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Enhancing Masonry Construction: Investigating the Impact of Mortar Thickness and Steel Fiber Reinforcement on Strength and Durability

Ahmed Hussein Ajei[1] and Amir Houshang Akhaveissy[1,*]
[1]Department of Civil Engineering, Faculty Engineering, Razi University, Kermanshah, Postcode: 67189–58894, Iran.
*** Corresponding author:**
A.H. Akhaveissy, E-mail: Ahakhaveissy@razi.ac.ir

Abstract

This study investigates the potential efficacy of incorporating steel fibers into cement mortar to reinforce masonry walls. The approach focused on the influence of height-to-length ratio, which was interpreted and administered through methodologies of material selection, testing, and experimental setup. Two locally manufactured bond bricks and cement mortar in brick laying were the prime materials selected for experimentation. Two formulations (one without and the second with steel fibers) of cement mortar were employed. The mixing ratio for both materials groups was 1 part cement to 3 parts sand during the experimental testing phase, while the steel fibers were mixed in the second group at a ratio of 0.2 by volume. A total of twelve samples were tested, first to compare the compressive behavior of locally manufactured bricks and cement mortar samples without and second with steel fibers, and subsequently to explore the impact of height-to-length ratio and mortar thickness on wall model behavior. Compressive strength and deflection of the samples were compared. The results revealed that the compressive strength of the masonry doubled and the deflection was halved by the introduction of steel fibers into the mortar, and a direct proportionality was observed between the height-to-length ratio and the strength of the masonry, with the strength robustness increasing and the deflection by the walls decreasing for its higher vertical to horizontal elements, and significant enhancement of the capacity to withstand load by the masonry, with the strength sometimes exceeding double, by the entrainment of steel fibers in the mortar, and the consequential deformation decreased by them, pointing to the importance of steel fiber reinforcement in cement mortar for brick walls, especially for strengthening existing structures, signalling the need for a detailed exploration of its axial flexural, shear, and impact resistance. Finally, a numerical model was built using the ABAQUS and the results obtained were matched between the numerical model and the experimental study we conducted, and the results were identical.

Keywords*:* Centrifugal pump; Impeller blades; Helical diffuser; Movable energy; Centrifugal pump efficiency.

1. Introduction

The most important characteristic of masonry construction is its simplicity. Laying pieces of stone, bricks, or blocks on top of each other, either with or without cohesion via mortar, is a simple, though adequate, technique that has been successfully used ever since remote ages. Naturally, innumerable variations of masonry materials, techniques, and applications occurred over time. The first masonry material to be used was probably stone [1]. Masonry wall construction has a number of advantages, the first of which is the fact that a single element can fulfil several functions, including structure, fire protection, thermal and sound insulation, weather protection, and sub-division of space. The second major advantage relates to the durability of the materials, which, with appropriate selection, may be expected to remain serviceable for many decades, if not centuries, with relatively little maintenance. Complex wall arrangements, including curved walls, are readily built without the need for expensive and wasteful formwork [2].

The fire resistance inherent to masonry materials depends on the careful construction of the building. Masonry structures fall into two types. The first components consist of brick units. The second components consist of Portland cement mortar which is used to interconnect the brick units and fill the interstitial spaces. Thus, the resulting resistance is the product of 3 resistances: an initial resistance of the brick units, a second resistance of the mortar, and a third resistance of the interlocking of the brick units [3]. An ancient method of manufacturing brick, in which relatively moist clay was pressed into simple rectangular moulds by hand, dating back to 6000 BC is called the soft mud process. The moulds may be dipped in water immediately before being filled to keep the sticky clay from adhering to them, producing brick with a relatively smooth, dense, surface know as water struck brick [4]

The units and mortar can have significantly different mechanical properties such as stiffness and Poisson's ratios. Stiffness is the material's capability to resist deformation under load, and Poisson's ratio is the ratio of transverse strain to axial strain when a material is stretched or compressed. When there are significant differences in these properties between the units and mortar, the system can develop significantly larger stress concentrations, load distribution can be quite non-uniform and premature masonry failure is expected [5-6].

