Evaluation of Shear Wall Configurations in RCC Structures for Seismic and Wind Load Resistance

Aashi Koshta
M.Tech Scholar
Gyan Ganga Institute of Technology and Science
Jabalpur, Madhya Pradesh, India
somyatiya25@gmail.com

Anubhav Rai
Assistant Professor
Gyan Ganga Institute of Technology and Science
Jabalpur, Madhya Pradesh, India

Satyendra Dubey
Assistant Professor
Gyan Ganga Institute of Technology and Science
Jabalpur, Madhya Pradesh, India

Abstract: RCC structures are extensively used due to their versatility and durability. The major problem in RCC structures is the dynamic forces like seismic and wind loads. Lateral forces generate stresses that cannot be resisted by a conventional RCC building without special design provisions. Shear walls are vertical elements of RCC structures, which resist lateral loads and increase the stability, strength, and safety of buildings. The review of roles, configurations, and benefits of shear walls in resisting seismic and wind-induced stresses relates their ability to check lateral displacement, minimize torsion, and maximize the dissipation of energy. There are various kinds of shear walls which include concrete variants and masonry variants and other configurations, namely flanged walls, rectangular coupled walls. In this context, discussions of challenges in their implementation, including architectural constraints and construction inaccuracies, are set alongside advancements in analytical and design techniques to optimize their performance. This review highlights the indispensable role of shear walls in ensuring compliance with modern building codes and standards while enhancing the resilience and longevity of RCC structures.

Keywords: RCC structures, shear walls, seismic loads, wind loads, lateral stability, energy dissipation, structural integrity, reinforced concrete.

1. INTRODUCTION

RCC structures, around the world, are among the most common types of construction systems. Known for durability and versatility and with a capability of withstanding numerous types of loads, RCC offers both tensile strength with the use of reinforcement and compressive strength by use of concrete. While RCC structures are stiff, they also present significant loads to the structure if subjected to dynamic forces, such as those caused by earthquakes and wind [1]. This causes lateral stress, which would make conventional RCC buildings vibrate in a way that they are not designed for. Structures that offer poor lateral stability or those structures which have irregular designs experience severe structural damage due to seismic loads when abrupt lateral forces happen during ground motions. Wind loads, although less sudden, may impose continuous lateral pressure over time, thereby accumulating stresses, fatigue, or progressive failure in tall structures. These forces are quite pronounced in seismically prone areas or in areas of cyclonic winds, for which special provision like shear walls, bracing systems, and base isolators are made. Without proper provisions, RCC structures tend to crack, spall, become torsional, or even collapse. Therefore, proper design strategies that address the need for safety and resilience are necessary.

Shear walls contribute significantly to the lateral stability of RCC buildings, as they resist horizontal forces from seismic activities, wind pressures, and other dynamic loads. The functions of shear walls are characterized by vertical structural members that act to counter lateral loads by transferring them from the upper parts of the structure to the foundation. Their stiff and high-strength configuration assists in the minimization of lateral displacements and checking inter-story drifts thus ensuring structural stability and integrity even in extreme conditions [2]. Shear walls are very essential in high-rise and irregularly shaped buildings because lateral forces tend to be more. They significantly enhance the situation concerning torsion and anomalies in mass or stiffness distribution. Well-designed and strategically located shear walls improve the ductility of the entire structure, thus enabling it to withstand and dissipate energy during seismic events. In addition, they increase the natural frequency of the structure, which, in turn, makes it less susceptible to the resonant effects of wind and earthquake forces [3]. Improvement in lateral stability does not only provide safety for occupants but also cuts down the costs of repair and maintenance throughout the life cycle of the structure.

