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INFLUENCE OF THE SUPPRESSION OF THE CORNER COLUMN ON THE COMPRESSIVE STRESSES OF L-SHAPED RC SHEAR WALLS

INFLUÊNCIA DA SUPRESSÃO DO PILAR DE CANTO NAS TENSÕES DE COMPRESSÃO DE PAREDES DE CORTINA EM FORMA DE L DE CONCRETO ARMADO

INFLUENCIA DE LA SUPRESIÓN DEL PILAR DE ESQUINA EN LAS TENSIONES DE COMPRESIÓN DE LOS MUROS DE CORTINA EN FORMA DE L DE HORMIGÓN ARMADO

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PALABRAS CLAVE: Edificios; Muros De Ccortante De Hormigón Armado; Aberturas; Supresión De Pilares; Esfuerzos De Compresión.

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ABSTRACT

Designing innovative, economical, and earthquake-resistant structures is a major concern for civil engineers. In this article, a comparison is made between the performance of columns in L-shaped shear walls in three different buildings subjected to a strong earthquake. Additionally, shear walls with centered openings of different sizes were also studied. The impact of column removal and opening size on compressive stresses was examined. The results revealed that the influence of column removal from the L-shaped shear wall on the compressive stress response during a high earthquake was relatively minor for the four-story building. However, the influence was significant for the seven- and eleven-story buildings, which were affected by the shear wall thickness and the percentage of opening. Specifically, when the eleven-story buildings are braced with 15-cm thick walls, the compressive stress difference reaches a value of 5.40 MPa. This stress difference becomes noticeable at an opening percentage of 30%.

RESUMO

Projetar estruturas inovadoras, econômicas e resistentes a terremotos é uma grande preocupação para os engenheiros civis. Neste artigo, é feita uma comparação entre o desempenho de colunas em paredes de cortina em forma de L em três edifícios diferentes submetidos a um terremoto forte. Além disso, também foram estudadas paredes de cortina com aberturas centrais de diferentes tamanhos. O impacto da remoção de colunas e do tamanho da abertura nas tensões de compressão foi examinado. Os resultados revelaram que a influência da remoção de colunas da parede de cortina em forma de L na resposta de tensão de compressão durante um terremoto forte foi relativamente menor para o prédio de quatro andares. No entanto, a influência foi significativa para os prédios de sete e onze andares, que foram afetados pela espessura da parede de cortina e pelo percentual de abertura. Especificamente, quando os prédios de onze andares são reforçados com paredes de 15 cm de espessura, a diferença de tensão de compressão atinge um valor de 5,40 MPa. Essa diferença de tensão se torna notável em um percentual de abertura de 30%.

RESUMEN

Diseñar estructuras innovadoras, económicas y resistentes a terremotos es una gran preocupación para los ingenieros civiles. En este artículo, se hace una comparación entre el rendimiento de las columnas en muros de cortina en forma de L en tres edificios diferentes sometidos a un terremoto fuerte. Además, también se estudiaron muros de cortina con aberturas centrales de diferentes tamaños. Se examinó el impacto de la eliminación de columnas y el tamaño de la abertura en las tensiones de compresión. Los resultados revelaron que la influencia de la eliminación de columnas del muro de cortina en forma de L en la respuesta de tensión de compresión durante un terremoto fuerte fue relativamente menor para el edificio de cuatro pisos. Sin embargo, la influencia fue significativa para los edificios de siete y once pisos, que fueron afectados por el grosor del muro de cortina y el porcentaje de abertura. Específicamente, cuando los edificios de once pisos están reforzados con muros de 15 cm de grosor, la diferencia de tensión de compresión alcanza un valor de 5,40 MPa. Esta diferencia de tensión se vuelve notable en un porcentaje de abertura del 30%.

1.INTRODUCTION

Reinforced concrete (RC) shear walls are key elements in the construction of high-rise buildings (Zhang et al., 2024; Ozkula et al., 2019; Khelladi et al., 2024). They play a crucial role in ensuring the safety and stability of the building, particularly when exposed to powerful horizontal forces such as earthquakes or strong winds (Ding et al. 2024; Merabti and Bezari., 2023; Zhao et al., 2019). These walls not only resist horizontal forces but also support vertical forces such as compression and tension, like load-bearing walls (Liang and Su., 2023). In the context of strong demand for housing, Algeria has experienced an expansion of existing cities and the creation of new construction sites in recent years. To meet these needs, high-rise buildings have been constructed and others are under construction (Merabti et al., 2022). To reduce the seismic risk associated with these constructions, a seismic code has been implemented (Cherifi et al., 2015). This code, or Algerian seismic regulation (RPA), recommends the use of reinforced concrete (RC) shear walls to resist seismic loads. These walls must withstand the total horizontal efforts induced by earthquakes, as well as 20% of additional vertical efforts (DTR-BC 2-48, 2003).