The mortar contained cement, sand, and fillers, that may be waste materials. Another possible use of both masonry rubble and waste fine material might be in mortars, that could contain instead of natural sand also recycled sand, or instead of also powder obtained by brick grinding, as partial cement substitution [7]. The mortar was necessary to bond the bricks unit together. The mortar was subjected to tensile forces and compression forces, and its properties could be bettered by adding steel fibre to it. Currently in the world, there were some 30 major producers of steel fibres for modifying concrete, and these companies offered over one hundred different types of fibre [8]. These steel fibres had circular, square, rectangular, or irregular cross sections, and each of the types was further varied by diameter and length [9]. The compressive strength of concrete block masonry varied greatly depending on the type of mortar, block, and mortar bedding. Zahra et al. [10] observed that masonry specimens made with cement-lime mortar exhibited higher compressive strength than the specimens made with cement mortar. Nwofor's pioneering study leaves no doubt about the paramount importance of informed decision-making regarding the water/cement ratio in mortar joints- owing to its direct impact on the long-term performance and durability of blockwork structures, effectively shielding them from the deleterious consequences of moisture penetration and environmental deterioration [11].

Unreinforced masonry (URM) structures are known to fail abruptly and in a brittle manner under seismic loading, posing a grave risk to life and property. Fiber-Reinforced Polymers (FRP) have drawn attention as a viable reinforcement material for masonry structures due to their high strength-to weight ratio and corrosion resistance. Osmanzadeh et al. [12] conducted a study in which they demonstrated the tremendous improvement in the seismic performance of URM walls reinforced with FRP laminates, including increased ductility and enhanced energy dissipation capacity. Arslan et al. [13] carried out a study concluding that URM walls retrofitted with steel bars experienced an increase in both strength and ductility, thereby reducing the likelihood of brittle failure under seismic loading. Epoxy injection was evaluated as a retrofitting measure for URM walls in a study conducted by Bagheri et al. [14] and was shown to not only enhance the overall structural performance but also to reduce the vulnerability of such walls to abrupt failure. Numerous experimental studies have been performed to assess the effectiveness of various reinforcement strategies for URM structures under seismic loading.

Despite the significant advancement in masonry reinforcement over the last few decades, there are several research gaps. Among these gaps is the need for comprehensive guidelines on how to design and implement reinforcement schemes that are specifically tailored to different masonry wall configurations and seismic hazard levels. The lack of knowledge on the long-term durability and sustainability of the reinforcement materials, whose deterioration due to environmental exposure and time is currently unknown, would also benefit from further research. Undertaking research on the use of steel fibres in masonry mortars was therefore crucial to: fully understand and optimise the benefits of this material; provide the scientific evidence to support the development of appropriate design guidelines and construction practices that would ensure the effective and safe implementation of this reinforcement technique; and contribute to the development of more resilient, durable and sustainable masonry construction. In the current study, the author aimed to investigate; the Influence of the mortar thickness on the strength of masonry resistance, the Influence of the presence of a percentage of steel fibers in the mortar on the strength and durability of masonry resistance, and the Influence of the ratio height/length on the strength and durability of masonry resistance.

2. Experimental setup

The testing procedure was carried out using technical equipment appropriate for the taking of specific measurements. To test for compressive strength, a device manufactured in Turkey with a 1800 KN capacity and accuracy to 0.01 KN was used. It is calibrated by the Iraqi Standardization and Quality Control Device, allowing for auto speed traveling with manual speed control, and set to 14 Newton/mm2 in accordance with the 1988 Iraqi standard for the bricks. For testing of tensile strength, another Turkish device, with 50 KN capacity and accuracy to 0.001 KN, was utilized. Speed was adjusted to a modulated speed of 1.27 Newton/mm2 in accordance with the Iraqi standard. Finally, a device for tensile and compressive strength of beams was used, manufactured in India with 600 KN capacity and accuracy to 0.01 KN, and calibrated by the Iraqi Standardization and Quality Control Device. The device applies rules of standards and allowed for control of the speed in accordance with the required setting. Fig. 1 displays the devices employed in the current study.

