International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 08 Issue: 07 | July - 2024 SJIF Rating: 8.448 ISSN: 2582-3930

SEISMIC ANALYSIS OF RC FRAMED STRUCTURE CONSIDERING L-SHAPED SHEAR WALL AND HOLLOW CORE SHEAR WALL USING ETABS

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Abstract - This paper conducts a seismic analysis of a 20-story RCC residential building with integrated shear walls, aiming to optimize their placement. Seven structural models were evaluated, exploring different placements of shear walls inside and outside the building envelope. Using the response spectrum method in ETABS software, the study analyzed the structure located in Zone III, with medium to stiff soil conditions. Key parameter assessed is story displacement. The findings reveal significant performance differences between conventional RCC structures and those with shear walls, showing enhanced resistance to shear forces and overall structural performance. Placing shear walls at interior center edges was found most effective, with corners also proving effective compared to interior placements. Optimal placement near the building core enhances resilience against seismic forces, emphasizing the critical role of strategic shear wall placement in fortifying buildings in earthquake-prone areas.

Key Words: Shear wall, RC Framed Building, Dynamic Analysis, Response Spectrum Analysis, Comparative Analysis, ETABS Software.

1 INTRODUCTION

Earthquakes, among all natural disasters like floods, tornadoes, hurricanes, droughts, and volcanic eruptions, are the least understood yet the most devastating. They result in significant annual losses globally, causing extensive human casualties and severe economic repercussions in many regions. While destructive earthquakes occur mainly in specific areas, their catastrophic impact near densely populated centers underscores the urgent need for enhanced safety measures against this formidable force of nature. An earthquake results from the sudden release of stored strain energy beneath or within the Earth's crust, leading to elastic vibrations or waves that propagate outward in all directions from the epicenter, causing tremors. An earthquake is a random phenomenon whose magnitude and intensity cannot be predicted. While it's impossible to prevent all damage in buildings during earthquakes, all structures, regardless of size, can be engineered to withstand earthquakes of a specific magnitude by implementing appropriate precautions.

During seismic events, the base of a building commonly vibrates due to its direct contact with ground. The seismic forces can generate significant stresses, causing swaying and vibrations. Consequently, structures must possess sufficient strength to withstand vertical loads and enough stiffness to withstand lateral forces. Here are several strategies aimed at reducing the impact of earthquakes.

1. Moment Resistant Frames
2. Tube Structures
3. Shear Wall Structures
4. Multi-Tube Structure
5. Braced Frames

1.1 Shear Wall

Shear walls (SW) are reinforced cement structural elements that plays a crucial role in high-rise buildings by offering resistance against lateral forces caused by wind and earthquakes. Shear wall structures are often considered the most effective among the methods mentioned above. Typically positioned between column lines, stairwells, lift shafts, and utility spaces, these walls effectively transfer wind or earthquake loads to the foundation. Beyond load transfer, they enhance the structural stiffness of the building and support vertical loads as well. Well-designed shear wall systems significantly enhance a building's seismic performance.

Shear walls and frames working together typically provides the necessary stiffness and strength to effectively withstand lateral loads in tall buildings. In some situations, shear walls are significantly stiffer than frames and therefore bear most of the lateral load. Consequently, the contribution of frames in resisting lateral loads is often disregarded, but this assumption may not always be conservative. As buildings grow taller, recognizing the role of both frames and walls becomes increasingly crucial. In very tall buildings, the flexural deformation of shear walls becomes more pronounced, affecting the adjacent frames. This interaction must be accounted for in structural analysis. The combined action of these elements results in frames restraining shear walls on upper floors and vice versa on lower floors. This interaction reduces free deflection and enhances the overall efficiency of the structural system.

The behavior of the structure is significantly influenced by the shape and horizontal position of the shear wall. There are essentially two main configurations: one located at the perimeter of the building, which can be either planar or flanged in shape. The other configuration is situated internally within the structure, often as channel sections or core walls.