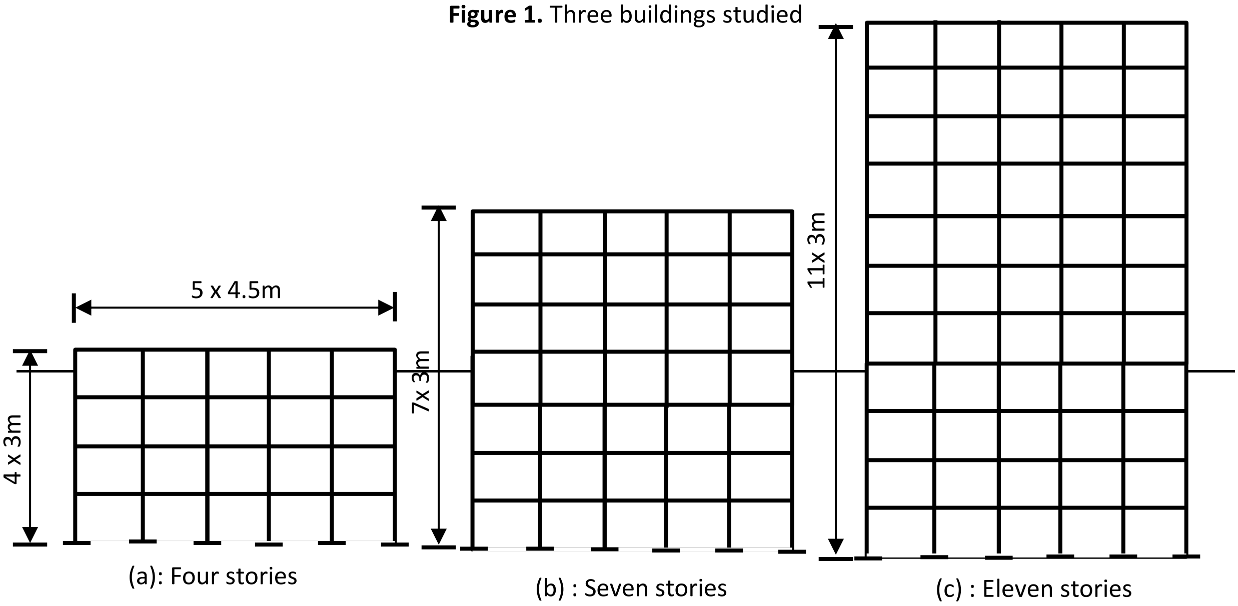
L-shaped shear walls are the most commonly used due to their seismic performance and architectural advantages (Ma et al., 2019; Liu et al., 2024). Consequently, numerous studies have been conducted, both theoretical and experimental (Chaouch et al., 2015; Merabti et al., 2023). To improve seismic resistance, Merabti and Guelmine found increasing the compressive strength of the L-shaped shear wall with openings up to 40 MPa (Merabti and Guelmine., 2024). The results show that the compressive and tensile stresses on the shear wall increase with the increase in the percentage of openings. However, the effect on shear stresses was negligible. Ahmed-Chaouch et al. (2016) proposed studying a braced structure with shear walls without openings, and the results show that the shear stresses concentrate at the intersection of the wall wings. However, when the walls have openings, the shear stresses shift towards the lintels and jambs (Lin and Kuo., 1988). The effect of the location of openings in shear walls has also been studied by researchers (Merabti et al., 2024). The results show that centered openings result in lower shear stress values, allowing for the design of larger openings in shear walls.

In this study, two types of L-shaped reinforced concrete (RC) shear walls were integrated into three buildings of different heights. The column was removed from the corner of one wall, while the other wall retained its column. Three thicknesses of shear walls with and without openings were tested. The effects of column removal, wall thickness, percentage of openings in the wall, and number of stories were analyzed to determine compressive stresses. A comparison of the two proposed walls was performed to provide practical guidance for structural designers.

