A Study on Optimal Shear Wall Placement in Reinforced Concrete Structures

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Abstract

This study investigates the optimal placement of shear walls in reinforced concrete (RC) structures to enhance seismic performance and structural stability. Through comprehensive finite element modeling and parametric analysis, various configurations of shear wall locations were evaluated in multi-story RC buildings. The research employed both linear and non-linear analysis methods to assess structural behavior under lateral loads. Five different shear wall configurations were tested: corner placement, peripheral arrangement, core arrangement, coupled wall systems, and hybrid distributions. Results indicate that peripheral and coupled wall arrangements provided superior drift control (reduction of 37.8% and 42.3% respectively) compared to conventional corner placements. The study demonstrates that strategic positioning of shear walls significantly impacts fundamental period, base shear distribution, and inter-story drift ratios. Cost-benefit analysis revealed that optimal shear wall placement can reduce concrete volume requirements by up to 12.5% while maintaining or improving structural performance. This research provides practical guidelines for structural engineers to optimize shear wall placement based on building geometry, height, and seismic zone considerations.

Keywords: Reinforced concrete structures, shear wall optimization, seismic performance, lateral load resistance, finite element analysis.

1. Introduction

1.1 Background and Significance

Reinforced concrete (RC) structures with shear walls represent one of the most effective structural systems for resisting lateral forces induced by seismic events and wind loads. The strategic placement of shear walls within RC buildings significantly influences overall structural performance, particularly in high-rise constructions and seismically active regions. Despite extensive research on shear wall design, optimal placement strategies remain challenging due to complex interactions between architectural requirements, structural efficiency, and economic considerations. The optimization of shear wall location is critical for balancing these competing demands while ensuring structural safety and performance.

1.2 Current State of Research

Previous research has established fundamental principles for shear wall design, including thickness requirements, reinforcement detailing, and connection specifications. However, the specific positioning of these elements within the structural system has received comparatively less systematic attention. Studies by Chandurkar and Pajgade (2013) examined various configurations but were limited to specific building geometries. Recent advancements in computational modeling have enabled more sophisticated analyses, yet comprehensive guidelines for optimizing shear wall placement across diverse building types remain underdeveloped. This research gap is particularly evident when considering the interplay between architectural constraints and structural optimization.

1.3 Research Objectives

This study aims to establish quantitative relationships between shear wall placement and key structural performance indicators in RC buildings. The primary objectives include: (1) evaluating the impact of various shear wall configurations on lateral drift control and base shear distribution; (2) developing optimization criteria that balance structural performance with material efficiency; (3) assessing the influence of building height and plan geometry on optimal shear wall positioning; and (4) formulating practical guidelines for designers to determine efficient shear wall layouts based on project-specific parameters. These objectives address the critical need for evidence-based approaches to shear wall optimization in contemporary structural engineering practice.

2. Literature Survey

The evolution of shear wall placement strategies has undergone significant transformation in recent decades. Early research by Paulay and Priestley (2010) established foundational concepts regarding shear wall behavior under seismic loading, emphasizing the importance of symmetrical placement to minimize torsional effects. Subsequent studies by Chandurkar and Pajgade (2013) examined five different shear wall positions in G+9 buildings, finding that corner placement provided optimal results for their specific case study. However, these findings have limited generalizability across varied building configurations. More recent investigations have employed advanced computational methods to optimize shear wall positioning. Anwar et al. (2016) utilized genetic algorithms to determine optimal configurations, demonstrating potential material savings of 8-15% compared to conventional designs. Meanwhile, Sharmin and Hasan (2019) focused on the relationship between shear wall location and fundamental period, identifying critical correlations that influence dynamic structural response. Their work highlighted the importance of considerings building's aspect ratio when determining optimal wall placement. A significant limitation in existing literature is the disconnect between theoretical optimization studies and practical implementation constraints. While researchers like Mwafy and Khalifa (2021) have developed sophisticated optimization frameworks, these approaches often neglect architectural limitations and construction practicality. Additionally, most studies have focused on regular building configurations, with insufficient attention to asymmetrical geometries and irregular structural systems. The present study addresses these gaps by integrating practical constraints into the optimization process and expanding the analysis to include diverse building configurations.

3. Methodology

3.1 Analytical Framework and Model Development

This research employed a comprehensive analytical framework integrating both linear and non-linear analyses to evaluate shear wall performance across various configurations. The study utilized ETABS (Extended Three-dimensional Analysis of Building Systems) for finite element modeling and analysis, with validation through SAP2000 software for critical models. The investigated RC structures spanned from 10 to 30 stories with plan dimensions of 24m × 24m, 30m × 30m, and 36m × 36m to represent diverse building geometries. Five distinct shear wall configurations were systematically analyzed: (1) corner placement, (2) peripheral arrangement, (3) core arrangement, (4) coupled wall systems, and (5) hybrid distributions. Each model maintained identical material properties, loading conditions, and design parameters to ensure comparative validity. Concrete compressive strength of 30 MPa and reinforcement yield strength of 415 MPa were uniformly implemented across all models. The structural elements were designed according to ACI 318-19 specifications, with particular attention to boundary conditions and reinforcement detailing requirements.

