Chapter 1
A Review of Shear Wall Location Response in High-Rise RCC Structures as a Result of Earthquake Effect

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Abstract The reinforced concrete shear walls are structural systems used in contemporary high-rise buildings to sustain lateral load structures such as wind, seismic loads, and carrying gravity loads. To make the structural system more efficient in resisting horizontal and gravity loads, ground motions and thus causing less damage to the structure during the earthquake. The high lateral load due to the earthquake is one of the adverse effects for high buildings. Shear walls have more strength, stiffness, and resist loads applied along with their height in the plane. Buildings with correctly constructed and recorded shear walls have performed admirably in previous earthquakes. Several studies on shear wall architecture and seismic force effectiveness have been reported. The main focus of this paper is to conduct comprehensive literature surveys and to evaluate the scope of work relevant to some investigation that is studied by adjusting different locations of the shear wall to identify the best position of the shear wall to produce minimal deflection by deciding parameters such as storey drift, storey shear and displacement.

Keywords Shear Wall · Shear Wall Location · High-Rise RC Building · Earthquake

1.1 Introduction

In recent times, the world has suffered dramatically from the natural disasters that occur from time to time, such as torpedo, earthquake, flood, hurricane and tsunami. Most of these natural disasters are unpredictable. However, the enormous hazards that may affect the existence of a building is an earthquake. Typically, areas are at risk of earthquakes, destroying buildings, loss of life, destruction of public services and infrastructure [1]. Earthquakes are among the natural hazards that have the greatest potential for causing substantial damage to engineered structures. Because earthquake forces are random and unpredictable in nature, engineers methods for studying structures under these forces influence must be sharpened. More than half of the

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Table 1.1 The common methods of earthquakes resistant

S. no	Element structure	Descriptive	Author
1	Shear walls	Strategically located stiffened walls using shear walls and is capable of transferring lateral forces from floors and roofs to the foundation	[3]
2	Braced Frames	Vertical frames that transfer lateral loads from floors and roofs to the foundations. Like shear walls, Braced Frames are designed to cater lateral loads but commonly used where shear walls are impractical	
3	Base Isolation	This seismic design strategy involves separating the building from the foundation and acts to absorb shock. As the ground moves, the building moves at a slower pace because the isolators dissipate a large part of the shock	
4	Diaphragm wall	Floors and roofs can be used as rigid horizontal planes, or diaphragms, to transfer lateral forces to vertical resisting elements such as walls or frames	

country is thought to be vulnerable to damaging earthquakes. The country's north-eastern area and the entire Himalayan belt are vulnerable to large earthquakes with a magnitude greater than 8.0. Due to these reasons, researchers and engineers have investigated how to increase the earthquake-resistant structures using several ways such as seismic isolator, high-tensile carbon fiber twine reinforcement buckling-restrained braces, fluid-filled shock absorbers, bracing frame and the shear wall. The studies report that incorporating lateral load resisting systems into the building configuration dramatically improves the structure's earthquake performance [2]. The major criteria for designing RCC structures in seismic zones control lateral displacement resulting from lateral forces.

1.1.1 The Common Methods of Earthquakes Resistant

There are known and practiced measures to protect against seismic threats. According to Abhijeet and Kanchan [3], some common resistant method is used nowadays by engineers worldwide to minimize damage to structures due to the earthquake's events (Table 1.1).

1.1.2 Shear Wall

Shear wall is one of the excellent means of providing earthquake resistance to a multistoried reinforced concrete building. During earthquake motion, the structure's behaviour depends on the distribution of weight, stiffness, and strength in both horizontal and vertical planes. This structural element will transfer the lateral forces created due to the wind and seismic forces to the diaphragm located below or to the foundation. The structural design of buildings for seismic loading is primarily concerned with structural safety during major earthquakes; in tall buildings, it is essential to ensure lateral stiffness to resist lateral load [4]. The continuous concrete vertical wall serves both architecturally as partitions and structurally to carry gravity and lateral loads. Their very high in-plane stiffness and strength make them ideal for tall buildings. In a shear wall structure, such walls are entirely responsible for the building's lateral load resistance [5]. They act as vertical cantilevers in separate planar walls and as non-planar assemblies of connected walls around elevator, stair and service shafts. Because they are much stiffer horizontally than rigid frames, shear wall structures can be economical to about 35 stories. The shear wall thickness for buildings may vary from 150 to 400 mm [6].

