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Seismic Performance of RC Buildings With and Without Shear Walls: A Finite Element Study Across Building Heights

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A B S T R A C T

The seismic vulnerability of reinforced concrete (RC) buildings has prompted structural engineers to incorporate lateral load-resisting systems that enhance structural stability and performance. Among these, shear walls have proven to be highly effective in controlling lateral displacements and increasing energy dissipation. This study investigates the effect of shear walls on the seismic behavior of 3D RC buildings with different heights—10, 20, and 30 stories—through detailed finite element analysis using LUSAS FEA 14.03 software.

A total of six models were analyzed: three without shear walls and three with shear walls symmetrically placed around the elevator core. Time-history analysis was conducted using the El Centro 1940 earthquake record over a 10-second interval. Peak displacement in the Y-direction was reduced from 0.1263 m to 0.0571 m in the 10-storey model (54.7% reduction), from 0.4666 m to 0.2669 m in the 20-storey model (42.7% reduction), and from 0.6466 m to 0.3033 m in the 30-storey model (53.1% reduction). Validation against ETABS software showed results within a 1.8–3% margin for displacement and modal frequencies.

The Modal analysis further revealed that shear walls significantly influence dynamic characteristics by increasing stiffness and shifting critical mode participation to higher frequencies. For instance, in the 10-storey configuration, mass participation exceeding 90% occurred at Mode 5 without shear walls and at Mode 35 with shear walls. These findings confirm that shear walls substantially improve seismic performance and are essential for RC buildings in earthquake-prone regions.

Keywords: Shear walls **-** Seismic response **-** Reinforced concrete buildings Time-history analysis - Finite element modeling

الأداء الزلزالي للمباني الخرسانية المسلحة مع أو بدون جدران القص، دراسة باستخدام طريقة العناصر المحدودة لارتفاعات المباني

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الملخص

نظرًا لهشاشة المباني الخرسانية المسلحة أمام الزلازل، اتجه المهندسون الإنشائيون إلى اعتماد أنظمة مقاومة للأحمال الجانبية لتحسين أداء المباني تحت تأثير الزلازل. وتُعد الجدران القصية من أكثر هذه الأنظمة فاعلية في الحد من الإزاحات الجانبية وزيادة قدرة المبنى على تبديد الطاقة الزلزالية. تهدف هذه الدراسة إلى تقييم تأثير الجدران القصية على السلوك الزلزالي لمبانٍ خرسانية ثلاثية الأبعاد بارتفاعات مختلفة (10، 20، و30 طابقًا)، من خلال نمذجة العناصر المحددة والتحليل الزمني للتاريخ الإنشائي باستخدام برنامج.LUSAS FEA 14.03

تم تحليل ستة نماذج: ثلاثة بدون جدران قصية وثلاثة أخرى تحتوي على جدران قصية موزعة حول نواة المصعد. استُخدم سجل زلزال إل سنترو لعام 1940 كمدخل زلزالي على مدى 10 ثوانٍ، وتم استخراج قيم الإزاحة والسرعة والتسارع وشكل الأطوار الطبيعية. أظهرت النتائج أن استخدام الجدران القصية خفّض الإزاحات القصوى من 0.1263 إلى 0.0571 متر (بنسبة 54.7%) في نموذج العشرة طوابق، ومن 0.4666 إلى 0.2669 متر (بنسبة 42.7%) في نموذج العشرين طابقًا، ومن 0.6466 إلى 0.3033 متر (بنسبة 53.1%) في نموذج الثلاثين طابقًا. كما تم التحقق من النتائج بمقارنتها مع برنامجETABS ، وكانت نسبة التفاوت أقل من 3.%

أظهرت التحليلات الديناميكية أن الجدران القصية تؤثر بشكل كبير على خصائص المبنى الزلزالية، من خلال رفع الترددات الطبيعية وتحويل مشاركة الكتلة إلى أطوار أعلى. على سبيل المثال، تجاوزت نسبة مشاركة الكتلة 90% في الطور الخامس للنموذج بدون جدران قصية، بينما تحققت في الطور الخامس والثلاثين عند وجود الجدران القصية. تؤكد هذه النتائج على أهمية إدماج الجدران القصية في تصميم المباني الخرسانية المسلحة الواقعة في المناطق المعرضة للزلازل.

