



Optimization of Shear Wall Placement to Improve Seismic Performance of High-Rise Buildings Using Pushover Analysis

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Abstract

High-rise reinforced concrete buildings are susceptible to seismic forces due to their slenderness and flexibility, necessitating effective lateral load-resisting systems. This study investigates the optimal placement of shear walls to enhance seismic performance. A seven-story symmetrical building model was developed in ETABS v.9.7.4, following ASCE/SEI 7-16 and ACI 318-19 standards. Five configurations were analyzed: one control model without shear walls and four others with different wall arrangements. Nonlinear static pushover analysis was employed to evaluate structural response under lateral loading. Performance metrics such as natural period, story displacement, drift ratio, base shear capacity, and pushover behavior were examined. Results indicate that shear wall presence and positioning significantly impact seismic response. The model with symmetrically placed shear walls (Model 3) achieved the best performance, showing a 44.7% reduction in fundamental period, a 40% increase in base shear capacity, and a 47.5% decrease in story drift. These findings highlight the effectiveness of symmetric shear wall layouts in improving seismic resilience. This research offers practical guidance for structural engineers in optimizing lateral systems for earthquake-resistant high-rise buildings.

Keywords: Shear wall, seismic performance, high-rise buildings, pushover analysis

Abstrak

Bangunan bertingkat tinggi rentan terhadap gaya gempa akibat kelangsingan dan fleksibilitasnya, sehingga sistem peredam beban lateral menjadi komponen penting dalam perancangan struktur. Penelitian ini bertujuan mengevaluasi dan mengoptimalkan penempatan dinding geser (shear wall) untuk meningkatkan kinerja seismik bangunan beton bertulang. Model bangunan simetris tujuh lantai dikembangkan menggunakan perangkat lunak ETABS v.9.7.4, mengacu pada standar ASCE/SEI 7-16 dan ACI 318-19. Lima konfigurasi struktur dianalisis, terdiri atas satu model kontrol tanpa shear wall dan empat model dengan variasi penempatan dinding geser. Analisis statik nonlinear pushover digunakan untuk mensimulasikan respons struktur terhadap beban lateral. Parameter performa seperti periode alami, perpindahan antar lantai, rasio simpangan (drift), kapasitas geser dasar, dan kurva pushover dianalisis. Hasil menunjukkan bahwa keberadaan dan posisi shear wall sangat memengaruhi respons seismik. Model dengan penempatan shear wall simetris (Model 3) memberikan kinerja terbaik, dengan penurunan periode fundamental sebesar 44,7%, peningkatan kapasitas geser dasar 40%, dan pengurangan drift hingga 47,5%. Penelitian ini memberikan panduan praktis dalam desain struktur tahan gempa melalui optimasi sistem dinding geser.

Kata kunci: Dinding geser, kinerja seismik, bangunan bertingkat, analisis pushover

Introduction

The increasing demand for vertical urban development has led to a significant rise in the construction of high-rise reinforced concrete buildings, particularly in seismically active regions (Soni et al., 2016). These structures are inherently vulnerable to seismic lateral forces due to their slender geometry, considerable height, and irregular mass distribution. Consequently, ensuring adequate lateral resistance is a fundamental concern in structural engineering. Among various lateral force-resisting systems, shear walls are widely acknowledged for their superior stiffness and energy dissipation capacity under seismic loads. However, the effectiveness of a shear wall system is highly influenced by its positioning, configuration, and integration within the overall structural system (Kumar et al., 2015; Khandelwal & Mhetre, 2017).

Numerous studies have examined the role of shear walls in improving seismic performance. Abou-Elfath and Ghobrial (2021) highlighted the significance of wall placement in minimizing torsional irregularities and lateral displacements. Shukla and Nallasivam (2023) employed genetic algorithms to optimize shear wall layouts, achieving notable enhancements in structural behavior. Nonlinear static analyses conducted in recent studies revealed that symmetrical wall configurations resulted in better control of story drift and improved structural stability. Lu et al. (2015) and Wang et al. (2023) utilized advanced modeling approaches to investigate the impact of shear wall positioning on structural stiffness and ductility. Although these contributions have enriched the current understanding of shear wall systems, few studies offer a direct comparison of multiple configurations under a unified modeling and loading framework using nonlinear pushover analysis (Faghirnejad et al., 2024; Banerjee et al., 2024).

