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A Review of Analysis of RC Shear Walls with Cutting Out Opening

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ABSTRACT

The global population rise has fostered the need for high buildings, which differ from traditional buildings of limited height in their resistance to lateral loads. So now, it's critical to think about lateral loads. To prevent possible collapse, compared to wind loads, which are only 1:3 percent of the structure's weight, and earthquake loads can reach 30:40 percent [1]. This necessitated us to use reinforced concrete walls. on the other hand, the existing structures frequently need to be modified to meet modern living standards, so cutting out openings in RC shear walls is one of the most widely used improvements. This study reviews some of the most recent experimental and finite element research that has been published in the literature and lists the major contributions until 2023. Also, this paper presents a summary of some studies available in the literature concerning the mode of failure commonly observed in RC shear walls and analyzes the impact of opening attributes such as size, position, and shape on shear wall behavior. Moreover, it investigates how variables like steel reinforcement ratio and opening arrangement affect the shear wall's response to lateral loads. The influence of aspect ratio on overall performance is also explored. Additionally, the research highlights design provisions and guidelines available for cases involving RC shear walls with openings. From this study, it is clear that the width of openings plays a more significant role than the height. Also, the small openings do not affect the flexural behavior of slender walls, and the creation of openings greatly reduces cumulative energy dissipation and increases the ductility of the RC shear walls.

1. Introduction

Structural walls have seen widespread use in recent years, particularly in countries with significant seismic risk. The capacity to reduce lateral drifts, the economy of design, and excellent performance in previous earthquakes are the main reasons for including structural walls [2]. Shear walls are frequently used as horizontal and vertical sideways resistance elements in high-rise building structures. So in the case of logical design in a typical shear wall which was constructed of reinforced concrete, the base of the concrete walls must be thick enough to ensure that the structure has suitable deformation capacity, which severely reduces the building's space available [3]. Reinforced concrete shear walls effectively strengthen a building's structural system under lateral loads. A shear wall's major purpose is to strengthen the building's lateral resistance by improving its rigidity and strength. Shear walls' capacity and in-plane

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hardness are extremely high and can be utilized to immediately withstand significant lateral loads like earthquake and wind loads, in addition, to enduring vertical loads, as shown in Fig. (1). For RC shear walls to be sufficiently ductile and strong, they need to be carefully designed [4]. Numerous codes divide reinforced concrete shear walls into bearing, non-bearing, and shear walls involving squat and flexural shear walls. Previous decades witnessed various strengthening schemes for reinforced concrete shear walls to enhance their seismic behavior regarding the overall capacity, flexibility, and energy dissipation capabilities [5]. When subjected to these forces, shear walls play an important role in energy absorption, which helps to maintain the stability of the building. However, in some cases, it may be necessary to cut out openings in shear walls to accommodate services or doorways due to architectural needs and taking into account the structure's service requirements. In such cases, the analysis of RC shear walls with openings becomes important to ensure the structural integrity and safety of the building [6].

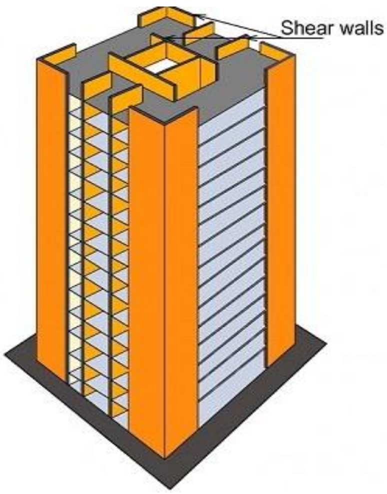


Fig. 1. Schematic layouts of Shear walls [4]

The inclusion of openings within shear walls has become a common practice due to the benefits they offer, such as improved aesthetics, increased natural lighting, enhanced ventilation, and space optimization. However, this architectural innovation introduces intricate interactions between the surrounding concrete and the openings themselves, altering the distribution of forces and potentially compromising the shear wall's ability to resist lateral loads. As such, a thorough and systematic analysis of RC shear walls with openings is essential to assess their behavior and performance under different loading scenarios accurately. The behavior of RC shear walls with openings differs significantly from that of solid shear walls. The presence of openings modifies the stress distribution and strain patterns along the shear wall's height and width, affecting the overall deformation and load-carrying capacity. Additionally, the irregularity introduced by openings may lead to stress concentrations, corner effects, and potential failure modes that need to be carefully addressed in the design and analysis process. The interaction between the boundary elements, such as the surrounding frame and the openings, further complicates the behavior of the shear wall system. Numerical simulations, such as finite element analysis (FEA), have become invaluable tools in studying the intricate behavior of such complex systems. These simulations enable researchers and engineers to assess various parameters, including shear wall aspect ratio, opening size and shape, boundary conditions, and loading configurations, thus providing insights into the structural response and potential failure mechanisms.

This study aims to contribute to the existing body of knowledge by conducting a comprehensive review of existing literature on the behavior of RC shear walls with openings. This review article delves into the multifaceted realm of RC shear walls with openings, investigating the intricate interplay between several key factors that significantly influence their strength and performance. Among these factors, the size and position of openings within shear walls emerge as critical determinants, as they can lead to alterations in stress distribution and force transmission mechanisms. Moreover, the shape of openings exerts a notable influence, affecting the shear wall's capacity to withstand lateral loads effectively. The role of the steel ratio in RC shear walls is also investigated, as it directly influences the capacity to resist shear and flexural forces. Furthermore, the arrangement of openings within the shear wall matrix and the resulting effect on its behavior are scrutinized. The impact of aspect ratio on shear wall performance is explored to elucidate its influence on overall stability and deformation patterns. Additionally, the article surveys prevailing design provisions for RC walls with openings according to design guidelines regarding.

