https://doi.org/10.47456/bjpe.v11i3.48650 ARTIGO ORIGINAL | OPEN ACCESS

A COMPARATIVE SIMULATION STUDY OF THE EFFECT OF COLUMN SUPPRESSION ON SHEAR STRESS IN AN L-SHAPED RC WALL WITH OPENINGS

Um estudo comparativo de simulação do efeito da supressão de colunas na tensão de cisalhamento em uma parede RC em forma de L com aberturas

Estudio comparativo de simulación del efecto de la supresión de pilares sobre el esfuerzo cortante en un muro de RC en forma de L con aberturas

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ARTICLE INFO.

Received: 20.05.2025
Approved: 30.08.2025
Available: 09.09.2025

Keywords: High seismicity; Buildings; L-shaped RC; Columns; Openings; Numerical analysis; Shear stress.
Palavras-chave: Alta sismicidade; Edifícios; RC em forma de L; Pilares; Aberturas; Análise numérica; Tensão de corte.
Palabras clave: Alta sismicidad; Edificios; CR en forma de L; Columnas; Aberturas; Análisis numérico; Esfuerzo cortante.

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ABSTRACT

Buildings require the use of reinforced concrete shear walls to ensure their stability and seismic resistance. Among the effective configurations, L-shaped reinforced concrete (RC) walls placed at the corners of buildings perfectly meet the seismic resistance criteria. In this study, a new approach was explored, consisting of removing the columns from the L-shaped walls, and its results were compared to those of walls with columns. To evaluate this configuration, numerical simulations were performed on buildings located in a high-seismicity area. The main parameters considered included the thickness of the shear walls, the percentage of openings, and the number of stories. The simulation results reveal that removing columns from L-shaped shear walls with openings leads to maximum shear stress reduction, regardless of wall thickness or number of stories. The study confirms the beneficial effect of column removal for openings below 25%, while retaining columns proves advantageous for larger openings.

RESUMO

Os edifícios exigem o uso de paredes de cisalhamento de concreto armado para garantir sua estabilidade e resistência sísmica. Entre as configurações eficazes, as paredes de concreto armado (RC) em forma de L colocadas nos cantos dos edifícios atendem perfeitamente aos critérios de resistência sísmica. Neste estudo, foi explorada uma nova abordagem, que consiste em remover as colunas das paredes em forma de L, e seus resultados foram comparados aos das paredes com colunas. Para avaliar essa configuração, foram realizadas simulações numéricas em edifícios localizados em uma área de alta sismicidade. Os principais parâmetros considerados incluíram a espessura das paredes de cisalhamento, a porcentagem de aberturas e o número de andares. Os resultados da simulação revelam que a remoção de colunas das paredes de cisalhamento em forma de L com aberturas leva à redução máxima da tensão de cisalhamento, independentemente da espessura da parede ou do número de andares. O estudo confirma o efeito benéfico da remoção de colunas para aberturas abaixo de 25%, enquanto a retenção de colunas se mostra vantajosa para aberturas maiores.

RESUMEN

Los edificios requieren el uso de muros de cortante de hormigón armado para garantizar su estabilidad y resistencia sísmica. Entre las configuraciones eficaces, los muros de hormigón armado en forma de L colocados en las esquinas de los edificios cumplen perfectamente los criterios de resistencia sísmica. En este estudio se exploró un nuevo enfoque, consistente en eliminar los pilares de los muros en forma de L, y sus resultados se compararon con los de los muros con pilares. Para evaluar esta configuración, se realizaron simulaciones numéricas en edificios situados en una zona de alta sismicidad. Los principales parámetros considerados fueron el grosor de los muros de corte, el porcentaje de aberturas y el número de plantas. Los resultados de la simulación revelan que la eliminación de los pilares de los muros de cortante en forma de L con aberturas conduce a la máxima reducción de la tensión de cortante, independientemente del espesor del muro o del número de plantas. El estudio confirma el efecto beneficioso de la eliminación de pilares para aberturas inferiores al 25%, mientras que la conservación de pilares resulta ventajosa para aberturas mayores.

INTRODUCTION

Seismic activity in Algeria is well-known for its intensity and frequency throughout history (Roussel., 1973; Harbi et al., 2007; Sohaib Mazari et al., 2023). The region has been hit by several devastating earthquakes in recent years, resulting in the loss of thousands of lives, leaving people homeless, and causing the destruction of many buildings, both old and modern (Khelladi et al., 2024). To ensure the safety of occupants, buildings have been reinforced with reinforced concrete shear walls. In this context, the Algerian seismic code (RPA, 2003) has been revised several times since 1981, based on recorded seismic data, to take into account the latest knowledge and technologies in the field of earthquake resistance (DTR B.C2-48., 1981; DTR B.C2-48., 1999/version 2003; DTR B.C2-48., 2024). Faced with rapid urbanization and high-rise construction (Amini et al. 2016; Merabti., 2022), this code requires reinforced concrete shear walls. Indeed, these resistant elements are essential for high-rise buildings to resist vertical loads, particularly seismic actions (Merabti & Bezari, 2023; Zhou, 2024; Dehghani and Tobber, 2024).

Numerous studies have been conducted on the seismic behavior of U, T, L, and H-shaped reinforced concrete shear walls (Merabti, 2023; Reydso et al., 2023; Yang et al., 2023). The results of studies such as those conducted by Ozkula et al. (2019) highlight several advantages of the seismic performance of buildings braced by shear walls. Other studies have evaluated thin-walled shear walls (Zhang et al., 2022; Karamlou & Kabir, 2020) and recommended the addition of longitudinal and horizontal reinforcement to improve the resistance to buckling and ductility of these walls. In a bid to innovate, researchers have recently introduced recycled aggregates into the fabrication of concrete for shear walls (Zhou et al., 2024; Yang et al., 2024; Du et al., 2024). Furthermore, the use of ultra-high-performance concrete (UHPC) for shear walls has demonstrated a significant improvement in the ductility and energy dissipation capacity of these walls (Ding et al., 2024). Additionally, lightweight reinforced concretes have also been used in shear walls (Yang et al., 2023; Deng et al., 2024), and studies have been conducted on precast shear walls made with lightweight or ordinary reinforced concretes (Wang et al., 2024). These studies have explored these new techniques to improve the performance of shear walls, increase construction speed, and enhance precision. These studies have explored these new techniques to improve the performance of shear walls, increase construction speed, and enhance precision (Guo et al., 2024).

