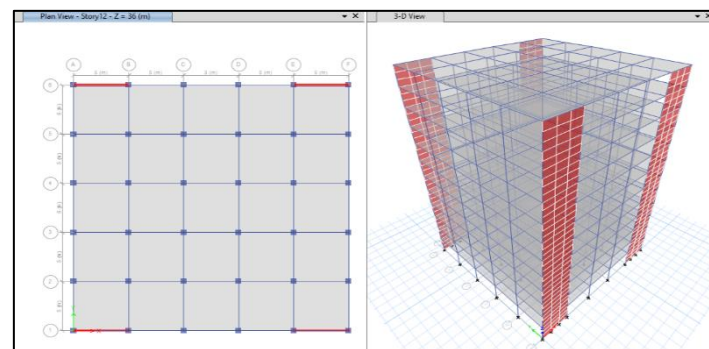


Figure 2. Model 2

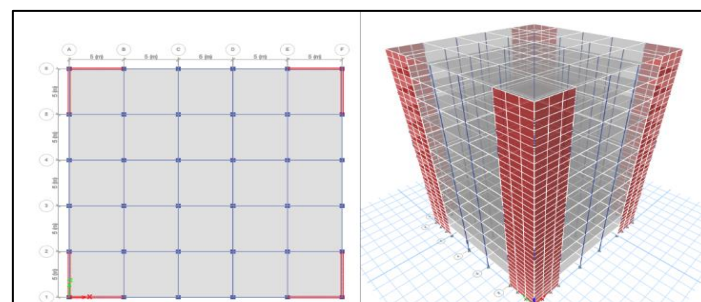


Figure 3. Model 3

The results are on storey displacement, storey drift, storey shear, and storey stiffness are obtained and presented in the table 6. Here's a breakdown of what each parameter represents:

Storey displacement: It represents the storey's absolute displacement caused by lateral forces. Units are mm.

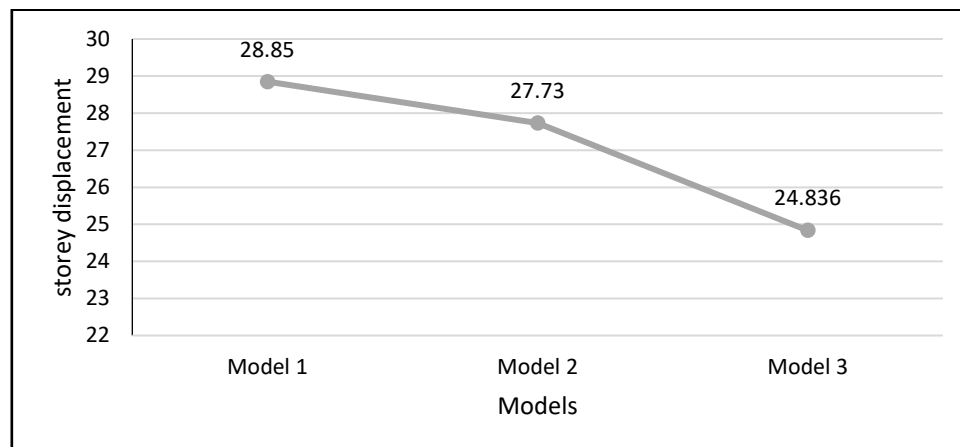
5.1.2 Storey drift: It refers to the relative space between the floors that are either above or below the storey that is being examined.

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

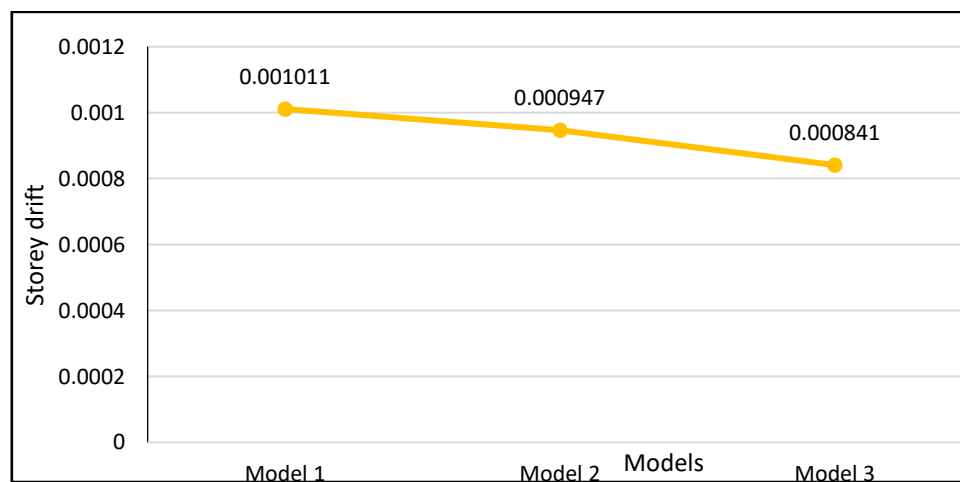
5.1.4 Storey stiffness: The capacity of a structure to withstand lateral displacement (storey drift) when subjected to a lateral force (storey shear).

