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Effect of Shear Wall Configuration on the Seismic Performance of a 20-Storey Reinforced Concrete Building: A Finite Element Analysis

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A B S T R A C T

The configuration and placement of shear walls play a critical role in determining the seismic response of reinforced concrete (RC) buildings. While the inclusion of shear walls has been widely recognized for enhancing lateral stiffness and reducing displacements, limited studies have explored how various wall layouts perform under identical seismic inputs. This study investigates the impact of different shear wall configurations—core wall, edge wall, and L-shaped wall layouts—on the dynamic behavior of a 20-storey RC structure using time-history and modal analysis. A consistent 3D building model was developed in LUSAS FEA software, and subjected to the El Centro 1940 ground motion, scaled for comparative analysis [1].

Results show that shear wall layout significantly influences peak roof displacement, torsional drift, and base shear forces. The core wall configuration achieved the lowest displacement and torsion values, whereas edge wall configurations were more vulnerable to asymmetric response. Modal analysis revealed that different layouts shift fundamental periods and modal participation ratios due to variations in global stiffness and wall symmetry. The dual layout combining core and edge walls showed improved seismic resilience but required higher structural mass and complexity. These findings offer new insights into configuration-specific design strategies and support the development of optimized shear wall systems for tall buildings in seismic-prone regions [2].

Keywords: Shear wall configuration -Reinforced concrete buildings - Seismic response - Finite element analysis - Modal and time-history analysis

تأثير تشكيل الجدران القصية على الأداء الزلزالي لمبنى خرساني مسلح مكون من 20 طابقًا: تحليل بالعناصر المحددة

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الملخص

يلعب تشكيل وتوزيع الجدران القصية دورًا حاسمًا في تحديد الاستجابة الزلزالية للمباني الخرسانية المسلحة. وعلى الرغم من الاعتراف الواسع بأهمية الجدران القصية في تعزيز الصلابة الجانبية وتقليل الإزاحات، إلا أن الدراسات التي تناولت أداء التوزيعات المختلفة للجدران القصية تحت نفس ظروف الزلازل تظل محدودة. تهدف هذه الدراسة إلى تقييم تأثير عدة تشكيلات للجدران القصية – مثل الجدار المركزي، الجدار الطرفي، وتشكيل الجدران على شكل حرف – "L" على السلوك الديناميكي لمبنى خرساني مكون من 20 طابقًا، وذلك باستخدام التحليل الزمني وتحليل الأنماط من خلال برنامجLUSAS FEA ، مع تطبيق سجل زلزال "إل سنترو" لعام 1940 بعد تحجيمه للتحليل المقارن.[1]

أظهرت النتائج أن تشكيل الجدران يؤثر بشكل كبير على الإزاحة القصوى عند السقف، والانحراف الالتوائي، وقوى القص القاعدية. حيث حقق التشكيل المركزي أقل معدلات الإزاحة والانحراف، بينما كانت التشكيلات الطرفية أكثر عرضة للسلوك غير المتماثل. كما كشف تحليل الأنماط أن كل تشكيل يؤدي إلى اختلاف في الفترات الطبيعية ونسب مشاركة الكتلة، نتيجة لتباين الصلابة وتوزيع الجدران وبيّنت التشكيلات المزدوجة (جدران مركزية وطرفية) أداءً زلزاليًا محسنًا، لكنها تطلبت كتلة إنشائية أكبر وتعقيدًا في التنفيذ. تسهم هذه النتائج في دعم توجهات تصميمية أكثر كفاءة ومرونة للمباني الخرسانية المرتفعة في المناطق الزلزالية [2].

الكلمات المفتاحية: تشكيل الجدران القصية– المباني الخرسانية المسلحة– الاستجابة الزلزالية تحليل العناصر المحددة– التحليل الزمني وتحليل الأنماط (الطور)

1. Introduction

Shear walls are among the most widely adopted structural elements for enhancing the seismic performance of reinforced concrete (RC) buildings. Their ability to resist lateral loads, increase global stiffness, and reduce inter-storey drift makes them an essential component in earthquake-prone regions [3]. However, while the presence of shear walls is widely recognized for improving structural behavior during earthquakes, the specific impact of their configuration and placement within a building remains less thoroughly investigated.