This study introduces a scientific novelty by comprehensively evaluating different shear wall configurations using consistent modeling parameters and seismic loading conditions within the context of pushover analysis. Rather than merely investigating the presence or absence of shear walls, the research systematically compares the impact of their configuration on key seismic performance metrics, including natural periods, story displacements, drift ratios, base shear capacity, and lateral deformation patterns. The ultimate goal is to determine the most effective configuration for enhancing structural resilience against seismic forces.

The research problem addressed in this study focuses on identifying the most efficient shear wall layout to improve the seismic performance of high-rise reinforced concrete buildings. The primary objective is to analyze and determine the optimal shear wall arrangement through nonlinear pushover analysis applied to a seven-story symmetrical building model, thereby offering practical insights for structural engineers involved in performance-based seismic design.

Methods

This study employed nonlinear static pushover analysis to evaluate and optimize the placement of shear walls in a high-rise reinforced concrete structure. The analysis was conducted using ETABS v.9.7.4 (CSI, 2016), based on ASCE/SEI 7-16 (2017) for seismic loading and ACI 318-19 (2019) for structural detailing.

The object of this study was a seven-story symmetrical reinforced concrete building representing a typical mid-rise structure in seismic regions. The structural system consisted of reinforced concrete columns (500 mm × 500 mm), beams (400 mm × 200 mm), and 120 mm thick floor slabs arranged on a 4 m × 4 m grid with a story height of 3.0 m. The reinforced concrete material was defined with a compressive strength of 30 MPa ($f'_c = 30$ MPa), while reinforcing steel had a yield strength of 420 MPa ($f_y = 420$ MPa). The modulus of elasticity of concrete was determined according to ACI 318-19, and the unit weight of reinforced concrete was taken as 24 kN/m³. Shear walls with a thickness of 300 mm were modeled as shell elements serving as the primary lateral-force-resisting system. Columns were reinforced with eight 20 mm diameter longitudinal bars and 40 mm concrete cover.