2. Mode of failure of RC shear walls

Reinforced concrete shear walls are normally utilized in constructing structures; Shear walls are concerned with internal forces like moment, normal, and shear forces. Shear walls are frequently classified as both slender ($h_w/l_w > 3.0$), moderate ($1.5 \leq h_w / l_w \leq 3.0$) and Squat ($h_w / l_w < 1.5$), according to the wall aspect ratio (height of shear wall divided by wall length) [7]. A ductile failure technique controlled via flexural cracking close to the bottom of the wall is more likely to exist in slender walls. Squat walls typically feature shear-controlled failure mechanisms because of their geometry, which makes them more inclined to display an unexpected shear failure, which is best referred to as an abrupt loss of stiffness and strength under seismic forces [7]. Reinforced concrete (RC) shear walls are a common structural element used to resist lateral loads such as wind or earthquakes in buildings. The failure modes of RC shear walls can be classified into several types, as shown in Fig. (2).

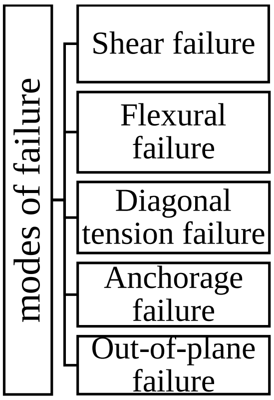


Fig. 2. Types of modes of failure

2.1. Shear failure

Shear failure occurs when the shear stresses in the shear wall exceed its shear strength. This typically happens when the lateral loads are concentrated on a small section of the wall or when there is irregular geometry, such as openings. Paulay and Priestley [8] identified three conditions for the shear failure mode of squat shear walls: failure of diagonal tension, failure of diagonal compression, and failure of sliding shear, as illustrated in Fig.(3,4). Failure of diagonal tension (4.b) is expected to happen if the wall does not have enough reinforcing to withstand horizontal shear. Failure of diagonal compression (4.c) happens When the wall is reinforced with sufficient and strong longitudinal reinforcement in the shear zone. Failure of sliding shear (4.d) It happens as a result of two reasons (1) significant fractures at the bottom of the wall and (2) breaking concrete and twisting rebar in a small area around the wall's base.

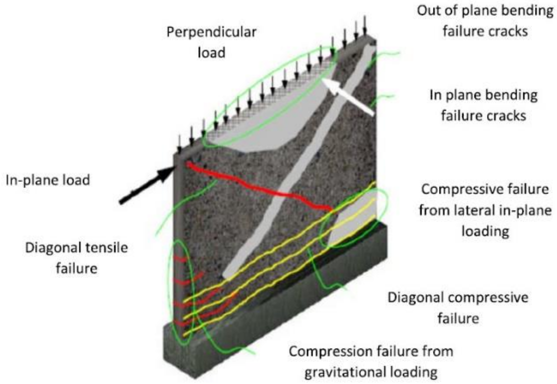


Fig. 3. Different failure modes depicted in the wall [9]

Wyllie et al. [10] observed damage in the shear wall was sliding in the structure joint, spalling and deterioration of the concrete at the wall's boundary base, and buckling of longitudinal steel bars adjacent to wall boundaries.

2.2. Flexural failure

This failure mode occurs when the shear wall is subjected to excessive bending moments due to lateral loads in which the RC wall's shear strength is greater than its bearing strength, causing it to fail in flexure. This type of failure is common in tall buildings with relatively slender walls. Tensile or compression rebar may yield when flexure cracks appear close to the wall's lowest point tensile zone, and concrete crushing in the compression side may develop to a critical stage. An example of this is the Chile earthquake in 2010. This event destroyed many modern buildings, particularly walls, which are the city's primary earthquake-resistant construction components. Wall damage that has been seen includes concrete breaking, local and global twisting, and horizontal rebar outer strengthening fracture [11], as shown in Fig.(4.a).

Nie et al. [12] explained that the engineering design should choose the flexural failure mode because it has higher flexibility than anchorage failure and shear failure, where the boundary element's fracture failure and the crushing of infilled concrete at the descending branch were observed.

Mosoarca, Marius [13] presented an experimental study illustrating various failure modes where the concrete starts to break down. Failure stage: during this stage, the concrete is crushed in regions of maximal compression, which is characterized by a rapid evolution of deformations under constant lateral loads. Two limit stages were established to provide a deeper comprehension of the failure modes that these analyzed experimental models developed:

(i) Limit stage: In designs with zigzag apertures, this stage represents the maximum lateral force at which the concrete is crushed by shear in the linking beams and at the bottom of the short pier.

(ii) Failure stage: denoted by P85% and equal to 85% of the maximal horizontal force. Concrete in point 1 is crushed at this maximum seismic value, and models with staggered openings experience vertical reinforcement buckles.

Galal et al. [14] explained that the brittle shear failure of the wall can be changed to ductile flexural failure by reducing the flexural strength.

2.3. Diagonal tension failure

Diagonal tension failure is a type of shear failure that occurs in the diagonal compression strut that forms in the wall when it is subjected to lateral loads. This mode of failure can occur when the wall is not designed properly or when the reinforcement detailing is inadequate.

2.4. Anchorage failure

Anchorage failure occurs when the steel reinforcement in the shear wall is not properly anchored to the foundation or the adjacent structural elements, leading to a failure of the connection.

2.5. In-Plane splitting failure

Out-of-plane failure occurs when the shear wall is subjected to an external force that causes it to fail in a direction perpendicular to its plane. This failure mode can occur when the wall is subjected to a blast or an impact load. This failure was found in lightweight RC walls under high compression forces that coupled walls or increased gravity loads could force on or by lateral loads under certain conditions [15]. This kind of failure happens unexpectedly and without warning. The wall's adequate confinement can prevent this failure. Lightweight reinforced concrete walls can split in the plane under high axial loads, especially if the walls are constructed with embedded steel elements. In that case, restricting the wall is the best course of action to stop such a brittle failure mechanism [14].

Mosalam et al. [15] showed that Partial-thickness confinement nails could not control the splitting failure of LWRC shear walls subjected to knife-edge loading. To avoid these types of failures, it is important to design RC shear walls properly, considering the expected loads, wall geometry, and material properties.