The L-shaped reinforced concrete (RC) shear walls are widely used in both low- and high-rise buildings. However, the Algerian code RPA99 does not mention this type of wall. Ma et al. (2019) investigated slender L-shaped shear walls, and the results showed that the shear span ratio had a significant effect on the seismic performance of these walls. Ahmed-Chaouch et al. (2016) conducted a comparative study between walls with and without columns and found that the maximum shear stress was slightly reduced with the wall having a column, regardless of the wall thickness. In another publication (Ahmed-Chaouch et al., 2015), the same authors explored the effect of varying the branches of the L-shaped shear wall, and the results of this research show that walls with thicknesses of 15 cm and 20 cm should have lengths of at least 15 times and 7 times the wall thickness, respectively. Sahraoui et al. (2023) numerically analyzed a non-linear L-shaped wall. The results revealed that the maximum stresses were concentrated at the intersection of the branches of the two wings, particularly at the columns and the boundary column. The addition of radial and diagonal reinforcement reduced the stresses and decreased the shear force.

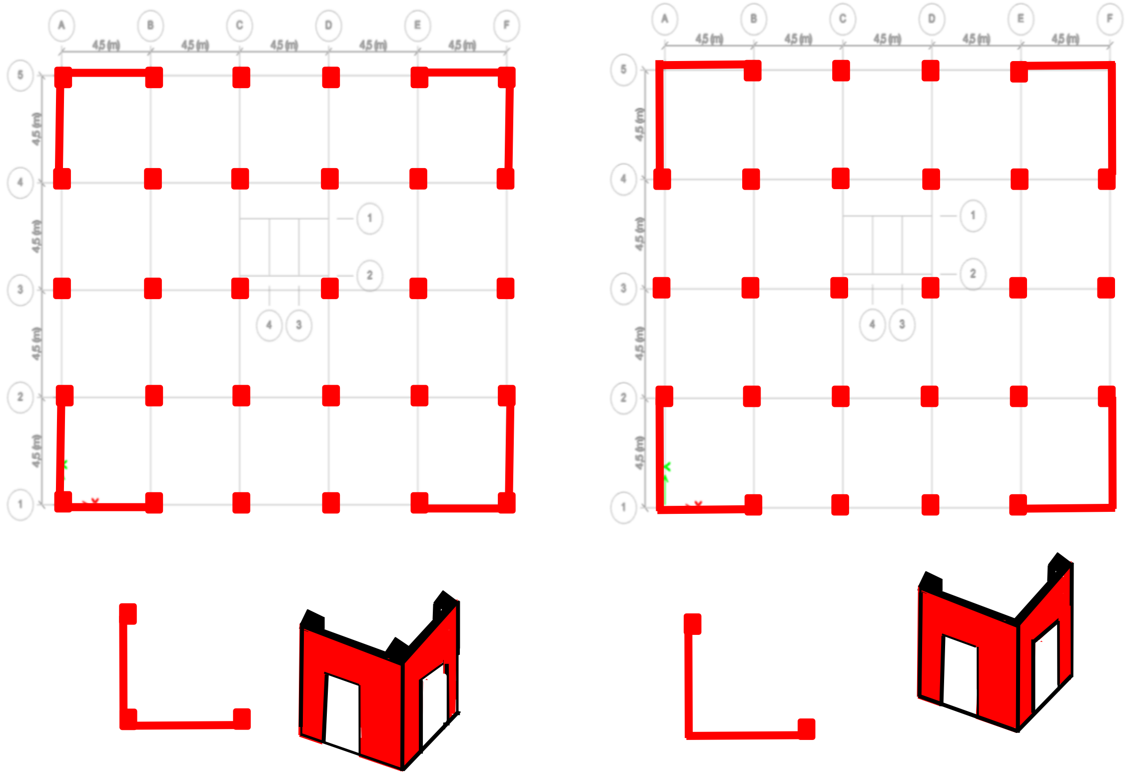
Other studies have examined the impact of openings on L-shaped shear walls. For example, Merabti and Guelmine (2024) found that increasing the concrete strength up to 40 MPa had a limited effect on shear stresses, while the percentage of openings had a significant influence. Indeed, openings play a crucial role in the behavior of L-shaped shear walls. The studies of Varma et al. (2021) and Pandey et al. (2017) showed that the size and location of openings have a significant impact on shear stresses. Numerical studies conducted by Montazeri et al. (2018) and Merabti et al. (2024) also examined the influence of centered and offset openings on shear stresses, revealing that centered openings were weaker. Additionally, Kalpana et al. (2016) found that the shape and number of openings affected the overall performance of buildings.

The main objective of this study is to numerically analyze structures braced by L-shaped reinforced concrete shear walls, with and without openings, to evaluate their behavior under seismic loading. Three dimensions of shear walls, with and without integrated columns, were compared for buildings with different numbers of stories. The analysis focused on the distribution of shear stresses and the evaluation of maximum stresses, to understand the impact of removing columns from the L-shaped shear wall on its shear stresses.