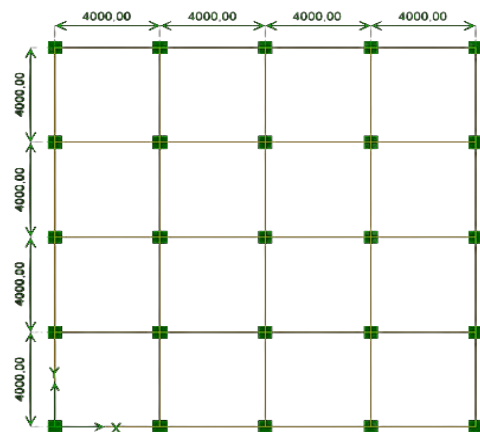


Figure 1. Control model without shear walls

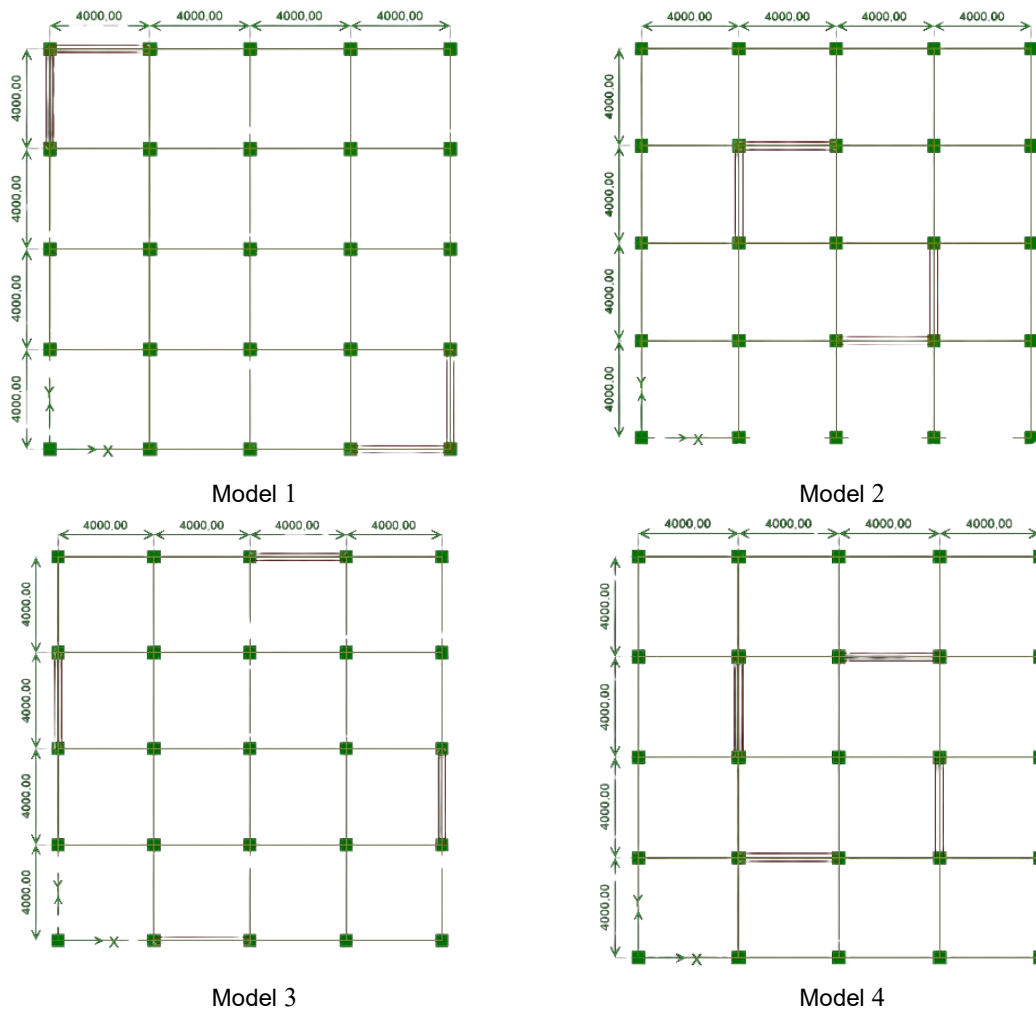


Figure 2. Shear wall configurations in Models 1–4

Five structural models were analyzed: one control model without shear walls (Figure 1) and four with various shear wall placements (Models 1–4, Figure 2). These configurations were designed to assess the impact of wall positioning on seismic behavior, particularly in terms of stiffness, strength, and lateral displacement, under uniform geometric and loading conditions.

The pushover analysis was carried out by first applying gravity loads, followed by a lateral load pattern simulating uniform seismic force of 350 kN per floor. The lateral loads were applied incrementally until the structure reached the target roof displacement or exhibited failure mechanisms. The analysis followed the guidelines set by FEMA 440 and ASCE/SEI 41 for nonlinear seismic evaluation (Hakim et al., 2024), and the approach has also been adopted in recent seismic evaluations of reinforced concrete structures in Indonesia (Erizal et al., 2024; Rahmantyo & Andayani, 2019).

Story displacement values were obtained directly from the ETABS nonlinear static pushover analysis

output after the target displacement was reached. The displacement at each floor level was extracted from the joint response corresponding to the center of mass of each story. Separate analyses were carried out for lateral loading in the global X- and Y-directions, and the resulting story displacements were plotted to evaluate the effectiveness of each shear wall configuration in controlling lateral deformation.

Several performance parameters were measured during the analysis: base shear versus roof displacement curves, inter-story drift ratios, plastic hinge formations, and overall stiffness and ductility of each model. These metrics were used to evaluate and compare the effectiveness of each shear wall configuration.

The optimal shear wall layout was identified by analyzing each model's ability to maximize base shear capacity, minimize story displacements and drift ratios, and distribute plastic hinges uniformly throughout the structure. This methodological approach ensures that the selection of the most

effective configuration is based on measurable improvements in seismic performance, providing structural engineers with a practical reference for performance-based seismic design in high-rise buildings.

Results and Discussion

The results of this study are derived from nonlinear pushover analyses conducted on a seven-story symmetrical reinforced concrete building with five different shear wall configurations. The models were assessed based on several key seismic performance indicators, including natural periods, base shear capacity, roof displacement, story displacements, drift, drift ratios, and story shear forces. The comparative analysis highlights the structural implications of each configuration and identifies the most effective layout for enhancing seismic resilience.

Figure 3 presents the structural model without shear walls, serving as a control baseline for comparison. Figure 4 shows Models 1 through 4 with varying shear wall placements, each designed to examine different stiffness distributions and structural behaviors.