3. Methodology

The methodology included in this study involves several steps such as material selection, method of testing and experimental set-up. The study mostly concentrates on the compressive behaviour of bricks and cement mortar samples of locally manufactured bricks with and without steel fibres. Additionally, it studies the effect of height to length ratio and thickness of cement mortar on the overall behaviour of the wall models.

Cement mortar was used as the binding agent in the brick laying process, with and without steel fibers. From trials, cement mortar surfaced as the cohesive substance that gracefully connected the bricks and formed buildings with remarkable strength. The choice of cement mortar was therefore critical. It needed to strike the balance between strength, durability, and cost effectiveness. As a result of this, two different types of mortar were formulated. The first type of mortar was comprised of cement and sand, whereas the second, incorporated steel fibers. The group for which steel fiber mortar was considered, used 1 cement: 3 sands for the mixing ratio of the cement mortar. The mixing ratio was the same for both groups during the testing phase. The mix of the second group included the steel fibers at a mix of 0.2.

(a) **(b)**

(c)

Fig. 1: Equipment employed in the current study (a) Compressive strength testing device, (b) Tensile strength testing device, and (c) Device for checking the tensile and compressive strength of beams.

3.1 Material selection

Locally manufactured bricks were chosen as the primary building material for constructing the wall models. These bricks, crafted with precision and expertise by local artisans, embody not only the essence of traditional craftsmanship but also ensure a sustainable approach to construction, minimizing environmental impact through reduced transportation requirements. The second component that was tested on was the cement mortar. Twelve samples of the cement mortar were approved and divided into two groups. The first without the use of additives contains six samples, from which three cubes were poured to test them under pressure, as well as three prisms to test them under the influence of tension by splitting. The mixing ratio was approved as 1 cement. : 3 sand without any other addition. As for the second group, it is the same as the first group, but it differed in the mixing ratio, as steel fibers were added, and the mixing ratios were as follows: 1 cement: 3 sands: 0.2steel fibers. Figure 2 represents selection material and prepare samples.

Fig. 2: Selection material and prepare samples.

To study the effect of the ratio of height to length, we chose two ratios. (0.25,0.5) H/L. The effect of the thickness of the cement mortar was also tested, as three values for the thickness of the cement mortar were used (5, 12, and 25 mm). These two cases were tested for the absence of steel fibres as well as the presence of steel fibres in the cement mortar. In order to obtain results, twelve samples were prepared from the wall built from cement mortar and bricks. The samples that were studied are shown Table (1).

Table 1: Samples of masonry wall

#	**H/L**	**Mortar thickness(mm)**	
		Without Fiber	**With Fiber**
1	0.25	5	5
		12	12
		25	25
2	0.5	5	5
		12	12
		25	25

The specimens that are prepared for the tests are shown in Figure 3. The wall is composed of two brick columns that overlap in a three-dimensional wall model. A total of 12 samples were produced using mortar and brick prepared with and without fiber (Figure 4). Table 2 shows samples with & without Steel Fiber. In total, 28 days were required after the casting of the 12 samples and then stored according to standard practices as shown in Figure 5.

Fig. 3: The model to be tested.