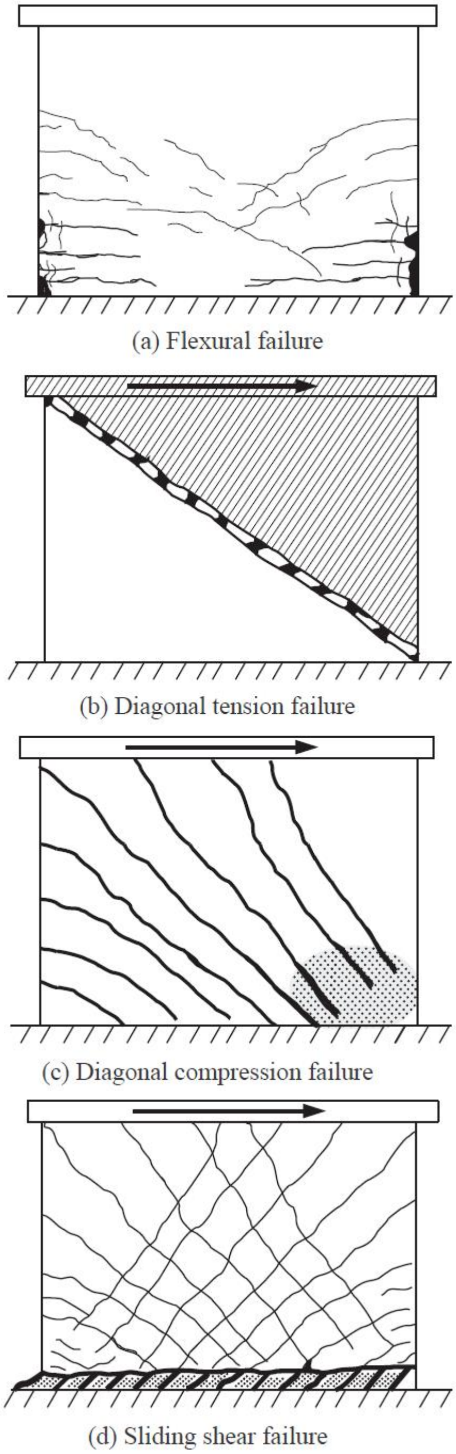


Fig. 4. Typical failure modes of shear walls [7]

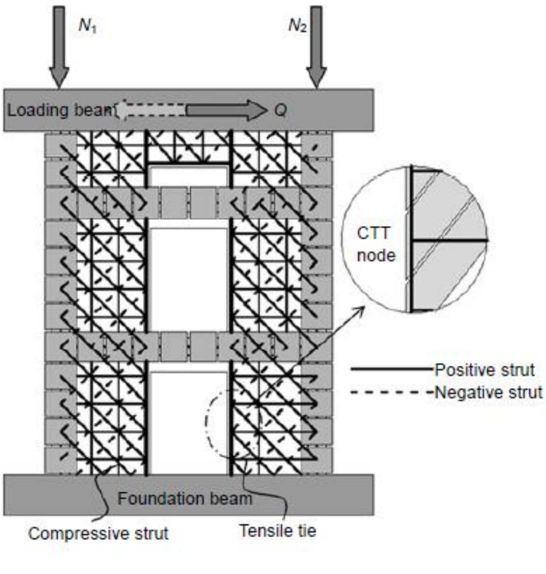
Additionally, appropriate detailing and reinforcement strategies should be used to ensure the shear wall can resist lateral loads effectively.

3. Factors affecting the strength of RC shear walls

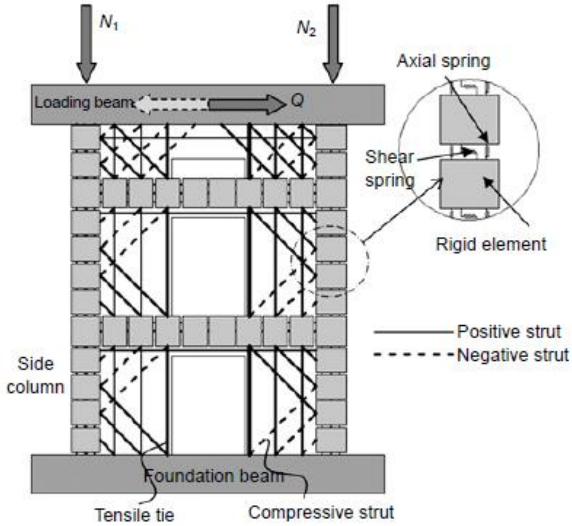
Reinforced concrete (RC) shear walls are important structural elements in buildings and other structures that resist lateral loads such as wind and earthquakes. The strength of RC shear walls can be affected by several factors, including:

3.1. Effect of opening size and position

Wang et al. [16] examined two Squat reinforced concrete structural wall specimens with big openings. Numerous opening locations indicated that an easy design method for a reinforced concrete shear wall was based on an original macro model (O-M model). The M-M model was developed by modifying an original macro model (O-M model) to obtain more accurate load-deformation relationships and behaviors in the case of multi-story walls with various large opening locations, as shown in Fig. (5). According to the findings, the behavior of a structural wall with eccentric openings changes with the location of the openings, as does the ultimate toughness of the wall. It changes with the direction of loading. The multiple modified macro model (M-M model) which was assembled by modifying the original model is better suitable when strength, stiffness, and the relationship between lateral load and drift angle are compared to the O-M model.



(a) Multiple original macro model (O-M model)



(b) multiple modified macro model (M-M model)

Fig. 5. Multiple macro model (a) O-M model and (b) M-M model [16]

MA Husain [17] Presented analytical research to examine the effect of perforations on the behavior of the sliding wall. Three sliding wall models with various opening sizes and positions were constructed using brick elements. The test results indicated that the lateral displacements and the maximum stresses at the base became smaller when the perforations were close to the middle of the shear wall.