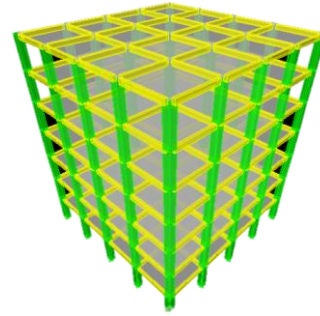


Figure 3. ETABS model of the structure without shear walls

A significant difference in dynamic behavior is observed through modal analysis, as illustrated in Figures 5 through 9. The control model exhibits the longest natural period (0.7010 seconds), indicating low stiffness and high flexibility. The presence of shear walls substantially shortens the natural period, with Model 3 achieving the lowest and most symmetrical values (0.3874 seconds for both modes), reflecting improved lateral stiffness and balanced structural response. These results support the assertion that the strategic placement of shear walls, particularly in symmetric configurations, leads to optimal global stiffness and dynamic stability.

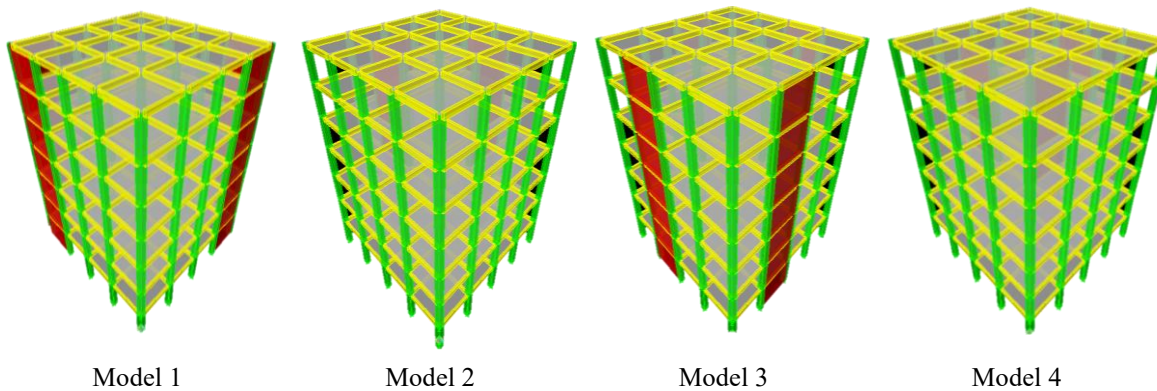


Figure 4. ETABS models of structures with various shear wall placements (Models 1–4)

