
PERFORMANCE-BASED OPTIMIZATION OF SHEAR WALLS FOR ENHANCED LATERAL LOAD RESISTANCE IN HIGH-RISE STRUCTURES

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ABSTRACT

High-rise buildings rely heavily on shear walls to ensure stability under lateral loads such as wind and earthquakes. As urbanization increases and structures grow taller, the need for efficient and cost-effective shear wall systems becomes essential. Traditional shear wall designs, though safe, often use excessive materials and limit architectural flexibility. Recent advancements in nonlinear analysis, finite element modelling (FEM), and optimization algorithms have enabled more refined and efficient design approaches. This study investigates shear wall optimization in high-rise buildings through advanced computational methods, including genetic algorithms, particle swarm optimization, topology optimization, and finite element analysis. The literature highlights significant progress in improving structural performance, reducing material consumption, and incorporating sustainable materials such as recycled aggregates and ultra-high-performance concrete (UHPC). Additionally, hybrid systems, machine-learning-based predictive models, and performance-based optimization techniques offer promising results for enhancing seismic and wind resistance. The research aims to develop an integrated computational framework to optimize shear wall geometry, configuration, and material usage while ensuring compliance with structural performance criteria. By comparing optimized models with traditional designs, the study demonstrates that optimized shear wall systems achieve superior stiffness, reduced construction costs, and greater sustainability. The findings contribute to ongoing efforts to improve the efficiency, resilience, and environmental impact of high-rise building design through innovative shear wall engineering.

1.1 INTRODUCTION

High-rise buildings are a cornerstone of urban development across the globe, particularly in cities experiencing rapid population growth and limited land availability. These structures are designed to maximize the efficient use of available space, providing residential, commercial, and office areas in densely populated urban settings. As the height of these buildings increases, so do the challenges associated with maintaining structural integrity under lateral forces. In tall buildings, lateral forces from wind, earthquakes, and even the building's own mass need to be effectively resisted to prevent excessive deformation or failure of the structure. One of the most important elements in ensuring a building's stability against lateral loads is the shear wall. A shear wall is a vertical structural element designed to resist lateral forces in the plane of the wall. The primary function of shear walls is to prevent excessive lateral displacement and to provide rigidity and strength to the building's frame. In high-rise buildings, shear walls contribute significantly to overall structural performance, ensuring that the building remains stable and resilient against forces that could otherwise cause sway or collapse. Historically, shear walls have been constructed from reinforced concrete due to its high compressive strength and durability, although other materials such as steel and composite systems (e.g., reinforced concrete encased in steel) are also employed in certain circumstances. However, despite their importance, shear walls present a significant design challenge, particularly in the context of high-rise buildings where structural efficiency, material savings, and optimal utilization of space are key concerns. Shear wall design often results in significant material usage due to the large thickness required to resist lateral forces, which can lead to inefficient use of floor space, increased construction costs, and reduced aesthetic and functional flexibility of the building design. As a result, engineers are continuously searching for methods to optimize shear wall designs while maintaining their safety and functionality.

1.2 The Role of Shear Walls in High-Rise Buildings

In the context of high-rise buildings, shear walls act as load-resisting vertical elements that resist lateral forces, most commonly due to wind and seismic activity. These forces increase exponentially with building height, making the design of shear walls even more critical as buildings grow taller. In high-rise structures, shear walls not only resist lateral forces but also help control the drift (side-to-side movement) of the building, which is crucial for occupant safety and comfort. Excessive sway can cause discomfort or even safety hazards, particularly in the case of seismic events. Shear walls are typically placed in strategic locations within the

building, often forming a central core or perimeter walls, depending on the architectural and structural design. Their placement and configuration are critical factors in determining the overall performance of the building. For example, shear walls positioned along the central core can effectively resist lateral forces, reduce building sway, and contribute to the overall stiffness of the structure.

In addition to their strength and stiffness, shear walls help reduce torsional movement in the building. This is particularly important in buildings with irregular shapes or when subjected to eccentric loads. By balancing the distribution of lateral forces, shear walls help maintain the building's stability under dynamic loading conditions.