Table 2: Samples With & Without Steel Fiber

No	H/L ratio	Length (cm)	Height (cm)	Mortar thickness (mm)
1	0.25	46	11.5	5
2	0.25	52	13	12
3	0.25	62	15.5	25
4	0.5	23	11.5	5
5	0.5	25.5	13	12
6	0.5	31	15.5	25

Fig. 4: Preparing samples with & without Steel Fiber

3.2 Testing of brick samples

Bricks, as elementary building materials, are subjected to a battery of structural testing to determine their fitness for construction. Among the bricks-testing methodologies, compression testing and tensile testing are vital, as they reveal key mechanical properties of the material; these properties are relied on by engineers, architects and builders in the development of safe and endurable structures. A compression test subjects a brick sample to an axial load that is applied perpendicular to the plane of the face of the test piece and determines the bricks ability to resist this load. The resulting compressive strength is a key decision-making factor relating to a bricks ability to bear loads and to resist crushing under loads. A tensile test subjects a brick sample that is pulled apart, or subjected to opposing stretched forces, or an attempted sorted of the test material. Such loads may occur when bricks are used in applications subject to bending or stretching loads. Failure in a tensile test involves testing a thin disk that is cut from the brick to failure, in a carefully created testing machine. Both tests involve detailed sample preparation, as well as careful and exact execution, to ensure accurate and legitimate results. Samples must be selected and prepared in conforming with exacting codes and standards to minimize variations in material properties that could influence the test results. In the tests, one of a variety of potent, automatic testing machines is used to exert the loads in accordance with the design load and speed details of the standard applied. During the test (and usually until the sample ruptures), the testing machine monitors the test equipment reads the testes force while a sophisticated and automatic test controller computes the stores, and plots (in iterant) or ultimate stress and properties.

Fig. 5: Treatment of samples

4. Results and discussion

Based on Table (3), the resistance values of the bricks under the influence of the compressive load ranged between (5.1-6.4) KN and there were no spikes in their resistance values. The collapse was suddenly brittle and did not contain any type of flexibility. Also, the results of the bricks under tension Loads. Where the value is between (1.5-1.85) KN It is less than the resistance of bricks to compression by about two to three times, which explains the brittle collapse due to the weak tensile resistance of bricks compared to its resistance to compression.

Table 3: Compression and tension strength of bricks units

Sample No.	Compression Force (Kn)	Tension Force (Kn)
1	6.4	1.7
2	5.1	1.5
3	5.3	1.85

Moving to Group 2 and based on Table 4, the values show that the compressive resistance of the cement mortar cubes were improved by the addition of steel fibres in comparison to the compressive resistance without steel fibres. This is an after effect of the fact that they have a tensile and compressive force passivating properties and have created cohesion in the cube samples. Figure 6 shows the experimental outcomes of groups 1 and 2.

Table 4: Compression strength for mortar cubic

Sample No	Compression strength With Fiber (KN)	Compression strength Without Fiber (KN)
1	25.8	9.5
2	32	11
3	23.6	9.77

(a)

(b)

Fig. 6: Experimental results (a) Group 1, and (b) Group 2

Table (5) show that the tensile strength for sample with steel fiber are more than it without fiber, the increasing is clear because of the addition of the fiber make the cement mortar prism arrive to higher level of carrying Loads, the fiber can carry tension Force and make cement mortar have bond force.

Table 5: Tension strength for mortar Prism

Sample No	tension strength With Fiber (KN)	tension strength Without Fiber (KN)
1	7.74	1.71
2	9.2	1.98
3	6.5	1.75

Moving to the model under consideration, several tests have been done. In order to carry out the test on the samples that had been cast, these samples were supported on the test table with two supports, and a load was applied in the middle using a hydraulic piston until the brick wall collapsed. Sensors were placed to measure the arrow occurring in the middle of the brick wall. The twelve samples were tested in the same way.