الكلمات المفتاحية:جدران القص– الاستجابة الزلزالية– المباني الخرسانية المسلحة– تحليل التاريخ الزمني – نمذجة العناصر المحدودة

1. Introduction

The increasing frequency and intensity of seismic events worldwide have highlighted the critical need for designing buildings that can effectively resist lateral forces [1]. Reinforced concrete (RC) buildings, commonly used for residential and commercial applications, must be engineered not only for vertical gravity loads but also for dynamic lateral forces caused by earthquakes. Inadequate seismic resistance in RC structures can lead to catastrophic consequences, including excessive deformation, structural damage, and potential collapse. Consequently, improving the seismic performance of RC buildings has become a key focus in structural engineering practice.

One of the most effective strategies for enhancing the lateral load resistance of RC buildings is the integration of shear walls. These vertical structural elements provide significant in-plane stiffness and strength, thereby reducing inter-storey drift, increasing energy dissipation, and limiting overall lateral displacement during seismic events [2]. Shear walls are particularly useful in mid- and high-rise buildings, where the effects of lateral loads are amplified due to increased building height and flexibility. International building codes, such as Eurocode 8 and ASCE 7, emphasize the importance of shear walls in seismic design and often require their incorporation in structures located in high-risk zones [3].

Despite their proven effectiveness, the placement, geometry, and interaction of shear walls with the surrounding structural system must be carefully considered to avoid adverse effects such as torsional irregularities or stress concentrations. Moreover, with increasing building heights, the dynamic characteristics of the structure become more complex, requiring detailed analysis methods capable of capturing time-dependent behavior. In this context, finite element modeling has emerged as a powerful tool for accurately assessing the performance of RC buildings under seismic loading [4].

This study aims to quantitatively investigate the impact of shear walls on the seismic response of RC buildings with varying heights. Using LUSAS FEA 14.03, three-dimensional models of 10-, 20-, and 30-storey buildings were developed, both with and without shear walls. Time-history analysis was performed using the El Centro 1940 earthquake ground motion. Key response metrics such as displacement, velocity, acceleration, and modal behavior were analyzed and compared across all models. The study also validates the simulation results through comparison with ETABS outputs. By providing a detailed understanding of the structural benefits of shear walls, this research contributes to more informed seismic design practices for tall RC buildings in earthquake-prone regions.

2. Literature Review

2.1 Overview of Seismic Effects on Buildings

Earthquakes generate ground motions that induce inertial forces within a building's structural system. Unlike wind loads that act more uniformly and gradually, seismic forces are dynamic, multi-directional, and can vary significantly in magnitude and frequency content. The primary structural response to earthquake motion is governed by a combination of mass, stiffness, and damping characteristics. As described by Chopra (2012), the inertial forces generated are proportional to the building's mass and the acceleration imposed by the earthquake [5]. Therefore, heavier and more flexible structures are often more vulnerable to significant lateral displacements and dynamic amplification.

A key aspect of earthquake engineering is controlling lateral deformations and inter-storey drift to prevent both structural and non-structural damage. The fundamental period of a building, its mode shapes, and the distribution of stiffness across the height significantly influence the amplitude of response. Buildings that resonate with the dominant frequencies of ground motion experience magnified responses, often leading to severe damage or collapse [6], [7].

2.2 Tall RC Buildings and Seismic Vulnerability

Tall buildings, particularly those composed of reinforced concrete (RC), present unique challenges in seismic design. Their height, slenderness, and long fundamental periods make them more susceptible to dynamic effects such as resonance and mode coupling. As noted by Taranath (1988), the flexibility of tall RC frames can lead to excessive sway, which, in turn, increases the risk of structural instability, especially when lateral loads from earthquakes are considered [8].

The growing trend of urban vertical expansion has necessitated the development of reliable lateral load-resisting systems to ensure seismic resilience in high-rise RC structures. Without adequate lateral stiffness, such buildings may exhibit high inter-storey drift ratios, posing risks to both structural integrity and occupant safety [9].

2.3 Shear Walls as a Seismic Solution

Shear walls are vertical structural components designed to resist lateral forces primarily through in-plane shear and flexural action. Integrated into the building's core or exterior, these walls form stiff vertical cantilevers that can carry substantial horizontal loads. According to Gunel and Ilgin (2006), shear walls offer superior performance compared to other systems like moment-resisting frames or braced frames, particularly in medium- to high-rise buildings [10].

Historically, shear walls gained prominence following observations from past seismic events where buildings with such systems outperformed those without. Their strategic placement and continuity from base to roof make them highly efficient in resisting seismic forces. Fintel (1995) emphasized that buildings designed with well-detailed shear walls often show minimal structural damage even under strong earthquake motions.