2. Shear Walls

Shear walls are the vertical structural members of buildings which resist the forces developed by winds, earthquakes, and other dynamic loads on a building. Usually made from reinforced concrete, these members have played an essential role in lateral stability and overall integrity of a structure in general and that of a tall or multistory structure. These walls work in transferring horizontal forces, such as those brought about by earthquakes or winds, from the building's upper section down to the foundation, thus not allowing such displacements or breaking beyond what is reasonable [4]. Shear walls are arranged within a building's plan to maximally mitigate forces transferred since they are usually located near elevator shafts, stairwells, and along external walls. They are pretty rigid and potent in the plan of action. They are mainly effective in minimizing inter-story drifts and further also restrain torsion movements owing to irregular distribution of mass or because of skew geometries. Furthermore, it elevates the natural frequency of a structure. In this respect, they circumvent the possible influences of the effects of the resonance during a seismic event. Shear walls not only serve the structural purpose but are often included in the design of a building so that they can be utilized as partitions or functional walls [5]. They are important for more than safety enhancement during extreme events but also as a cost-effective solution to satisfy modern building code requirements for lateral stability and resilience.

In RCC structures, shear walls offer their contribution in resisting lateral forces from dynamic loads like seismic activities, wind pressures, and other external forces. These vertical structural members are devised to transfer horizontal forces from the top parts of the structure down to the foundation, which prevent undue lateral displacements, thereby causing damage or partial collapse of the structure. Shear walls significantly enhance the strength of a structure by minimizing drifts between successive stories and the overall stability of the structure under powerful lateral forces [7]. The resistance provided to torsion, which usually arises from irregular mass configurations or asymmetrical designs, also helps in maintaining the balance of the overall structure. Shear walls can be an excellent solution in tall buildings where lateral forces are significantly more pronounced than in low-rise buildings. Such shear walls mitigate all the potential risks by improving the building's performance during extreme loading conditions. Beyond its functional role, a shear wall contributes to seismic performance of an RCC structure in terms of increase in ductility and energy dissipation capacity. During an earthquake, they absorb and redistribute the seismic energy, thereby minimizing structural damage and enhancing safety for occupants. Moreover, in regions prone to high winds, shear walls are effective in countering wind-induced vibrations, thereby ensuring stability and comfort for people inside. In this way, they enhance structural redundancy by acting as an additional load path, thereby allowing the building to maintain stability even if other structural elements fail. Shear walls are also often designed into architectural schemes without seams visible to the human eye, functioning as partitions, stairwell enclosures, or elevator shafts; thus, they fully optimize space without sacrificing functionality [8]. In general, shear walls are a cost-effective, reliable, and indispensable means of achieving lateral stability, ensuring the safety, durability, and compliance of RCC structures with modern building codes and standards.

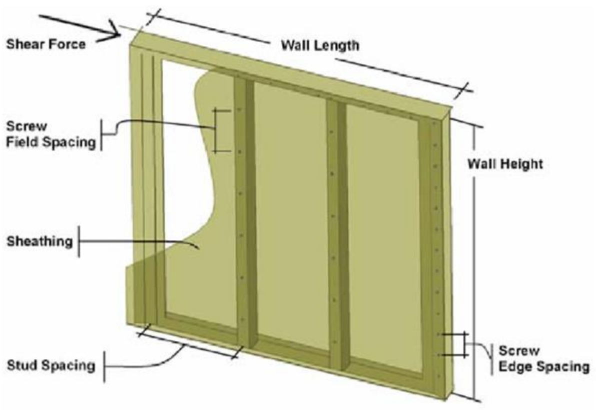

Figure 1 Schematic View of Shear Wall Panel [20]

Figure 1 shows the components and layout of a shear wall, one of the fundamental components that contributes to lateral resistance of buildings. Wall length and wall height define this wall as crucial dimensions which directly affect stiffness and resisting capacity for horizontal forces like shear force. The stud spacing, on the other hand, relates to the centre-to-centre spacing of the vertical framing members; these serve as the primary framework elements of the wall. Sheathing usually made of plywood, oriented strand board (OSB), or other material is used to cover the studs, which is significant in resisting lateral forces. The screw edge spacing and screw field spacing are two concepts that refer to the distance along the edges and interior of sheathing at which screws or fasteners are applied. Proper spacing ensures that load transfer occurs effectively and avoids deformation or even detachment of the sheathing in case of a shear force. Figure 1 depicts the relevance of proper design and detailing for shear walls for optimized performance under lateral loads.