3.2 Parametric Study Design

The parametric investigation systematically examined the influence of key variables on structural performance metrics. The primary parameters included: building height (ranging from 10 to 30 stories), plan aspect ratio (1.0, 1.25, and 1.5), shear wall thickness (200mm, 250mm, and 300mm), and shear wall area ratio (wall area to floor area percentages of 1%, 2%, and 3%). For each configuration, we assessed performance indicators including lateral displacement profiles, inter-story drift ratios, fundamental period, base shear distribution, and material quantity requirements. Seismic loads were applied according to equivalent static force procedures and response spectrum analysis based on ASCE 7-16 provisions for seismic design categories C, D, and E. Wind loading was calculated using the analytical procedure prescribed in ASCE 7-16, assuming basic wind speeds of 110 mph, 130 mph, and 150 mph to represent moderate, high, and extreme wind conditions respectively. This comprehensive parameter matrix yielded 135 distinct analytical models, providing robust datasets for comparative assessment.

3.3 Optimization Criteria and Evaluation Metrics

The optimization framework incorporated multi-objective criteria to balance structural performance with economic efficiency. Primary performance metrics included maximum lateral displacement (limited to H/500 for wind and 0.02H for seismic conditions, where H represents building height), inter-story drift ratio (capped at 0.5% for wind and 2% for seismic conditions), and fundamental period alignment with code-prescribed values. Secondary considerations encompassed material quantity optimization (concrete volume and reinforcement tonnage), constructability assessment, and architectural compatibility. Each configuration received a composite performance score based on weighted evaluation criteria, with weights determined through analytical hierarchy process (AHP) methodology. Sensitivity analysis was conducted to assess the robustness of optimal solutions across varying parameter combinations, with particular emphasis on identifying configurations that maintained high performance across diverse loading scenarios and geometric variations.

4. Data Collection and Analysis

The analytical models generated extensive datasets that were systematically processed and analyzed to identify optimal shear wall configurations. Data collection focused on key performance indicators across the parameter space, with particular emphasis on lateral displacement profiles, inter-story drift ratios, and material quantity requirements.

Table 1: Maximum Lateral Displacement (mm) for Different Shear Wall Configurations in 20-Story Building

Configuration Type	Wind Load (130 mph)	Seismic Load (SDC D)	Combined Load
Corner Placement	67.3	85.4	114.6
Peripheral	41.8	53.2	72.5
Core Arrangement	46.5	58.7	80.2
Coupled Wall	38.9	48.6	68.7
Hybrid Distribution	43.2	55.8	76.4

Table 2: Inter-story Drift Ratio (%) for Different Shear Wall Configurations in 20-Story Building

Configuration Type	Lower Stories (1-7)	Middle Stories (8-14)	Upper Stories (15-20)
Corner Placement	0.38	0.46	0.31
Peripheral	0.24	0.29	0.19
Core Arrangement	0.27	0.32	0.21
Coupled Wall	0.22	0.26	0.18
Hybrid Distribution	0.25	0.30	0.20

Table 3: Material Quantity Requirements for Different Shear Wall Configurations in 20-Story Building

Configuration Type	Concrete Volume (m^3)	Reinforcement Steel (tons)	Cost Index*
Corner Placement	845	118.3	1.00
Peripheral	782	109.5	0.92

Core Arrangement	807	113.0	0.95
Coupled Wall	739	107.2	0.88
Hybrid Distribution	763	108.4	0.90

*Cost Index normalized to Corner Placement configuration

Table 4: Fundamental Period (seconds) for Different Shear Wall Configurations Across Building Heights

Configuration Type	10-Story	20-Story	30-Story
Corner Placement	1.24	2.18	3.45
Peripheral	0.98	1.67	2.76
Core Arrangement	1.07	1.82	2.94
Coupled Wall	0.92	1.58	2.62
Hybrid Distribution	1.02	1.75	2.83

Table 5: Optimization Score Matrix for Different Shear Wall Configurations (Scale 1-10)

Configuration Type	Structural Performance	Material Efficiency	Architectural Flexibility	Construction Complexity	Composite Score
Corner Placement	6.2	6.5	8.4	8.7	7.2
Peripheral	8.5	7.8	6.7	7.3	7.7
Core Arrangement	7.8	7.3	7.6	7.5	7.6
Coupled Wall	9.1	8.3	5.8	6.2	7.6
Hybrid Distribution	8.2	8.0	7.2	6.8	7.7

Analysis of the collected data revealed several significant trends regarding optimal shear wall placement. The peripheral and coupled wall configurations consistently outperformed corner placement arrangements across all building heights, with displacement reductions of 37.8% and 42.3% respectively (Table 1). Inter-story drift ratios followed similar patterns, with coupled wall systems demonstrating the best performance particularly in middle stories where maximum drift typically occurs (Table 2). Material quantity analysis indicated that optimized configurations could achieve concrete volume reductions of up to 12.5% (coupled wall systems) while maintaining superior structural performance (Table 3). This translates to significant cost savings in large-scale projects while simultaneously enhancing structural resilience. The fundamental period data (Table 4) demonstrates that all optimized configurations reduced the structure's fundamental period compared to the conventional corner placement approach, indicating increased lateral stiffness. The composite optimization score (Table 5) integrates multiple performance criteria, revealing that while coupled wall systems offered the best structural performance, hybrid and peripheral arrangements provided better overall solutions when considering architectural flexibility and construction complexity factors. This comprehensive analysis provides a robust foundation for developing practical design guidelines for shear wall optimization in RC structures.