1.1.3 Shear Wall Configurations

Shear wall is a structural member in a reinforced concrete framed structure to resist the shear produced due to lateral forces. When a high-rise building subjected to lateral wind and seismic forces, the shear wall typically used to reduce lateral displacement. Shear walls are rectangle in cross-section, i.e. one dimension is much larger than the other. In contrast, the rectangular cross-section is frequently used, such as L- and U-shaped sections. Thin-walled hollow RC shafts around the structure's elevator core also act as shear walls and should be taken advantage of to resist the earthquake forces. The Shear Wall sections are classified into six types, as shown in Fig. 1.1 [7].

1.1.4 Types of Shear Wall

1. RC Shear Wall.
2. Plywood Shear Wall.
3. Mid ply Shear Wall.
4. RC Hollow Concrete Block Masonry Wall.
5. Steel Plate Shear Wall [8].

1.1.5 Advantages of Shear Walls in RC Buildings

1. Shear wall resistance to horizontal lateral force and exposure to the earthquake.
2. It has a very high level of rigidity that resists lateral load.
3. Shear walls are useful for deflection control.
4. RCC shear walls are easy to build detailed reinforcement.

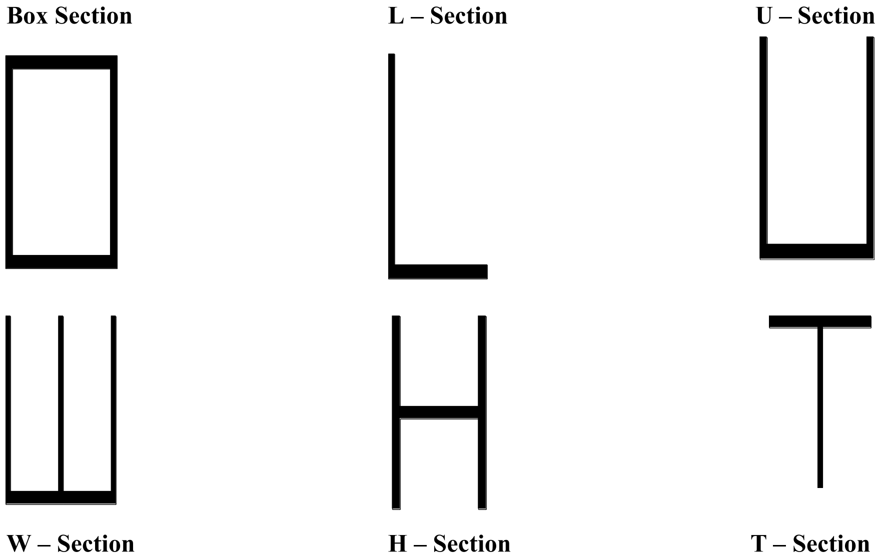

Fig. 1.1 Different shapes or geometries of shear walls

5. It minimizes damage to structural and non-structural damage caused by the earthquake.
6. Well-designed shear walls provide adequate safety and provide a high level of protection against expensive non-structural damage during moderate seismic damage [9].

1.1.6 Strengthening of RCC Building with Shear Wall

In addition to slabs, beams, and columns, reinforced concrete (RC) structures sometimes have vertical plate-like RC walls known as shear walls. These walls typically begin at the foundation level and run the length of the building. In high-rise towers, it can be as thin as 200 mm or as thick as 400 mm [10]. Shear walls, similar to vertically-oriented wide beams that carry earthquake loads downwards to the foundation, are commonly supported along both the buildings' length and width. Buildings with shear walls that have been properly constructed and detailed have performed admirably in previous earthquakes [11]. In seismically active areas, shear walls must be meticulously detailed. However, even buildings with a sufficient amount of not specially detailed walls for seismic performance (but had enough well-distributed reinforcement) were rescued from collapse in previous earthquakes [12]. Lateral loads are the most important in tall buildings, and they increase dramatically as the building rises in height [13]. Strength, rigidity, and stability are all taken into consideration in the construction. The structural system intended to support vertical loads may not be capable of withstanding lateral loads [14]. The lateral load design would increase the structural cost significantly with an increase in the storey even though it has. Special structures to resist lateral loads can be used in tall buildings to achieve cost savings. Below is a list of some of the systems.