Table 6: Results of shear walls

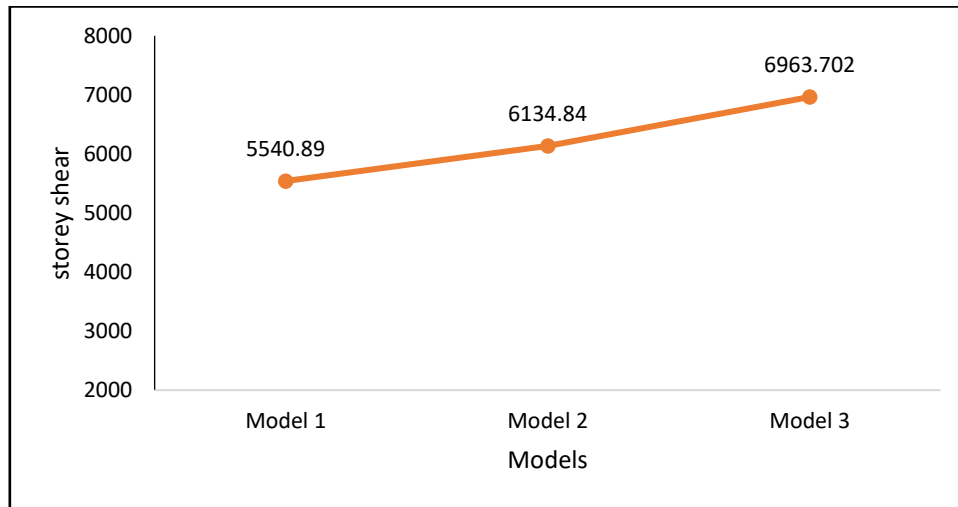
Model	Storey displacement	Storey drift	Storey shear	Storey stiffness
Model 1	28.85	0.001011	5540.89	5180859
Model 2	27.73	0.000947	6134.84	7409302
Model 3	24.836	0.000841	6963.702	8664092



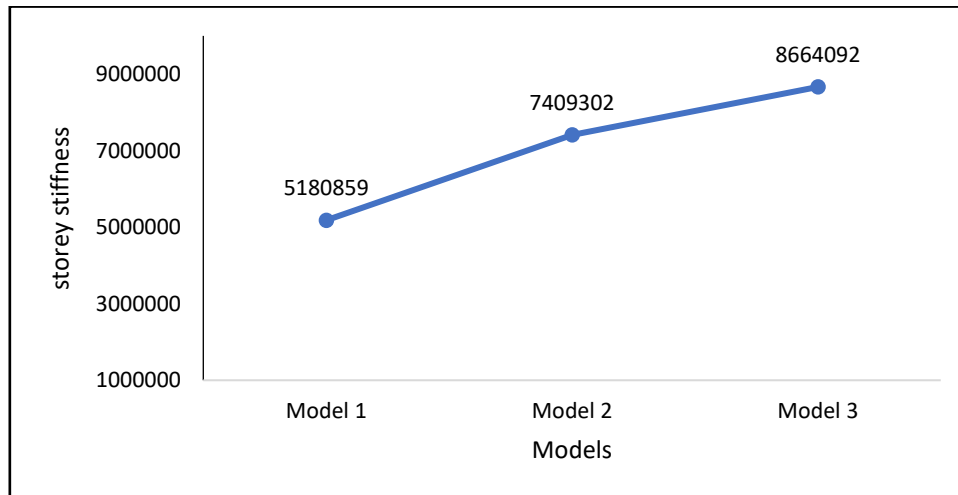
a) Story displacement



b) Story drift



c) Story shear



d) Story stiffness

Figure 5 Response of shear walls

The preceding charts shows maximum values of the parameters and it shows the shear walls at corners are providing better results compared with the shear walls at corner only in X direction and shear walls at center.

3.2. Analysis of shear walls with openings

As the openings in shear walls are required, the study is aimed to decide to increase the strength of shear walls with openings. The models with regular openings are shown in figure 5, figure 7 and with staggered openings are shown in figure 8 and figure 9.