2. BUILDINGS AND PROPOSED VARIABLES

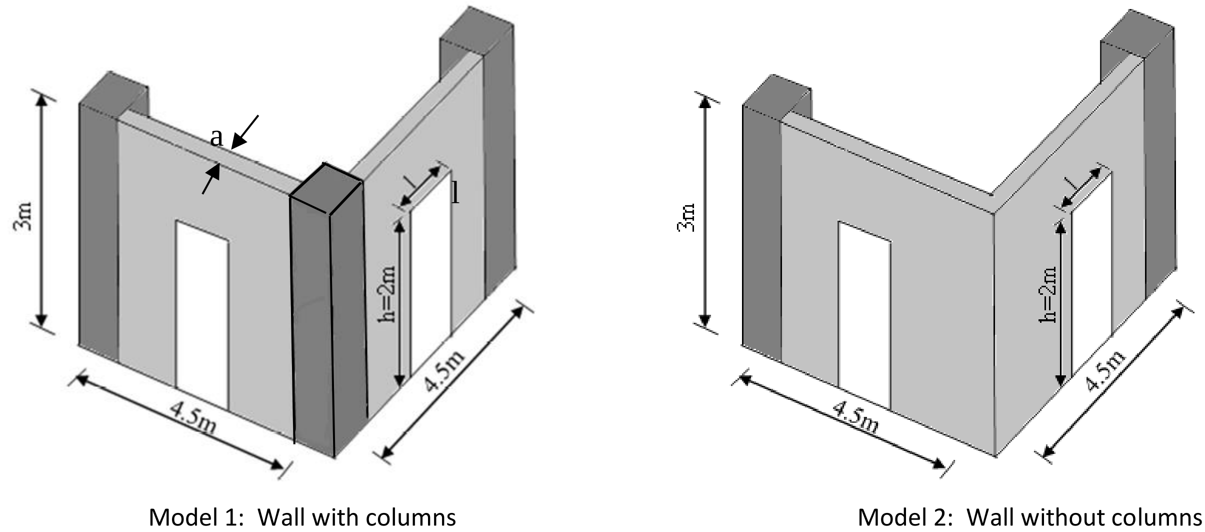
In this research, three different buildings were considered, which had the same length (5 x 4.5 m) and the same width (4 x 4.5 m) but different heights (see Fig. 1). These buildings were braced at the four corners with L-shaped shear walls used to resist horizontal loads due to earthquakes and vertical loads, including compressive stresses. The two models of shear walls are presented in Figure 2. The first wall model contains a column at the intersection of two wall wings, while the second wall has the column removed. In this work, centered openings were created at the levels of the shear walls to simulate the effects of different opening configurations on the compressive stress of the walls. Indeed, variable opening proportions were applied to the shear walls for these three buildings, namely 15%, 20%, 30%, 35%, 40%, 45%, and 50%. All opening heights were fixed at 2 m, while the opening width was variable depending on the percentage of opening. Twenty-seven (27) buildings were analyzed numerically for each type of building. The thicknesses of the shear walls of 15 cm, 20 cm, and 25 cm were also used for each type of building. All buildings were located in a high seismicity zone (zone III) on soft soil (S3) according to the RPA 99/2003 seismic regulation (DTR-BC 2-48, 2003).

Figure 1. Three buildings studied



Sources: The author (2024).

Figure 2. Models of L-shaped shear walls



Sources: The author (2024).

The combinations of actions to be considered, according to the Algerian seismic regulation RPA99/2003 [10], for the determination of loads and deformations are:

$G + Q \pm E$ (1)

$0.8G \pm E$ (2)

According to the design and calculation rules for reinforced concrete structures CBA 93 [19], the two combinations used were:

$1.35G + 1.5Q$ (3)

$G + Q$ (4)

With:
G: Permanent loads,
Q: Live loads,
E: Seismic action.