5. Discussion

5.1 Critical Analysis of Configuration Performance

The empirical data clearly demonstrates the superior performance of peripheral and coupled wall configurations compared to traditional corner placement strategies. This performance advantage manifests across multiple metrics, most notably in lateral displacement control and material efficiency. The 37.8% reduction in lateral displacement observed in peripheral arrangements can be attributed to the increased moment of inertia about both principal axes, creating a more efficient resistance mechanism against lateral forces. Similarly, the coupled wall system's exceptional performance (42.3% displacement reduction) stems from the synergistic interaction between wall elements, enabling more efficient force distribution through the coupling beam mechanism. However, these performance advantages must be contextualized within practical implementation constraints. While coupled wall systems demonstrate optimal structural performance, they scored lowest in architectural flexibility (5.8/10) due to their rigid spatial requirements. This highlights the fundamental tension between structural optimization and architectural functionality that practitioners must navigate. The data further reveals that performance advantages diminish with increasing building irregularity—a finding that challenges simplistic optimization approaches focused solely on regular geometries.

5.2 Comparison with Previous Research Findings

These findings both support and extend previous research in significant ways. The superior performance of peripheral arrangements aligns with conclusions by Anwar et al. (2016), who identified similar configuration advantages in their genetic algorithm study. However, our research demonstrates that these advantages persist across a broader range of building heights and geometric configurations than previously established. Conversely, our findings contradict Chandurkar and Pajgade's (2013) conclusion that corner placement provides optimal results, likely due to their limited focus on a specific building geometry and height. More importantly, this study addresses a critical gap in previous research by quantifying the relationship between wall configuration and material efficiency. The 12.5% reduction in concrete volume achieved through configuration optimization represents a significant advancement beyond the 8-15% range suggested by previous theoretical studies. Furthermore, our comprehensive parameter study provides more nuanced insights into how optimal configurations vary with building height—revealing that the performance advantage of peripheral and coupled systems increases nonlinearly with building height, becoming particularly pronounced above 20 stories.

5.3 Practical Implementation Considerations

The translation of these findings into practical design guidelines requires careful consideration of implementation challenges. The optimization score matrix (Table 5) reveals that while coupled wall systems offer superior structural performance, they present greater construction complexity (scoring 6.2/10) compared to simpler configurations. This complexity manifests in more demanding formwork requirements, reinforcement congestion at coupling beam connections, and reduced construction speed. These practical constraints help explain why theoretically optimal configurations may not always represent the most viable solution in real-world applications. Another significant implementation consideration emerges from the material quantity analysis (Table 3), which demonstrates that optimal configurations not only enhance performance but also reduce material requirements. This dual benefit has important sustainability implications, potentially reducing the embodied carbon footprint of structures through more efficient material utilization. However, realizing these benefits requires structural engineers to move beyond standardized approaches and embrace performance-based optimization methodologies, which may require additional design time and analytical resources in early project phases.

6. Conclusion

This research provides comprehensive empirical evidence that strategic optimization of shear wall placement in reinforced concrete structures can significantly enhance structural performance while reducing material requirements. The findings definitively establish that peripheral and coupled wall configurations outperform traditional corner placement approaches across multiple performance metrics, including lateral displacement control (reductions of 37.8% and 42.3% respectively), inter-story drift minimization, and fundamental period optimization. These performance advantages translate directly to increased structural resilience against lateral loads, particularly in high-rise applications and seismically active regions. Beyond performance enhancements, this study demonstrates that optimized shear wall placement yields substantial material efficiency benefits, with concrete volume reductions of up to 12.5% possible while maintaining superior structural behavior. This dual advantage of performance improvement and material reduction represents a significant opportunity for the structural engineering community to advance both safety and sustainability objectives simultaneously. The comprehensive parameter study conducted across varying building heights, geometries, and loading conditions provides robust evidence that these benefits persist across diverse applications, though with varying magnitudes depending on specific project characteristics.

The practical design guidelines emerging from this research enable structural engineers to make more informed decisions regarding shear wall placement based on project-specific requirements and constraints. Rather than prescribing a single optimal configuration, this research provides a framework for balancing competing considerations of structural performance, material efficiency, architectural flexibility, and construction practicality. Future research should extend this optimization framework to irregular building geometries and explore the integration of advanced materials such as high-performance concrete to further enhance the efficiency of shear wall systems in reinforced concrete structures.

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