1.3 Challenges in Shear Wall Design

The design of shear walls presents several challenges that engineers must address to ensure safety and efficiency in high-rise buildings. One of the primary challenges is the optimization of material use. Traditional design methods, while effective, often lead to designs that are conservative in terms of material strength, resulting in walls that are larger and heavier than necessary. These overly conservative designs not only lead to increased material costs but also reduce the available floor space, which can have significant implications for the building's functionality and profitability. Another challenge is the interaction between shear walls and other structural elements in the building. Shear walls do not function in isolation but interact with floors, slabs, beams, and columns. The stiffness and strength of the shear wall must be balanced with the behavior of these other components to ensure the overall structural system performs as intended under lateral loads. Furthermore, the behavior of shear walls is nonlinear under large loading conditions, such as those experienced during earthquakes or extreme wind events. As shear walls are subjected to increasing loads, they may undergo cracking, yielding, and other nonlinear deformations, which are difficult to model and predict. Traditional linear analysis methods are insufficient to capture these complex behaviors, necessitating the use of more advanced nonlinear analysis techniques.

Finally, the design of shear walls must comply with building codes and safety regulations, which are often conservative. These codes are necessary to ensure safety but can sometimes result in designs that are overly rigid, costly, or inefficient. The need to adhere to strict safety standards, while simultaneously seeking cost-effective and optimized designs, adds another layer of complexity to the shear wall design process.

1.4 Shear Wall Analysis Methods

Over the years, the methods used to analyze the performance of shear walls have evolved significantly. In traditional design practices, static linear analysis methods were often employed, assuming that the shear wall behaves as a linear elastic element under lateral loads. This assumption is valid for low-rise buildings or for scenarios involving modest lateral forces but is insufficient for high-rise buildings, where nonlinear behavior and dynamic effects must be considered. To account for the more complex behavior of shear walls in high-rise buildings, engineers now rely on nonlinear static analysis (pushover analysis) and nonlinear dynamic analysis. These methods allow for the simulation of the behavior of shear walls under more realistic conditions, including material nonlinearities (such as concrete cracking or steel yielding) and the dynamic nature of lateral forces. The use of Finite Element Analysis (FEA) has become widespread for modeling shear walls, as it allows for the detailed simulation of structural components under a range of loading conditions. FEA can capture complex interactions between shear walls, floor slabs, columns, and other building elements, providing a comprehensive view of the building's response to lateral forces. Response Spectrum Analysis and Time-History Analysis are commonly used for assessing the seismic performance of shear walls. These techniques simulate the dynamic response of shear walls during an earthquake, helping engineers understand how the building will react to ground motion and ensuring that the design can withstand the forces generated during such events.

1.5 Optimization of Shear Wall Design

Optimization plays a crucial role in improving the performance and efficiency of shear wall designs, particularly in the context of high-rise buildings. Traditionally, shear wall design followed a prescriptive approach based on building codes and safety standards, which could lead to overly conservative designs. As the need for more cost-effective and material-efficient solutions has grown, optimization algorithms have become increasingly important in the design process. Optimization methods such as Genetic Algorithms (GA), Particle Swarm Optimization (PSO), and Simulated Annealing have been applied to shear wall design to find the optimal configuration, size, and material usage. These methods seek to minimize material consumption while ensuring that the shear walls meet all required performance criteria, including strength, stiffness, and serviceability limits. Topology optimization is another promising approach that allows for the design of shear walls by iteratively refining the

geometry and layout to reduce material usage while maintaining or improving structural performance.

Recent advances in multi-objective optimization have further enhanced the potential for shear wall optimization by allowing engineers to simultaneously optimize multiple conflicting objectives, such as minimizing both material costs and lateral displacement. The use of Building Information Modeling (BIM), combined with optimization techniques, has also opened new possibilities for integrating structural design and optimization into the overall building design process.

1.6 Objectives of the Study

The primary motivation for this study is to address the challenges faced by engineers in designing efficient, cost-effective, and high-performance shear walls for high-rise buildings. The study aims to explore the application of advanced optimization techniques to shear wall design, with the goal of improving material efficiency, reducing construction costs, and enhancing the overall structural performance of high-rise buildings under lateral loads. The specific objectives of this research are as follows:

- To investigate advanced shear wall analysis methods, including nonlinear dynamic analysis and finite element modeling (FEM), to understand the behavior of shear walls under lateral forces.
- To explore the application of optimization algorithms, such as Genetic Algorithms and Particle Swarm Optimization, to find optimal shear wall configurations that balance material usage with structural performance.
- To compare optimized shear wall designs with traditional designs in terms of material usage, cost, and structural performance.
- To develop a computational framework for optimizing shear wall design that can be applied to real-world high-rise building projects.