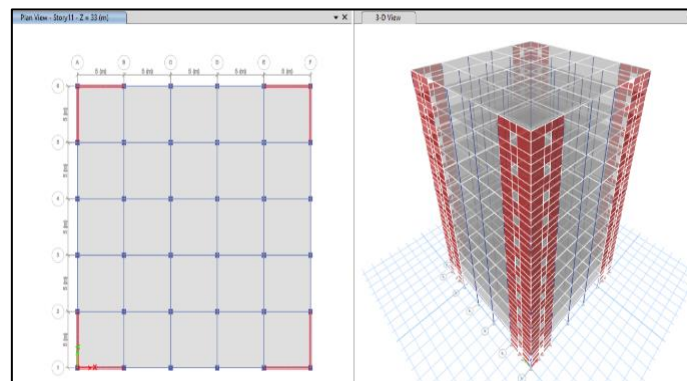


Figure 6. Model 4

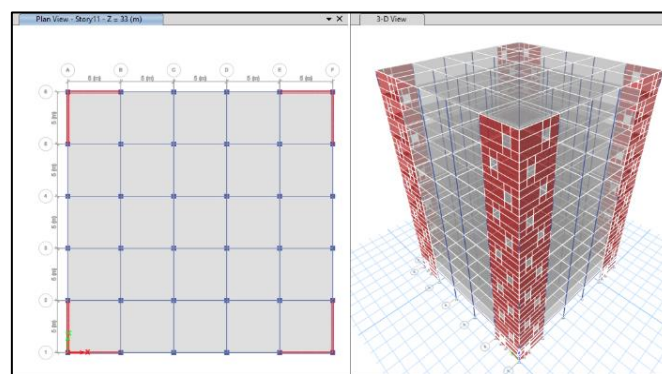


Figure 7. Model 5

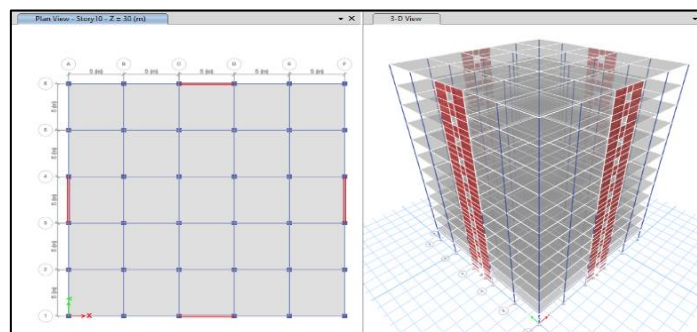


Figure 8. Model 6

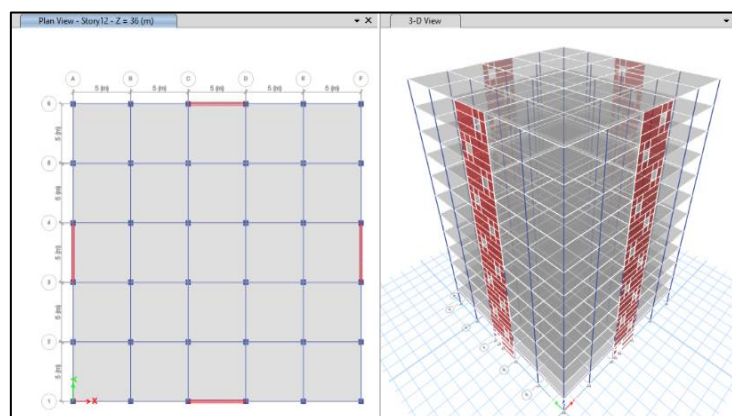
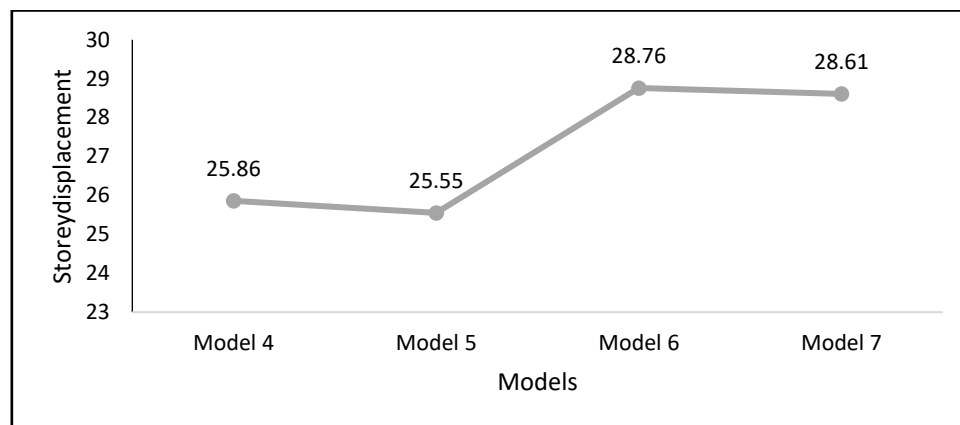


Figure 9. Model 7

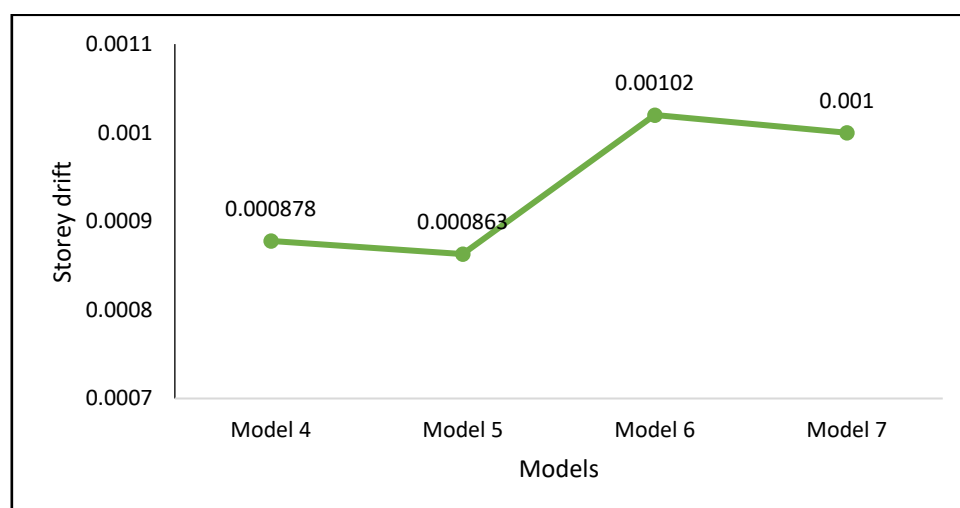
The results of the analysis of shear walls with openings are shown in Table 7. Similar to Table 6, the table lists the maximum values of parameters of different models, each representing a specific configuration of shear walls with openings.