2.4 Structural Performance Benefits of Shear Walls

Several studies have demonstrated that the inclusion of shear walls significantly improves seismic performance by reducing roof displacements, base shear, and inter-storey drifts. In numerical simulations conducted by Hyun-Su et al. (2005), buildings with shear walls exhibited up to 60% lower displacement values compared to frame-only structures when subjected to similar ground motions [11]. Additionally, the presence of shear walls contributes to torsional stiffness, reducing asymmetric behavior in irregular floor plans.

Shear walls also influence the modal characteristics of the structure. As shown in this study and others, they increase the overall stiffness of the system, leading to a reduction in the fundamental period and shifting the dominant modes to higher frequencies. This detunes the structure from the predominant periods of seismic excitation, thus lowering dynamic amplification.

2.5 Modeling Approaches and Tools in Literature

With the advancement of computational tools, finite element modeling (FEM) has become a primary method for analyzing complex structural behavior under seismic loading. Software such as LUSAS, ETABS, SAP2000, and ABAQUS allow for precise simulation of time-history and modal responses, incorporating both geometric and material nonlinearities when necessary [12].

Numerous studies have employed FEM to evaluate the effectiveness of shear walls. For example, Rosman (1966) used early analytical models to study wall-frame interactions under lateral loading. More recent work by Dutta et al. (2001) utilized modern FEM platforms to assess the seismic torsional response of elevated tanks supported on RC frames. Despite these advancements, validation remains a critical component. Comparisons between different software tools, as conducted in this study between LUSAS and ETABS, ensure that modeling assumptions and boundary conditions do not overly influence the results.

Furthermore, researchers such as Reddy (1993) and Brebbia (1985) have emphasized the importance of mesh refinement, element selection, and dynamic integration parameters in capturing accurate structural responses [13]. When studying shear wall behavior, thin-shell elements are often preferred due to their ability to represent wall flexure and shear deformation effectively.

2.6 Gaps in the Literature and Research Contribution

While the benefits of shear walls are well-documented, most existing studies focus on either isolated case studies or specific building configurations. There remains a lack of comparative investigations that examine how the seismic performance of RC buildings evolves across different heights when shear walls are introduced. Additionally, few studies integrate time-history analysis with modal evaluation across a consistent modeling framework and validate their results with multiple software platforms [14].

This study addresses these gaps by analyzing the same structural typology (10-, 20-, and 30-storey RC buildings) with and without shear walls under the same seismic input. The findings offer valuable insights into how shear walls alter displacement, acceleration, and modal participation at varying heights. By validating LUSAS results with ETABS, this research also contributes a cross-platform verification layer that enhances the credibility of its outcomes. Ultimately, the study supports the development of more resilient design practices for RC buildings in seismic-prone areas.

3. Methodology

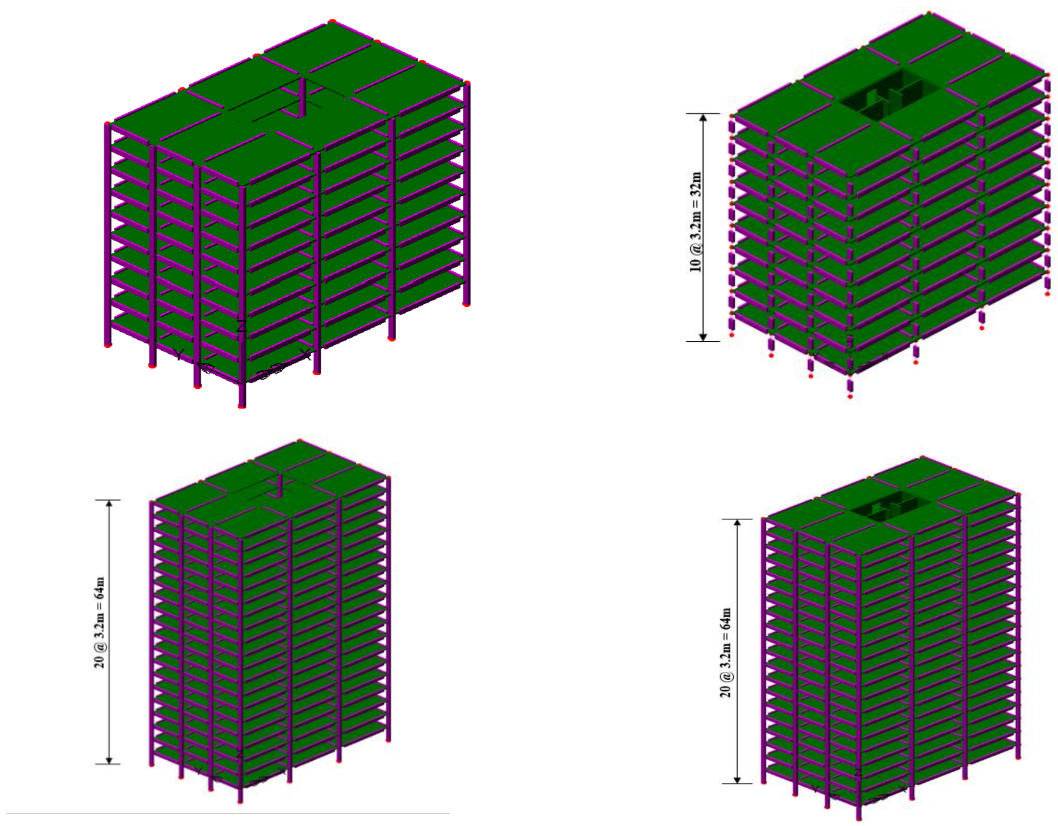
This section outlines the modeling, analysis procedures, material assumptions, and validation techniques used to assess the seismic performance of reinforced concrete buildings with and without shear walls. The study employed time-history and modal analyses through LUSAS FEA 14.03 software, with further verification using ETABS software. A total of six structural models were developed and examined under the same seismic loading conditions to enable direct comparison.