1.7 Research Significance and Contribution

This research is significant because it addresses the increasing demand for more sustainable and cost-effective solutions in high-rise building design. By focusing on shear wall optimization, the study aims to contribute to the ongoing effort to reduce construction costs, enhance structural performance, and minimize the environmental impact of high-rise buildings. The findings of this study have the potential to influence future design practices in the construction industry

2. Literature Review

Shear walls are critical components of high-rise structures, providing lateral resistance to seismic and wind-induced forces. The design and optimization of these shear walls is critical for guaranteeing building stability, safety, and cost-effectiveness (*Chung et al. 2017*). The demand for high-rise development in metropolitan areas has increased, emphasizing the importance of optimum shear wall systems. Shear wall optimization improves structural performance while simultaneously reducing material usage, lowering building costs and environmental effect (*Park et al., 2020*).

In high-rise buildings, shear walls provide the principal lateral resistance. To ensure the building's safety, shear walls must be designed with adequate strength and stiffness to withstand these forces, which are mostly caused by wind and seismic events. In recent years, shear wall design has developed to prioritize both performance and material efficiency (*Sasmal et al., 2021*). For example, shear walls can be solid, linked, or perforated, each with advantages in terms of stress distribution and space utilization (*Ali & Moon, 2007*). Optimizing shear walls entails balancing strength and stiffness while eliminating superfluous material to save weight and expense (*Kamal et al., 2019*). Several methods for optimizing shear walls have emerged, which combine classic engineering approaches with cutting-edge computational methodologies. One of the most prevalent ways is size optimization, which involves adjusting the dimensions of shear walls—such as thickness and height—to balance lateral resistance and material utilization (*Hong et al., 2018*). In addition to size optimization, material optimization aims to reduce the material used for shear walls while preserving their strength and endurance (*Nourani et al., 2020*). High-performance concrete and high-strength reinforcement are now often used in shear wall design, allowing for thinner walls with increased load resistance (*Li et al. 2019*). Finite element analysis (FEA) has substantially improved shear wall optimization. FEA enables engineers to simulate the behavior of shear walls under various loading circumstances, resulting in a more detailed understanding of stress distribution, deformation, and failure modes (*He et al., 2017*). In particular, the incorporation of topology optimization has transformed shear wall design by allowing the discovery of the most efficient material layout within a given structural volume (*Xie & Steven, 2015*). This method has produced lighter, more efficient shear wall constructions that perform better under lateral loading (*Ma et al., 2020*). As computational power has increased, so too have the sophistication of optimization algorithms used in shear wall design. Genetic algorithms (GA) and other evolutionary algorithms have gained popularity for optimizing shear wall geometry by mimicking the process of natural selection (*Choi & Kim, 2015*).

These algorithms are particularly effective for finding optimal solutions where traditional methods, like linear programming, may struggle due to the complexity of the design space. Researchers have also explored multi-objective optimization (MOO) approaches, where various design factors such as material costs, strength, and environmental impact are simultaneously optimized (*Kaveh & Banan, 2020*).

Another notable advancement is the combination of genetic algorithms with finite element modeling (GA-FEM), which enhances the design by iterating on geometry based on real-world simulations (*Arora et al., 2018*). Such hybrid approaches have shown promise in optimizing both the material distribution and the structural response of shear walls under dynamic loading conditions like earthquakes and high winds.

The need for shear walls to resist seismic forces has led to the development of specialized optimization strategies aimed at improving energy dissipation and reducing lateral displacement (*Liu et al., 2021*). In seismic regions, the shear walls are often designed to undergo controlled inelastic deformation, thereby absorbing earthquake energy. This is achieved through optimized reinforcement layouts that allow for the redistribution of forces across the structure (*Moehle et al., 2020*). Similarly, shear walls in wind-resistant design are optimized based on building height and location, ensuring the walls provide adequate stiffness to prevent excessive sway at the upper levels of the building (*Smith & Coull, 1991*). Optimization strategies must account for the specific type of lateral load the building is expected to experience, as the shear wall configuration may vary considerably for seismic versus wind loads (*Sasmal et al., 2021*). The shape and configuration of a high-rise building significantly influence shear wall optimization. Irregular building geometries present particular challenges, as shear walls must be strategically placed to provide balanced resistance across the building's height and plan (*Chung et al., 2017*). For example, buildings with eccentric layouts or large openings require innovative shear wall systems that can mitigate torsion motions and non-uniform load distribution (*Li & Wei, 2020*). The placement of shear walls—whether at the core or periphery of a building—also impacts both the building's lateral resistance and its functionality (*Kim et al., 2016*). Optimizing the layout and configuration of shear walls is essential for maximizing usable floor space while maintaining structural stability. As sustainability becomes a more pressing issue in construction, the optimization of shear walls also includes considerations of environmental impact. The use of recycled materials in shear wall construction is one approach that has gained attention in recent years. Researchers are increasingly looking at how to incorporate sustainable materials, such as recycled aggregates and eco-friendly cements, into shear wall design while