Table 7: Results of shear walls with openings

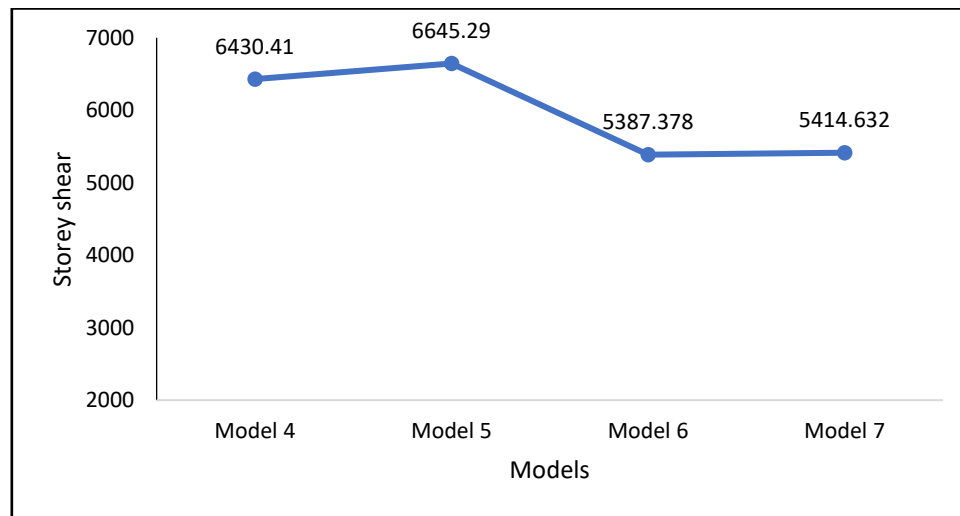
Model	Storey displacement	Storey drift	Storey shear	Storey stiffness
Model 4	25.86	0.000878	6430.41	8257856
Model 5	25.55	0.000863	6645.290	8275486
Model 6	28.76	0.00102	5387.378	4774422
Model 7	28.61	0.001	5414.632	4785472



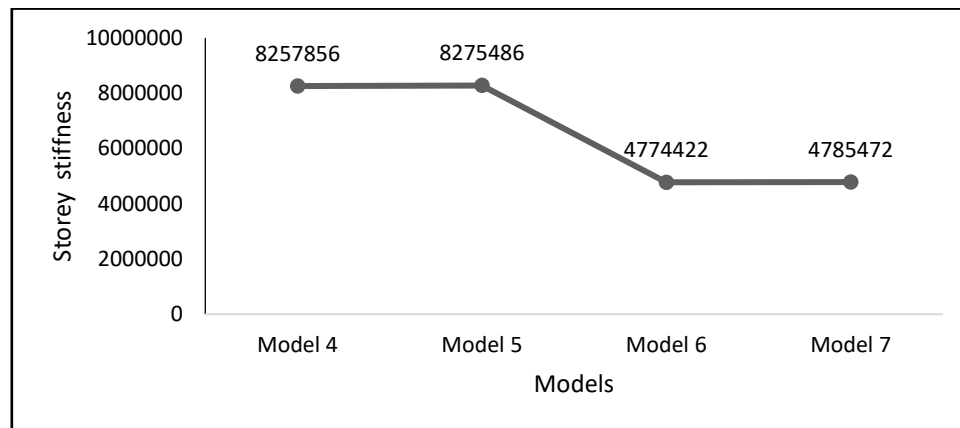
a) Story displacement



b) Story drift



c) Story shear

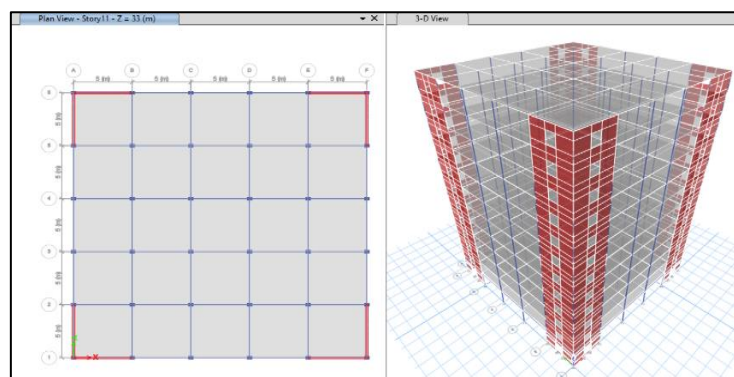


d) Story stiffness

Figure 10 Response of shear walls with openings

Shear walls at corners are better than those at the center with openings because corners of buildings are structurally stronger than the center due to increased bracing from adjoining walls. The above graphs in Figure 10 demonstrate that shear walls with staggered openings are good compared with regular openings. This could be due to factors such as increased structural integrity or better distribution of forces in the staggered design.