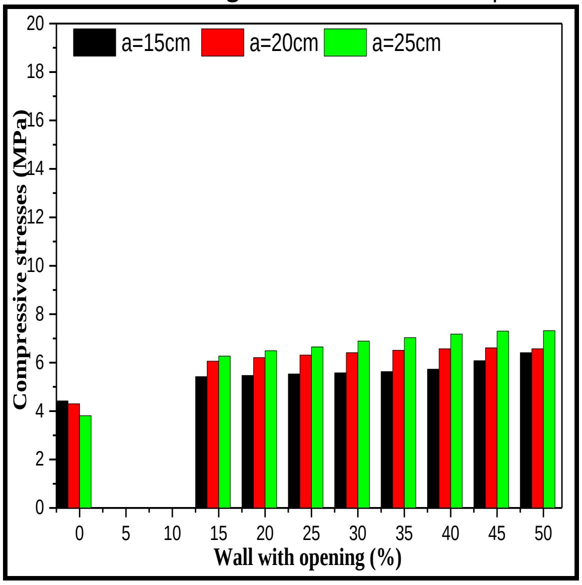
The concrete is defined by its characteristic compressive strength at 28 days, denoted as fc28. During this research work, the compressive strength at 28 days (fc28) of the concrete is set to 25 MPa, and the allowable stresses are calculated using the formula (5).

$\sigma_{bc} = 0.6\ fc28$ (5)

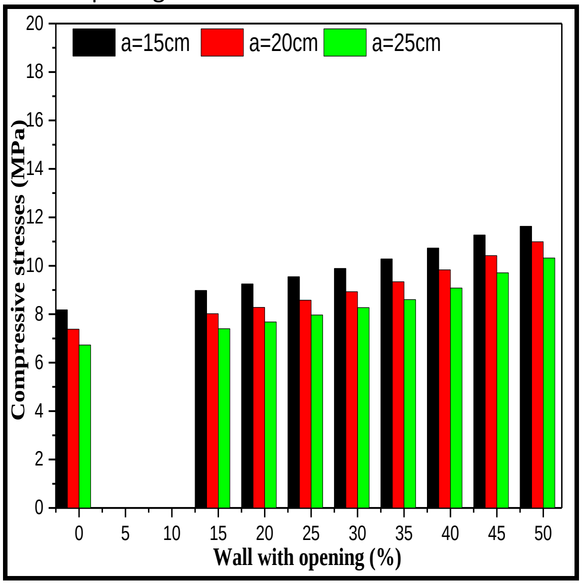
3. RESULTS AND DISCUSSION

The histograms representing the maximum compressive stresses in the shear wall of Model 1 as a function of the percentage of openings are presented in Figure 2(a), (b), and (c). These histograms highlight an increase in compressive stresses with the number of stories and percentage of openings. For the 4-story building, it was found that increasing the wall thickness results in an increase in compressive stresses. In contrast, the N=7 and N=11 buildings exhibit lower compressive stress results with increasing wall thickness. Notably, the increase in compressive stresses of the three wall thicknesses is less pronounced with the increasing number of levels. The N=4 building records a more significant increase in compressive stresses. The shear walls without openings to 50% opening of the N=4 building show values of 45.02%, 52.79%, and 92.13% for wall thicknesses of 15 cm, 20 cm, and 25 cm, respectively.

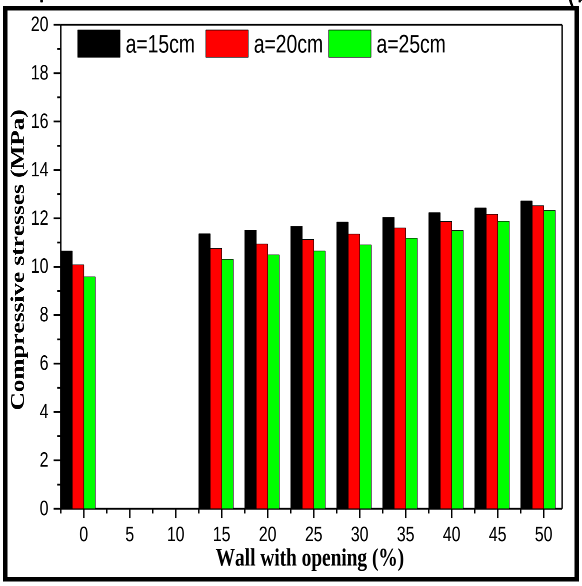
Figure 3. Evolution of compressive stresses vs openings: case of Model 1