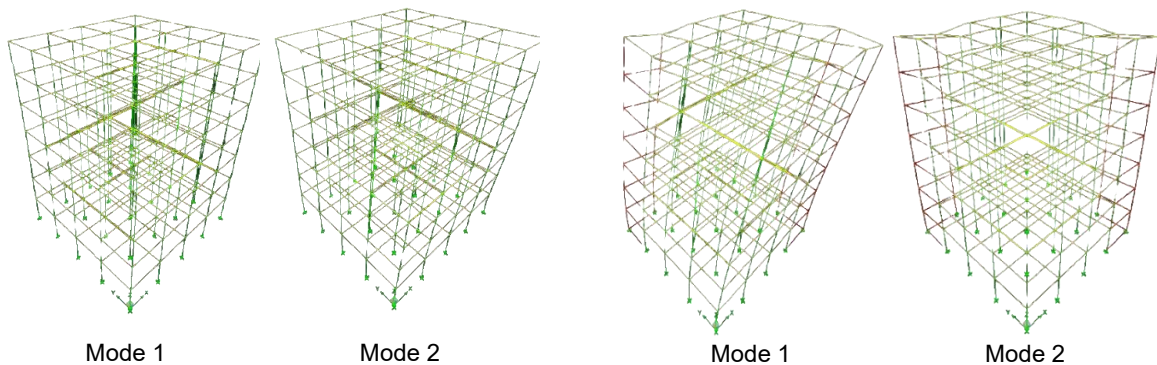


Figure 5. Natural periods for modes 1 and 2 of the structure without shear walls

Figure 6. Natural periods for modes 1 and 2 of Model 1

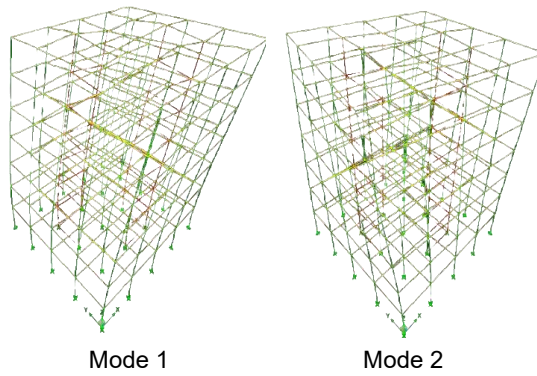


Figure 7. Natural periods for modes 1 and 2 of Model 2

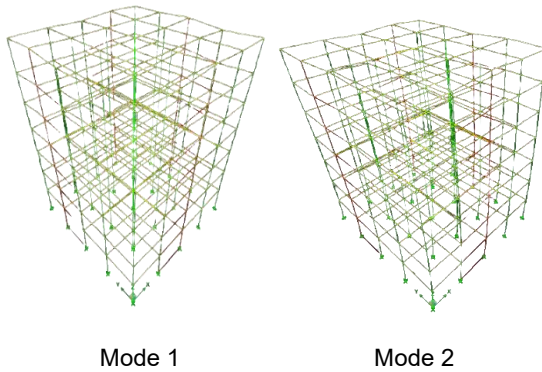


Figure 8. Natural periods for modes 1 and 2 of Model 3

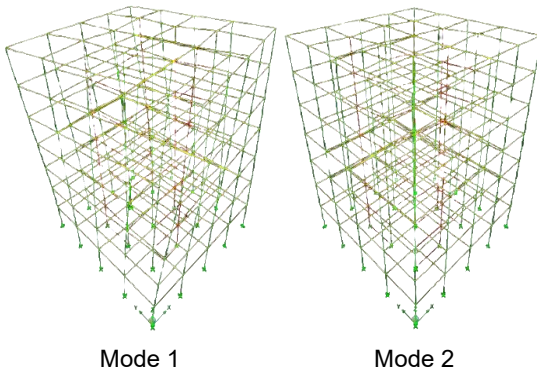


Figure 9. Natural periods for modes 1 and 2 of Model 4

The pushover curves, depicted in Figures 10 and 11, reveal the nonlinear behavior of each model under increasing lateral loads. The control model experiences the highest roof displacement (340 mm) and lowest base shear capacity (2450 kN), indicating reduced lateral strength and high deformability. In contrast, Model 3 demonstrates superior seismic performance with a peak base shear of 3430 kN and reduced roof displacement (185 mm). These findings indicate that symmetrical shear wall placement not only increases energy dissipation capacity but also delays the onset of structural yielding and plastic hinge formation, and

improved ductility as found in similar pushover-based studies (Faghirnejad et al., 2025; Cheng et al., 2024).