BUILDINGS ANALYZED

In this study, the maximum shear stresses applied to L-shaped reinforced concrete (RC) shear walls were determined. We focused on L-shaped shear walls composed of two perpendicular branches. Buildings with regular rectangular shapes in both plan and elevation were examined. In this research, 72 buildings were simulated with L-shaped walls (4.5 m length for each wing) at all four building corners, both with and without 50×50 cm columns (Figure 1). Vertical openings with a constant height of 2 m were created for all studied buildings. These openings were created as a percentage of the wall surface area and positioned at the wall center. It should be noted that a previous study by the same author demonstrated that shear stress is lower when openings are offset [16]. The story height remained constant at 3.00 m throughout the study. ETABS was used for modeling the different structures. Three key parameters were investigated in this numerical analysis: shear wall thickness (15 cm, 20 cm, and 25 cm), building stories (N=4, 7, 11, and 15 stories), and opening percentage (15% to 50% in 5% increments). Additionally, control buildings equipped with L-shaped shear walls (both with and without columns) and without openings were used as reference cases for comparisons.

Figure 1. Horizontal section of simulated structures



(a) : Structure with column (b) : Structure without column

Sources: The author (2025).

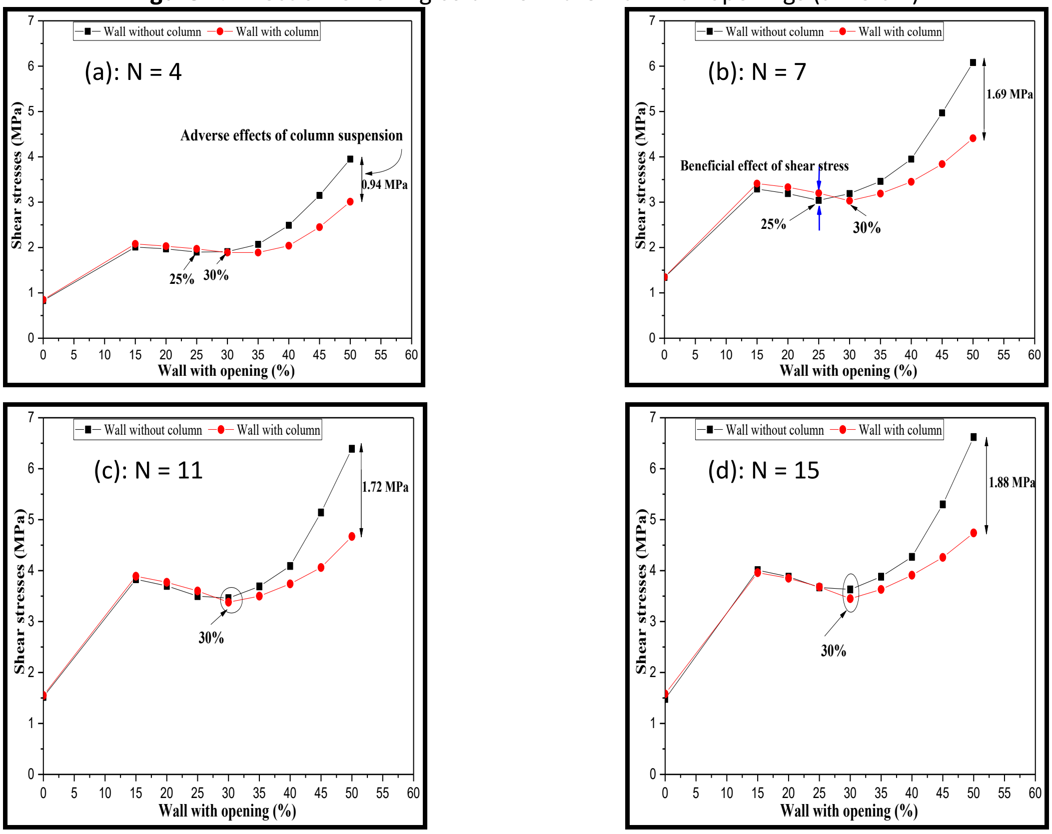
The studied residential buildings are in seismic zone III. According to Algerian seismic regulations (DTR B.C2-48, 1999/2003 version; DTR B.C2-48, 2024), this zone is classified as high seismicity. The site is categorized as S2 type, with characteristic response spectrum periods of T1=0.15 s and T2=0.40 s. The characteristic compressive strength of the concrete used is 25 MPa, a value commonly employed in local construction practice.

Analysis and Discussion of Results

This research primarily focuses on the simulation of buildings braced with L-shaped shear walls with and without openings, with and without columns. Subsequently, the concentration of maximum shear stresses in the shear walls was determined. The maximum stress in the walls with columns without openings was obtained at the intersection of the two wings of the walls, and their distribution was more uniform. The removal of columns did not produce any change in the point of concentration of maximum shear stresses, but it was concentrated in a reduced area. These results were confirmed by the authors Ahmed-Chaouch. Al. (2015). The incorporation of openings revealed that the distribution of maximum shear stresses shifts towards the boundary columns (piers) and lintels, affecting a larger surface area in both cases studied, with and without columns.