3.3. Analysis of shear walls by varying size of openings

**Figure 11. Model 8**

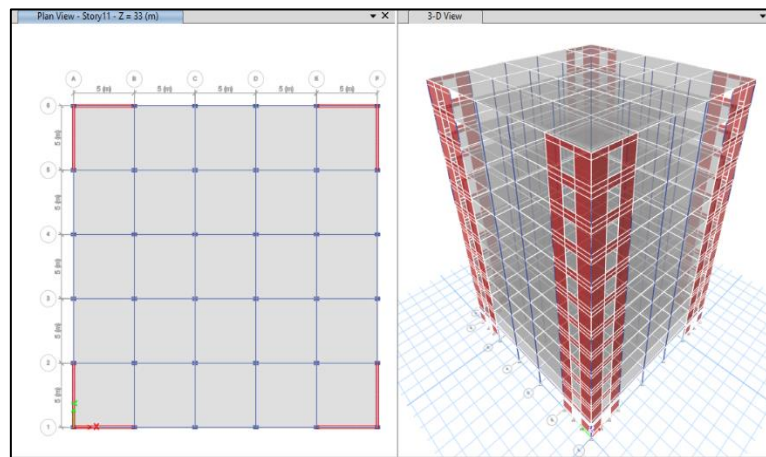
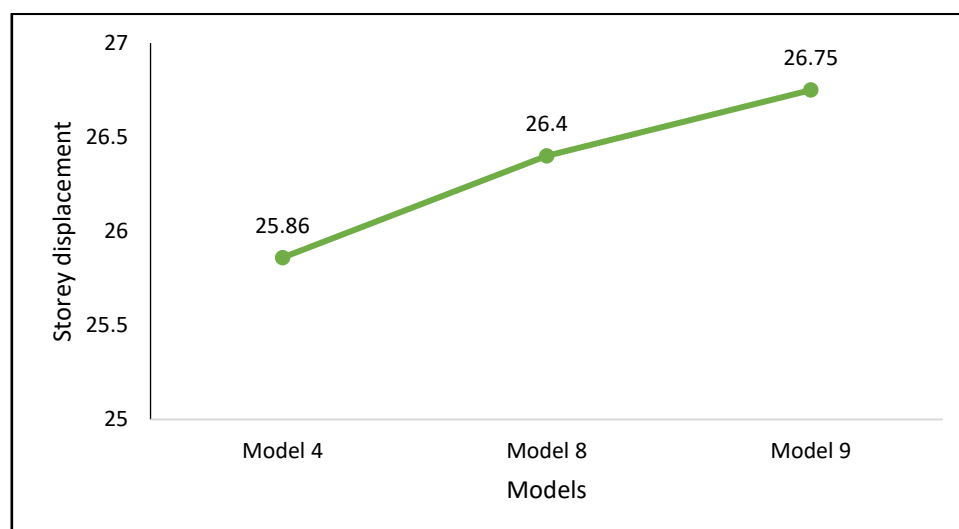


Figure 12. Model 9

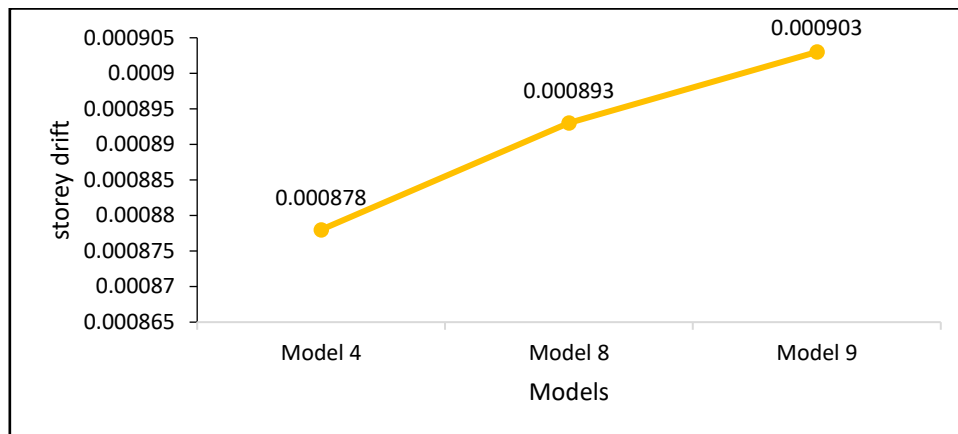
The table 8 displays the maximum values of these parameters for different models of shear walls by varying size of openings.

Model	Storey displacement	Storey drift	Storey shear	Storey stiffness
Model 4	25.86	0.000878	6430.41	8257856
Model 8	26.40	0.000893	6302.70	7395689
Model 9	26.75	0.000903	6067.483	6281022

Table 8: Results of shear walls by varying size of openings



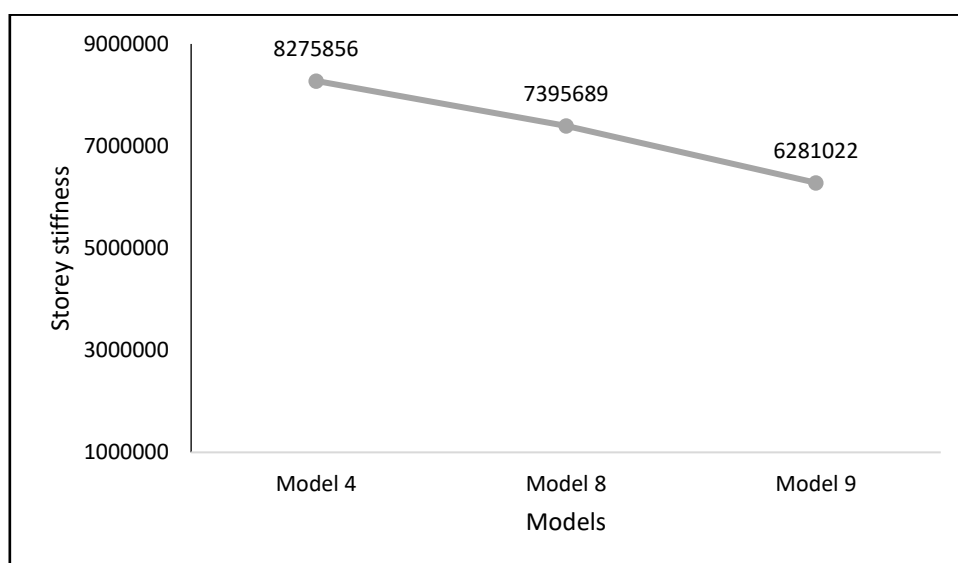
a) Story displacement



b) Story drift



c) Story shear



d) Story stiffness

Figure 13 Response of shear walls by varying size of openings

The figure 13 shows that as the size of openings increases, there is a corresponding increase in displacement and a reduction in stiffness. Therefore, the effective size for openings in the shear wall is set at 1000mmx1200mm. In smaller openings, the displacement is nearly equivalent to that without any openings. However, in larger openings, the displacement increases. To mitigate this and enhance stiffness, concrete is substituted with fiber-reinforced concrete.