Shear walls often include openings for functional purposes such as windows, doors, and other types of access points. The size and placement of these openings can vary depending on their intended use. The dimensions and positioning of shear

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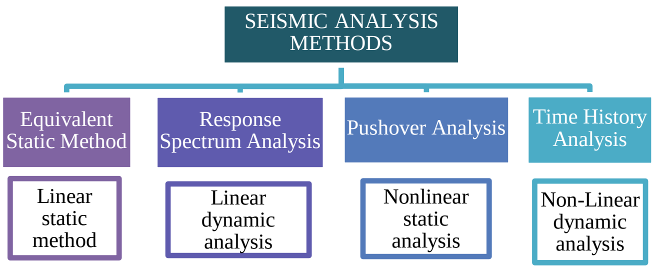
walls are crucially important. Buildings that are carefully designed and detailed with shear walls have demonstrated strong performance in previous earthquake events.

1.2 Seismic Analysis

Earthquakes cause the ground to shake violently due to sudden movements along fault lines. This shaking creates seismic waves that travel through the earth and reach buildings through their foundations. These waves make the building move in complex ways, with strong horizontal and vertical shaking. This shaking creates accelerations, which are forces that try to move the building in different directions. The building resists these forces thanks to its inertia, a property that makes objects resist changes in motion. The heavier a building, the stronger this resistance. However, the earthquake's energy is also absorbed by the building materials, which flex and bend. This absorption of energy is called damping. Unfortunately, this ability to absorb energy weakens over time [1].

The seismic analysis assesses how structures respond to dynamic loads like earthquakes, wind, and other forces. Structure on earth experiences two primary type of loads: static and dynamic primary types of loads: static and dynamic. Static loads remain constant over time, whereas dynamic loads vary with time. Typically, civil engineering structures are designed under the assumption that all applied loads are static. Dynamic loads are often neglected due to their complexity and the additional time required for analysis. However, this oversight can lead to catastrophic consequences, especially during earthquakes, as demonstrated by the Bhuj earthquake on January 26, 2001. Therefore, it is crucial to adopt the most appropriate methods for seismic analysis to accurately account for dynamic forces and ensure structural safety and resilience. Figure 1 shows types of seismic analysis methods commonly used in structural engineering.

Figure 1. *Seismic Analysis Methods*



1.3 Response Spectrum Analysis

Response spectrum analysis is utilized to predict how structures will respond to brief, unpredictable, transient dynamic events such as earthquakes or shocks. Since the exact time history of these events is unknown, conducting a time-dependent analysis is challenging. Moreover, these events are too short to be treated as ergodic (stationary) processes, making a random response approach inappropriate. This analysis is conducted when the structural response is notably influenced by modes other than the fundamental mode. It involves representing the response of a Multiple-Degree-of-Freedom System (MDOF) as a combination of modal responses, where each modal response is determined independently using spectral analysis of a Single-Degree-of-Freedom System (SDOF). These individual modal responses are then combined to calculate the total structural response.

1.4 ETABS Software

ETABS is a specialized engineering software designed for the analysis and design of multi-story buildings. It provides a range of modelling tools and templates tailored to the grid-like geometry typical of such structures. The software incorporates code-based load prescriptions and offers various analysis methods and solution techniques. The software's intuitive interface and integrated features make it practical to handle projects of any complexity, from simple 2D frames to intricate modern high-rise buildings. Additionally, ETABS ensures interoperability with a variety of design and documentation platforms, enhancing its utility as a coordinated and productive tool for structural design engineers.

1.5 OBJECTIVE OF STUDY

The principal objectives of this study are:

1. To investigate the seismic performance of G+20 buildings by placing shear wall at different position, such as L-shaped shear walls at four corners and RC core shear wall, using the response spectrum method and compare the results to determine the most optimal configuration.
2. To quantify the storey displacement for each shear wall configuration.
3. To graphically compare the seismic performance of the different shear wall configurations.
4. The interpretation of results and research findings.