As building height increases, so does the importance of lateral resistance systems. In tall buildings, improper shear wall layout can lead to a range of structural problems, such as torsional irregularities, eccentric responses, and non-uniform energy distribution. These effects can result in increased displacement demands and higher damage potential, even if shear walls are technically present in the system. Therefore, it is not only the presence of shear walls that matters but also how and where they are arranged.

Despite recognition of the importance of layout, design codes tend to provide only general guidance regarding the inclusion of shear walls, without prescribing or analyzing the performance outcomes of different configurations. With the advent of powerful finite element modeling tools, engineers now have the capability to simulate and compare various shear wall arrangements under identical seismic inputs to better inform their design choices [4].

This study aims to address that gap by examining the seismic response of a 20-storey RC building modeled with three different shear wall configurations: core wall, edge wall, and L-shaped wall layouts. All other design parameters, including material properties, load conditions, and geometric dimensions, are kept constant across models to isolate the effect of wall configuration. The structures are subjected to dynamic analysis using a representative seismic input, and their performance is evaluated in terms of peak displacement, torsional behavior, modal characteristics, and base shear forces.

Through this focused comparison, the research seeks to identify which wall configurations offer the most favorable seismic performance, and under what conditions. The findings are intended to support performance-based design strategies and provide practical recommendations for engineers and architects designing RC buildings in seismic zones.

2. Literature Review

2.1 The Role of Shear Walls in Seismic Design

Shear walls are essential structural elements used to resist lateral loads in reinforced concrete (RC) buildings. Their vertical alignment and high in-plane stiffness allow them to carry significant horizontal forces induced by seismic events. Traditionally, they have been used to reduce inter-storey drifts, limit damage, and improve overall energy dissipation in mid- and high-rise buildings.

Early research emphasized the effectiveness of shear walls compared to alternative lateral load-resisting systems such as braced frames and moment-resisting frames. These studies established the fundamental understanding of how shear walls increase stiffness and strength in structures subjected to ground shaking.

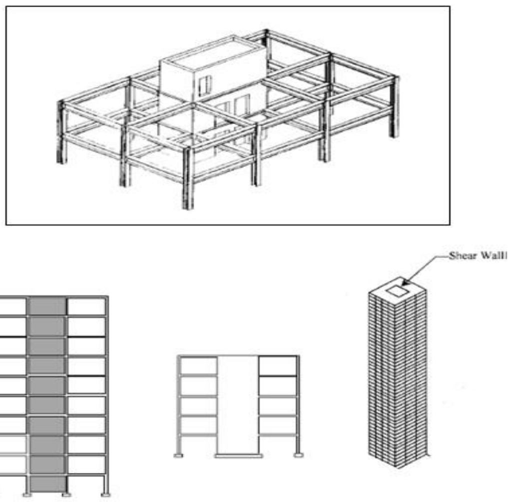

Figure 1. Shear Wall Structure

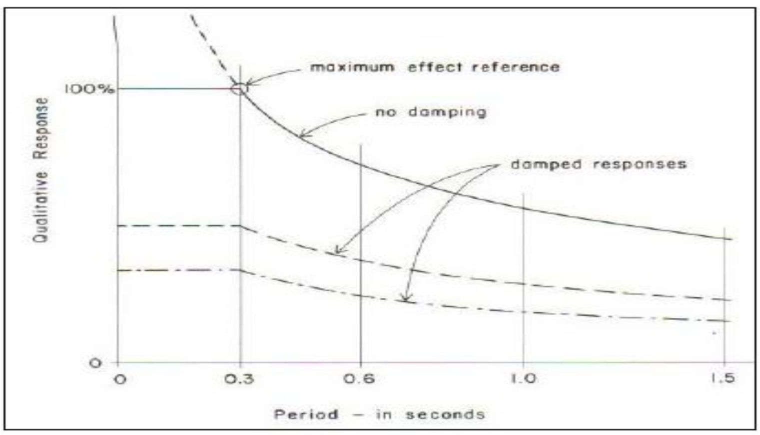

Figure 2. Spectrum response graph.