3.4. Analysis of shear walls with fiber reinforced concrete

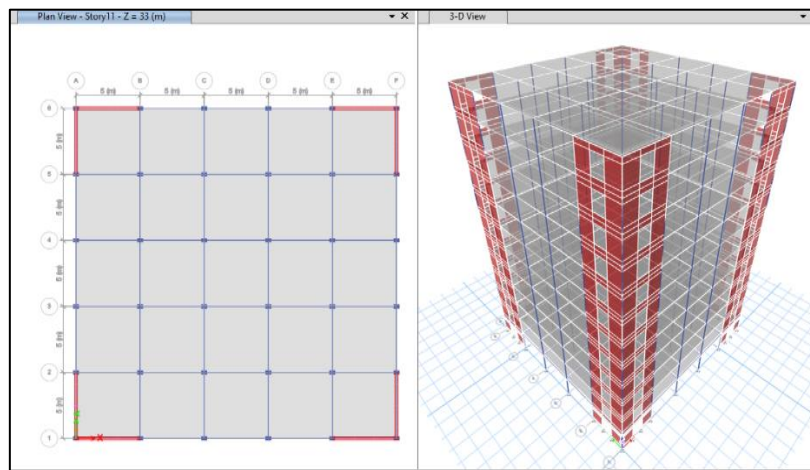


Figure 14. Model 10

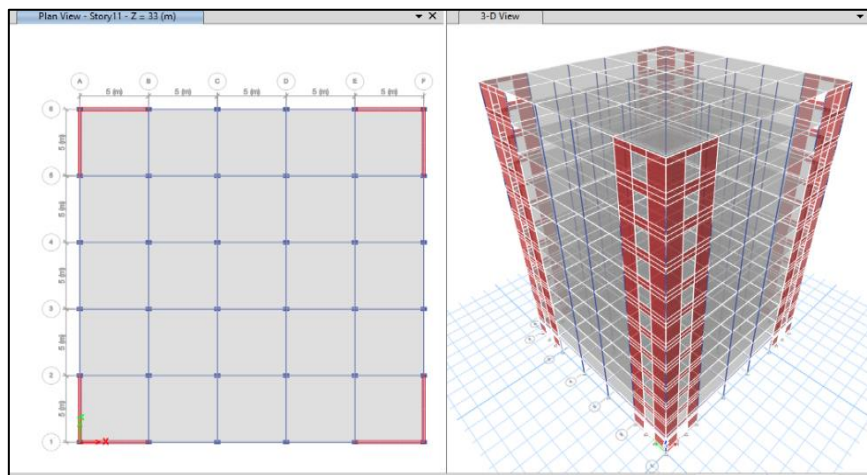
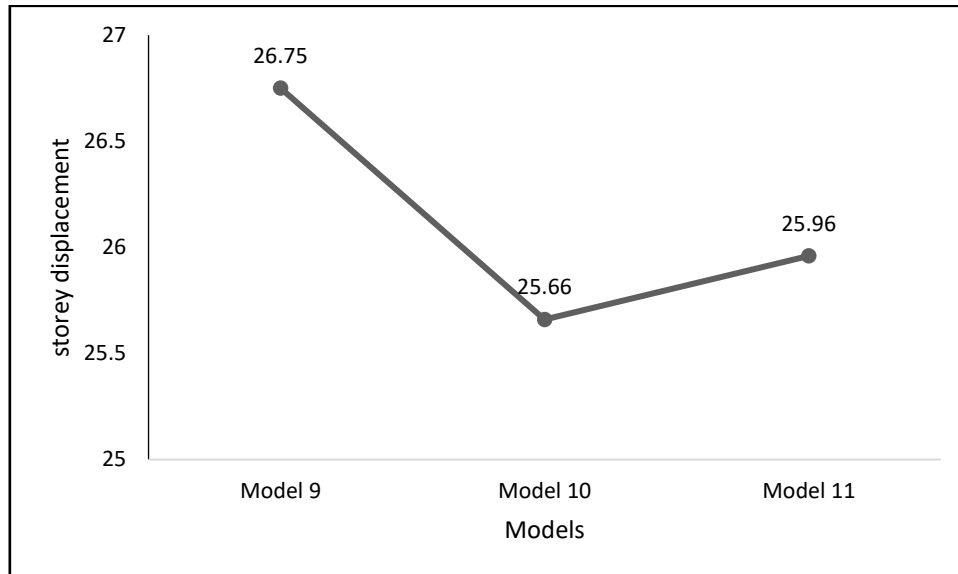