2 LITERATURE REVIEW

Ensuring the safety and stability of structures in earthquake-prone regions is paramount. Shear walls, vertical elements within a building, emerging as a crucial line of defense against lateral forces exerted by wind and earthquakes. Extensive research underlines their effectiveness in minimizing building sway and enhancing overall seismic performance. This literature review delves into the critical role of shear wall placement, size, and openings in influencing a structure's response to lateral loads.

Simon et al. (2023) studied the seismic behavior of a G+10 building and compared various RC shear wall configurations: rectangle, L-section, C-section, and crisscross. They found that placing shear walls along the interior perimeter was more effective than exterior locations. This positioning enhanced the building's ability to withstand lateral seismic forces, minimizing deformation and improving stability. Symmetrical shear wall placement balanced seismic loads and optimized effectiveness, safeguarding the structure against vulnerabilities. The study underscores the critical role of strategic RC shear wall design in fortifying mid-rise buildings against seismic events [2] .

Ahamad & Pratap (2021) studied the seismic performance of a 20-story reinforced concrete (RC) building using dynamic analysis, essential for assessing earthquake effects on high-rise structures. The research focuses on shear walls, vertical elements crucial for resisting lateral forces. They used ETABS software to model different shear wall configurations (core, perimeter, combinations) based on Indian Standard Codes for seismic zones. The corner placement also contributed to minimizing maximum allowable displacements, underscoring its effectiveness in enhancing the building's overall seismic resilience [3].

Anya & Ghosh (2021) explored earthquake resistant buildings in their study. They focused on shear walls, robust structures that help buildings withstand lateral shaking during earthquakes. Using computer models, they analyzed building designs with and without shear walls to assess their impact on factors like sway, stress distribution, and compliance with building codes. Their research aimed to demonstrate the effectiveness of shear walls in enhancing buildings' earthquake resilience. The study observes that placing shear walls in the building core and at the corners results in lower story drift compared to other placements of shear walls [4].

Varma & Uppuluri (2021) studies how openings (doors, windows) in shear walls impact seismic performance in multi-story buildings. Shear walls resist lateral loads from wind and earthquakes but can weaken with openings. Using ETABS software, the study models multi-story buildings with various opening configurations. Dynamic analysis considers earthquake dynamics crucial for high-rise buildings in seismic zones defined by building codes (e.g., IS codes). Buildings with shear walls containing openings show increased deflection, drift, and stress compared to those with solid shear walls. Recommendations may advise limiting and strategically placing openings within shear walls to enhance seismic performance, aiding engineers in designing earthquake-resistant buildings [5].

Shreelakshmi & Kavitha (2020) analyzed the optimal thickness and positioning of shear walls in a G+20-story building located in Zone IV with medium soil. Using ETABS 2016 software and linear static methods, they assessed shear wall thicknesses of 150mm, 175mm, 200mm, and 225mm at different positions: corners, mid-span, and as a central core divider. Parameters studied include storey displacements, drifts, overturning moments, base shear forces, and modal time periods. The study aims to identify the most effective shear wall thickness and placement to minimize structural responses to lateral forces under seismic conditions. It can be inferred that increasing the thickness of the shear wall reduces displacement [6].

Jamle et al. (2020) conducted seismic analysis of an RC framed structure with L-shaped shear walls at each corner in Zone III. They examined changes in parameters such as base shear, story drift, moments, and axial forces in columns, as well as moments and shear forces in beams (x and z directions) when reducing shear wall area. Graphical analysis revealed that reducing shear wall area beyond 20% significantly decreased stiffness, indicating increased vulnerability to seismic failure [7].

Husain & Mahmood (2017) studied shear walls crucial for resisting lateral forces in multi-story buildings like earthquakes and wind. Their effectiveness hinges on type, configuration, building geometry, and height. Using SAP2000 V14 software and the finite element method, they analyzed fifty-six ten-story building models under earthquake loads. Models included side shear walls, middle shear cores, and double shear cores with equal material volume. Strategic shear wall placements significantly enhance seismic resistance in frame buildings, with sidewall arrangements preferred for lengths ≤20m and double-core configurations for lengths >20m, minimizing drift, base shear, and bending moments effectively [8].