A. Types of Shear Walls in RCC structures

Shear walls in RCC, based on material, design, and placement, classify them according to certain structural requirements and architectural preferences. Here follow the most common types of shear walls used in RCC buildings:

1. Based on Material

Concrete shear walls, which are mainly made of reinforced concrete, are widely recognized as the most common and effective type of shear walls, mainly because of their exceptional stiffness and strength, which make them highly capable of resisting both seismic and wind loads in structures. These walls are not only robust but can be strategically enhanced by the addition of steel reinforcements, which will enhance their ductility and energy absorption capacity considerably-a critical feature in ensuring structural integrity during extreme events like earthquakes [9]. This high strength and adaptability combination make reinforced concrete shear walls the preferred choice for engineered structures, especially in regions prone to heavy lateral loads. Masonry shear walls, usually consisting of bricks or concrete blocks, are more economic and are normally used in low-rise structures or smaller, non-engineered buildings. Though they perform reasonably on less demanding applications, they don't compare well to reinforced concrete walls in handling high loads and thus are typically more appropriate in smaller construction projects where cost-effectiveness and simplicity outweigh the load-handling capabilities that advanced construction would provide [10]. Although limited, masonry shear walls remain a very viable alternative, where high performance is not a primary requirement for achieving the objective, pointing to the broad applicability of construction.

2. Based on Shape and Layout

Rectangular shear walls, known for their simplicity in shape and ease of construction, are commonly employed along the peripheries of buildings or within structural cores, serving as straightforward yet effective solutions for lateral load resistance. Flanged shear walls have more projections or flanges, which are usually T-shaped or L-shaped, significantly increasing their moment-resisting capacity and overall stiffness, making them suitable for locations that require higher structural support. Core shear walls around elevators and staircases contribute to a central box-like rigid body that provides a robust form of lateral resistance as well as contributes to essential torsional stability within the building for its resilience in dynamic forces from wind and seismic loads. Together, these varied forms of shear wall types offer different solutions tailored for the various forms of structural demand in modern construction.

3. Based on Function and Design

Coupled shear walls are an advanced structural feature made up of two or more interconnected shear walls using beams or slabs, and hence, these make a composite system that is designed to act together to counteract lateral forces better than isolated walls. Such coupling action contributes to the increase in the total lateral stiffness of the structure with improved performance in the presence of wind and seismic loads. Furthermore, the interlocking nature of these walls enhances the energy dissipation in seismic activities, which is an important feature in reducing damage and preserving the integrity of the structure during such dynamic forces [11]. The coupling beams or slabs are designed to resist significant stress and deformation so that the combined system acts cohesively under extreme conditions. Perforated shear walls have been specifically engineered to have an opening in form of windows or doors or perhaps a ventilation shaft, yet none of these details compromises their strength.

These walls are designed with meticulous attention to the placement and size of the openings. Improper design could weaken their ability to resist lateral forces. By carefully considering factors such as the size, location, and distribution of these openings, engineers ensure that the walls maintain sufficient strength and stiffness to perform their load-bearing functions while meeting the architectural and practical needs of the building [12]. This balance between functionality and structural integrity makes perforated shear walls an essential feature in modern construction, where versatility and performance are equally prioritized. Together, coupled and perforated shear walls demonstrate the adaptability and efficiency of shear wall systems in addressing the complex demands of contemporary structural design.

3. Seismic and Wind Loads on RCC Structures

RCC structures are normally subjected to so many forces after their construction time, with major ones being wind and seismic load. Seismic loads are sudden dynamic forces acting at the time when the ground gets shaken during the earthquake. Thus, these are lateral forces together with vibrations of the structure if it is not designed to withhold them. The level of seismic forces can depend on parameters such as magnitude of earthquake, distance from the epicentre, soil conditions, and structural configuration of the building. In addition to stiffness and mass, the potential to cause severe effects on a ground motion basis exists with the nature of an RCC building [13]. The forces may cause cracking and spalling of concrete or even structural failure; hence, designing RCC structures with adequate ductility, lateral stability, and energy-dissipation mechanisms, such as shear walls or base isolation systems, is critical.