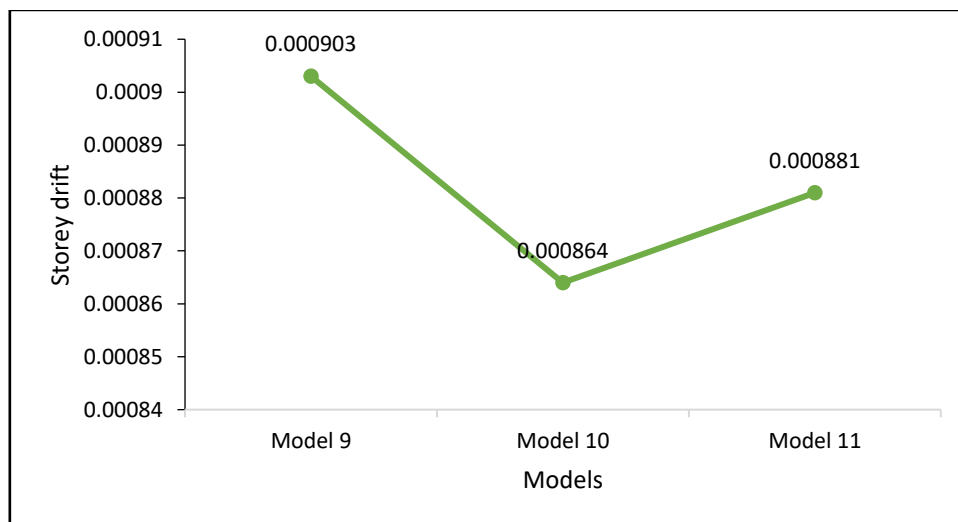
Figure 15. Model 11

Table 8: Results of shear walls with fiber reinforced concrete

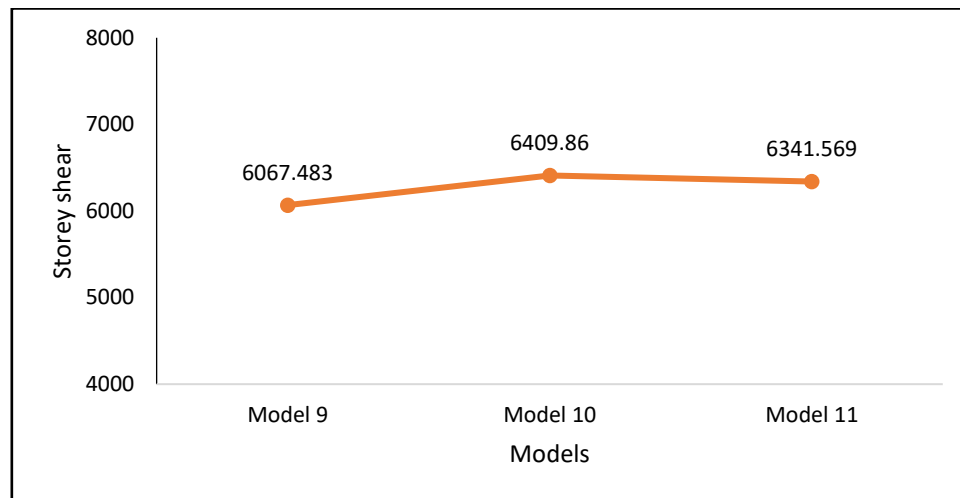
Model	Storey displacement	Storey drift	Storey shear	Storey stiffness
Model 9	26.75	0.000903	6067.483	6281022
Model 10	25.66	0.000864	6409.86	6365638
Model 11	25.96	0.000881	6341.569	6252432



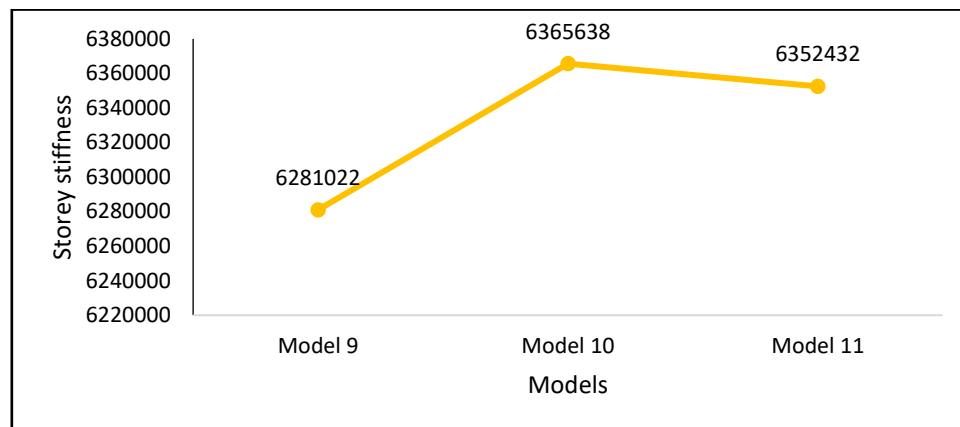
a) Story displacement



b) Story drift



c) Story shear



d) Story stiffness

Figure 14 Response of shear walls with fiber reinforced concrete

The comparison of storey displacement between Model 9 (conventional concrete), Model 10 (steel fiber-reinforced concrete), and Model 11 (glass fiber-reinforced concrete) is shown in Figure 14-a. The displacement in Models 10 and 11 is 3.04% and 4.24% less than in Model 9, respectively.

As seen in Figure 14-b, the Model 10 displays a value of 0.000864, whereas the Models 9 and 11 display values of 0.000903 and 0.000881, respectively. Model 10 appears to have the least storey drift (0.000864) when these data are compared, indicating the largest storey drift. The statement concludes that when compared to Models 9 and 11, Model 10 shows reduced storey drift.

At narrative level, Model 10 displays a value of 6409.86, while Model 9 displays 6067.483 and Model 11 displays 6341.569. Figure 14-c illustrates this. Notably, when compared to Models 9 and 11, Model 10 has greater storey shear.