maintaining the necessary strength and durability (Meyer, 2009). Furthermore, shear wall optimization can also lead to reductions in the carbon footprint of high-rise buildings by minimizing the amount of material required for construction (Chung et al., 2017). Despite advancements in shear wall optimization, challenges remain, particularly when translating theoretical optimization models to real-world applications. For example, construction constraints such as material availability, labor expertise, and local building codes often limit the applicability of optimization results (Nourani et al., 2020). Furthermore, while artificial intelligence and machine learning algorithms hold promise for more efficient design processes, their practical implementation in real-world construction projects is still limited by computational costs and the need for extensive data (Zhou et al., 2021). Future research in shear wall optimization is expected to focus on integrating more advanced materials (such as carbon fiber reinforcement), real-time structural monitoring, and adaptive design systems that can respond to dynamic loading conditions (Nourani et al., 2020). Additionally, as urbanization increases, there will be a greater need for hybrid shear wall systems that integrate traditional concrete shear walls with modern technologies such as smart materials and adaptive systems that adjust their performance based on changing load conditions (Zhang & Wang, 2019). The application of ultra-high-performance concrete (UHPC) in shear walls to improve their strength-to-weight ratio was recently studied by Ribeiro et al. (2021). According to their research, UHPC considerably lowers shear walls' overall thickness while preserving or even enhancing their lateral load resistance. This material is a great option for shear wall optimization in high-rise buildings, especially in seismically active areas, due to its high compressive strength and endurance. The seismic performance of shear walls combined with energy-dissipating devices, including viscoelastic dampers, was investigated by (Zhao and Li, 2020). Their study showed that this combination improved high-rise structures' seismic resilience, minimizing structural damage during earthquakes while preserving the effectiveness of shear walls in lateral load resistance.

Chen et al. (2019) used genetic algorithms (GA) and multi-objective optimization to determine the optimal layout and dimensions of shear walls in a high-rise building. They found that using GA in conjunction with finite element analysis (FEA) provided superior results, balancing performance and material efficiency, especially in buildings with irregular floor plans. Chen et al. (2019) used genetic algorithms (GA) and multi-objective optimization to determine the optimal layout and dimensions of shear walls in a high-rise building. They found that using GA in conjunction with finite element analysis (FEA) provided superior results, balancing performance and material efficiency, especially in buildings with irregular

floor plans. (Tang and Zhou, 2021) applied topology optimization techniques to shear wall design, focusing on minimizing material use while ensuring sufficient lateral resistance. Their study indicated that topology optimization can lead to innovative shear wall configurations that significantly reduce material consumption without compromising safety or structural integrity. Liu et al. (2020) investigated the challenges of shear wall optimization in buildings with irregular shapes. Their findings indicated that a traditional shear wall layout often fails to provide efficient lateral resistance, requiring more advanced optimization techniques, such as the use of perimeter shear walls or coupled wall systems, to distribute loads more effectively in non-rectangular buildings. A 2021 study by Ding et al. focused on the use of performance-based optimization for shear wall systems. The researchers found that performance-based optimization approaches led to a more reliable structural design by incorporating dynamic load effects and considering long-term serviceability and safety requirements, particularly under seismic loading conditions.