Based on Fig.7, various samples without fiber have been tested under different conditions. In Figure 7a, it is noticeable that the mortar initiated the first crack at the middle of the brick wall and the crack propagated from bottom to top because of the tensile force created and mortar was weaker to resist. And their expansion reflects that the tensile forces the mortar could not resist led to this crack's formations. Thus, this failure occurrence is as a result of the mortar not resisting these tensile forces. In Figure 7b, the mortar also initiated the first crack at the same place then cracked were propagated vertically with tensile forces. When mortar thickness increased, then the bearing capacity was decreased, and more deformation was increased more. That's why its feature is that the load supporting capacity of the mortar is decreased as its thickness is increased and the deformation is much more. The mortar initiated the first crack in itself and the crack was also propagated in itself and then the whole mortar collapsed in Figure 7c. As we see from the mortar that has increased thickness in this photograph, we saw the same reduction in the bearing capacity, and that it is much deformed. That says that the deformation behavior and structural integrity is related to this mortar thickness.

While Figure 7d represents the second height-to-length group, the collapse mechanism of them is same. He initiated the first crack himself in the middle of the structure and it was propagated. The load bearing capacity of it was high with compared the first one of that height-to-length for example but its deformation was less. When we looked, there was a complex relationship between its geometry and bearing capacity clearly. In Figure 7e, the same collapse mechanism is shown up there; initiated first crack himself in the middle of the structure and it was propagated. This time, the load bearing capacity of it has been higher than the first one. Also, as the deformation lessened in comparison with the others, structural geometry can be optimized as the load bearing capacity is increased and the deformation resistance. The same as above, in Figure 7f, they have been also initiated first crack in the middle of it and then they are also propagated in same way. And the load bearing capacity of them has been also increased than the first one of the other height-to-length. And less deformation has been also observed. This is exactly as known that the structural parameters can be considered with the optimization of this and the deformation resistance for the desired load bearing capacity and shows us that this is a such a photo.

(a) (b)

(c) (d)

(e) (f)

Fig. 7: Findings of tests simples without fiber for: (a) Sample H/l=0.25, t=5mm, P=1.4KN, d=3mm; (b) Sample H/l=0.25, t=12mm, P=1.2KN, d=3.6mm; (c) Sample H/l=0.25, t=25mm, P=1.18KN, d=3.93mm; (d) Sample H/l=0. 5, t=5mm, P=5.28KN, d=2mm; (e) Sample H/l=0. 5, t=12mm, P=3.75KN, d=2.4mm; and (f) Sample H/l=0. 5, t=25mm, P=1.96KN, d=2.95mm

In order to better understand the above results, we represented and studied the relationship between load and average displacement for samples without fibers. Fig. 8 shows the relationship between load and mid-displacement for samples without fibers. From the diagrams, we notice that the general behaviour of the block is brittle, where deformations are sudden, and this behaviour did not differ for the samples without the use of steel fibres, but with the difference in the values of the resistances and arrows, as the resistance increased with the increase in the ratio H/L and the arrow decreased with its increase. The strength ranged between 1.4 and 5.28 kN, and the displacement was between 2.93 and 3.93 mm for the sample without using a mortar with steel fibre.

Fig. 8: Relationship between Load and mid displacement for samples without fibers

As mentioned earlier, several tests have been conducted to show the effects of using steel fibers. Based on the results depicted in Figure 9a, it is clear that steel fibres, when incorporated in the mortar, significantly enhance its tensile load-bearing capacity, thereby leading to better bonding between the brick units and an increase in joint work between brick units, ultimately leading to a substantial increase in the capacity of the mortar to withstand external forces, accompanied by a significant reduction in its deformation. The resistance increased by 270% with respect to its fibre-less counterpart, whereas its deformation decreased by 46%, thus unequivocally reinforcing the integrity of the mortar under tensile loads. It is thus evident that steel fibres have measurably improved the mortar's resistance.

Figure 9b features an interesting observation. It is evident that the mortar has demonstrated the ability to withhold tension and compression loads, as evidenced by the fact that the breaking of some brick units suggests that the mortar is tolerating the tension and compression loads quite well, as the fracture line does not propagate along the surface separating the brick units but instead passes through them in a manner suggesting mortar adaptation to the varying flexural stress conditions across the thickness of the mortar, indicating its robust performance.