2.2 Influence of Shear Wall Configuration and Placement

While the presence of shear walls improves seismic performance, their configuration and placement within a building can significantly influence dynamic behavior. Different wall layouts result in varied stiffness distribution, torsional behavior, and energy dissipation across the structure.

Common configurations include:

- Core walls: Centrally located, often surrounding elevator shafts or stairwells.
- Edge walls: Positioned along the building perimeter.
- L-shaped or T-shaped walls: Asymmetrical geometries that create irregular stiffness paths.

Buildings with symmetric wall placement tend to have balanced seismic behavior, while asymmetric or unevenly distributed walls may introduce torsional effects and shift the center of stiffness away from the center of mass. This can lead to non-uniform displacement, increased rotational demands, and damage concentration [5].

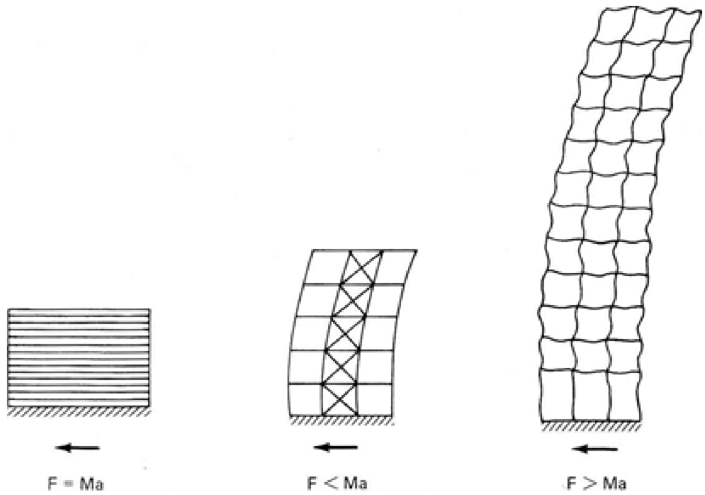

Figure 3. Conceptual illustration of seismic force distribution across low-, mid-, and high-rise buildings. Taller structures are subject to larger lateral forces and increased dynamic amplification.

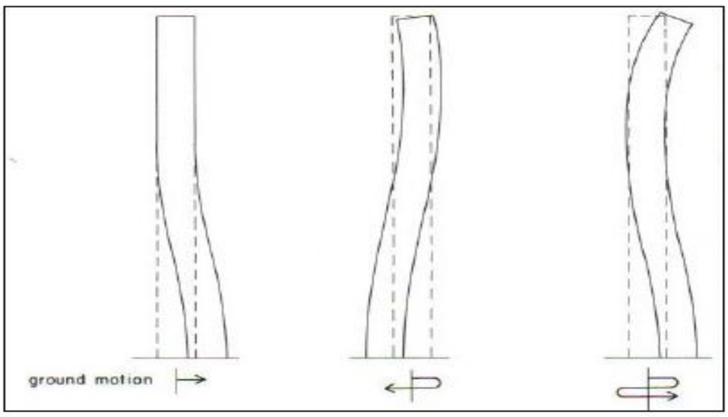

Figure 4: Earthquake motion of a tall building.

2.3 Torsional Behavior and Modal Interaction

One of the key challenges associated with wall configuration is **torsional irregularity**, especially in high-rise structures. When walls are placed away from the center of mass, they can induce unintended rotations under lateral excitation.

This torsional response becomes more significant in taller and slender buildings, where natural periods are longer and higher modes become more active. As such, modal analysis is essential for evaluating how wall placement shifts the dominant modes, affects mass participation ratios, and alters the fundamental period of the building [6].

Asymmetrical configurations often require more detailed modeling and design refinement to ensure that seismic forces are distributed safely and predictably.