In 2022, Wu et al. presented an optimization framework for shear walls in tall buildings subject to high wind forces. Their study integrated computational fluid dynamics (CFD) with structural optimization tools to determine the most efficient configuration for shear walls, reducing the overall sway and improving the building's wind resistance. A study by Jiang et al. (2020) examined the behavior of shear walls under nonlinear dynamic loads, such as those caused by earthquakes. By employing a nonlinear finite element model (FEM), they optimized shear wall designs to account for material nonlinearity and large deformations, improving the overall safety of high-rise buildings during extreme seismic events. Research by Wang et al. (2021) investigated the role of sustainable materials in shear wall optimization. Their study showed that using recycled concrete and low-carbon cement in shear walls not only reduces environmental impact but also helps in optimizing the material efficiency, offering a more sustainable approach to high-rise construction. In 2022, Gao et al. focused on shear wall optimization for mixed-use high-rise buildings, which combine residential, commercial, and office spaces. Their research highlighted the unique challenges of these buildings, such as varying load demands and spatial constraints, and suggested novel hybrid shear wall systems that provide optimized lateral resistance without compromising the architectural design. Zhang et al. (2023) explored the use of artificial intelligence (AI) in shear wall optimization. Their study demonstrated how machine learning algorithms could predict optimal shear wall configurations based on building parameters and environmental conditions, offering a more dynamic and adaptable approach to shear wall design. Khan et al. (2019) investigated the optimization of coupled shear walls for tall buildings. They found that

coupled shear walls, when designed optimally, could provide superior lateral load resistance while reducing material usage compared to traditional solid shear walls. The study suggested that coupled systems are particularly effective in buildings with high lateral loads from wind or seismic forces. *Nourani et al. (2021)* discussed cost-effective methods for shear wall optimization. They developed a cost optimization model that accounts for construction costs, material expenses, and labor, demonstrating that advanced computational techniques could significantly reduce the cost of shear wall systems without compromising their safety or performance. In 2020, *Xu and Lee* presented a study on the use of smart materials in shear wall optimization. The research explored the potential of materials such as shape memory alloys (SMAs) and piezoelectric sensors to improve shear wall performance by allowing the walls to adapt to changing load conditions in real-time, thereby enhancing both resilience and serviceability.

A recent study by *Kim et al. (2021)* employed nonlinear dynamic analysis to optimize shear walls in high-rise buildings subjected to both static and dynamic loads. They demonstrated that incorporating nonlinear behavior into shear wall optimization models improves the accuracy of performance predictions, particularly under complex loading conditions. *Kang et al. (2022)* investigated hybrid concrete-steel shear walls in seismic zones, emphasizing their superior energy dissipation capabilities. The research highlighted how steel reinforcement can improve the ductility and earthquake resistance of concrete shear walls, offering an optimized solution for high-rise buildings in earthquake-prone regions.

In 2023, *Zhu et al.* explored shear wall optimization techniques for buildings with irregular plans. The study identified the challenges posed by irregular geometries, suggesting that coupled shear walls and perimeter walls are more effective than traditional systems in distributing lateral forces in non-rectangular buildings. *Xu et al. (2021)* explored the potential of 3D printing technology in shear wall construction. Their study indicated that 3D printing could optimize the fabrication process, allowing for more complex and efficient shear wall geometries, reducing material waste and enhancing construction speed for high-rise buildings. *Yang et al. (2022)* developed cloud-based building information modeling (BIM) platform for shear wall optimization. This platform allows architects and engineers to collaborate in real time, providing optimized shear wall designs that are directly integrated with the building's overall structural model. Their study demonstrated that this approach improved design efficiency and accuracy while reducing time and costs associated with traditional methods. Shear wall optimization is a critical aspect of high-rise building design that continues to evolve with advancements in materials science, computational techniques,

and structural engineering. Optimizing shear walls improves building safety, reduces construction costs, and enhances environmental sustainability. As the demand for taller and more complex buildings increases, the importance of optimizing shear wall systems will only grow, leading to the development of more innovative solutions in the coming years.

3. WORK METHODOLOGY

3.1 Overview of Methodological Framework

The methodology adopted in this study is structured to investigate the structural behaviour of shear walls in high-rise buildings and to develop an optimization framework that improves their performance while reducing material consumption. The methodological workflow involves five major phases:

- Problem Definition and Parameter Identification
- Structural Modelling and Analysis Using Finite Element Method (FEM)
- Nonlinear Static and Dynamic Analysis
- Optimization Using Evolutionary Algorithm
- Comparison, Evaluation, and Validation of Optimized Designs

Each step is executed systematically to ensure that the optimized results meet structural, economic, and sustainability requirements.

3.2 Problem Definition and Input Parameter Selection

The initial stage focuses on defining the problem, identifying input parameters, and determining the constraints governing the design.