(a): N = 4



(b): N = 7



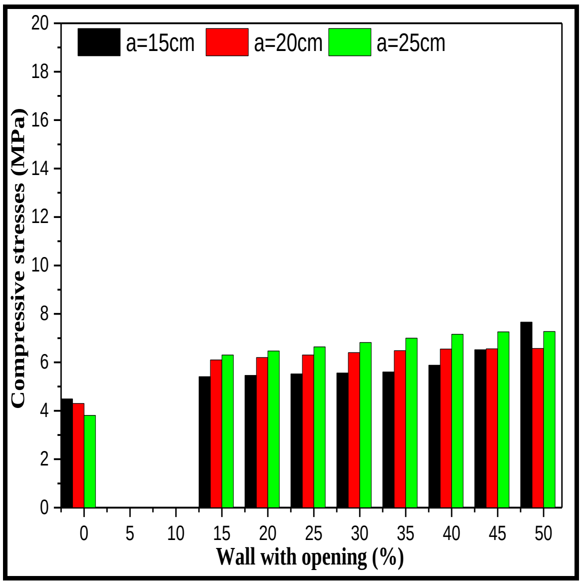
(c): N = 11

Sources: Author (2024).

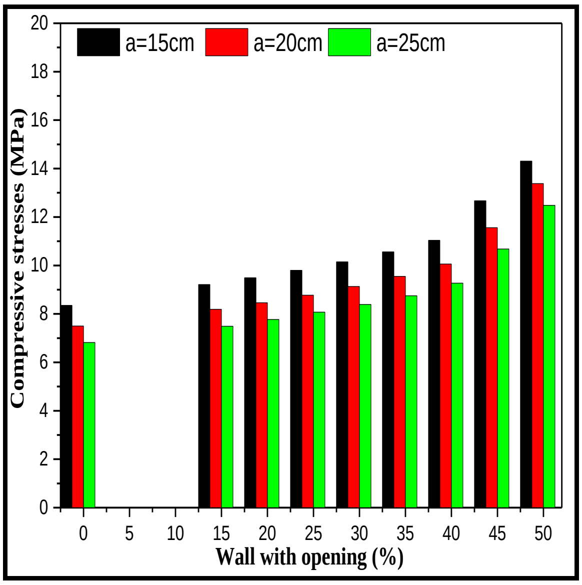
The results of the compressive stresses for Model 2 for the three buildings are presented in Figures 4(a), (b), and (c). These stresses were obtained for three buildings and three shear wall thicknesses. Figure 4(c) also includes the maximum allowable compressive stress of the concrete determined by Formula 5. Based on the results obtained, it is observed that the distribution pattern of compressive stresses for Model 2 is similar to that of Model 1. However, the increase in maximum compressive stresses in the walls without a column with a thickness of 25 cm between 0% and 50% opening for the N=4 building is significant, reaching 90.81%. The N=7 building records a maximum increase in compressive stresses of 71.38% and 78.40% for the 15 cm and 20 cm thicknesses, respectively. This suggests that the increase in compressive stresses for Model 2 is not directly related to the number of stories.

The results also show that the N=11 building records compressive stress higher than the allowable compressive stress, which is 15 MPa (Fig. 4(c)). This implies that the maximum accepted openings for the N=11 building are 40% for the 15 cm and 20 cm thicknesses. In contrast, the maximum accepted opening percentage for a building braced with 25 cm thick walls is 45%. According to this study, it appears that the removal of the column in the L-shaped shear walls (Model 2) decreases the opening percentage, which is an important consideration when applying this shear wall model.

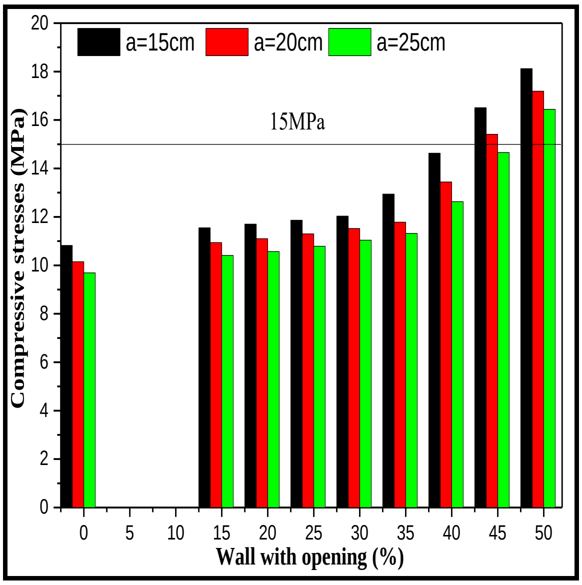
Figure. 4. Evolution of compressive stresses vs openings: case of Model 2