On the other hand, wind loads are horizontal forces applied to RCC structures by the pressure of the wind. Loads are generally distributed over the building surface, with increasing intensity in taller and more slender structures. Factors that influence the wind forces include wind speed, building height, shape, and surrounding terrain. Unlike seismic loads, wind loads act continuously, and their effects are cumulative, causing stresses, vibrations, and potential fatigue over time. In tall RCC buildings, wind-induced sway can also cause discomfort to occupants and lead to progressive structural issues if not properly managed [14]. RCC structures should be designed to withstand wind loads, considering aerodynamic shapes, lateral stability systems, and materials that can withstand long-term stress. High wind speed areas or cyclonic events should be designed to incorporate shear walls, bracing systems, or dampers to ensure safety and long-term performance.

4. Structural parameters for evaluation

The structural performance of RCC structures under seismic and wind loads is dependent on the examination of key parameters that affect the stability, strength, and safety of the RCC buildings. Some of the main parameters are distribution of loads coming from dead loads, live loads, wind loads, and loads due to earthquake, stiffness, ductility, natural frequency, and dynamic responses to resist deformation and dissipate energy [15]. Lateral stability, base shear, and structural irregularities such as asymmetry or vertical discontinuities are important to resist loads, whereas material quality, reinforcement, and construction practices ensure the integrity of a structure. In addition, the design of a foundation, soil-structure interaction, serviceability (drift, deflection, and comfort), and building codes ensure that the structure satisfies performance and safety standards.

A. Lateral Displacement

Lateral displacement is that horizontal movement occurring when a structure is subjected to lateral forces, such as those from seismic and wind loads, while drift occurs as the relative displacement between two consecutive floors in the structure. Such movements could cause structural damage, cracking of non-structural elements such as walls or partitions, and even discomfort for its occupants if left unchecked. The codes also ensure drift ratios do not go beyond limit and safety while damaging as little as possible [16]. Assessments of lateral displacement and drift play an important role for engineers, so that their designed solutions incorporating shear walls or braces are going to control movements like those described, add stability to structures, and avoid complete collapse of a building.

B. Base Shear and Overturning Moments

Forces and rotational effects at the bottom of a building, such as base shear and overturning moments, are extremely important in a structure's safety and stability from external influences, like earthquakes or wind. The base shear would be the overall horizontal force that the foundation must resist. Overturning moments are referred to as rotational forces that cause the structure to tilt or fall over if the moment is big enough. These parameters are essential in the assessment of the adequacy of the foundation and its capacity to support the structure under such lateral loads [17]. The base shear and overturning moments analysis by engineers enables the design of foundations and structural systems that effectively counteract these forces, ensuring that the building remains stable, upright, and securely grounded even during extreme loading events.

C. Natural Frequency and Mode Shapes

The rate at which a structure will oscillate due to dynamic forces without any damping from external means is known as the natural frequency. Mode shapes refer to the way deformation or movement in the structure takes place during vibration. These parameters help understand how a structure behaves during seismic or wind-induced vibrations. If the building's natural frequency coincides with the frequency of external forces called resonance, that can cause maximum vibrations and subsequent failure [18]. To avoid such incidents, engineers take into consideration this natural frequency and their mode shapes before designing the construction.

D. Stress Distribution in Walls and Connections

Stress distribution is defined as the method by which loads are distributed to the shear walls and their connectors. Poor distribution of stress would cause weak spots, cracking, or failure in the walls and connectors. The check of stress distribution is necessary so that the expected loads do not cause failure of the walls and connections [19]. Proper reinforcement, material selection, and connection detailing are critical to achieving uniform stress distribution and ensuring the structural integrity of RCC buildings under lateral forces.

5. Challenges and Limitations

Designing and implementation of shear wall configurations in RCC structures pose severe practical problems essentially because of the complex interplay between architectural, functional, and structural requirements. Probably the major problem is where to locate shear walls to achieve sufficient lateral stability without interfering with usable space and architectural aesthetics. For example, although shear walls erected near the centre of a building may be most structurally perfect, they do limit flexibility for interior design arrangements, such as limiting elevator or stairwell placements. Furthermore, the construction of shear walls within high-rise structures demands precise and accurate alignment combined with high quality materials to counter substantial lateral forces without failure. Poor workmanship, improper detailing of reinforcement, or inaccuracies in construction all compromise their performance. In addition, incorporating shear walls in retrofitted or existing buildings is not without its problems because their position could necessitate drastic changes in the building layout and foundation at a high expense.