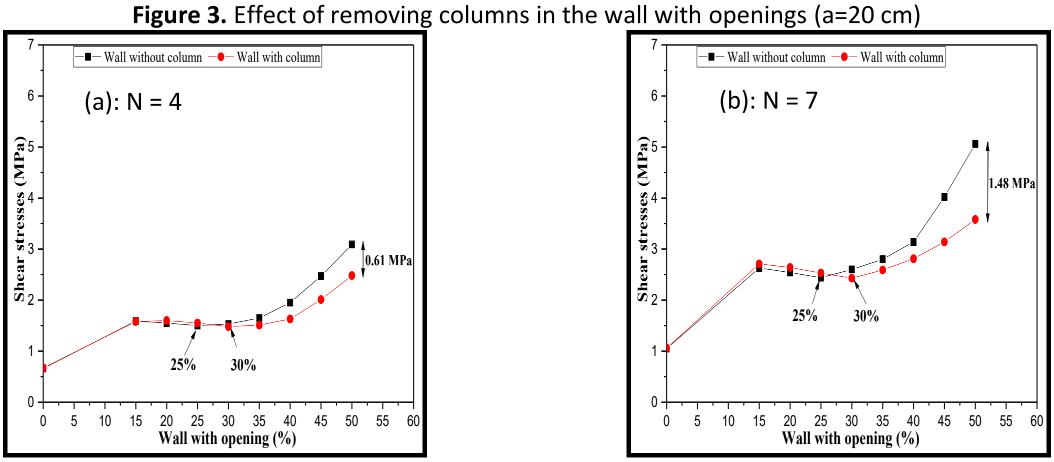
Figures 2, 3 and 4 illustrate the evolution of maximum shear stresses as a function of openings in the two wings of the L-shaped wall, ranging from 15% to 50% for the three thicknesses of 15cm, 20cm, and 25cm and buildings of 4, 7, 11, and 15 stories, including the case without openings. It is observed that the introduction of openings has a non-linear effect on shear stresses, which initially increase, then decrease to an optimal point, before increasing gradually thereafter, regardless of the wall thickness and number of stories. By comparing the different types of shear walls of buildings, it is clear that the shear stress increases when the opening rate exceeds 25% for walls without columns and 30% for walls with columns, despite the differences in thickness between the three types of walls studied and the number of stories. However, for buildings of 11 and 15 stories with a thickness of 15cm, the optimal stresses were obtained for a percentage of 30% for both walls, with and without columns. The removal of columns from the wall with openings below 25% had a beneficial effect on shear stresses, as shown in Figure 2b. However, it is worth noting that walls with columns were more beneficial beyond 30% openings in terms of shear stress. The gap between the stresses exerted on the shear walls increases with the increase in the number of stories but decreases with the increase in the thickness of the shear wall.

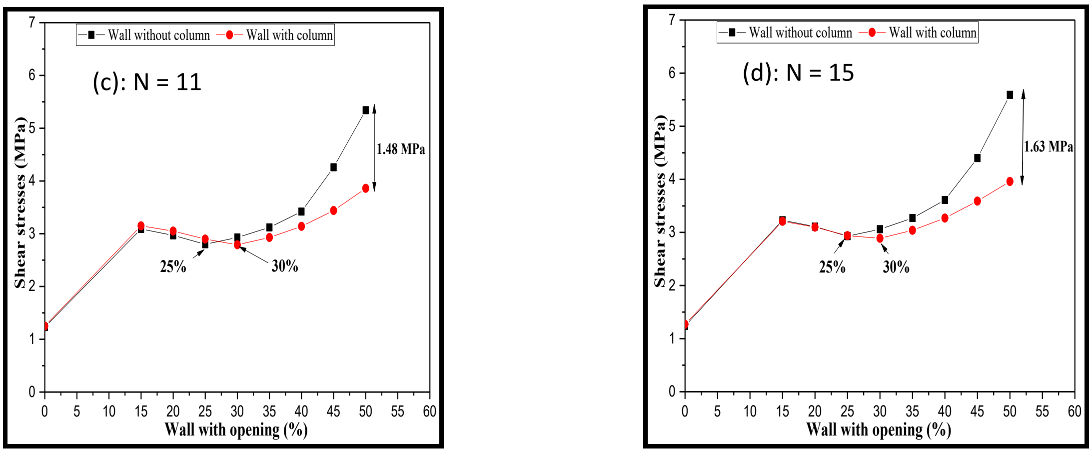
Figure 2. Effect of removing columns in the wall with openings (a=15 cm)



Sources: The author (2025).

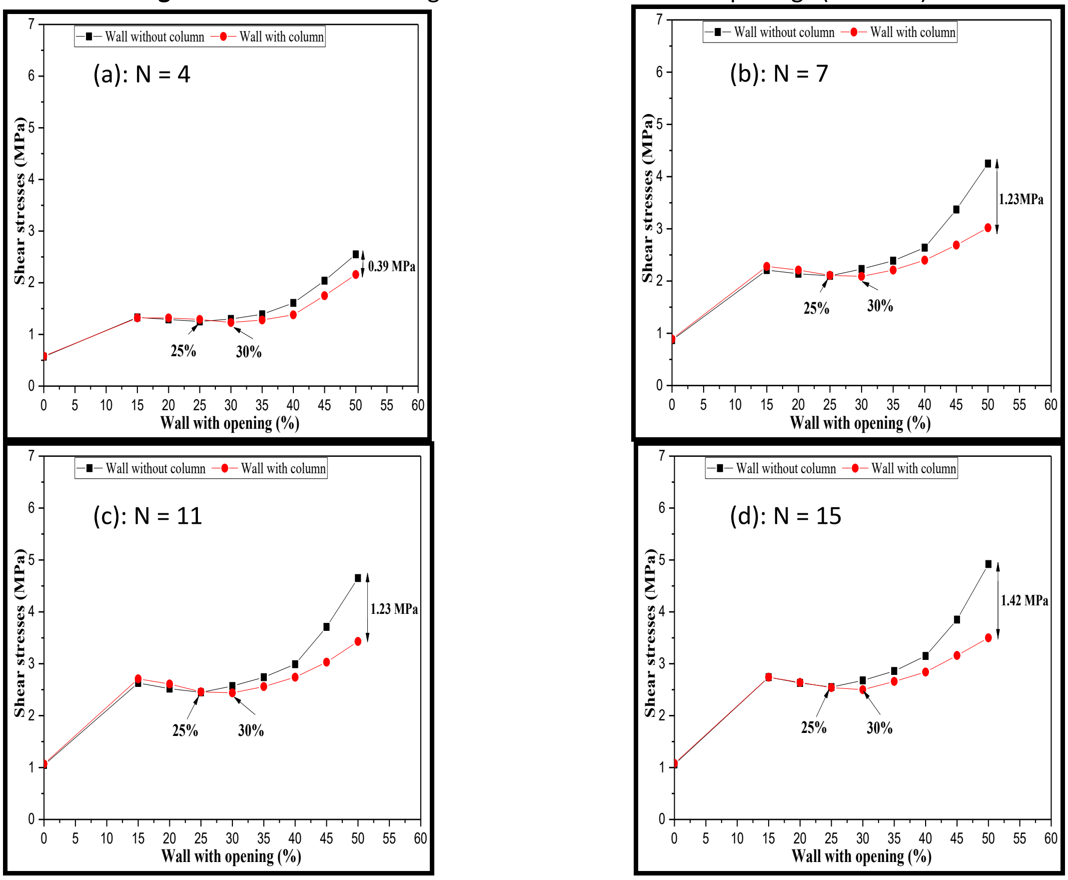
Figure 3. Effect of removing columns in the wall with openings (a=20 cm)





Sources: The author (2025).