SM Khatami et al. [18] investigated the impact of cracks in concrete shear walls during ground vibrations caused by earthquakes near the fault. Two near-fault earthquakes were chosen for this challenge from various earthquake records. Three alternative lateral resisting system types were used to model a ten-story structure in the location of the opening. The analysis revealed that shear wall openings significantly reduced a wall's strength. A panel with an opening that initiated finite element analysis revealed a sharp drop in ultimate force of up to 54%. Compared to entire shear walls, this study demonstrated that shear walls with openings are more ductile and can withstand substantial lateral displacements.

Chowdhury et al. [19] used ETABS for equivalent static analysis to examine the structural behavior of six-story framed shear wall structures under earthquake motions, considering the size and location of shear wall openings. The findings indicate that the area and position of the openings in the shear wall influence the structures' stiffness and seismic responses. In addition, it is being investigated whether thickening the model element surrounding the shear wall opening can reduce the system's upper lateral drift.

Wang et al. [20] experimented with three single-span, three-storied, 40 percent scale specimens RC structural wall samples with different eccentric opening ratios, each with a single span and three stories. The primary goals of these tests were to evaluate the shear performance and recognition of the impact of different opening ratios on the shear and cracking resistance of structural walls during cyclic loading. Due to the eccentric opening location, shear strength changes with loading direction, and the Short span beams' span length may affect the fracturing phase and failure mechanism. It is found that opening ratios impact shear behavior when structural wall openings are in the same location.

Musmar [21] investigated how the behavior of the reinforced concrete shear walls was affected by the area of the openings. According to the research, shear walls' responses to the highest displacement and normal pressures at the wall's base level are only marginally affected by small openings. Cantilever behavior is comparable to coupled shear walls and solid shear walls. Further, Shear walls behave like linked shear walls and exhibit frame action behavior when openings are large enough.

Muthukumar et al. [22] utilizing a degenerated shell element with an assumed strain technique, non-linear finite element analysis was used to examine the dynamic performance of shear walls under varied opening sizes and positions, as shown in Fig. (6). For undamped shear walls in particular, strengthening has been deemed essential. The shear wall with four windows has been deemed the most effective for both types. In the instance of a thin shear wall with staggered openings, it has been determined that reinforcing ductile details is important. However, the strengthening has not been deemed necessary for higher damping.

Ali et al. [23] presented analytical research on the shear walls for the stock exchange building with the aid of the ETABS software by changing the cross-section and position. Depending on the location of the shear wall, response spectrum analysis has been performed on four instances. The best case is then chosen, and it is then compared to the actual building. It has been determined that, given the permitted lateral drift and base shear forces, the framework can have smaller dimensions because of the low base shear forces, which increases structural performance.

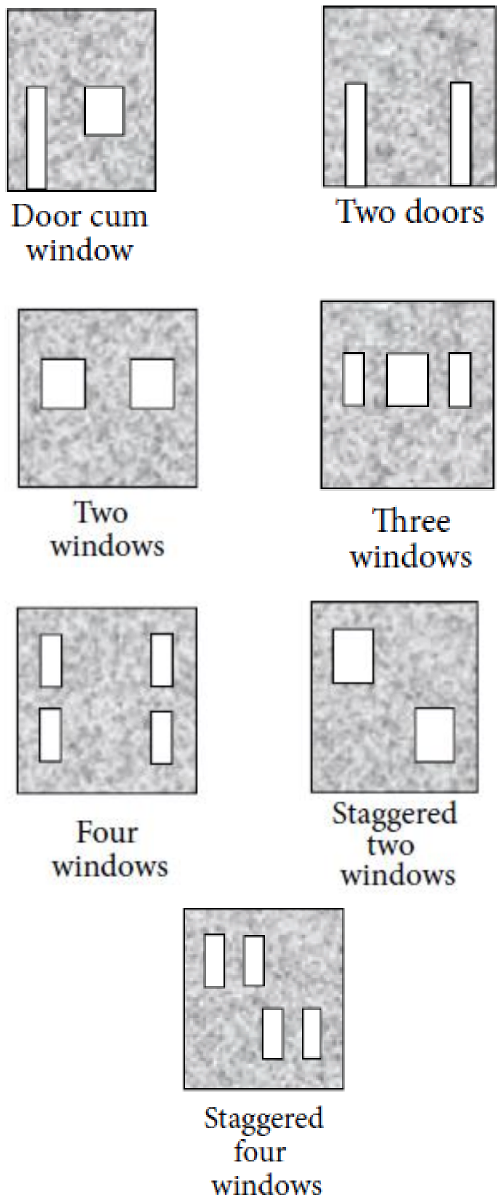


Fig. 6. Classification of openings in RC shear walls [22]

Itware et al. [24] presented analytical research to study the effects of shear wall openings on structures' seismic responses. As a result, when opening dimensions are fewer than 20% of the total wall side area, they have a greater impact on the structure's stiffness than their location in the shear walls. When the dimension of the opening is greater than 20% of the area of the shear wall, the placement of openings in shear walls significantly impacts the system's stiffness. The system's rigidity may not be affected by placing door openings 1×2.1 m horizontally. However, the vertical window opening significantly impacts the system's stiffness.

Gandhi et al. [25] examined the impact of shear wall opening size and location. As a result, there is a clear relationship between the deflection and the opening ratio. When the percentage of the opening is greater than 40% of the total wall-side area for each floor, the deflection and stresses around the opening occur very quickly. Additionally, the deflection of the zigzag opening has a smaller effect than the square opening, and the axial loading has a smaller deflection than the straight Non-central load.

Popescu et al. [26] experimented with studying the impacts of openings on the longitudinal capacity of large concrete wall panels. A small eccentricity was applied. There were two opening arrangements on each of the three shear walls, one for each tiny and one for a large door opening. The axial load was uniformly distributed. The fundamental analysis of buckling capacity revealed that the material failure (inelastic buckling) occurred first, instead of a stability issue, and that The solid wall's cross-sectional area was reduced by 25 and 50 percent by the tiny and large holes., respectively, and reducing the capacity to handle loads by almost 36 and 50%.