1.1.6.1 Moment Resistant Frames (MRF)

MRF consists of linear, horizontal members (beams) in the plane with linear vertical members (columns) by rigid or semi-rigid joints.

1.1.6.2 Braced Frames

Pure rigid frame structures are inefficient for buildings greater than about twenty stories because the deflection caused by the bending of columns and girders is too high, and the buildings drift. A braced frame tries to enhance the effectiveness of pure rigid frames by adding truss members between floor systems, such as diagonals so that the shear is absorbed primarily by the diagonals [15, 16].

1.1.6.3 Shear Wall Structures

A shear wall is a structural system that provides stability against wind, earthquake and blast from inherent structural forms. The shear wall may be either planar, open or closed portions around elevators and stairwells. These structures can be either built-in steel or concrete or solid or perforated, and shear walls act as deep, slender cantilevers [17]. These can be structurally divided into coupled shear walls, shear wall frames, shear panel and staggered wall into two walls coupled with beams on each floor.

1.1.6.4 Tube Structures

A three-dimensional space frame composed of three or more frames braced frames or shear walls joined at or near their edges to form a vertical tube-like structural system capable of resisting lateral forces in any direction by cantilevering from the foundation [18]. There are different types of shear walls which are as given below:

1. Cantilever shear walls
2. Flanged cantilever shear walls
3. Coupled shear walls
4. Shear wall with openings
5. Box system.

1.1.6.5 Parameters Influencing the Response of Shear Walls

1. Height to Width Ratio
2. Type of Loading
3. Flexural Reinforcement
4. Shear reinforcement
5. Diagonal Reinforcement
6. Special Transverse reinforcement
7. Concrete Strength
8. Construction Joint
9. Axial Compressive stress
10. Moment to Shear Ratio.

Thus the design philosophy can be summarized with the following requirements. The structure must be able to withstand low-intensity earthquakes without sustaining any damage. As a result, during minor and regular earthquakes, the entire structure should remain elastomeric. The structure should be able to withstand a moderately strong earthquake with only minor structural damage that is easily repaired. Without collapsing, the structure should be able to withstand a high-intensity earthquake with a return time much longer than its design life. At this time, the shear wall is an essential part of an earthquake-resistant structure. As a result, supplying a shear wall in various positions and determining which position produces the best results is done with the help of software.

1.2 Literature Review

In reinforced concrete buildings, shear walls, which are vertical plates similar to RC walls, are prevalent. Shear walls, which are similar to vertically-oriented wide beams that contain and transfer earthquake loads to the foundation, are used to contain and transfer earthquake loads. These walls start at the foundation and go all the way up to the roof. Their width in a high-rise building will be between 150 and 400 mm [19]. Shear walls are typically supported by columns and run the length and breadth of the structure. These columns' main purpose is to support gravity loads. Existing buildings that are not designed to withstand seismic and lateral loads suffer considerable damage as a result of lateral loads. This type of structure is extremely complicated and impossible to design [20]. Height considerations, section properties considerations, and the number of shear walls to be connected are all examples of different aspects of shear walls classified. Monolithic shear walls are classified as short, squat, or cantilever, depending on their height to depth ratio.

Tall towers and multi-story structures have intrigued mankind from the beginning of civilization, with their construction served first as a defense mechanism and subsequently for ecclesiastical purposes [21]. Because of their height, tall buildings are subjected to lateral forces caused by wind or earthquakes, which can cause the structure to snap in shear or bend over. Rigidity (i.e. resistance to lateral deflection) and stability (i.e. resistance to overturning moments) standards have become increasingly critical in recent years. Shear walls (structural walls) play an important role in lateral stiffness, strength, ductility, and energy dissipation capacity [22]. Due to numerous functional criteria, a regular openings pattern must be supplied in many structural walls to accommodate doors, windows, and service ducts. Depending on the opening's shape, this type of opening decreases the shear wall's stiffness to some extent. This parametric study aims to look into the impacts of different shapes of openings in shear walls on multi-storey building's reactions and behaviours. The software ETABS9 was used to investigate the 8, 10, 12, and 15 storey prototype buildings with different openings and without openings in the shear wall. To lessen the negative impacts of twist in buildings, the opening area percentage in a shear wall should be less than or equal to 30% of the total area of that particular shear wall in the RCC building. Shear walls can form an effective lateral force resistance system by minimizing lateral displacements during earthquakes where they are positioned with the building's proper opening [23].