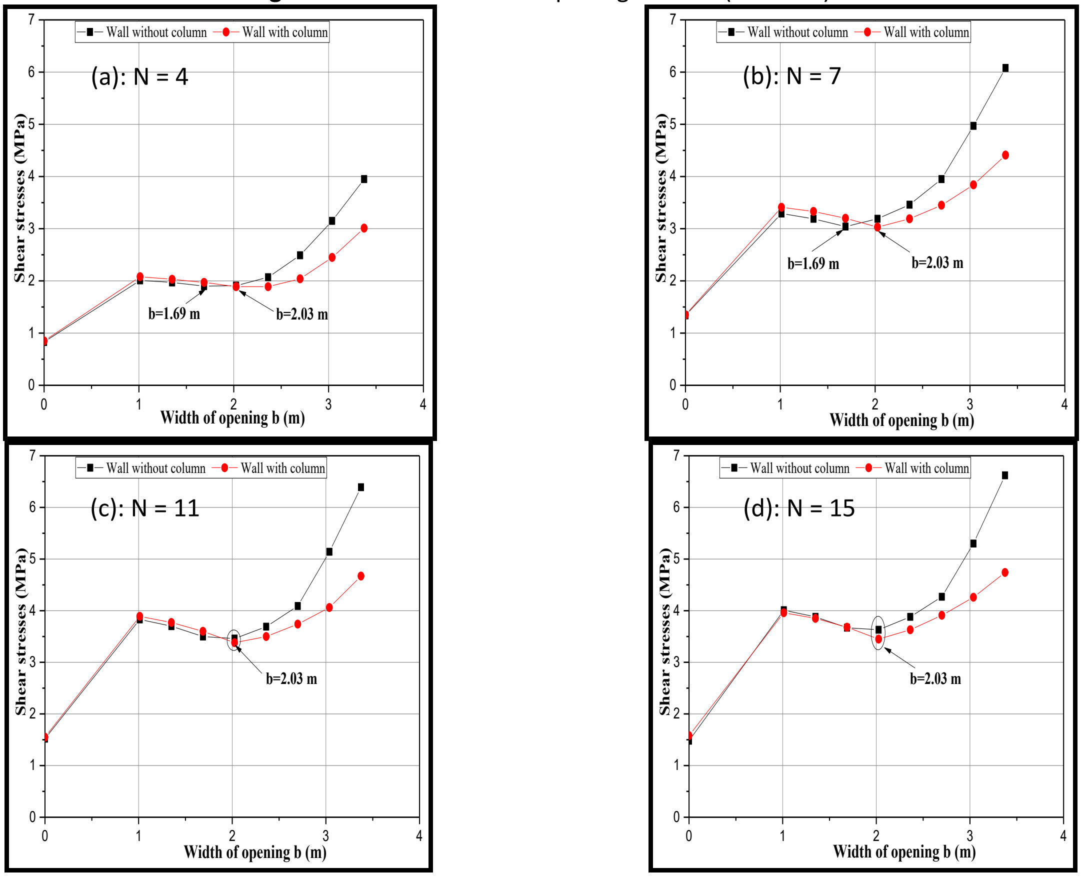
Figure 4. Effect of removing columns in the wall with openings (a=25 cm)



Sources: The author (2025).