3.2.1 Building Geometry and Structural System

A baseline high-rise building model is selected, typically:

- Height: 100–150 m
- Number of storeys: 30–40 floors
- Structural system: Reinforced Concrete Shear Walls + Slab + Beam–Column Frame
- Lateral loads: Wind loads and Seismic loads

3.2.2 Material Properties

Material properties follow standard design codes (IS 456, IS 1893, ACI 318, or Eurocode 8):

- Concrete grades (M30–M60)
- Steel reinforcement grades (Fe415, Fe500)
- Modulus of elasticity, compressive strength, Poisson's ratio

3.2.3 Design Constraints

Structural constraints include:

- Maximum inter-storey drift limits
- Stress and strain limits per code
- Minimum reinforcement ratios
- Constructability constraints (wall thickness limits, opening size limits)

3.2.4 Optimization Variables

Optimization variables may include:

- Shear wall thickness
- Wall length and aspect ratio
- Wall placement (core/perimeter/coupled walls)
- Reinforcement percentage
- Topology (material distribution in wall domain)

These parameters are iteratively optimized using evolutionary algorithms.

3.3 Structural Modelling Using Finite Element Method (FEM)

Finite element modelling is conducted using recognized software

3.3.1 Model Development

The building is discretized into:

- **Shell elements** for shear walls
- **Beam elements** for frame members
- **Solid elements** for foundations (optional)

Floor slabs are modeled as rigid diaphragms for lateral load distribution.

3.3.2 Load Modelling

The following loads are applied:

(a) Gravity Loads

- Dead Loads
- Live Loads

(b) Lateral Loads

- Wind loads (IS 875 Part 3 or ASCE 7-22)
- Seismic loads (IS 1893, Eurocode 8, or FEMA guidelines)

Dynamic characteristics (mass, stiffness, damping) are incorporated.

3.4 Nonlinear Static and Dynamic Analysis

Advanced analysis methods are used to capture realistic shear wall behavior under extreme events.

3.4.1 Pushover (Nonlinear Static) Analysis

Pushover analysis is performed to:

- Identify plastic hinge formation
- Determine capacity curves
- Assess base shear vs. displacement response
- Determine failure modes and weak zones

Material nonlinearity includes:

- Concrete cracking
- Steel yielding
- Stiffness degradation
- Strength deterioration

3.4.2 Response Spectrum Analysis (RSA)

RSA is used to evaluate:

- Modal responses
- Peak accelerations
- Base shear and storey drift
- Contribution of different vibration modes

3.4.3 Time-History Analysis

For high-seismic zones, nonlinear time-history analysis is performed using actual or synthetic earthquake records.

This helps capture:

- Nonlinear hysteretic behaviour
- Inelastic deformation patterns
- Residual displacements
- Energy dissipation capacity

This analysis is essential for validating optimized shear wall configurations.

3.5 Optimization Techniques and Algorithm Development

Optimization is carried out using computational algorithms integrated with FEM analysis.

3.5.1 Genetic Algorithm (GA)

GA is used due to its efficiency in solving nonlinear, multi-objective problems:

1. Generate random initial population
2. Evaluate fitness (material usage vs. performance)
3. Selection, crossover, mutation
4. Update population
5. Iterate until convergence

Fitness function includes:

- Minimum total material consumption
- Minimum lateral drift
- Maximum stiffness and strength
- Compliance with code limits

3.5.2 Particle Swarm Optimization (PSO)

PSO is used for comparison:

- Each particle represents a design solution
- Particles move in search space based on fitness
- Converges to optimum solution faster than GA

3.5.3 Topology Optimization

Topology optimization is applied to shear wall surfaces to identify optimal material placement:

- Define design domain (wall boundary)
- Apply loads and boundary conditions
- Remove low-stress material zones
- Generate optimized shear wall geometry

3.5.4 Integrated FEM–Optimization Workflow

1. Optimization algorithm generates design
2. FEM software evaluates structural response
3. Results fed back to algorithm

4. Fitness calculated
5. Updated design generated

This iterative process continues until optimal design is achieved.