1.2.1 RC Shear Wall

In addition to slabs, beams, and columns, reinforced concrete (RC) structures have vertical plate-like RC partitions called shear walls. Those walls usually begin at the foundation and continue to the top of the structure [24]. In high-rise buildings, they can be as thin as 150 mm or as thick as 400 mm. Buildings with RC shear walls installed inside their orientation path gain considerable strength and stiffness, reducing lateral sway and minimizing damage to the structure and its components. The overturning results are important because shear walls include large horizontal earthquake forces [25]. In their orientation, RC shear walls provide substantial strength and stiffness to structures, reducing lateral sway and minimizing damage to the structure and its contents. The overturning effects on shear walls are significant because they carry large horizontal earthquake forces. Shear walls are more effective when placed along the building's exterior perimeter; this layout improves the structure's resistance to twisting.

1.2.2 Function of Shear Wall

Shear walls provide the necessary lateral energy for horizontal earthquake forces to be resisted. While shear walls are strong enough, the horizontal forces will be transferred to the next detail in the load path underneath them. Different shear walls, floors, foundation walls, slabs, or footings may be used in some analyses of the RC shear wall's strength at an outstanding position in various ways. Shear walls also provide lateral stiffness, preventing excessive sideways movement of the roof or floor above [26]. Sufficiently rigid shear walls will keep floor and roof framing members from moving out of their support. Furthermore, sufficiently strong buildings are more likely to sustain less non-structural damage [27].

1.2.3 Past Earthquake Effect on High Rise Building

The history of earthquakes shows that if buildings are not properly designed and built to the necessary standard, they will cause significant damage. As a result of this reality, buildings have been made safe from earthquake forces. Subsequently, there is a need to determine a high-rise building's seismic responses to design earthquake-resistant structures by carrying seismic analysis of the structure. A considerable increase in high-rise buildings and modern development headed for more complex structures in recent days. The space constraints, especially in urban areas, face structural engineer with sufficient strength and stability of these tall buildings against the lateral load. Thus, the effect of lateral loads, such as wind loads and earthquake loads, are attaining extreme importance for high-rise buildings [28]. Well-designed shear walls provide adequate safety and provide a great measure of protection against costly non-structural damage during moderate seismic damages. Shear walls provide significant strength and stiffness to buildings in their orientation, significantly reducing the building's lateral sway and reducing damage to the structure and its contents [29].

1.2.4 Performance of Location of Shear Wall for Multi-Storey

Suwalka et al. [30] proposed the shear wall's prime location and its effectiveness of best shear wall in the bare frame system. The study of the 16-storey building presented some investigations analyzed in both the structural system, i.e. shear wall frame structure and without shear wall structure. The building located in Zone-IV, according to IS 1893:2002. The construction model 3D was analyzed using the linear static method, response spectrum and surface messing were done to a model shear wall. Suwalka's research shows that models were compared to various parameters such as lateral displacement in the X and Y directions, tale drift, and axial force in columns using Etabs software. Results assessed the efficiency of varying interface and found that the shear wall located in a building with a shear wall at all corners is the effective approach to cater for the lateral load. The provision of a shear wall with an appropriate location is advantageous. The structure performs better if the optimum configuration and its footprint identified before the entire structure's design was conducted [30].

A study has been carried out by Titiksh and Bhatt [29] to determine the effects of additions of shear walls and also the optimum structural configuration of multi-storey buildings by transposition the locations of the shear wall. Four various shear wall positions for 11-storey buildings have analyzed by computer software ETABS. The framed structure subjected to lateral and gravity loads according to Indian Standards, and the results determine the best location for the shear walls. The results indicate when shear walls placed at the center of the geometry in the form of a box or the corners, the structures behave in a more stable manner. In conclusion, among all other studied possibilities, building with a box-type shear wall at the core of the structure is the optimum framing technique for middle and high-rise buildings. In order to increase the performance of the structure, earthquake resisting techniques such as Seismic Dampers and Base Isolation can be used [10].

Snell (2004) studied a shear wall provision represents a structurally efficient way to stiffen a building structural system because a shear wall's primary function is to increase the rigidity for lateral load resistance. In modern-day tall buildings, shear walls are typically used as a vertical structural element for resisting the lateral masses that can be prompted by the effect of wind and earthquakes, which cause the failure of structure as proven in parent shear walls of varying sections, i.e. square shapes to greater irregular cores consisting of the channel, T, L, Barbell shape, Box and so forth can be used. Provision of walls allows to divide an enclosed area, whereas cores include and bring services together with the elevator. Wall openings are necessarily required for building windows in outside partitions and for doors or corridors in internal walls or carry cores.