3.1 Modeling Approach Using LUSAS FEA

The finite element models were created in LUSAS FEA 14.03 using a three-dimensional representation of reinforced concrete (RC) buildings. Each model consisted of rigid beam-column elements to simulate the moment-resisting frame and thin-shell elements to represent shear walls. Shear walls were integrated vertically from foundation to roof level, located symmetrically around the core of the structure. A total of six models were created:

- Model 1, 3, 5: 10-, 20-, and 30-storey buildings *without* shear walls
- Model 2, 4, 6: 10-, 20-, and 30-storey buildings *with* shear walls

All floors were assumed to act as rigid diaphragms to ensure uniform horizontal distribution of lateral loads. Mesh sensitivity was considered in defining the finite element mesh, with finer elements applied to high-stress regions such as connections and base-wall interfaces.



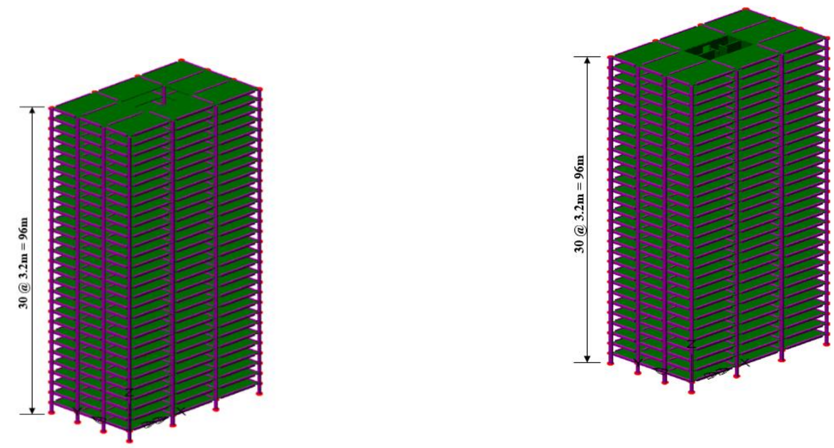


Figure 1. 3D models of 10-, 20-, and 30-storey RC buildings with and without shear walls.

No of stories	Without shear walls Model No	With shear walls Model No
10	1	2-7
20	3	4
30	5	6

Table 1. Summary of building models analyzed (10-, 20-, and 30-storey, with and without shear walls).

3.2 Structural Assumptions (Materials and Geometry)

The primary structural system consists of a reinforced concrete frame, with the following material and geometric properties:

- Concrete compressive strength (f'c): 30 MPa
- Modulus of elasticity (E): 25 GPa
- Reinforcement yield strength: 500 MPa
- Unit weight of concrete: 25 kN/m³
- Storey height: 3.5 meters
- Plan dimensions: 25 m × 25 m
- Shear wall thickness: 300 mm

The same cross-sectional dimensions and floor plans were used across all models to ensure uniform comparison, with the only variable being the inclusion or exclusion of shear walls.