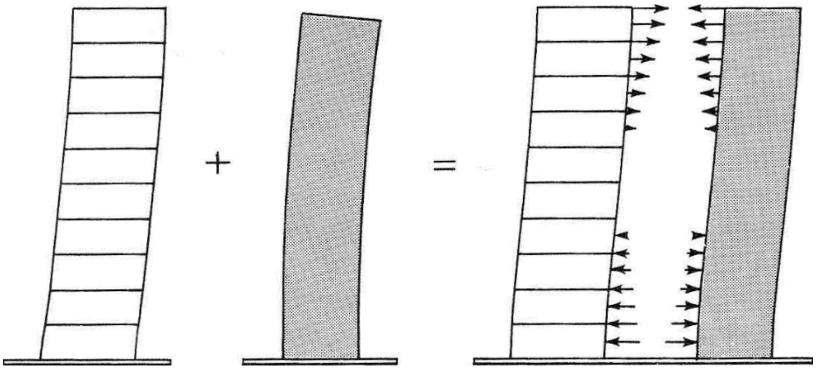

Figure 5 Deflected Shapes of Wall Frame Systems

2.4 Modeling Approaches in Shear Wall Studies

Finite Element Modeling (FEM) has become the primary method for evaluating complex structural responses to seismic loading. Tools such as LUSAS, ETABS, SAP2000, and ABAQUS allow researchers to simulate full-scale buildings under ground motion records using detailed shell, frame, or solid elements.

Researchers have used FEM to explore:

- The effect of wall thickness and boundary conditions
- The impact of wall openings on stiffness and ductility
- Differences in performance between symmetrical and asymmetrical layouts
- Modal coupling effects introduced by irregular wall placement

These platforms also support nonlinear dynamic analysis, enabling more accurate predictions of cracking, plasticity, and residual deformation during extreme events.

2.5 Performance-Based Design and Configuration Optimization

In recent years, there has been a shift from prescriptive design toward performance-based seismic design (PBSD). In PBSD, the aim is not only to ensure life safety but also to minimize damage, economic loss, and downtime. Under this framework, wall configuration plays a strategic role in balancing structural performance, architectural constraints, and construction feasibility.

Some advanced studies have introduced optimization techniques to evaluate multiple wall configurations simultaneously, identifying those that offer optimal trade-offs between stiffness, mass, and cost. However, such approaches often remain theoretical or limited to simplified models, highlighting the need for more comparative studies using consistent, realistic building data [7].

2.6 Identified Research Gap

Despite progress in modeling techniques and case-specific analysis, a notable gap remains in the literature. Few studies offer a direct comparison of multiple shear wall configurations under identical conditions — same building geometry, material properties, and seismic input.

This lack of standardized comparison limits the generalizability of results and leaves engineers with few guidelines on how to prioritize wall placement for performance. Furthermore, many existing works do not validate their simulations using multiple software platforms or experimental benchmarking.

This paper seeks to address that gap by systematically analyzing different shear wall layouts in a single 20-storey RC building model using finite element analysis. By isolating wall configuration as the variable, the study aims to generate actionable insights for more effective seismic design strategies.

3. Methodology

3.1 Overview of the Modeling Approach

This study employs a comparative finite element analysis (FEA) to evaluate how different shear wall configurations affect the seismic performance of a high-rise RC building. The modeling was conducted using LUSAS FEA Version 14.03, a powerful analysis platform for simulating structural behavior under dynamic loading [8]. All building models share identical geometry, loading, and material properties, with the only difference being the arrangement of shear walls. This ensures that any observed variations in response are attributable solely to the configuration of the shear walls.