3 METHODOLOGY

This study focuses on a G+20 residential building modelled as a reinforced concrete structure comprising beams, columns, and slabs. Shear walls are strategically placed in different configurations within the same floor plan. The structural design adheres to the Indian standard code for seismic-resistant buildings. ETABS software was utilized for structural modelling and analysis. The models were analyzed under seismic zone III conditions with medium soil characteristics. The comparison primarily considers storey displacements. Figure 2 provides an overview of the methodology using a flowchart format.

Figure 2. *Flow Diagram of Study*

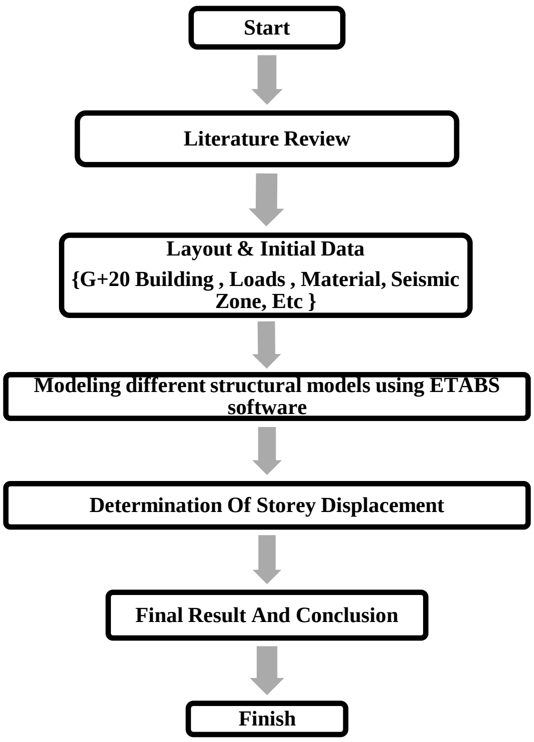


Table 1 presents the physical properties of the structure.

Table 1. *Detail of the Structure*

S.No.	Details	Data
1.	Number of stories	G+20
2.	Plan size	20 m X 20 m
3.	Area of building	400 m^2
4.	Floor-to-floor height	3 m
5.	Height of building	60m
6.	Grade of concrete	M30
7.	Grade of steel	Fe415
8.	Beam size	500mm X 300mm
9.	Column size	600mm X 600mm
10.	Slab thickness	150mm
11.	Wall thickness	200mm
12.	Shear wall thickness	230mm

Load applied for the studies are as follows:

Floor finish = 1 kN/m^2

Live load for residential building = 3 kN/m^2

Table 2 shows the detail of seismic properties as per IS 1893 (Part 1):2016 [9].

Table 2. *Seismic Parameters*

S. No.	Details	Data
1.	Seismic zone	III
2.	Response reduction factor, R	5
3.	Importance factor, I	1.2
4.	Damping ratio	0.05
5.	Soil condition	Type II
6.	Zone factor	0.16

4 STRUCTURAL MODELING AND ANALYSIS

Model 1: RCC Structure without Shear Wall.
Model 2: Shear Wall at Four Exterior Corners
Model 3: Shear Wall at Exterior Centre Edge.
Model 4: Shear Walls at Shaft Cores Without Openings
Model 5: Shear Walls at Shafts with Openings
Model 6: Shear Walls at Core
Model 7: Shear Wall at Interior Centre Edge