3.3 Earthquake Input: El Centro 1940 Ground Motion

Dynamic excitation was applied using the north-south component of the El Centro earthquake recorded on May 18, 1940. This ground motion is widely used in seismic research due to its strong amplitude and detailed historical recording [15]. The input data consisted of a 10-second acceleration record with a time interval of 0.02 seconds. The ground motion was scaled and applied as a base excitation in the horizontal (Y) direction for all models.

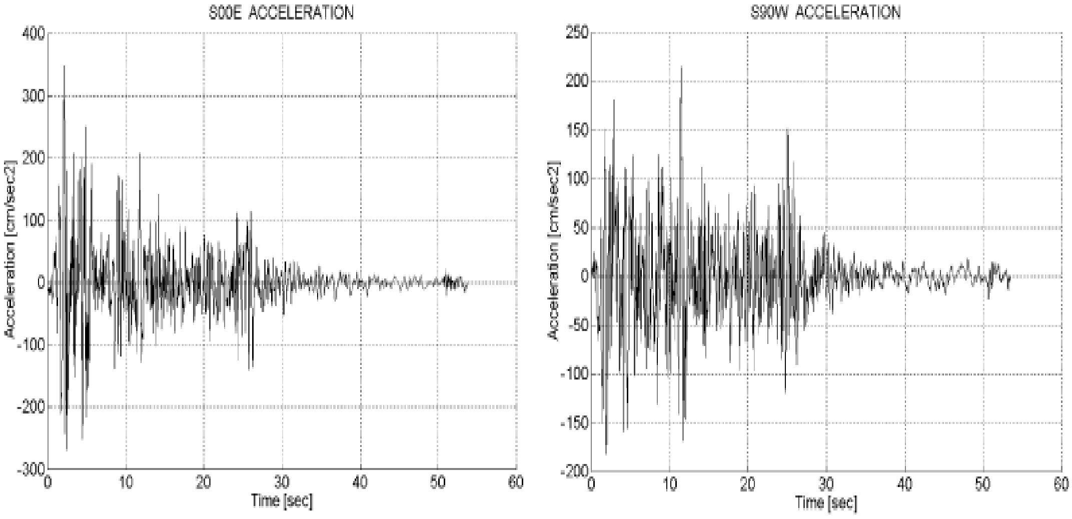


Figure 2. North-South component of El Centro 1940 ground motion acceleration record.

3.4 Time-History and Modal Analysis Setup

Two types of analysis were conducted:

- Time-history analysis: A linear-elastic dynamic analysis was performed to obtain roof displacement, velocity, and acceleration responses for each model over the 10-second duration of the seismic input. Damping was set at 5% of critical damping to simulate energy dissipation in RC structures.
- Modal analysis: Natural frequencies, mode shapes, and modal mass participation ratios were extracted. Modal data were used to interpret how shear walls affect the distribution of dynamic response across different vibration modes.

A total of 100 modes were calculated for each model to ensure mass participation exceeded 90% in both X and Y directions.

3.5 Validation Using ETABS

To validate the LUSAS modeling approach and ensure computational accuracy, Model 1 (10-storey RC frame without shear walls) was replicated in ETABS 18.2.2. Results for maximum roof displacement and natural frequencies were compared. Displacement differences ranged between 1.8% and 2.8%, while modal frequencies differed by less than 3%. This close agreement between platforms confirmed that the finite element modeling, boundary conditions, and material assumptions in LUSAS were reliable and suitable for the objectives of the study [16].

MODE	Displacement LUSAS	Displacement ETABS	Difference %
1	0.824	0.843	2.25
4	0.808	0.821	1.58
7	1.275	1.105	1.34
11	0.780	0.561	2.8

Table 2. Comparison of results between LUSAS and ETABS for 10-storey model validation.

4. Results and Analysis

This section presents the outcomes of the time-history and modal analyses conducted on six structural models. The focus is on evaluating the impact of shear walls on seismic displacement, acceleration, and dynamic characteristics across three building heights. The comparative results provide insight into how structural performance improves when shear walls are included in reinforced concrete (RC) buildings subjected to seismic loading.