Rajkolhe and Khan [31] researched the shear wall's optimum location in high-rise R.C building under lateral loading. In this research, the analysis was done following the earthquake code IS 1893[PART-I] 2002 and wind code IS 875 [PART-I]-1987 [31]. The study was carried away by taking the irregular plan of building 21-storeys on medium [ZONE-II] and severe [ZONE-V] and soil [TYPE-II]. Furthermore, the seismic analysis of the building's irregular plan for static earthquake and static wind analysis. The comparison by providing shear wall at four edges with and without the shear wall in the irregular plan investigated to determine the shear wall's ideal position.

In conclusion, the plan without a shear wall gives more displacement and more drift than a plan with a shear wall lengthwise four edges. Hence, by providing shear wall lengthwise, four edges can diminish storey displacement, storey drift, storey shear and increase the structure's strength and stiffness. These results demonstrated that giving a shear wall along four edges is ideal for a shear wall [2].

Patil et al. [32] studied the optimal location of shear wall in high-rise building subjected to seismic loading. In this project, a high-level building with 15 storeys in zone IV considered all the regular and irregular building models. Two different types of models are considered in every shape of the building by changing the shear wall's location in the structure plan, located at the corners of the building and the building's central core section [32].

In this seismic analysis, storey drift and displacement are essential parameters to be considered and analyzed using standard package Etab-2013—producing a 3D building model for both Equivalent Static Method and Response Spectrum Methods. The storey displacement reported in the models where shear walls provided at corners of the building provide maximum displacement compared with the models with a shear wall at the building's central core location. Hence maximum lateral displacement always occurs at the topmost level for both types of locations of shear walls for all models. In the meantime, storey drift ratios for all stories in the models having a shear wall at the building's central core location are less than those in the models where shear walls provided at corners of the building. Generally, the storey drift ratio is meagre in bottom stories but very high at the middle levels and finally decreases towards the upper levels. This study indicates that the storey drifts were reduced due to the shear wall's primer at the building's core sections, enabling the structure to behave as almost ideally stiff. In this way, the damage risk of the structure & non-structural elements is minimized.

Haque et al. [33] focused on analyzing shear wall location due to earthquake effect in high rise RCC structures. The most common and usual trend of shear wall location and shape have also been discussed here. The methodology is mainly concerned with defining the different location cases for shear wall and their model generation. For this study, five different location cases for a shear wall keep all the other structural elements unchanged.

The cases include:

Case 1: the original plan,

Case 2: moving the shear wall 35 inches inward,

Case 3: moving the shear wall 70 inches inward,

Case 4: moving the shear wall 105 inches inward,

Case 5: moving the shear wall 140 inches inward.

Software ETABS9 has developed the model generation process of these 5 cases considering the loads such as Dead, Live, Wind, Earthquake. The comparative results have shown that shear walls are more effective at the outer periphery and near columns. The structure has analysed without basements. So, their responses to loads are not included in the paper [33].

1.3 Conclusion

From the above literature review, various researchers have studied different types of earthquake-related issues and addressed that shear wall is more prominent in resisting lateral force due to earthquakes. Software review such as Etabs combined with manual work, models created, and shear walls are positioned in various building positions to find the structure's most minor displacement due to shear walls. Researchers have found out that changes in shear wall positions affect the attraction of forces. Shear wall position in any building significantly reduces displacements and reduces the structural effect. Besides dead & live loads, the other loads also effect the lateral displacement of the building. In a frame structure, all the frames are subjected to additional moments and deflections due to earthquake loads. Shear walls can reduce the deflection of a building; shear walls placed at the outer edge portion, periphery and near the column provide more stiffness to the structure resulting in less deflection. Buildings without a shear wall are a source of concern and must be retrofitted in seismic/earthquake and wind-prone areas. Various type of shear walls such as L shaped, O shaped, and I shaped shear walls should be tested for their performances. The reduction of storey drifts due to the shear wall's introduction at the building's core sections enables the structure to behave as almost ideally stiff. In this way, the damage risk of the structure & non-structural elements minimized.

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