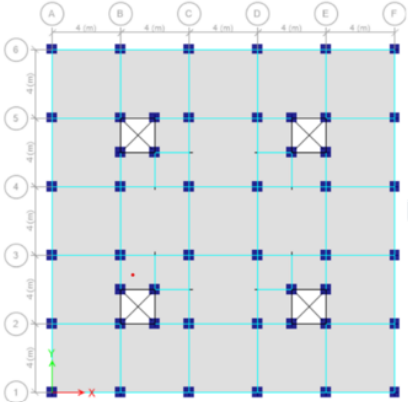


Figure 3. Plan of Model 1

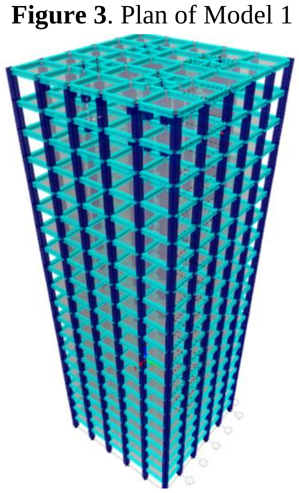


Figure 4. Elevation of Model 1

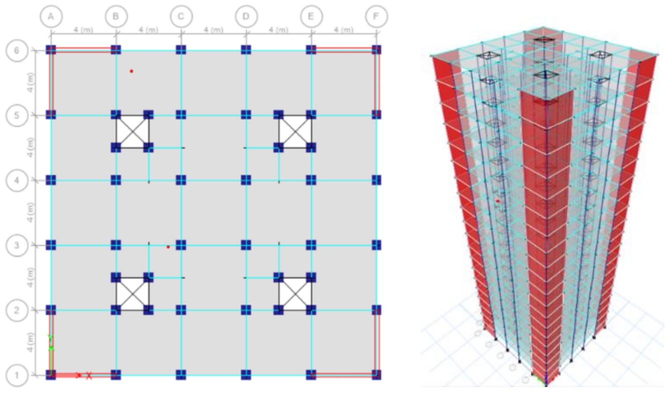


Figure 5. Plan and Elevation of Model 2

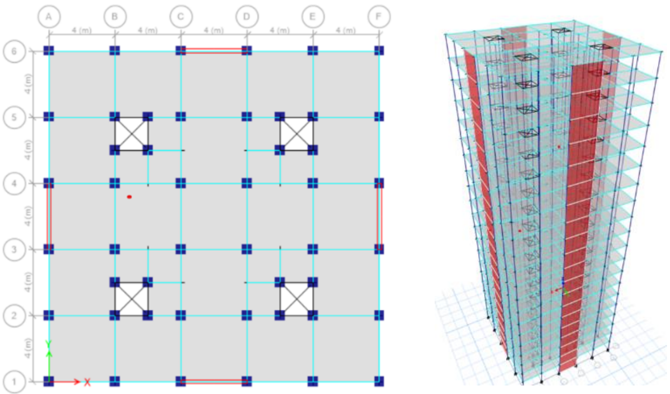


Figure 6. Plan and Elevation of Model 3

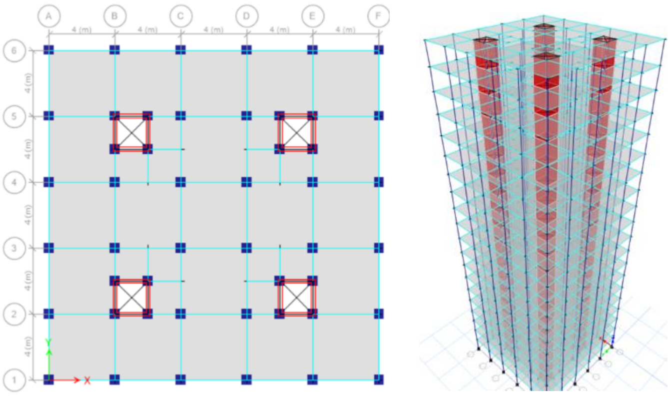


Figure 7. Plan and Elevation of Model 4

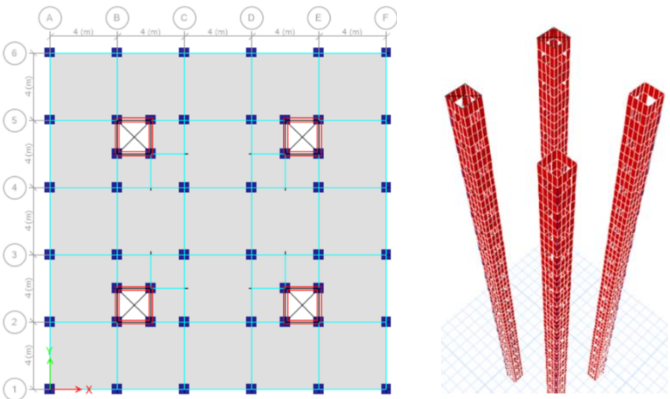


Figure 8. Plan and Elevation of Model 5

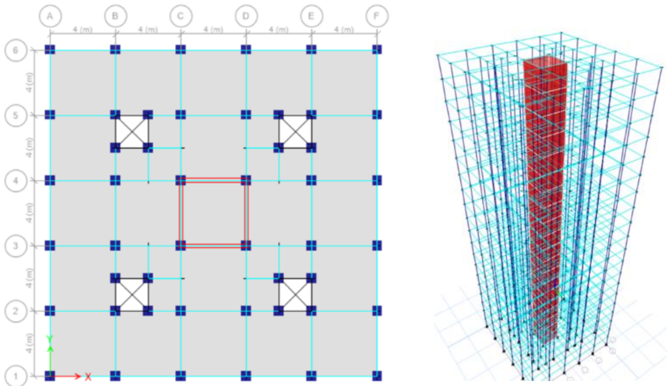


Figure 9. Plan and Elevation of Model 6

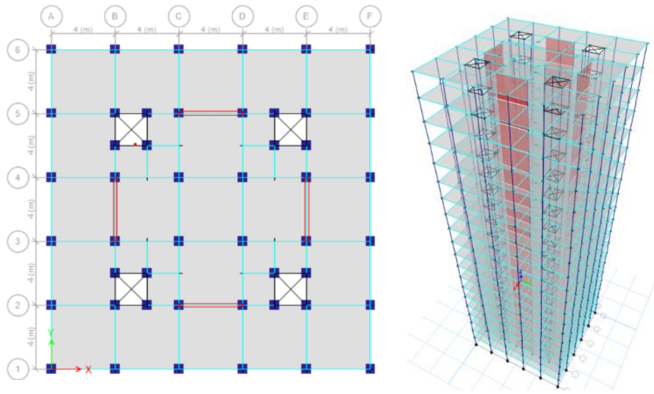


Figure 10. Plan and Elevation of Model 7

5 RESULTS AND DISCUSSIONS

5.1 Storey Displacement

Table 3. Storey Displacement (mm) in X Direction for Load Case- 1.5DL+1.5EQ-X

Storey	RCC structure without SW	SW @ Four Corner	SW @ Exterior Edge center	SW @ Shaft without Openings	SW @ Shaft with Openings	SW @Core	SW @ Interior Centre Edge
0	0	0	0	0	0	0	0
1	1.088	0.402	0.566	0.461	0.444	0.502	0.554
2	2.981	1.113	1.577	1.387	1.365	1.431	1.491