(a): N = 4



(b): N = 7

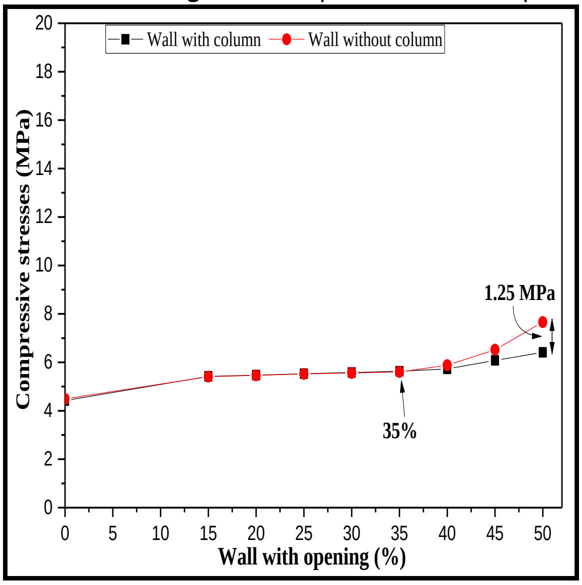


(c): N = 11

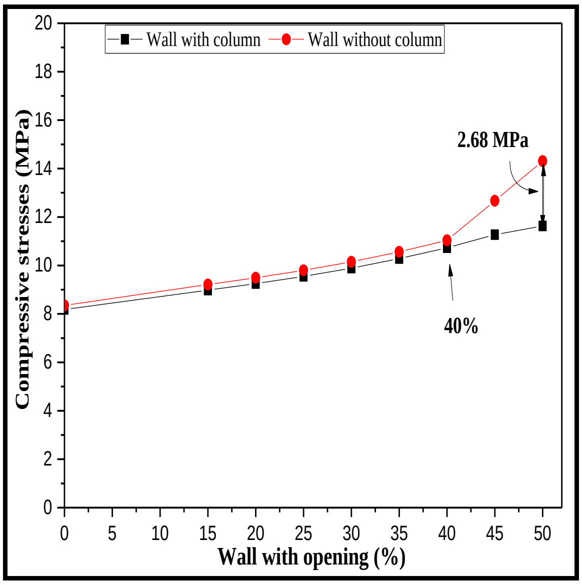
Sources: Author (2024).

The primary objective of this study was to compare the compressive stresses of two L-shaped shear wall models. The results obtained for the two walls are presented in Figures 5, 6, and 7. The building-by-building analysis shows a superiority of compressive stresses for Model 2. This superiority is affected by the introduction of openings in the shear walls, the wall thickness, and the number of stories. However, for the N=4 building, equipped with walls of Models 1 and 2 with respective thicknesses of 20 cm and 25 cm, no significant difference in compressive stresses was observed (See Figures 6(a) and 7(a)). Overall, it is observed that increasing the wall thickness increases the opening percentage of buildings braced with Model 2 walls. On the other hand, the number of stories has a contrary effect, as shown in Figures 5(c), 6(c), and 7(c). However, the N=7 and N=11 buildings record the same opening percentages for the 20 cm and 25 cm thicknesses. Furthermore, it is observed that the compressive stress difference is higher with the increase in the number of stories, and this difference decreases with the increase in the thickness of the shear wall.

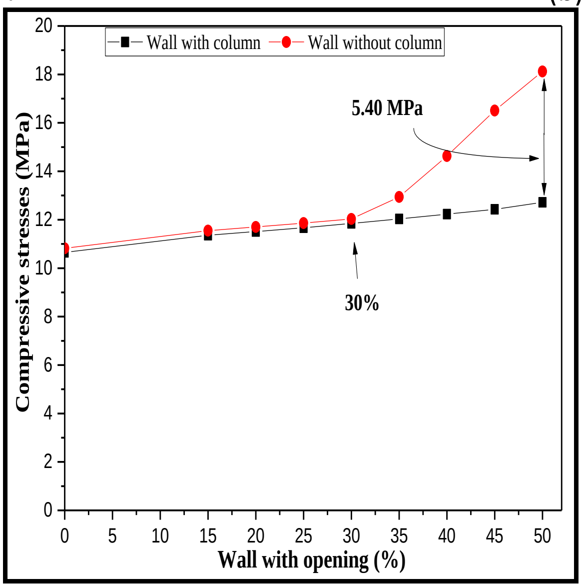
Figure 5. Comparison of the compressive stresses of two models: case of a=15cm