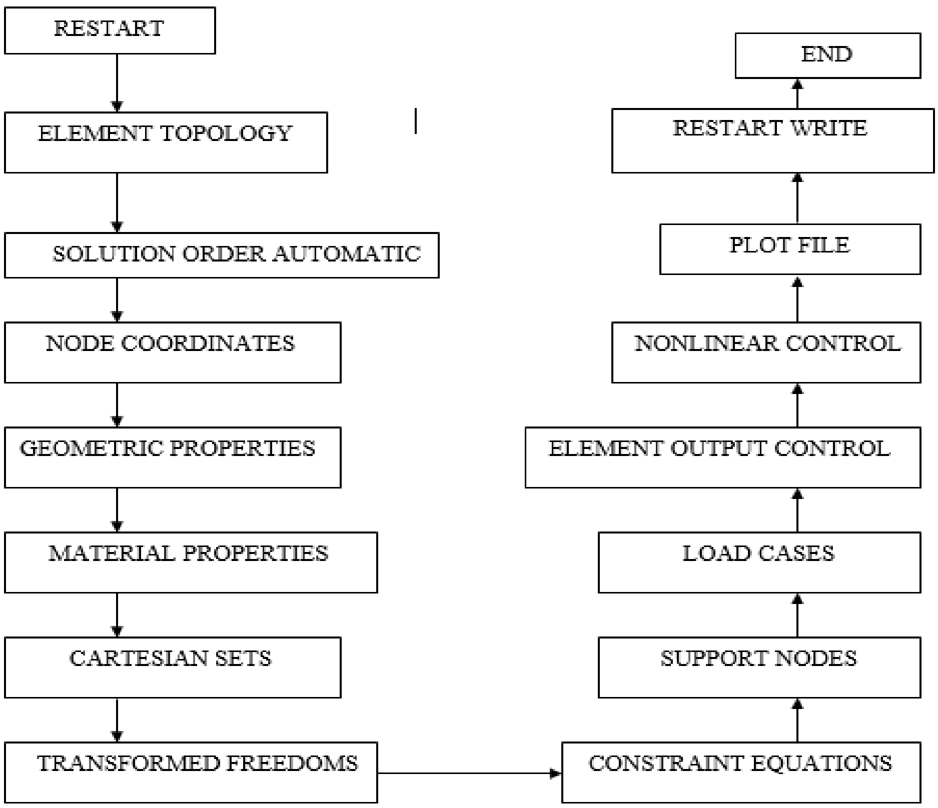

Figure 6. Workflow of data processing stages in LUSAS finite element analysis, including pre-processing, finite element solution, and result interpretation phases.

3.2 Building Description and Structural Assumptions

The structure analyzed is a 20-storey reinforced concrete building with a square plan. Each storey has a height of 3 meters, giving a total building height of 60 meters. The plan dimensions are 30 m × 30 m, with five bays in both directions. Columns and beams were modeled as frame elements, and floor slabs were considered rigid diaphragms to enforce uniform lateral displacement across each level [9].

Concrete with a compressive strength of 30 MPa and reinforcing steel with a yield strength of 420 MPa were used throughout the structure. Dead and live loads were applied as uniformly distributed gravity loads. Shear walls were modeled using thin-shell elements with appropriate thickness (generally 250 mm), and all models were fixed at the base to represent full interaction with the foundation [10].

3.3 Shear Wall Configurations Studied

Three shear wall layouts were modeled:

- Core Wall Configuration: Shear walls placed symmetrically around the central core, enclosing elevator shafts and staircases.
- Edge Wall Configuration: Shear walls distributed along the outer periphery of the building plan.
- L-Shaped Wall Configuration: Asymmetric placement of walls at building corners forming an "L" shape in plan.

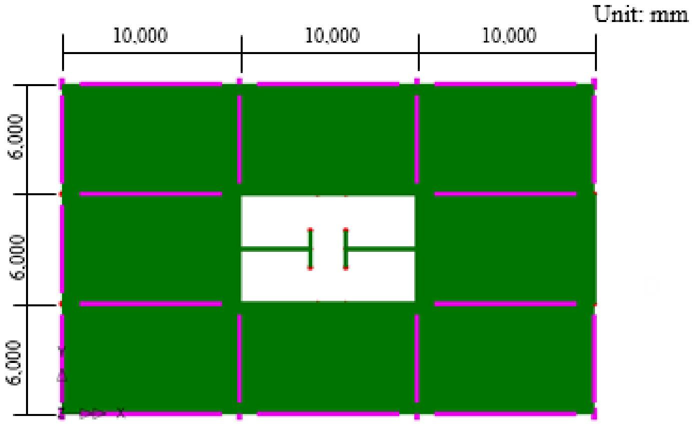

Figure 7. Plan view of the 20-storey reinforced concrete building with a core wall configuration. Shear walls are symmetrically arranged around the central core.