3	5.068	2.09	2.913	2.658	2.625	2.596	2.697
4	7.203	3.273	4.464	4.17	4.131	3.946	4.069
5	9.348	4.614	6.154	5.85	5.809	5.433	5.546
6	11.483	6.071	7.929	7.64	7.6	7.014	7.083
7	13.594	7.612	9.748	9.496	9.461	8.655	8.651
8	15.669	9.206	11.578	11.382	11.356	10.326	10.225
9	17.696	10.829	13.393	13.271	13.255	12.004	11.787
10	19.66	12.457	15.173	15.139	15.135	13.667	13.32
11	21.55	14.073	16.899	16.965	16.974	15.299	14.812
12	23.353	15.659	18.555	18.732	18.755	16.883	16.249
13	25.055	17.202	20.128	20.425	20.463	18.407	17.619
14	26.642	18.69	21.605	22.031	22.084	19.858	18.913
15	28.102	20.114	22.977	23.541	23.609	21.228	20.121
16	29.42	21.469	24.237	24.946	25.032	22.51	21.235
17	30.583	22.752	25.383	26.247	26.349	23.703	22.251
18	31.579	23.962	26.421	27.445	27.566	24.808	23.168
19	32.403	25.112	27.366	28.556	28.699	25.829	23.998
20	33.073	26.247	28.208	29.576	29.735	26.716	24.72

The comprehensive data on displacements generated from ETABS analysis across all seven models, offering a detailed comparison of the results is shown in Table 3.