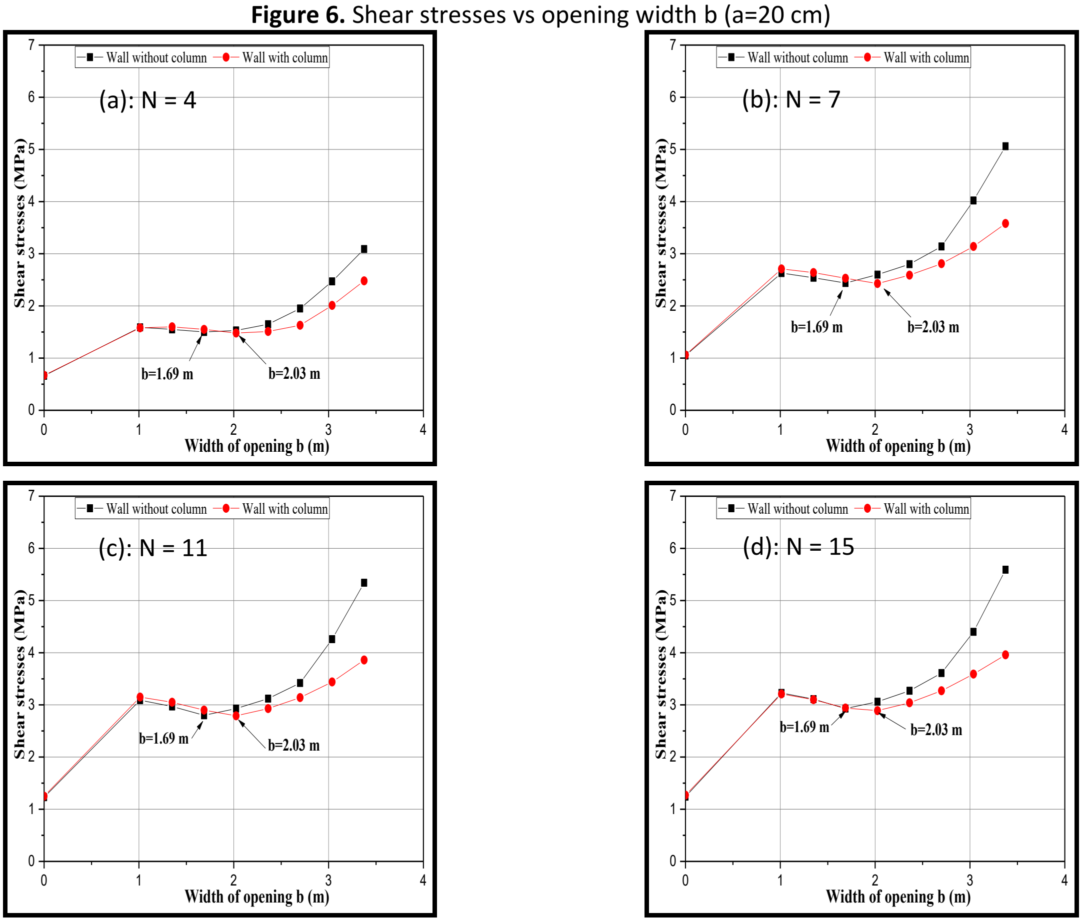
The curves of the evolution of shear stresses as a function of the width of the opening applied in the shear wall are represented in Figures 5, 6, and 7. The analysis of the results by step of evolution of the width of the openings in the wall without columns reveals that the optimal openings correspond to a width between 1 and 1.69m for walls without columns and between 1 and 2.03m for walls with columns. These values are valid for all the buildings analyzed and for walls of thickness 15cm, 20cm, and 25cm. However, for buildings of 11 and 15 stories with walls of 15cm thickness, the optimal value of shear stress is reached for an opening width of 2.03m. This indicates that buildings braced with walls without columns harm the opening rate in the shear walls. In fact, for the same shear stresses, buildings braced with shear walls with columns can have openings of width up to 2.03m. These numerical simulations allowed us to evaluate ratios between the height and width of the wall (h/b) of approximately 1 and 1.18 for walls with and without columns, respectively.

Figure 5. Shear stresses vs opening width b (a=15 cm)



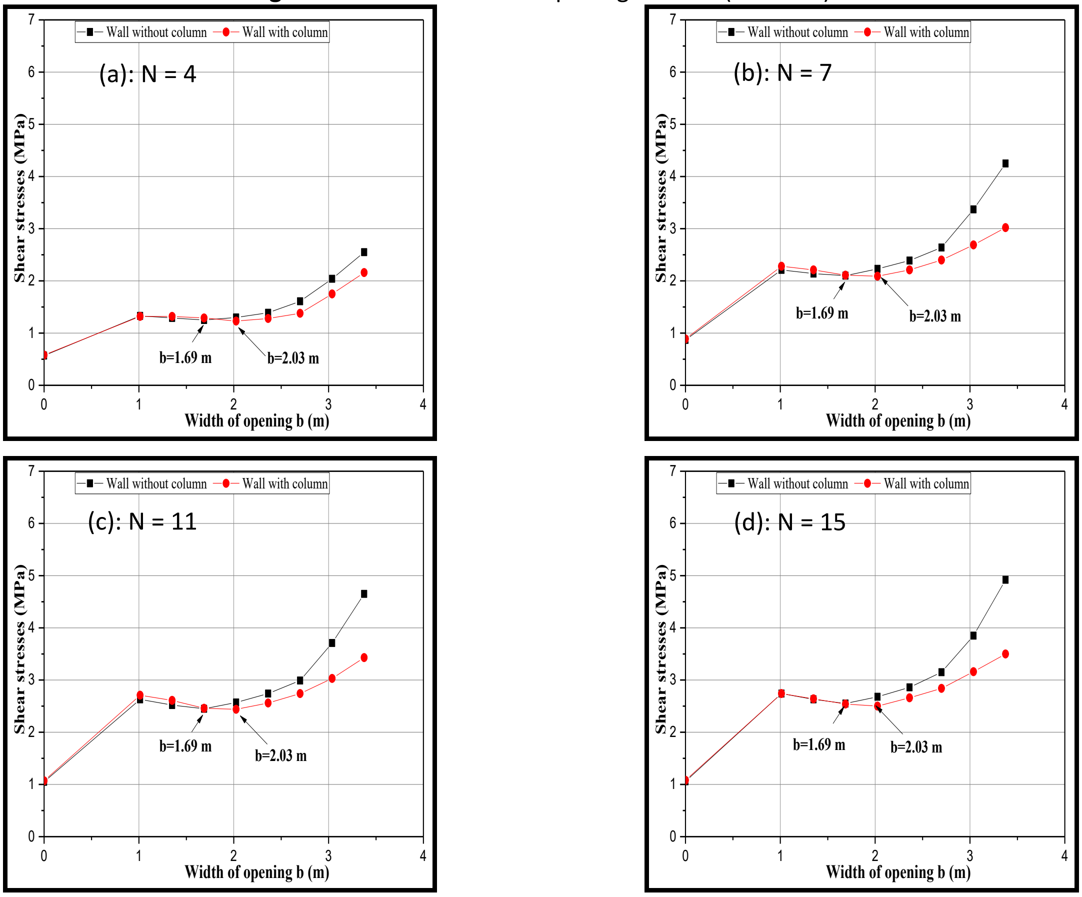
Sources: The author (2025).

Figure 6. Shear stresses vs opening width b (a=20 cm)



Sources: The author (2025).