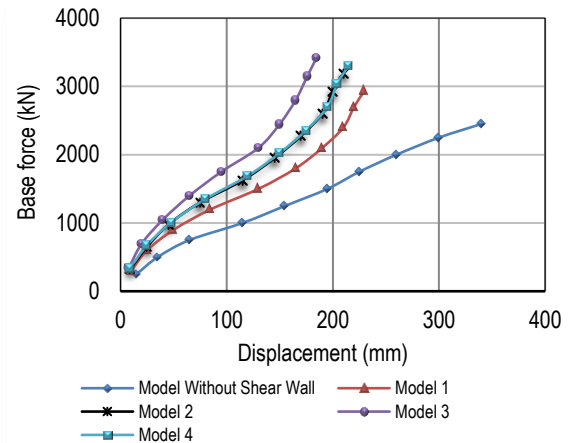


Figure 10. Pushover curves comparison in X direction

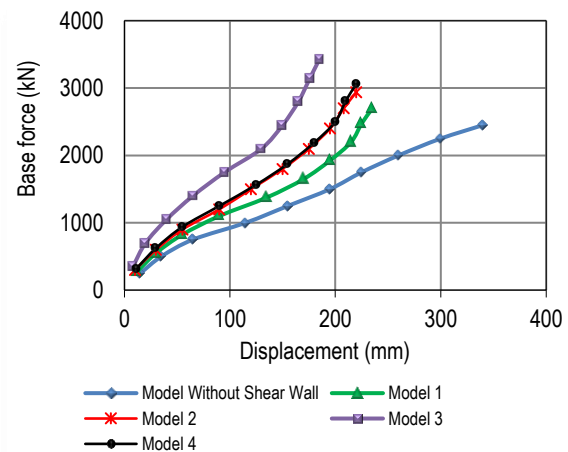


Figure 11. Pushover curves comparison in Y direction

Figures 12 and 13 present the story displacement profiles obtained from nonlinear static pushover analyses under lateral loading in the global X-direction (Figure 12) and global Y-direction (Figure 13). The displacement values represent the lateral translation of each story relative to the fixed base and were extracted from the ETABS analysis output after the target displacement was reached. The control model consistently exhibits the largest story displacements across all floor levels, indicating lower lateral stiffness. In contrast, Model 3 demonstrates the best seismic performance, achieving up to a 32% reduction in top-story displacement compared with the control model. These results indicate that the strategic placement of symmetrically arranged shear walls effectively controls lateral deformation and enhances the overall seismic stability of the structure.

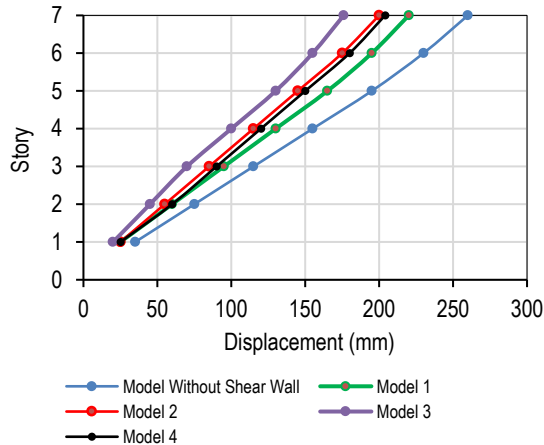


Figure 12. Story displacement profiles in the global X-direction obtained from nonlinear pushover analysis.

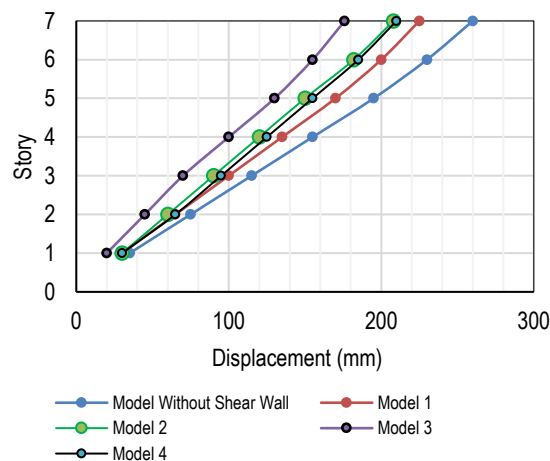


Figure 13. Story displacement profiles in the global Y-direction obtained from nonlinear pushover analysis.

Further examination of story drift values, presented in Figures 14 and 15, reveals that the absence of shear walls results in higher drift (35–40 mm), especially in the lower stories, which are critical for maintaining overall structural stability. In contrast, Model 3 achieves the lowest story drift (20–30 mm), representing a reduction of up to 47.5% compared with the control model. This improvement is attributed to the increased lateral stiffness provided by the symmetrically arranged shear walls, which distribute seismic forces more uniformly and reduce inter-story deformation, highlighting the influence of shear wall configuration on structural response (Guettala et al., 2024; Khelaifia et al., 2024).

To evaluate compliance with seismic design requirements, the story drift results were further assessed using the corresponding story drift ratios, as required by ASCE/SEI 7-16. Figures 16 and 17 present the story drift ratios, which are normalized

indicators of lateral deformation. The control model reaches a maximum drift ratio of 1.33%, whereas Model 3 maintains drift ratios below 1.0% throughout the building height. These values satisfy the allowable inter-story drift limits specified by ASCE/SEI 7-16 for reinforced concrete buildings, indicating that all structural models meet the code requirements, with Model 3 providing the greatest safety margin due to its superior lateral stiffness and deformation control. This behavior is consistent with previous studies on ductile shear wall systems (AlHamaydeh et al., 2022; Aly & Galal, 2020).