(a): N = 4



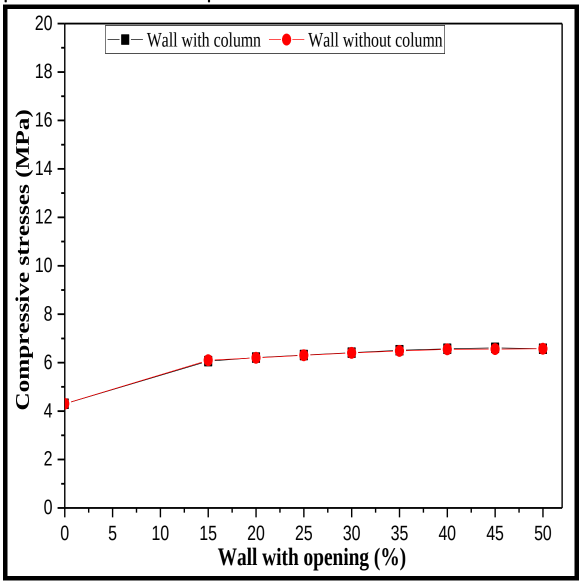
(b): N = 7



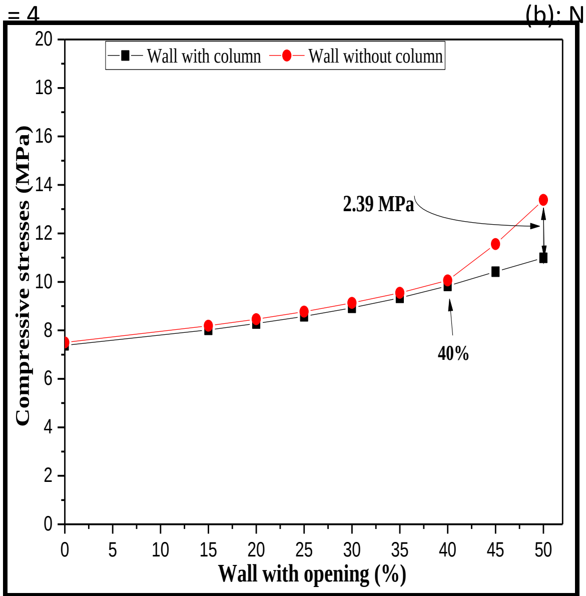
(c): N = 11

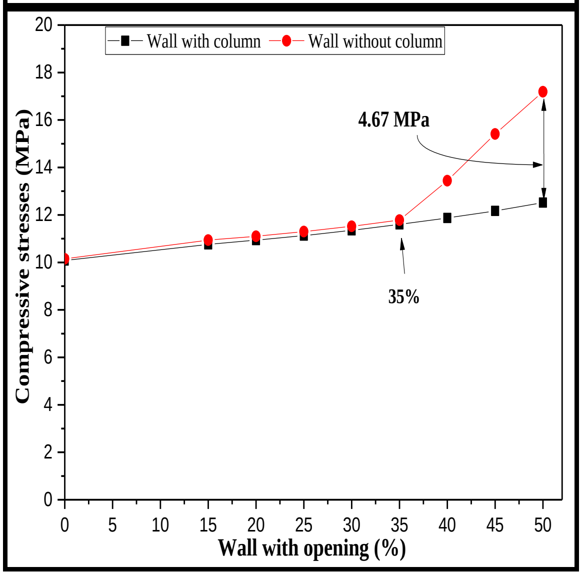
Sources: Author (2024).