Kankuntla et al. [27] analyzed Modeling RC Shear wall numerically. It means that the shear wall's opening position is changed for various story heights. Changes are made to the shear wall's opening sizes and shapes. The buildings are analyzed for severe earthquake load. According to the research findings, depending on the dimensions and forms of the apertures, the shear wall's capacity and stiffness are affected by the decrease when there are apertures in it. Additionally, as the plan length of the shear wall increases, the effect of the openings decreases, and the shape of the openings does not affect the responses of the structure, but their height and width do.

Massone et al. [28] studied two analytical models by calibrating the longitudinal border rebar ratio using a non-linear finite element model simulation analysis. According to the findings, these differences may have a significant impact on both the inelastic component and the elastic component by increasing the bending and stress at the bottom of the wall as a result of the opening's tendency to confine the plastic hinge therein, but also The elastic displacement decreased because there is a more substantial part above the opening.

Aslani et al. [29] investigated the effect that various sizes and locations of openings had on reinforced concrete shear walls. Shear wall structural behavior was also examined using CFRP polymer sheets in various designs and thicknesses to study openings in specimens. According to the findings, opening increased wall displacement while reducing bearing capacity, energy absorption capability, and rigidity. Shear walls improved structurally depending on CFRP polymer sheets' thickness and reinforcement pattern.

Ghaderi et al. [30] investigated using the ANSYS software to model the structures with varying percentages of opening to the entire wall and perform the non-linear static analysis (hysteresis) per ATC 24 [31]. The results of the hysteresis analysis of the models reveal a reduction in system power and their complicity in the system's collapse in energy dissipation during cycling loading.

Hosseini et al. [32] examined the mechanical performance of three specimens of RC shear walls with cut-out openings experimentally by increasing the eccentricity of the openings. In addition, the impacts and eccentricities of the openings were compared using a single reference RC shear wall with no openings. When RC shear walls were exposed to reversed cyclic loading, it was found that the imposing eccentricity and the creation of openings substantially impacted the failure modes of RC shear walls. In addition, it was discovered that squat RC shear walls had more flexibility at the end of loading because of their eccentric openings. In addition, it was discovered that openings significantly reduced cumulative energy loss.

Massone et al. [11] conducted a numerical and experimental investigation on walls with an opening in the middle at the base. Four thin walls have various opening geometries. But the same basic dimensions. The results indicate that the opening causes a redistribution of wall strains, with the largest tensile strain occurring at the upper edge of the opening rather than at the wall's lower end. This increases the risk of buckling in the horizontal reinforcement bars next to the hole.

Ou et al. [33] investigated The effects of the location and size of the window aperture on five specimens of a reinforced concrete shear wall under lateral periodic loading to study their seismic response. According to the findings of the tests, compared to the wall with the window aperture in the center of the wall web, the wall with the window aperture on the edge of the wall web had stronger average lateral strength. The lateral strength was less affected by an increase in opening height than by an increase in opening length.

Yu et al. [34] investigated the performance of five RC shear walls with small openings, and an aspect ratio of 2.6 underwent cyclic lateral loading tests. The smallest opening size was the primary test parameter. It is founded that small apertures do not affect the flexural performance of thin walls as long as they have a sufficient amount of shear resistance, are not located in the high compressive end, and are on the compression side where compressive stress does not decrease.

Xu et al. [35] presented an experimental and numerical study on three concrete shear walls (with and without opening) under axial force and lateral monotonic and reversed cyclic loads. The results show that the cavity shear walls' ductility has increased while their ultimate capacity and stiffness have decreased. The continuous link method can calculate the lateral reactions for shear walls with and without opening, as demonstrated by theoretical calculation models. Additionally, the verification results are accurate enough.

Massone et al. [36] examined the effects of discontinuities in RC walls as a setback (flag-wall). One specimen of a structural wall had no discontinuity, and the other three had setbacks of varying sizes. They were put through their paces with cyclic lateral loads that increased at particular drift levels and with an axial load that is nominally fixed of $0.1F_c'A_g$. The findings of the experiments demonstrate that although the plastic hinge length expands with drift, it still restricted to the setback zone. Around the reinforcement of the setback, there is another discontinuity where many strains can cause the wall to fail prematurely.

Yadav et al. [37] examined the effects of shear wall opening types and locations. According to the findings, as the size of the opening in the shear wall increases, so do deflection, bending moment, and shear force. As a result, it is possible to conclude that, as the structure's height increases, the shear wall's aperture should be minimized or avoided entirely.

Ma'moun [38] evaluated the response modification factor (RMF) of reinforced concrete structures with shear walls using the pushover analysis method and the ETABS software to test various sizes of openings resistant to the lateral load. The ratio of aperture dimensions to shear wall area affects the RMF, and if the ratio is less than 85 percent, it affects the RMF. The maximal base shear is affected by the apertures, and the maximum displacement, both of which affect the RMF values, as shown by the study's RMF results.

Varma et al. [39] investigated how the story drift, story stiffness, shear and moments, and stress within the shear walls were affected by The magnitude and position of these apertures. When openings are provided near the walls' edges, overall displacements are higher than when apertures are in the middle of the wall. Additionally, story rigidity is higher in shear wall structures than in non-shear wall structures, and story drift is lower in shear wall structures than in non-shear wall structures.

Fares [40] utilizing linear elastic analysis at SAP2000, the impact of window and door apertures was examined on reinforced concrete shear walls. The lateral stiffness is found to be influenced by the size of the openings. If the ratio of the aperture area cutting out to the area of the wall side is greater than 3%, The window aperture is expected to have no impact on the lateral strength and should be disregarded. Additionally, the effect of the opening reduces as the ratio of the wall's height to its length rises. In addition, the minimal door opening percentage required to convert a solid wall into a frame is 65% of the wall's overall surface area.

Nasr et al. [1] investigated the effect of holes in shear walls on the response reduction factor. They provided an overview of recent research that evaluated the impact of openings on the behavior of reinforced concrete shear walls using finite element simulation and experimental tests. The size and position of the apertures in the reinforced shear wall affect the buildings' stiffness and seismic reactions, as shown in Fig. (7). The findings indicate that increasing the opening area decreased the R-factor. However, the width has less of an impact on it than the opening height. For apertures that occupy less than 30% of the wall's surface area, the reduction percentage in the R-Factor controlled by relation as the number of stories increased also rose. When half of the reinforcement bars are added, the R-factor slightly increases.