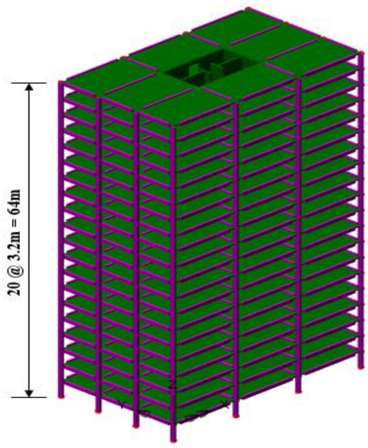

Figure 8. 3D model of the 20-storey RC building with a core shear wall configuration using LUSAS FEA. Shear walls are concentrated around the building core.

Each configuration was designed to use the same total wall area to maintain mass and stiffness equivalency, allowing for fair performance comparison.

3.4 Seismic Input and Dynamic Analysis

All models were subjected to dynamic excitation using the north-south component of the El Centro 1940 earthquake record. The ground motion was applied as a base excitation in the Y-direction, scaled to a peak ground acceleration (PGA) of 0.35g to represent moderate-to-high seismic intensity [11].

Time-history analysis was conducted to track displacement, acceleration, and base shear over time [12]. Modal analysis was also performed to extract natural frequencies, dominant modes, and participation ratios. The first five modes were considered in the interpretation of results [13].

3.5 Model Validation

To ensure modeling reliability, the core wall configuration was replicated in ETABS software, and the results of modal periods and maximum displacements were compared. The consistency between the two platforms confirmed the accuracy of element definitions, material properties, and boundary conditions used in LUSAS.

3**.6 Output Parameters**

The key output parameters extracted for comparison among the configurations included:

- Peak roof displacement
- Maximum base shear
- Torsional drift ratio
- Fundamental period and mode shapes

These indicators were selected as they collectively describe both translational and rotational seismic responses, providing a comprehensive understanding of how wall placement affects overall performance.

4. Results and Analysis

4.1 Overview of Comparative Findings

The dynamic analysis results reveal significant differences in seismic response across the three shear wall configurations. Despite identical building mass, geometry, and loading conditions, wall placement had a clear impact on lateral stiffness, displacement control, and torsional behavior.

4.2 Roof Displacement Response

The core wall configuration achieved the lowest peak roof displacement, confirming its superior stiffness and central resistance to lateral forces. The edge wall configuration exhibited greater displacement, particularly due to increased flexibility and potential eccentricity. The L-shaped layout resulted in an intermediate performance but introduced a directional asymmetry that affected displacement in both lateral directions.

The peak displacements recorded were approximately:

- Core Wall: 0.2669 m
- Edge Wall: 0.3595 m
- L-Shaped Wall: 0.3048 m

This shows a reduction of over 25% in displacement for the core layout compared to edge walls.

Configuration	Peak Displacement (Y-dir) (m)
No Shear Wall	0.1263
Shear Walls at Center	0.0571
Shear Walls at Edge	0.0255

Table 1. Comparison of peak displacement in the Y-direction for 10-storey models with no shear wall, center shear wall, and edge shear wall configurations.

4.3 Torsional Behavior

Torsional drift was most pronounced in the edge wall configuration due to the separation between the center of stiffness and the center of mass. The L-shaped wall layout also experienced torsional rotation, though to a lesser degree. In contrast, the core wall layout maintained a balanced distribution of stiffness, minimizing torsional effects and resulting in the most uniform lateral displacement across the building footprint.

4.4 Base Shear Response

Base shear values reflected the distribution of lateral resistance. The edge wall layout recorded the lowest base shear, while the core and L-shaped layouts generated slightly higher base shear due to their increased stiffness. This implies that while edge walls reduce shear force demands, they do so at the cost of increased displacement and torsion.