4.1 Roof Displacement Performance

The most direct indicator of seismic response is roof displacement. Time-history plots were generated for the Y-direction (lateral) displacement at the top of each building under the El Centro 1940 earthquake. The peak displacements for each configuration are summarized below:

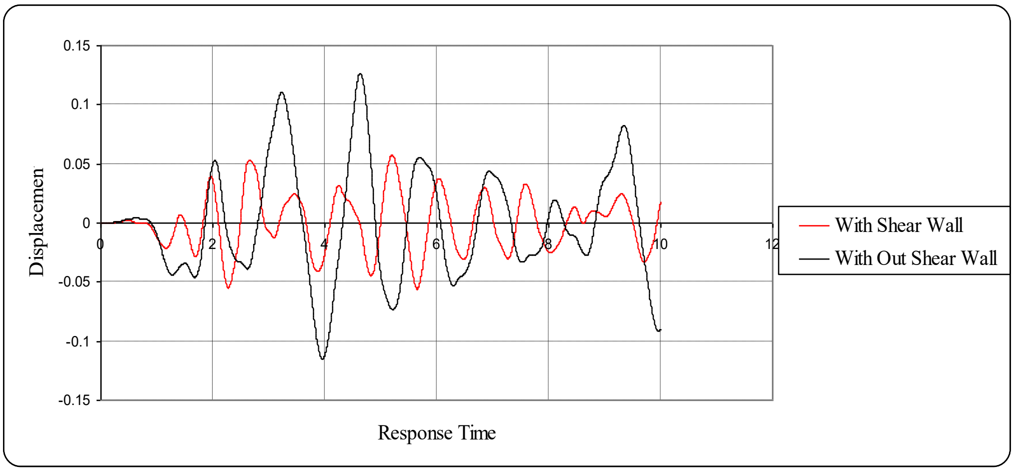


Figure 3. Time-history displacement response for 10-storey buildings.

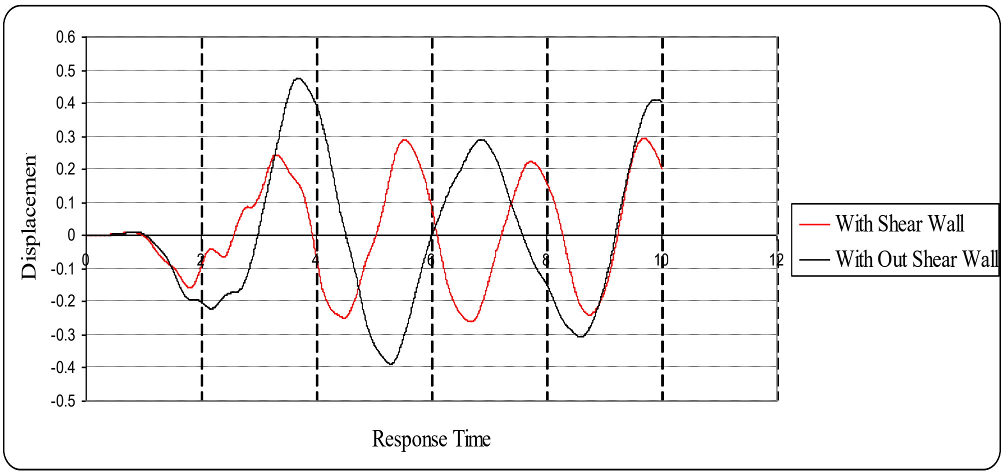


Figure 4. Time-history displacement response for 20-storey buildings.

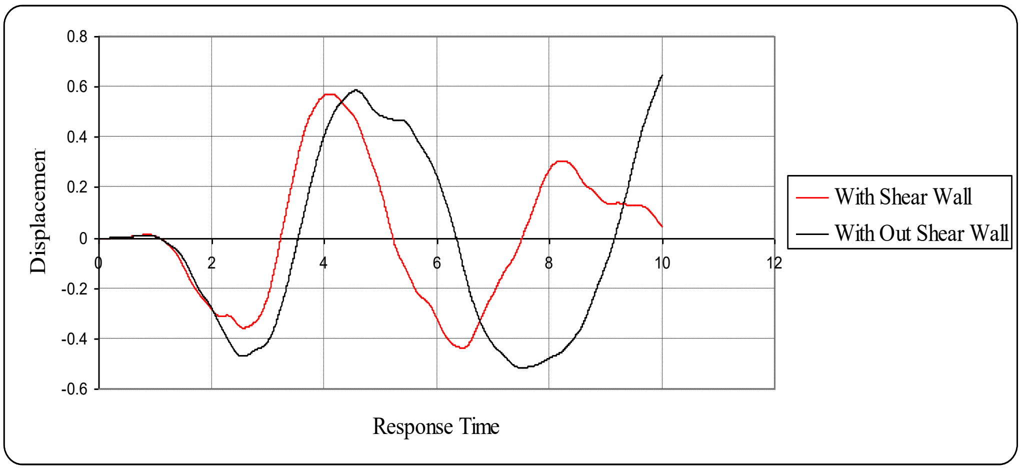


Figure 5. Time-history displacement response for 30-storey buildings.