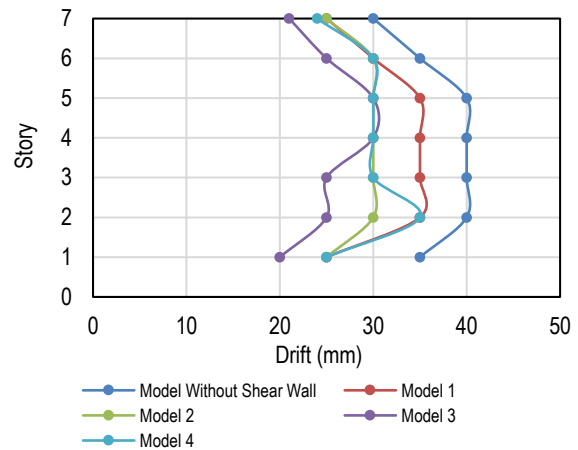


Figure 14. Story drift comparison in X direction

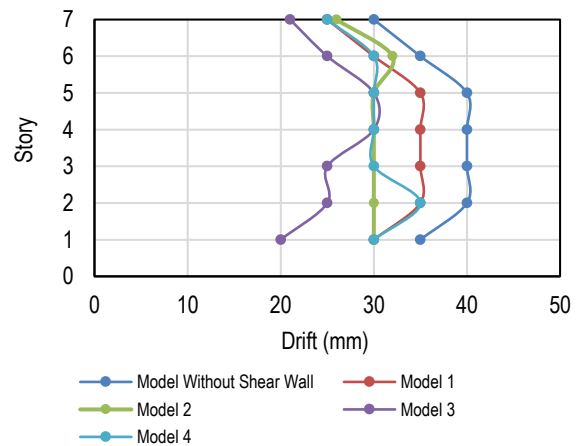


Figure 15. Story drift comparison in Y direction

Lastly, Figures 18 and 19 illustrate the distribution of story shear forces. The control model sustains a maximum base shear of 2450 kN, while Model 3 achieves 3430 kN representing a 40% improvement in lateral load capacity, as similarly observed in other studies examining dual structural systems (Bai et al., 2021; Aguayo et al., 2024). The uniformity in shear distribution in Model 3 further indicates efficient force transmission from floor diaphragms to the foundation, highlighting the structural advantages of symmetric and well-anchored shear wall layouts.