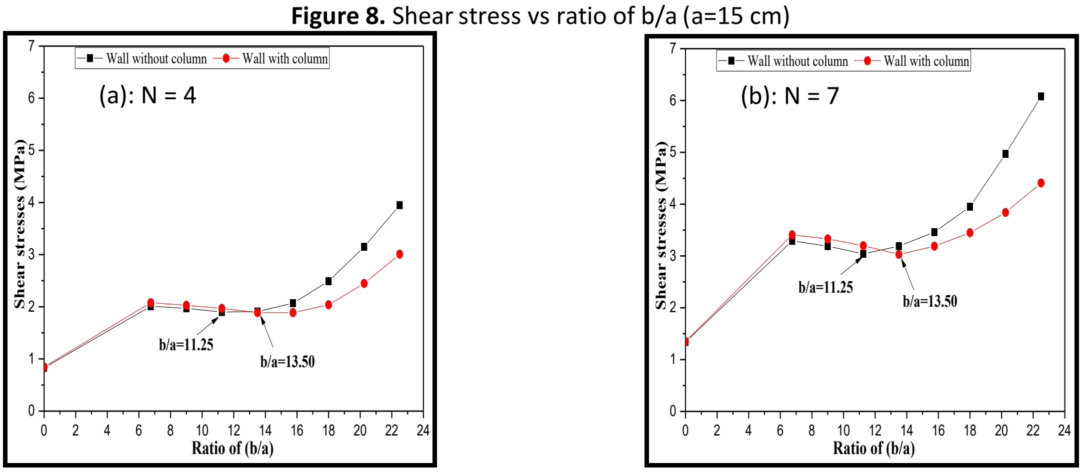
Figure 7. Shear stresses vs opening width b (a=25 cm)

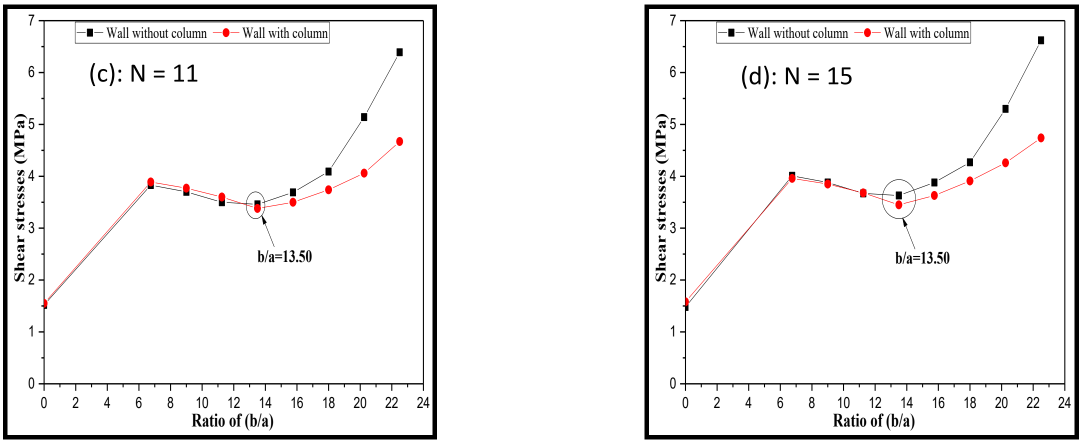


Sources: The author (2025).

The influence of the opening width (b) to wall thickness (a) ratio on the maximum shear stress was illustrated in Figures 8, 9, and 10. It was observed that the shear walls with a thickness of 15cm without columns recorded a ratio (b/a) of 11.25 for buildings of 4 and 7 stories. However, buildings of 11 and 15 stories gave a constant ratio of 13.50. The increase in wall thickness, according to Figures 9 and 10, was followed by a decrease in the (b/a) ratios. The optimal (b/a) ratio for the 20 cm thick wall was 8.44 for the shear wall without columns and 10.33 regardless of the number of stories (Figure 9).

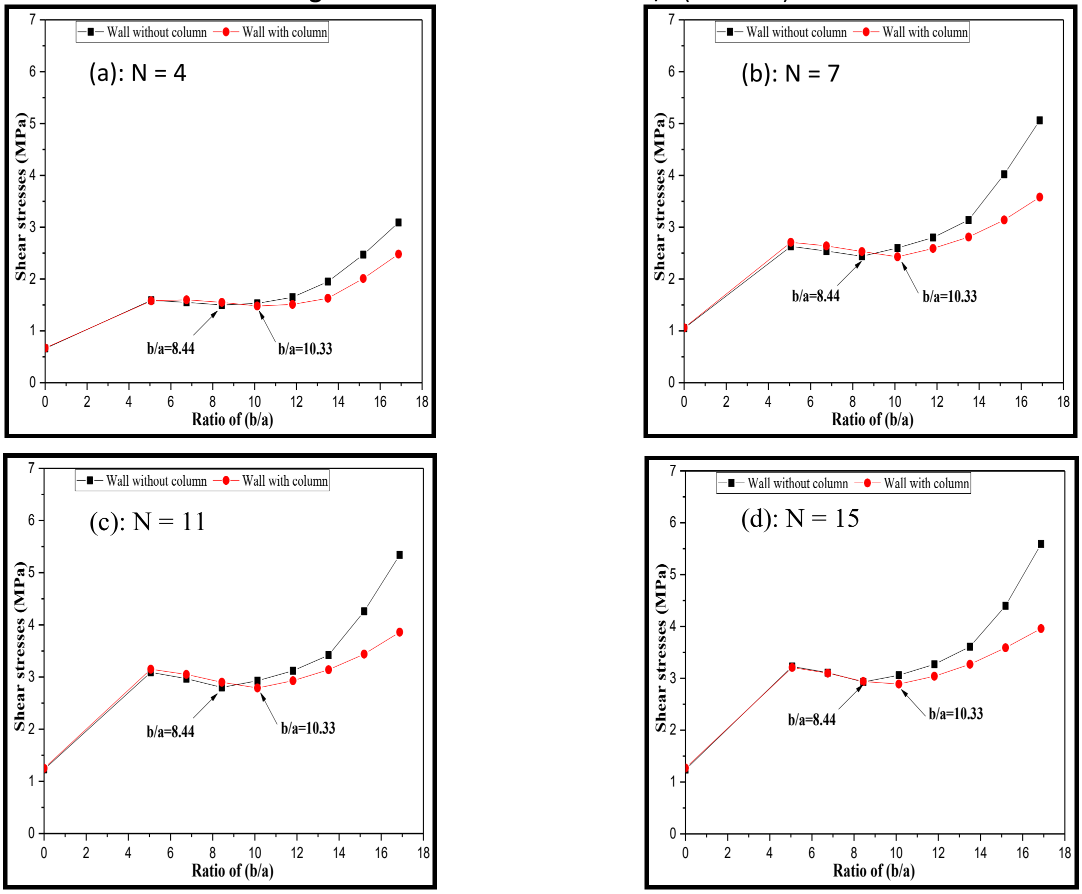
Figure 8. Shear stress vs ratio of b/a (a=15 cm)