Building Height	Without Shear Walls	With Shear Walls	Displacement Reduction
10 Storeys	0.1263 m	0.0571 m	54.7%
20 Storeys	0.4666 m	0.2669 m	42.7%
30 Storeys	0.6466 m	0.3033 m	53.1%

Table 3. Comparison of Peak Roof Displacements With and Without Shear Walls Across Building Heights

In all three height categories, buildings with shear walls exhibited significantly reduced lateral displacements. The most substantial reduction was observed in the 10- and 30-storey models, suggesting that shear walls are particularly effective in controlling sway in both low- and high-rise configurations.

4.2 Acceleration and Velocity Responses

In addition to displacement, velocity and acceleration responses were extracted to assess how the dynamic forces evolve over time. Buildings without shear walls displayed larger fluctuations and higher peak accelerations, indicating greater susceptibility to dynamic amplification. In contrast, models with shear walls demonstrated more controlled and dampened responses.

For instance, in the 20-storey building:

- Peak acceleration (without shear wall): ~5.2 m/s²
- Peak acceleration (with shear wall): ~3.4 m/s²
- Reduction: ~34.6%

These reductions in acceleration translate to lower base shear forces and reduced demand on structural and non-structural components.

4.3 Mode Shape and Period Comparison

Modal analysis was conducted to determine natural periods, mode shapes, and mass participation ratios. The presence of shear walls had a significant influence on the dynamic characteristics of each building.

- 10-storey model:
  - Without shear wall: Mass participation (Y-direction) >90% in Mode 5
  - With shear wall: Same threshold reached at Mode 35

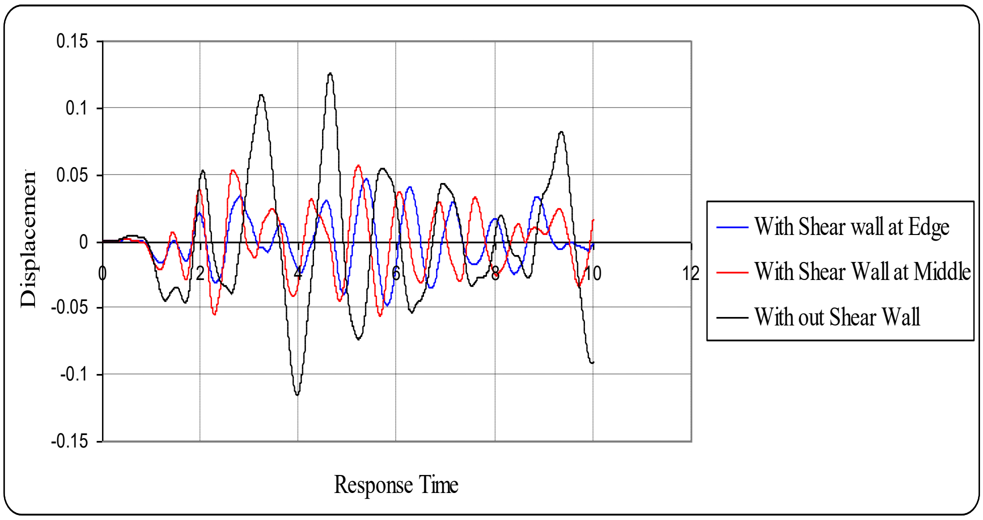


Figure 6. Modal participation comparison of 10-storey models (with and without shear walls).

- 30-storey model:
  - Fundamental period decreased from 2.86 s (no walls) to 1.54 s (with walls)

The inclusion of shear walls increased lateral stiffness, thus reducing the fundamental period and pushing the dominant vibration modes to higher frequencies. This shift is desirable, as it moves the structure away from resonance with typical seismic energy content.

4.4 Interpretation of Trends with Building Height

The effectiveness of shear walls became more pronounced as building height increased. In the 10-storey case, stiffness alone provided some resistance; however, in the 30-storey configuration, the difference in displacement was more than 0.34 m. This suggests that the role of shear walls becomes increasingly critical as the structure becomes taller and more flexible.