Despite extensive research conducted on shear walls, there is a limitation in the scope and applicability of studies and methodologies. Most of the studies focus on idealized or simplified models that do not consider the real complexities such as irregular shapes of buildings, varying soil conditions, or imperfections in construction. Further, most studies only examine the shear walls' performance due to seismic loads or wind loads separately and normally ignore the potential combined effect, which could happen in areas of a region experiencing earthquakes and strong winds. Experimental verification is limited in large-scale structures due to the difficulties and costs of testing entire building structures at their full scale under extreme loads. Current design codes are comprehensive but based on generalized assumptions that may not be optimal for specific cases, such as high-rise buildings with unique geometries or structures located in regions with extreme loading conditions.

Addressing the aforementioned challenges and limitations calls for more sophisticated modelling and simulation techniques to gain insight into shear wall behavior under different loading conditions more accurately and in detail. Finite element analysis, non-linear dynamic analysis, and performance-based design become crucial tools to understand the interactions between shear walls and the overall structure. These methods allow engineers to simulate real-world scenarios such as multi-hazard events, material non-linearity, and structural irregularity; phenomena that cannot be easily replicated in traditional studies. This availability further helps with improving computational power and software tools to conduct extensive parametric analyses, thus enabling better optimization of shear wall placement and design. Despite these developments, the adoption of these techniques is often limited by their complexity, the need for specialized expertise, and the high computational resources required. Bridging this gap will require further development of user-friendly tools and the integration of advanced methods into standard engineering practice to overcome the challenges in designing and implementing shear wall configurations effectively.

Conventional RC shear walls are widely used in mid- to high-rise buildings in seismic regions but suffer issues with reusability due to permanent damage following earthquakes. PT shear walls, developed in the 1990s, possess self-cantering capabilities as well as excellent rocking behavior, thus becoming reusable after seismic events, though they lack adequate energy dissipation [21]. Energy dissipators may either be internal or external. Various PT shear wall configurations, such as single rocking, multi-panel, hybrid, and precast walls with end columns (PreWEC), have been developed and tested experimentally. This review examines past experimental studies on PT shear walls, their energy dissipation enhancements, interactions with structural elements, and provides insights the study in this field. Industrial civil buildings have seen an increase in reinforced concrete structures exposed to ambient electromagnetic radiation. It is thus important to study its impact on structural integrity. This article focuses on the influence of electromagnetic fields as a hazard factor in the degradation of reinforced concrete. It classifies electromagnetic radiation into ionizing and non-ionizing types, highlighting their distinct effects [22]. The presence of ionizing radiation can decrease the strength of reinforced concrete up to 60%, and extended exposure to non-ionizing radiation accelerates the corrosion of metal reinforcements, particularly in the case of water filling pores and capillaries. The article also emphasizes the requirement for further study on how length, frequency, and energy in electromagnetic radiation are involved in the degradation processes. It also underlines the need to develop scientific methods and protective measures to protect reinforced concrete structures from the adverse impacts of electromagnetic radiation.

The use of stainless steel instead of ordinary steel would improve the durability of concrete under harsh conditions; however, the mechanical properties and the stress-strain behavior of stainless-steel reinforcements differ from those of ordinary steel [23]. Therefore, design codes applicable for ordinary steel reinforcement are not available for stainless steel-reinforced concrete. Based on decades of research, this paper summarizes the mechanical properties, corrosion resistance, and bond characteristics of stainless-steel reinforcements, as well as the performance of stainless steel-reinforced concrete members and their applications in engineering. It has to be underlined that there is a big scope for further studies and improvement of design theory for stainless steel-reinforced concrete to fully take advantage of the presented advantages in durability and performance.

Advanced imaging techniques have developed from stacking through migration to the inversion-based techniques, with better accuracy. It is a crucial aspect of high-precision seismic imaging in geophysical and geological interpretation in seismic exploration, particularly for complex targets like subsalt formations and steeply dipping layers [24]. This review compiles the evolution of seismic imaging, including CRS stacking, Gaussian-beam migration, reverse-time migration, and least-squares reverse-time migration. It examines their performance on complex models and land data, and addresses issues of low-quality data and ultra-deep reservoirs, while talking about future advancement in seismic imaging.