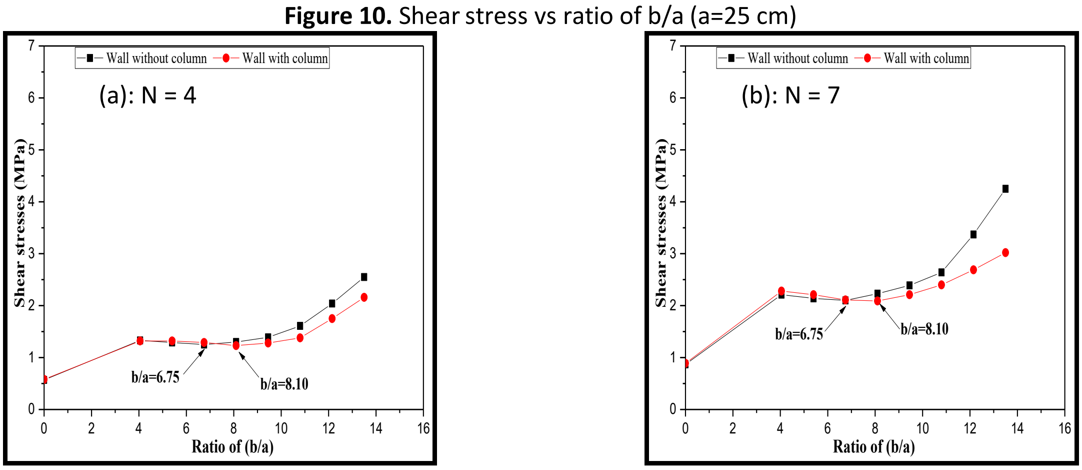
Sources: The author (2025).

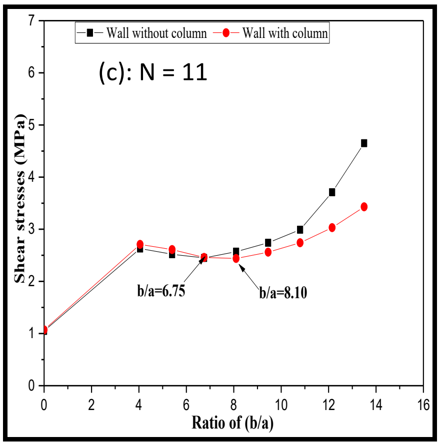
Figure 9. Shear stress vs ratio of b/a (a=20 cm)

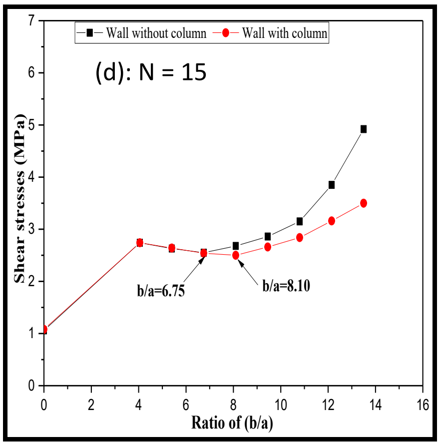


Sources: The author (2025).

Figure 10. Shear stress vs ratio of b/a (a=25 cm)







Sources: The author (2025)

The results of Figure 10 indicate that the (b/a) ratio of all buildings, regardless of their number of stories, improved with the introduction of a column at the intersection between the two wings of the shear wall. This improvement was attributed to the presence of this column, and the recorded (b/a) ratio was 8.10. While the walls without columns recorded a (b/a) ratio of 6.75.

CONCLUSIONS

This study highlights the critical importance of geometric configuration, the presence of columns, and the introduction of openings on the shear behavior of L-shaped reinforced concrete shear walls. A parametric analysis was conducted considering three main parameters: wall thickness, number of stories, and opening width. The results show that the location and magnitude of maximum shear stresses are highly sensitive to these parameters. Shear walls with columns exhibit a more uniform distribution of stresses and a greater tolerance to large openings, particularly when the opening ratio exceeds 30%. Conversely, walls without columns are less effective in reducing shear stresses when the opening ratio remains within the lower range (up to 25%).

Thicker walls contribute to reducing the (b/a) ratio, thereby enhancing mechanical performance. Moreover, introducing a column at the intersection of the two wings of the L-shaped wall proves beneficial, especially for high-rise buildings (11 and 15 stories), as it allows for opening widths of up to 2.03 m without compromising shear resistance. These findings underscore the need for careful optimization of wall configurations that balance architectural requirements (e.g., openings) with structural safety demands, particularly in seismic zones.

In summary, the numerical simulations carried out provide valuable guidance for the design of L-shaped shear walls, offering a framework to evaluate trade-offs between mechanical efficiency and functional needs. Future studies could include experimental validation and extended analysis under dynamic loading to further reinforce design recommendations for complex structural systems.

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