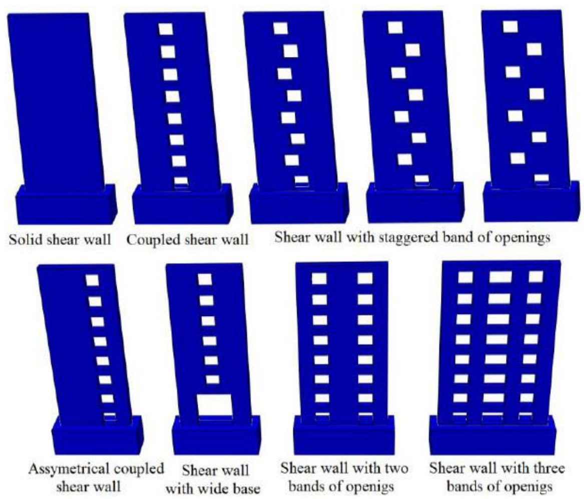


Fig. 7. Typical types of opening locations in walls [1]

3.2. Effect of opening shape on the shear wall

Sakurai et al. [41] investigated a study to display RC shear walls with apertures subjected to a static loading test to determine how the number and arrangement of the openings affected the results. The equivalent perimeter ratio of openings across all specimens is the same at 0.4. The test's outcomes demonstrated that the apertures' quantity and positioning significantly impacted the shear strength, failure mechanism, and deformability of RC shear walls with holes. Additionally, there was a finding that the rotation at the bottom of shear walls with openings decreased due to the presence of the openings, resulting in a smaller overturning moment than for shear walls without openings.

Marsono et al. [42] studied the effect of creating octagonal openings and putting haunches to the edges of rectangle-shaped gaps to strengthen coupling beams, as shown in Fig. (8). The results show that the effective length of coupling beams is reduced when corners of rectangular holes are equipped with hunches, the location of cracks is shifted, and coupling beam strength is increased. Additionally, up to the point of failure, the quantity of loads that were applied to the structure increases when the length of the wall is increased when coupling beams are present.

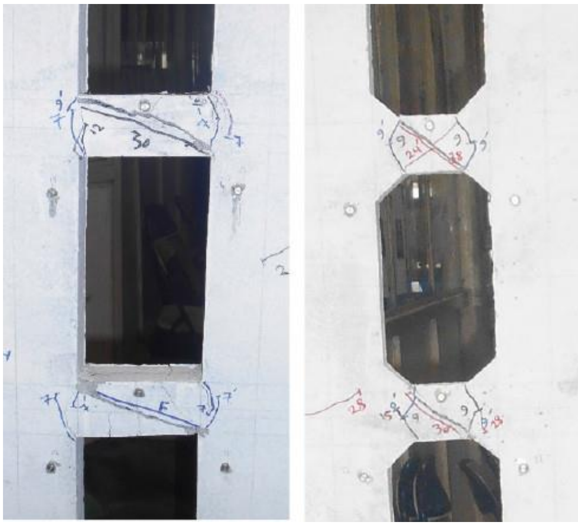


Fig. 8. Typical types of opening shapes in walls [42]

Sharma et al. [43] investigated the responses and behaviors of multi-story buildings with the sizes of openings in shear walls. The 30-story prototype buildings featured a variety of shear wall openings, both with and without incorporating a volume reduction in the boundary elements of the shear wall. It was discovered that the shape of the opening and size significantly impact displacement and drift when the aspect ratio is high.

Chaudhary et al. [44] investigated various approaches to find a shape that produces either less or more results than a rectangular opening and is advantageous from an architectural perspective. Different shapes like rectangular, semi-circular, triangular, and so on are used to reduce the load at the wall's opening. Are examined. The software ANSYS 16.0 is used for static analysis, which yields load transfer path parameters like stress-strain and deformation. The results show that semi-circular and rectangular opening shows good result in terms of stress and strain than the triangular opening. It is noted that all the shapes of the opening show similar deformation.

Massone et al. [11] presented a numerical and experimental investigation of base-opening walls. The four thin walls have the same fundamental dimensions, but the openings have various shapes. The specimens were put through their paces at the top of the wall, repetitive horizontal loading and constant axial load. According to the findings, all cases exhibit comparable lateral strength; However, the displacement capacity varies with opening size. The displacement capacity of all specimens with openings was influenced more by the width of the opening than by its height.

Ali et al. [45] examined the concrete shear wall's seismic behavior in light of the opening's various shapes and constant cross-section. The 3D abaqus Software was used to model these case studies. Based on the diagram results, it is possible to conclude that the various types of openings affect the resistance and hardening of samples. Additionally, the shear wall without openings is harder than those with openings. It can be deduced from the seismic changes in profiles and rectangular samples of varying length and width that the openings' strength decreases as they get closer to the wall's edge.

Dadayan et al. [46] investigated the stress-strain condition of RC wall-frame structures with various wall apertures subjected to seismic forces using eight models. The paper considers Armenia's building code in limiting the dimensions and location of openings. The findings demonstrate a significant increase in stresses in both the walls and the RC walls when The openings are longer than they are by more than 50%.

Rajesh et al. [47] presented a study that modeled and analyzed RC walls with the pushover analysis feature of SAP 2000. several parameters are selected, including the walls' aspect ratio, strengthening detailing, and the existence of apertures. The analysis has shown that including ductile detailing as a boundary feature greatly improves RC walls' seismic behavior, particularly the wall's deformation ductility. The wall's base shear capacity decreases when the aspect ratio is reduced, but its deformation capacities remain unaffected.

Yarnal et al. [48] utilizing the E-TABS software, the performance of the shear wall was investigated and compared to different ratios of openings in the shear wall area. The story drift of a building in a shear wall with an opening is greater than in a shear wall that does not have an opening, and the period increases as the opening increases.