A typhoon is a tropical cyclone in the western Pacific Ocean and the China seas. Typhoons are among the most destructive natural disasters on Earth. In China, typhoons have greatly affected the stability and structural integrity of offshore wind turbines in the complex and harsh marine environment. In this paper, the leading causes of damages to wind turbine structures were researched based on a typhoon profile and a typhoon-induced accident during typical typhoon conditions [25]. It also summarized recent research progress for anti-typhoon design of an offshore wind farm and the overall anti-typhoon strategy used in the operational and maintenance policy of a wind farm. Finally, problems that need further solutions in the said research areas were presented as references for developing offshore wind turbines, especially floating wind turbines, in typhoon-prone areas.

Table 1 Comparative Analysis of Advancements in Structural and Seismic Studies

Topic	**Focus**	**Challenges**	**Future Directions**
RC and PT Shear Walls	Comparison of conventional RC shear walls and PT shear walls, highlighting their performance under seismic conditions and energy dissipation techniques.	RC walls lack reusability after earthquakes; PT walls have limited energy dissipation capabilities.	Development of energy dissipation mechanisms for PT walls and further study of their interaction with structural elements.
Electromagnetic Radiation on RC Structures	Impact of ionizing and non-ionizing electromagnetic radiation on the degradation of RC structures, focusing on corrosion and strength loss.	Ionizing radiation reduces RC strength by up to 60%; non-ionizing radiation accelerates metal corrosion in the presence of water.	Research on the effects of electromagnetic radiation's length, frequency, and energy, and development of protective measures for RC structures.

Stainless Steel Reinforcements in Concrete	Mechanical properties, corrosion resistance, and bond characteristics of stainless steel reinforcements compared to ordinary steel in concrete.	Lack of suitable design codes for stainless steel-reinforced concrete due to differing mechanical properties from ordinary steel.	Further research to improve design codes and fully leverage the advantages of stainless steel reinforcements in durability and performance.
High-Precision Seismic Imaging	Development of advanced seismic imaging techniques for complex geological targets like subsalt formations and ultra-deep reservoirs.	Difficulty in producing high-precision images for low-quality data and highly complex geological structures.	Advancing imaging techniques like LSRTM and exploring methods to handle low-quality data and extreme geological conditions.
Typhoon Effects on Offshore Wind Turbines	Effects of typhoons on the structural stability of offshore wind turbines and strategies for anti-typhoon design and maintenance.	Structural damages to wind turbines caused by harsh marine environments and strong typhoon-induced forces.	Enhancing anti-typhoon design, operational strategies, and maintenance policies, especially for floating offshore wind turbines.

6. Conclusion

Shear walls are an essential reinforcement of lateral stability and general safety in Reinforced Cement Concrete (RCC) structures. These elements are designed specifically to resist the lateral forces like seismic and wind loads that may otherwise compromise the integrity of buildings. Shear walls absorb and redistribute these dynamic forces, thus preventing damage or collapse of the structure, ensuring safety for the occupants and extending the life of the building. The most important benefit of shear walls is that they minimize lateral displacements and control torsion, which is usually caused by irregular mass distribution or asymmetrical designs. They improve the ductility of buildings; hence it can absorb and dissipate the seismic energy that is very crucial for earthquake-prone regions. Shear walls, in high wind load regions, counteract the continuous lateral pressures, hence there is no chance of fatigue, and thus stability is maintained over a long period of time. Along with their functional benefits, shear walls are cost-effective since there is no necessity for frequent repair and maintenance work as they avoid structural damage due to extreme events. Moreover, the technologies and simulation tools in construction have improved significantly with regard to design and implementation. Techniques such as finite element analysis and performance-based design allow for precise placement and optimal configuration of shear walls, maximizing their effectiveness in diverse structural scenarios. Challenges persist, including integrating shear walls into architectural designs and ensuring high-quality construction practices. These setbacks notwithstanding, new studies and ideas continually improve shear wall performance in RCC construction to the point that their use in the modern day cannot be waived. Shear walls combine all functions such as functionality, safety, and strength to conform to building code regulations and establish sound infrastructure, which withstands dynamic loads and forces applied during its entire lifecycle.

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose

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