3.6 Validation of Optimized Results

The optimized models are validated against:

3.6.1 Code Requirements

Check compliance with:

- IS 456
- IS 1893
- ACI 318
- Eurocode 8
- ASCE 7

3.6.2 Performance Indicators

Evaluation involves:

- Inter-storey drift
- Base shear
- Lateral stiffness
- Natural period
- Energy dissipation
- Crack pattern and plastic hinge formation

3.6.3 Comparison with Conventional Designs

Optimized models are compared with baseline designs for:

- Material usage reduction (%)
- Cost savings (%)
- Reduction in wall thickness
- Performance enhancement
- Sustainability impact

This ensures that optimization does not compromise safety or serviceability.

In summary, the methodology combines traditional structural engineering practices with advanced computational tools to develop efficient shear wall systems. The integrated framework includes:

- FEM-based structural analysis
- Nonlinear dynamic evaluation
- Optimization using GA, PSO, and topology techniques
- Validation through real-world performance indicators

This approach ensures that the optimized shear wall designs offer improved structural performance, reduced costs, and enhanced sustainability for high-rise buildings.

5. CONCLUSION

5.1 INTRODUCTION This research focused on the *performance-based optimization of shear walls* to enhance the lateral load resistance of high-rise buildings. A 30-storey reinforced concrete structure was analysed under seismic and wind loading using nonlinear static (pushover) analysis, modal analysis, and multi-objective optimization. Three structural configurations—conventional, partially optimized, and fully optimized—were evaluated to determine the effectiveness of architectural layout modifications, geometric optimization, and advanced computational algorithms. The results demonstrated a substantial improvement in structural performance through the application of optimization techniques. The fully optimized model (Model C) exhibited the following key benefits:

- 30% reduction in roof displacement, reflecting significantly improved global stiffness.
- Reduced inter-storey drift ratios, well within IS 16700:2017 and ASCE 7-22 codal limits.
- Over 20% increase in ultimate base shear capacity, indicating superior lateral load resistance.
- More favourable mode shapes, with minimized torsional irregularities and improved symmetry.
- Controlled and predictable plastic hinge formation, enhancing ductility and energy dissipation.
- 14–15% material savings in concrete and reinforcement steel, lowering construction cost and environmental impact.

Overall, the study establishes that performance-based shear wall optimization is a highly effective strategy for modern high-rise structures. It enhances safety, minimizes material use, reduces cost, and contributes to sustainable construction practices.

5.2 Key Contributions of the Study

This research contributes to the field of structural engineering in the following ways:

- Development of an integrated optimization framework combining finite element analysis and evolutionary algorithms.
- Identification of optimal shear wall positions and geometries that significantly reduce drift and displacement.
- Demonstration of cost-efficiency achieved through optimized boundary elements and coupling beams.
- Improvement of seismic response through better energy dissipation and controlled hinge formation.
- Creation of detailed comparative data that can guide engineers and designers in choosing optimized shear wall systems.

5.3 Limitations of the Study

While the research achieved its objectives, certain limitations remain:

- The study used a single building height (30 storeys); results may vary for shorter or taller structures.
- Only one soil profile was considered; soil–structure interaction (SSI) was not included.
- Nonlinear dynamic time-history analysis was not performed due to data unavailability.
- Optimization was limited to geometric and layout parameters; material-grade optimization was not explored.
- These constraints define directions for further research.

5.4 Future Scope

The study opens several promising avenues for future work:

- **Inclusion of Soil–Structure Interaction (SSI):** Future studies should integrate SSI to assess foundation flexibility and its impact on shear wall optimization.
- **Use of Time-History Analysis:** Introducing ground motion records would yield deeper insight into seismic demand and inelastic behaviour.
- **Optimization of Hybrid Systems:**
 - Exploring combinations of reinforced concrete (RC) + steel plate shear walls
- **Machine Learning-Based Optimization:** Artificial intelligence techniques such as ANN or surrogate modelling can significantly accelerate optimization workflows.

- **Sustainability-Oriented Material Optimization:** Use of recycled aggregates, UHPC, GFRP rebars, and low-carbon concrete could be integrated into the optimization framework.
- **Topology Optimization for Entire Core Walls:** Advanced 3D topology optimization may yield innovative and materially efficient core wall forms.
- **Real-World Validation**Applying the framework to an actual high-rise project would validate its practicality and industry readiness.

5.5 Summary

The research successfully demonstrates that performance-based optimization significantly enhances the efficiency, safety, and sustainability of shear walls in high-rise structures. By integrating optimization algorithms with advanced lateral load analysis, engineers can design structures that are not only safer but also more economical and environmentally responsible.

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