Sivaguru et al. [49] investigated RC Squat walls with openings compared to controlled walls without openings. RC shear walls have been the subject of experimental studies, both with and without openings. Due to earthquake motions' effect on buildings, lateral loads were applied to the walls under gravity loads. Non-linear finite element analysis (ANSYS15.0 [50]) was used to evaluate the load transfer paths and shear strength. The presence of an opening in the wall has been found to have significantly reduced the shear strength and flexibility of the shear wall.

3.3. Effect of steel ratio on the shear wall

The reinforcement used in the shear wall, expressed as a percentage of the total concrete area, can also affect its strength. A higher reinforcement ratio can improve the wall's resistance to shear and bending forces.

Peng et al. [51] presented the experimental test to comprehend the performance of squat reinforced concrete shear walls and support the use of repurposed concrete used in construction by testing six rectangular squat recycled concrete wall samples under in-plane cyclic loads at minimal horizontal and vertical reinforcing ratios of 0.25% and 1.0%, respectively. The findings indicate that when vertical web reinforcement remained constant, increasing horizontal web reinforcement had little impact on maximum stress but could increase drift capacity.

Li et al. [52] investigated an experimental study on eight RC walls with boundary components, five of which had an aspect ratio of 1.125 and three of which had an aspect ratio of 1.625. which is made of reinforced concrete with less restricting reinforcement than ACI 318 [53] recommends. The samples with a stronger bending contribution to the overall displacement had more transverse reinforcement in the wall border components. This shows that adding more transverse reinforcement to a wall's boundary elements can improve seismic performance like drift and energy dissipation capacity.

Terzioglu et al. [54] investigated eleven squat reinforced concrete walls experimentally for their proportions, web reinforcement quantities (horizontal and vertical), boundary reinforcement quantities, and axial load levels. Due to a lack of web reinforcement, the results did not hold up under diagonal tension. Additionally, it was discovered that the distribution of the diagonal cracks and the side load capability is affected by the amount of vertical web reinforcement. The side load capability increased due to an increased vertical web reinforcement ratio.

Park et al. [55] investigated how shear friction strength were affected by high-strength reinforcement. Under cyclic lateral loading, six RC wall specimens with grades 420 to 550 MPa or higher were tested. On the one hand, failure mechanism, safety factor, and average fracture width, the test outcomes for 550 MPa rebar walls were equivalent to those for 420 MPa rebar walls. This test's findings indicate that grade 550 MPa shear reinforcement can be used for shear providing in walls.

Dhanasekar et al. [56] presented a non-linear finite element modeling approach. Shear walls with various concrete compression strengths, ratios, and steel elaboration (single layer to double layer) were analyzed. Each lateral in-plane load strength and the flexibility of shear walls reinforced with single- and double-layer materials are comparable.

3.4. Effect of opening arrangement on the shear wall

Hatami [57] evaluated the shear wall structure's behavior when haunches were present. Five small-scale samples of reinforced concrete shear wall with different patterns of rectangular and octagonal holes were tested under a periodic static horizontal load imposed at the top of the walls. The findings demonstrated that the haunches delayed the formation of cracks, increased coupling beam capacity, and improved shear wall structures' ultimate strength and stiffness.

Jagadale et al. [58] demonstrated the effectiveness of shear walls of varying thicknesses and the studies of vertical opening, staggered opening, and no opening with the help of different models. Also, they analyzed and observed shear wall behavior with and without apertures in the shear wall under seismic loads. It has been discovered that the staggered opening performed better than the vertical one. The staggered openings have a lower base shear. Compared to the opening, the base shear without opening is greater, and the period is also longer when compared to the vertical opening without opening.

Swetha et al. [59] investigated the attitude of a shear wall with varying proportions of zigzag openings and openings arranged vertically, horizontally, or both. Using the finite element software ETABS, the research is conducted on a seven-story frame shear wall construction utilizing the time history method and linear ETABS software. According to the comparison results, the zigzag positioning of the apertures in shear walls is recommended for practice because it outperforms other opening arrangements by 4%.

Zhang et al. [60] investigated the finite element calculations and quasi-static tests of a single specimen shear wall without holes and three specimens shear walls with different post-construction opening arrangements but the same total area. The findings demonstrated that the failure mode of the shear wall is impacted differently by the arrangement of post-openings. The opening causes the strains in the wall to be redistributed, demonstrating that the corners of the holes, both top and bottom, are under the greatest strain, not the bottom of the wall. As a result, the vertical reinforcement close to the opening is subjected to a greater amount of stress, and as a result, it reaches yield earlier than in a wall that does not have an opening.

3.5. Effect of aspect ratio on the shear wall

The ratio of the height to the length of the shear wall can also influence its strength. Taller, more-slender walls may be more susceptible to buckling or instability under lateral loads.

Rajesh et al. [47] presented the effects of various aspect ratio-related parameters on the seismic behavior of RC walls. The pushover analysis capabilities of SAP 2000 are utilized to model and analyze a typical 6-story RC wall element. Analytical findings are inconsequential; It is abundantly clear that increasing the slenderness ratio or aspect ratio does not affect the structures' displacement ductility but does affect the wall's base shear capacity.

Li et al. [52] showed that an experiment was conducted on eight specimens of RC walls with boundary elements, with five walls having an aspect ratio of 1.125 and three specimens having a 1.625 aspect ratio. Specimen (1), which had an aspect ratio of 1.125, was found to have a displacement ductility below 3.0. When it came to the strength and deformation capacities that were achieved, specimen one demonstrated crucial seismic performance. It is crucial to remember that sample (2) and specimen (1) are identical. However, specimen (2) has a ductility level of 3.6 because it has a higher aspect ratio than specimen (1).

Huang et al. [61] presented an experimental study. Under cyclic loading, six concrete shear walls were classified into two groups. The first was a steel RC shear wall, and the second was five reinforced walls with CFRP grids in either a vertical, vertical, or horizontal reinforcement orientation that was tested until they failed. Some factors have been used as comparison parameters, such as the horizontal reinforcement proportion, the aspect percentage, and reinforcement direction. The six samples with aspect percentages between 1.0 and 1.4 demonstrate the failure due to diagonal compression shear abundantly.