Interestingly, while absolute displacement increased with height, the percentage reduction remained consistently above 40% across all models. This highlights the scalable benefit of shear walls in high-rise seismic design.

5. Discussion

The results of this study clearly demonstrate the critical role that shear walls play in improving the seismic performance of reinforced concrete buildings across a range of building heights. The inclusion of shear walls led to consistent and substantial reductions in lateral displacement, peak acceleration, and overall structural response during time-history analysis. These findings support the theoretical and experimental conclusions of past studies, while also offering new insight into how the efficiency of shear walls scales with building height.

The most striking result was the consistent reduction in peak displacement, ranging from 42.7% in 20-storey buildings to over 54% in both 10- and 30-storey structures. This confirms that shear walls serve as highly effective lateral stiffness elements, limiting deformation under dynamic loading. The results also align with previous studies by Hyun-Su et al. (2005), which indicated similar displacement control in high-rise RC buildings [17].

In addition to displacement, the acceleration response was notably improved by the presence of shear walls, reducing the inertial demands placed on the building's structural and non-structural systems. This not only improves structural safety but also reduces the likelihood of secondary damage (e.g., to partitions, cladding, and equipment) that often results from high acceleration levels during earthquakes.

The modal analysis findings are also significant. The shift in dominant mode shapes to higher modes—e.g., from Mode 5 (without shear walls) to Mode 35 (with shear walls) in the 10-storey case—reflects a clear increase in overall system stiffness. This shift reduces the risk of resonance with typical seismic ground motions, which often carry the most energy in the 0.5 to 2.5-second period range. By shortening the building's fundamental period, shear walls effectively reduce dynamic amplification and contribute to more stable structural behavior.

Moreover, the effectiveness of shear walls was found to increase with building height, particularly in the 30-storey model, where the displacement difference exceeded 0.34 meters. This trend highlights the importance of lateral load-resisting systems in taller and more flexible buildings, where moment frames alone may not provide sufficient stiffness.

Another important observation is the close agreement between LUSAS and ETABS simulations, which provides validation for the modeling approach. This adds confidence in using LUSAS for advanced seismic performance evaluations, especially when detailed shell modeling of shear walls is required.

In summary, the findings strongly support the integration of shear walls into RC building designs, especially in regions of moderate to high seismic risk. The performance improvements observed are both quantitatively significant and consistent with current seismic design philosophies promoted in standards such as Eurocode 8 and ASCE 7-22 [18].

6. Future Work

While this study focused on linear-elastic seismic response, future investigations should explore the nonlinear behavior of RC buildings with shear walls, particularly under near-fault ground motions. Considerations such as cracking, yielding, and plastic hinge formation can provide a more realistic representation of performance during severe earthquakes [19].

Other areas of interest include:

- Evaluating the effect of shear wall openings on seismic response
- Studying non-rectangular shear wall geometries and irregular layouts
- Assessing the interaction of shear walls with base isolation systems
- Incorporating soil-structure interaction (SSI) effects in the analysis
- Comparing performance using other ground motion records from different seismic zones

Additionally, expanding the scope to include multi-objective optimization for the placement and sizing of shear walls can support more efficient, performance-based design strategies. These future studies would provide further insights for structural engineers seeking to design resilient and cost-effective RC buildings in earthquake-prone environments.

Conclusion

This study examined the seismic performance of reinforced concrete buildings with and without shear walls using finite element modeling through LUSAS FEA 14.03 and time-history analysis based on the El Centro 1940 earthquake record. Six models representing 10-, 20-, and 30-storey RC buildings were analyzed to investigate how the inclusion of shear walls influences displacement, acceleration, and modal response.

The results clearly demonstrated that incorporating shear walls significantly enhances seismic performance. Peak lateral displacements were reduced by 54.7%

in the 10-storey, 42.7% in the 20-storey, and 53.1% in the 30-storey models. Acceleration responses were also notably lower, and velocity time-histories showed smoother and more stable trends in buildings with shear walls. Additionally, modal analysis revealed a substantial shift in natural frequencies and mass participation to higher vibration modes, indicating increased stiffness and reduced susceptibility to resonance.

These findings validate the effectiveness of shear walls as a lateral load-resisting system and highlight their importance in tall building design. The consistent improvements across varying heights suggest that shear walls are beneficial not only in high-rise configurations but also in medium- and low-rise structures. The results also confirm the reliability of LUSAS software for advanced structural simulations, with verification via ETABS showing high consistency.

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