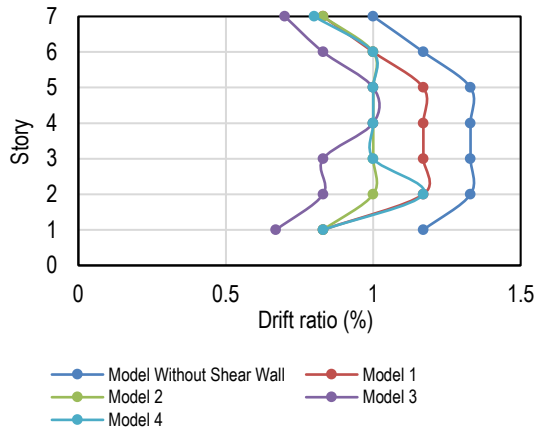


Figure 16. Story drift ratio comparison in X direction

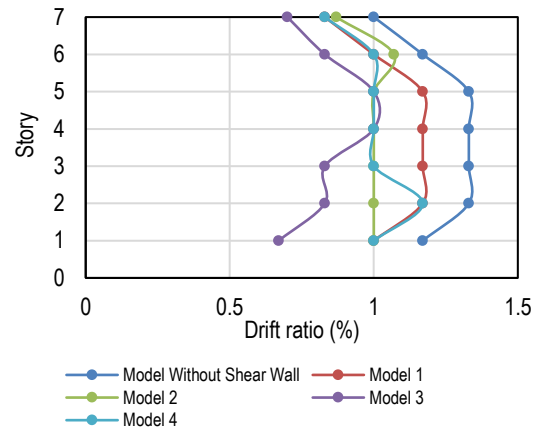


Figure 17. Story drift ratio comparison in Y direction

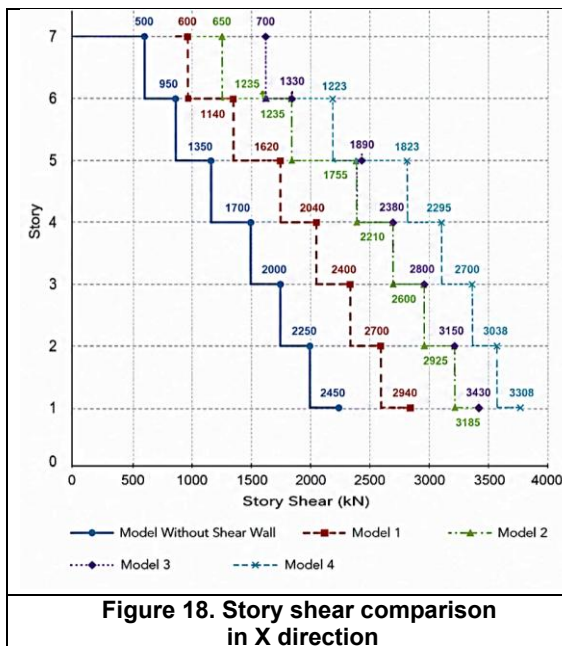


Figure 18. Story shear comparison in X direction

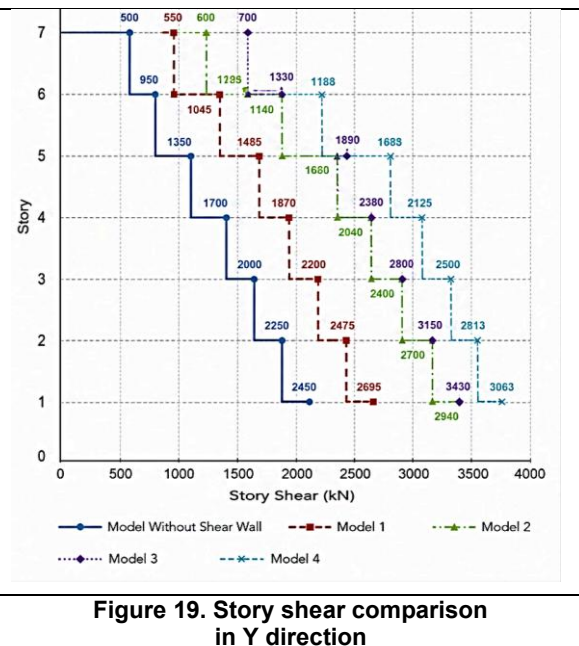


Figure 19. Story shear comparison in Y direction

Overall, the results of this study confirm that the configuration of shear walls significantly affects the seismic behavior of high-rise structures. Among the models evaluated, Model 3 consistently demonstrated superior performance in terms of stiffness, strength, deformation control, and energy dissipation. The findings emphasize the necessity of strategic, symmetrical placement of shear walls in performance-based seismic design to ensure both safety and structural efficiency.

Conclusion

This study has demonstrated that the configuration of shear walls plays a critical role in enhancing the seismic performance of high-rise reinforced concrete structures. Through nonlinear pushover analysis of a seven-story symmetrical building, it was found that strategic placement of shear walls

significantly improves key structural performance indicators, including stiffness, base shear capacity, drift control, and lateral deformation distribution.

Among the five configurations analyzed, the symmetrical layout of Model 3 consistently outperformed the others. This finding confirms the hypothesis that balanced and well-distributed lateral-force-resisting elements provide superior seismic resilience. The optimized arrangement of shear walls in Model 3 not only enhanced energy dissipation and lateral stiffness but also contributed to a more uniform and predictable structural response under seismic loading. The scientific contribution of this research lies in its ability to quantify the impact of wall placement using consistent analytical metrics and modeling assumptions, offering practical guidance for structural engineers in the implementation of

performance-based seismic design. The results also provide a foundation for future performance-based seismic design strategies, particularly those involving computational optimization and structural innovation (Malik et al., 2024; Almajhali et al., 2024).

Future research may expand on this work by incorporating more complex building geometries, varying seismic hazard levels, or integrating optimization algorithms to automate shear wall placement. Additionally, time-history analyses can be employed to complement the pushover approach and validate dynamic performance under real earthquake scenarios. This could be extended using bidirectional ground motion models and hybrid lateral systems to capture more realistic structural responses (Hussain et al., 2024; Sulonteh & Mahajan, 2024). Further studies may also explore optimization-based strategies and global sensitivity analyses for intelligent shear wall system design (Djafar-Henni & Chebili, 2023; Xu et al., 2021).

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