Configuration	Fundamental Mode Frequency (Hz)	Dominant Mode No.	Total Base Shear (kN)
Core Wall	1.12	4	4,963.98
Edge Wall	1.56	7	2,947.32
L-Shaped Wall	1.31	6	4,353.86

Table 2. Fundamental mode frequency, dominant modal shape, and base shear for 20-storey RC building with core, edge, and L-shaped wall configurations.

4.5 Modal Characteristics

Modal analysis indicated that the core wall configuration had the highest fundamental frequency and the shortest fundamental period. The edge wall configuration, being more flexible, exhibited the lowest frequency. The shift in modal values reflects the contribution of wall placement to global stiffness and mass participation.

5. Discussion

The results of this study clearly demonstrate that the placement of shear walls significantly influences the seismic performance of reinforced concrete buildings, even when all other design parameters are held constant. Among the three configurations analyzed, the core wall layout provided the most favorable response, achieving the lowest displacement and torsional drift while maintaining a relatively high base shear. This suggests that a central concentration of stiffness offers a well-balanced lateral resistance system, especially in regular building geometries [14].

The edge wall configuration, despite being common in architectural practice for maximizing usable floor space, exhibited inferior seismic performance. The increased displacement and torsional effects observed in this configuration can be attributed to the eccentricity between the center of stiffness and the center of mass. This separation introduces rotational motion under lateral loading, which not only increases drift in certain areas of the structure but also complicates the design of non-structural elements such as cladding and partitions [15].

The L-shaped wall layout yielded intermediate performance, reducing displacement more effectively than edge walls but not achieving the stability of core walls. This configuration introduced directional stiffness asymmetry, making its performance highly dependent on the direction of ground motion. While it may serve as a compromise in constrained design scenarios, it does not offer consistent performance across multiple seismic directions [16].

These findings reinforce the importance of shear wall layout as a critical design variable, not just a structural detail. Designers must consider not only the presence of shear walls but also their geometric arrangement, especially in high-rise structures where dynamic effects are more pronounced. While practical and architectural considerations often drive wall placement, performance-based design requires that structural efficiency and safety be weighed equally. In regions with high seismic risk, central wall systems may be recommended over eccentric or perimeter layouts, unless supplemented by additional systems such as outriggers or base isolation [17].

6. Conclusion and Future Work

This study investigated the effect of shear wall configuration on the seismic response of a 20-storey reinforced concrete building using finite element analysis. By analyzing three distinct shear wall layouts—core, edge, and L-shaped—under identical loading and modeling conditions, the research isolated the influence of wall placement on key performance indicators such as displacement, torsional drift, base shear, and modal behavior.

The results show that shear wall configuration plays a vital role in shaping a building's seismic performance. The core wall layout provided the most efficient resistance to lateral loads, reducing both displacement and torsional response while maintaining desirable stiffness and modal characteristics. This configuration aligned the center of stiffness with the center of mass, resulting in minimal rotational effects and uniform lateral behavior.

In contrast, the edge wall configuration, although potentially advantageous in terms of floor plan flexibility, demonstrated the poorest performance. It exhibited the highest roof displacement and significant torsional behavior due to eccentric stiffness distribution. The L-shaped wall layout offered intermediate performance, showing that asymmetrical arrangements can achieve reasonable results but must be evaluated directionally.

These insights emphasize the importance of incorporating configuration considerations into performance-based seismic design. Structural engineers must evaluate not only the quantity and size of shear walls, but also their spatial distribution, especially in high-rise buildings where dynamic and torsional effects are more pronounced [18].

For future research, several extensions are proposed. Nonlinear time-history analysis could be conducted to explore cracking, yielding, and post-elastic behavior of various wall layouts [19]. Additional parameters such as wall openings, interaction with moment-resisting frames, and soil-structure interaction should also be investigated. Moreover, the effect of different seismic records, especially near-fault

ground motions, could provide deeper insight into configuration-specific vulnerabilities [20].
Optimizing wall placement through multi-objective frameworks may lead to more resilient and cost-effective designs. Ultimately, this work contributes to a growing body of research aimed at refining seismic design strategies for modern RC buildings.

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