4. Design provisions for RC walls with openings

According to ACI318-19 [53] section 18.10.8, the introduction of door and window openings may lead to the creation of narrow wall segments that are designated as wall piers where the ratio of the width of the wall portion located between the two openings or between an opening and the end of the wall (l_w) to the thickness of the wall (b_w) is less than or equal to 2.5, i.e.

$$\frac{l_w}{b_w} \leq 2.5 \tag{1}$$

During earthquake events, these wall piers are susceptible to shear failure [53][62] and these portions of the walls behaves essentially as columns. For this reason, ACI318 requires that the design of these portions must satisfies the exact requirements for seismic design of columns (sections 18.7.4 through 18.7.6, ACI318-19 [53]). The code also differentiates between the required reinforcement of vertical wall piers (vertical segments of the wall between two horizontally aligned openings or one horizontally aligned opening and wall end) and horizontal wall piers (horizontal wall segments between two vertically aligned openings or one vertically aligned opening and wall top) and requires two different internal steel reinforcement ratios, ρ_t, and ρ_l, respectively (see Fig. 9). In cases where the ratio of the wall or wall segment height to wall or wall segment length, l_w, does not exceed 2.0, then:

$$\rho_l \geq \rho_t \quad \left(when: \frac{h_w}{l_w} \leq 2.0\right) \tag{2}$$

In addition, the code mandate that the nominal shear strength, V_n , of such walls should not exceed the following value:

$$V_n = A_{cv}\left(\alpha_c \lambda \sqrt{f_c'} + \rho_t f_y\right) \quad (3)$$

where: α_c is coefficient equal to 0.25 for walls with $h_w/l_w \leq 1.5$, and equal to 0.17 for walls with $h_w/l_w \geq 2.0$. This coefficient varies linearly between 0.25 and 0.17 for wall height-to-length ratios between 1.5 and 2.0. It should be noted that the value of ratio h_w/l_w used to calculate V_n in Eqn. (3) for segments of a wall shall be taken as the larger of the ratios for the entirewall and the segment of wall considered λ is a coefficient related to concrete weight that is taken 1.0 for normal weight concrete, f_c' is the 28-day concrete compressive strength and f_y is the yield stress of the internal steel reinforcement. For all vertical wall piers, the nominal shear strength value calculated from Eqn. (3) should not exceed the described in Eqn. (4), and for any individual vertical wall segments, this nominal strength should not exceed the value prescribed by Eqn. (5).

$$V_n \leq 0.66 A_{cv}\sqrt{f_c'} \qquad [SI\ units] \quad (4)$$
$$V_n \leq 0.83 A_{cv}\sqrt{f_c'} \qquad [SI\ units] \quad (5)$$

The maximum nominal wall shear strength described in Eqn. (5), can also be used for setting the shear strength limit for horizontal wall segments. However, for vertical segments, A_{cv} is the gross area of concrete bounded by web thickness and length of section, while for horizontal wall segments, this term is taken as is the area of concrete section of a horizontal wall segment or coupling beam [63].

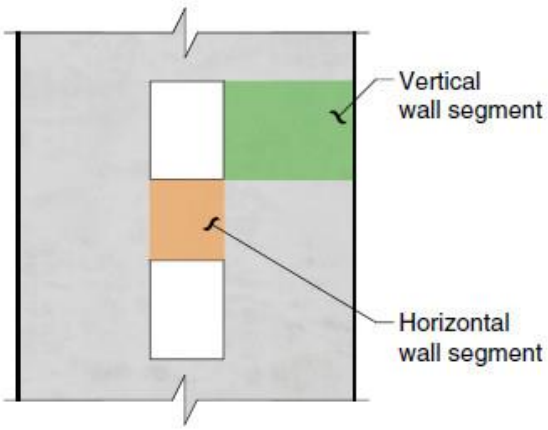


Fig. 9. Typical RC wall with openings [53].

5. Conclusions

The above literature review clearly demonstrates the relevance of reinforced concrete shear walls in buildings and the impact of cutting out openings on RC Shear walls. Through a systematic exploration of key aspects, the paper has shed light on the diverse range of factors influencing the structural integrity and performance of such systems. The elucidation of the various modes of failure in RC shear walls serves as a foundation for understanding their complex behavior under different loading conditions. This research summarizes review papers to illustrate the factors impacting the strength of RC shear walls, including opening size and position, opening shape, steel ratio, arrangement of openings, and aspect ratio, which have been meticulously analyzed to reveal their individual and collective effects on the structural response. A review of a number of the earlier and more recent experimental, computational, and analytical works related to the opening on RC shear walls is discussed in this article. The following points provide a summary of this review's findings:

- When the opening size was increased, the hardness, energy absorption capability, and lateral bearing capability decreased and increased wall displacement.
- It is established that a construction with a shear wall with a zigzag aperture has a four percent lower incidence of story shear, displacement, drift, and acceleration than a structure with openings arranged vertically or horizontally.
- It is seen that semi-circular and rectangular opening shows good result in terms of stress and strain than the triangular opening.
- It is shown that adding haunches to the corners of rectangular apertures reduces the effective length of coupling beams, shifts the site of cracks, and increases coupling beam strength. Furthermore, when coupling beams are present, the number of load cycles applied to the structure up until failure increases as the length of the wall grows.
- After yielding, the flexural reinforcement in all samples displayed significant strains, regardless of the number, dimensions, or additional reinforcement for the openings. There was no major shear damage and no yielding of horizontal shear reinforcements. This indicates that small

apertures do not affect the walls' strength and deformation capability.

- When vertical web reinforcement remained constant, adding horizontal reinforcement had little impact on the ultimate load, but it could increase drifting capability.
- The structure's base shear capacity decreases when the wall's aspect ratio is reduced, but the walls' deformation capacities remain unaffected.

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