Figure 11 and Figure 12 explores shear wall positions' impact on storey displacement, showing lower displacements at corners, cores, and interior center edges compared to other placements. Models with shear walls at intermediate positions experience the least displacement, indicating varied influences on structural response and displacement patterns. Effective shear wall placement is crucial for reducing displacement and enhancing stability in high-rise buildings.

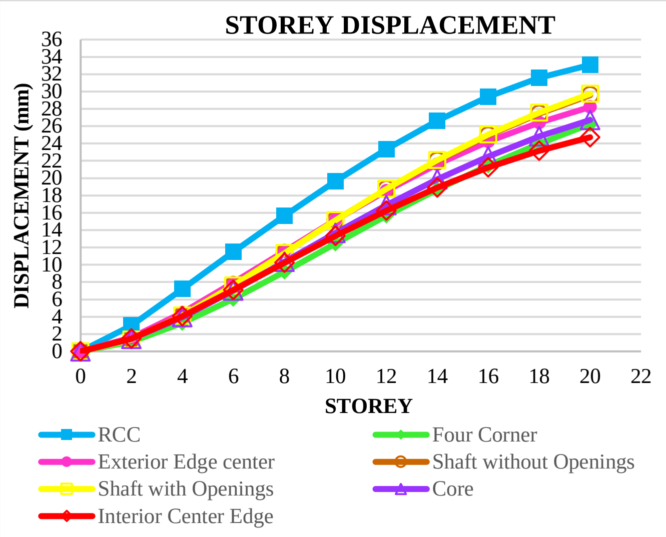


Figure 11. Line Graphs for Storey Displacement

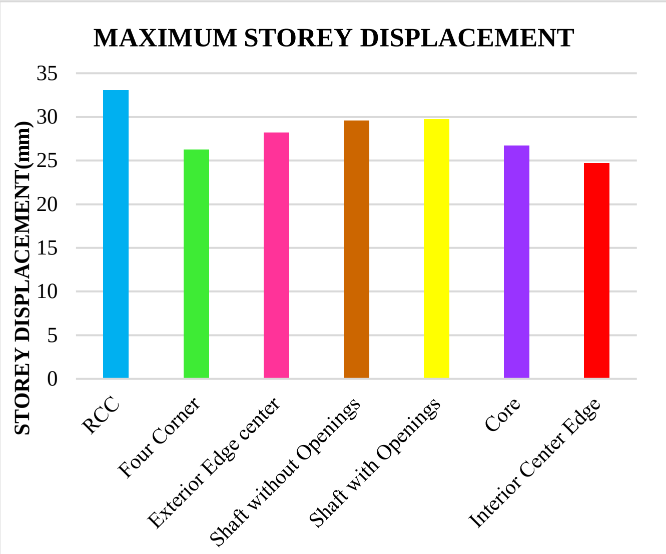


Figure 12. Bar Chart for Storey Displacement

6 CONCLUSION

According to the response spectrum approach, the impact of the shear wall's location on storey displacement is seen below:

1. Among all models, the RCC frame exhibited the highest displacement of 33mm, whereas the model featuring shear walls at the interior edge center demonstrated the least displacement, followed by those with shear walls at the four corners and at the core.
2. The incorporation of shear walls into RCC framed structures resulted in a significant reduction in deflection by 27%. This improvement in structural performance can be attributed to the enhanced stiffness and lateral load resistance provided by the shear walls.
3. Models incorporating shear walls at the shaft showed a 12% decrease in displacement compared to RCC structures. However, no significant difference in displacement was observed between models with shear walls at the shaft, whether with or without openings.
4. It can finally be concluded that placing shear walls at the interior center edge proved to be the most efficient positioning in terms of displacement. Additionally, shear walls at the four corners demonstrated nearly comparable efficiency to those at the interior edges.

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