Figure 6. Comparison of the compressive stresses of two models: case of a=20cm



(a): N = 4 (b): N = 7

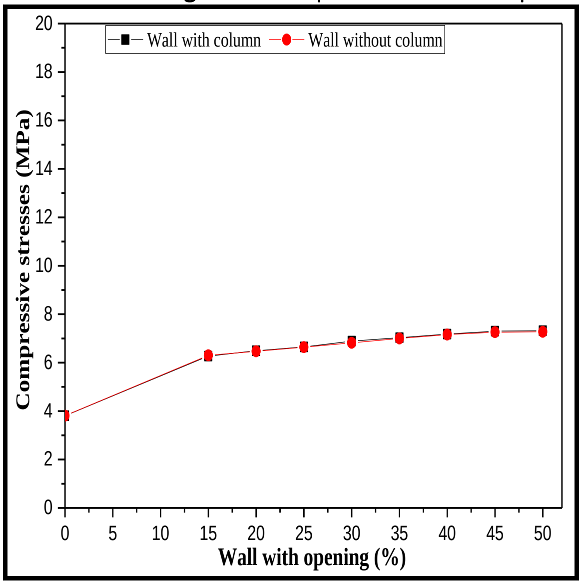




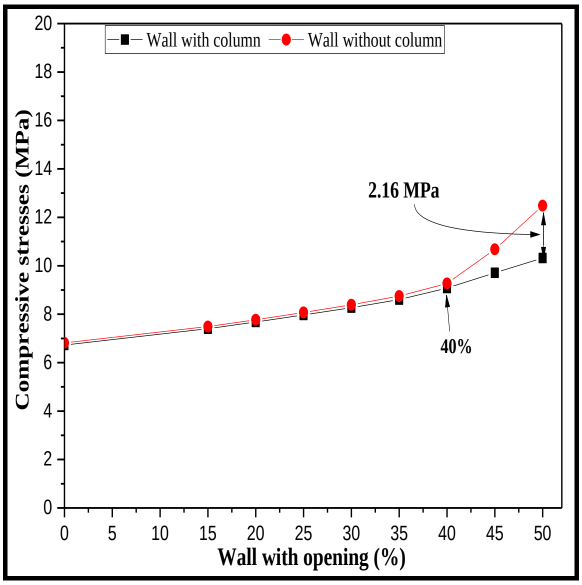
(c): N = 11

Sources: Author (2024)

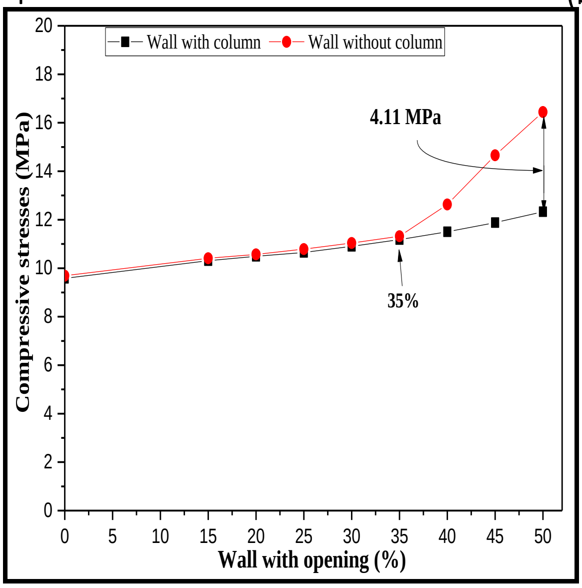
Figure 7. Comparison of the compressive stresses of two models: case of a=25cm.



(a): N = 4



(b): N = 7



(c): N = 11

Sources: Author (2024)

4. CONCLUSIONS

This article presents the compressive stresses of L-shaped walls of three different thicknesses for three types of buildings of varying heights. The focus was on the removal of the column from the wall and its comparison with the wall with a column, which was the main objective of the study. The following results highlight the main findings of this study.

- The removal of the column from the shear wall tends to increase the compressive stresses, which reduces the opening percentage, particularly for the 15cm thick shear wall.
- The openings in the two wall models of the N=4 building have no impact on the compressive stresses. Further investigations are needed to explore other types of stresses, such as shear stresses, to gain a more comprehensive understanding of the behavior of the wall without a column.
- The compressive stress is influenced by the opening percentages in the two wall models. When the opening percentage is optimal, the compressive stresses are approximately

identical. However, when the opening rate exceeds the optimal percentage, the compressive stresses increase exponentially with the increase in the number of stories and the decrease in the thickness of the shear wall.

The innovative approach presented provides useful recommendations for civil engineers, but further investigations are needed to deepen and enrich this study.

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