The storey stiffness is maximum at storey 1, as Figure 14-d demonstrates. A structure with a higher degree of narrative stiffness is less likely to distort or shift. Compared to Models 9 and 11, which are both made of conventional concrete and glass fiber-reinforced concrete, Model 10, which is made of steel fiber-reinforced concrete, has a more rigid storey.

The substitution of fiber reinforced concrete replaced by concrete results in an augmentation of stiffness, leading to reduced displacement and drift. Steel fiber has increased the stiffness of structure compared with glass fiber

reinforced concrete which means the properties of the steel fiber plays an important role in influencing the structural response.

4. Conclusions

- The results indicated that, shear walls without any openings gave best performance compared with openings. Base shear and story stiffness is more for the model without openings at corner compared with the shear wall at center of building.
- When compared to ordinary openings, shear walls with staggered openings exhibit greater rigidity. Displacement and drift were observed to be least for the shear walls at corner with staggered openings between any type that has shear wall openings. From the above case, the shear walls at corner with staggered openings have more effective under seismic loads.
- By altering the opening sizes, the shear walls at corners with regular openings are examined in the opening size comparison.
- The displacement with size of opening 1200mmx1500mm has increased of 2.08% and with size of opening 1500mmx2000mm has increased of 3.44% comparing with the size of opening 1000mmx1200mm.
- To enhance the rigidity of the building the conventional concrete in shear wall is replaced with fiber reinforced concrete.
- The displacement reduced to 3.04% and 4.24% of glass fiber and steel fiber compared with conventional concrete shear wall. Drift was reduced to 2.49% and 4.51% of glass fiber and steel fiber compared with conventional concrete shear wall.
- Comparing the steel fiber reinforced concrete shear wall to the other two models, the base shear and stiffness are greater.
- Hence the steel fiber reinforced concrete shear walls are rigid when openings are large.

References

- [1] Rishab Jain, Siddhartha Deb and Vedant Shrivastava, (2022), "Seismic Analysis of RCC Building Without and With Shear Wall", International research journal of engineering and technology, pp2792-2799.
- [2] Vinay S. D., (2015), "Comparative Study on Multistoried RCC Structure with and without Shear Wall by Using SAP2000 v 17", International research journal of engineering and technology, pp 1261-1266.
- [3] A. Neuenhofer, P.E., (2006), "Lateral Stiffness Of Shear Walls With Openings", Journal of structural engineering @ ASCE, pp 1846-1851.
- [4] Ruchi Sharma, Jignesh A. Amin, (2015), "Effects Of Opening In Shear Walls Of 30 Storey Building", Journal of materials and engineering structures, pp 44-55.
- [5] Tejus S, Prashant Sunagar, (2015), "Numerical investigation on concrete shear wall with different percentages of openings", International research journal of engineering and technology, pp 1407-1414.
- [6] V Naresh Kumar Varma, Uppuluri Praveen Kumar, (2021), "Seismic Response on Multi
- [7] Storied Building Having Shear Walls with and Without Openings", Materials today: Proceedings Elsevier, pp 801-805.
- [8] Hui Wu, Bing Li, (2003) "Parametric Study of Reinforced Concrete Walls with Irregular openings" Earthquake engineering, pp 124.
- [9] Hamdy H.A. Abd-el-rahim, Ahmed Abdelraheem Farghaly, (2010), "Influence of Requisite Architectural Openings on Shear Walls Efficiency", Journal of engineering sciences, pp 421-435.
- [10] K. Behfarnia, A.R. Sayah, (2012), "Frp Strengthening Of Shear Walls With Openings", Asian journal of civil engineering, pp 691-704.

- [11] Mosoarca Marius, (2013) “Seismic Behavior of Reinforced Concrete Shear Walls with Regular and Staggered Openings After the Strong Earthquakes Between 2009 and 2011”, Engineering failure analysis Elsevier, pp 537-565.
- [12] Saeed.A, Najm H.M, Hassan A, Qaidi S, Mohanad Muayad Sabri Sabri and Mashaan N.S, (2022), “A Comprehensive Study on the Effect of Regular and Staggered Openings on the Seismic Performance of Shear Walls”, Buildings.
- [13] Bush R.C., Shirkol A.I., Sruthi J.S., Ajay Kuma, (2022), “Study of Seismic Analysis of Asymmetric Building with Different Shapes of Staggered Openings and Without Openings in Shear Wall”, Material Today: Proceedings Elsevier, 64 pp 964-969.
- [14] Alguhi H, Douglas Tomlinson (2023), “Crack behavior and flexural response of steel and chopped glass fiber reinforced concrete: Experimental and analytical study”, Journal of building engineering, Elsevier 106914.
- [15] Aarthi Harini T (2015), “Behavior of R.C. Shear Wall with Staggered Openings Under Seismic Loads”, International journal for research in emerging science and technology, pp95-96.
- [16] S.H.Jagadale,(2016), Analysis Of Various Thickness Of Shear Wall With Openings And Without Openings And Their Percentage Reinforcement”, International journal of research in engineering science and technologies, pp 212-218.
- [17] Anand S.Attal and Jyoti P.Bhusari (2016), “ Effect Of Opening In Shear Wall” , International journal of engineering research, pp 572-577.
- [18] Axay Thapa and Sajal Sarkar, (2017), “Comparative Study of Multi Storied RCC Building with and Without Shear wall” International journal of civil engineering, pp 2278-9987.