Go through Figure 9c, it is clear that the resistance that the sample is able to put up is significantly higher when compared to its fibre-less counterpart, accompanied by reduced deformations. This is primarily due to the reinforcement provided by steel fibres, which significantly augmented the overall structural integrity of the mortar, accompanied by a lowering of deformations at the peak beyond which the collapse mechanism manifested itself, thereby further reinforcing the substantial increase in resistance, where the cracks propagate through some of the brick pieces, consequently augmenting its overall stability and thereby minimising deformations, an observation that is valid from Fig. 9d.

The existence and collapse of the collapse mechanism are dependent on the thickness of the mortar. As seen in Figure 9e, as the thickness of the mortar increases, the resistance decreases, hence the resulting deformations increase. Consequently, a very complex relationship with varying mortar thickness between resistance and deformations is witnessed, necessitating a very careful selection of mortar thickness in any structural design.

In concordance with this are the results shown in Figure 9f, which illustrates how the relationship between increasing mortar thickness and decreasing resistance with increasing resulting deformations is upheld. Thus, this necessitates a judicious selection and reconciliation between the structural toughness and deformability of mortar, with a carefully measured response of the mortar thickness, in order to bring about an optimally performing mortar with respect to the desired outcome in its mechanical performance.

Consequently, the comprehensive analysis of these figures brings to light the very complicated effects of the steel fibres and the mortar thickness on the mechanical behaviour of mortar-brick assemblies, thus providing very important information on how crucial informed design choice and material selection become in ensuring both strength and performance robustness in any construction application.

(a) (b)

(c) (d)

(e) (f)

Fig. 9: Findings of tests simples with steel fiber for: (a) Sample H/l=0.25, t=5mm , P=3.8KN, d=1.9mm; (b) Sample H/l=0.25, t=12mm , P=3.1KN, d=2.35mm; (c) Sample H/l=0.25, t=25mm , P=2.55KN, d=2.85mm; (d) Sample H/l=0.5, t=5mm , P=10.85KN, d=0.35mm; (e) Sample H/l=0.5, t=12mm , P=7.47KN, d=1.05mm; and (f) Sample H/l=0.5, t=25mm , P=5.15KN, d=1.5mm

In general, Table 6 shows Findings tests of various samples, with and without steel fiber, under consideration. Considering the results from Table 6, it can clearly be said that the presence of the fibres in both cases increases the strength. This increase, in many cases, can exceed twice which means that the impact of fibres in the strength of the brick wall is positive since with fibres, the brick wall increased its bearing capacity. In reference to the deformations from the same ratios, since in each case with fibres the deformations are less than those in the case of the absence of steel fibres, it is deduced that with the use of steel fibres in the mortar or with the reinforcement of its steel fibres, the samples were essentially contributed to the mitigation of deformations observed in the samples.

Table 6: Findings testes of various samples under consideration

No	H/L ratio	Without steel Fiber		With steel Fiber		Mortar thickness. (mm)
		P(KN)	D(mm)	P(KN)	D(mm)	
1	0.25	1.4	3	3.8	1.9	5
2	0.25	1.2	3.6	3.1	2.35	12
3	0.25	1.18	3.93	2.55	2.85	25
4	0.5	5.28	2	10.85	0.35	5
5	0.5	3.75	2.4	7.47	1.05	12
6	0.5	1.96	2.95	5.15	1.5	25

In order to better understand the above results, we represented and studied the relationship between load and average displacement for samples without fibers. Fig. 10 shows the relationship between load and mid-displacement for samples with fibers. From the diagrams, it is evident from the drawings that its general shape differed from what it was in the previous case. This was due to the role of the steel fibres, which gave the block wall more resistance and reduced the arrow, as the strength value ranged between (3.1–10.58) KN and the displacement between (0.3–5.85) mm. This indicates the role of steel fibre-reinforced mortar in improving the performance of block walls, strengthening them, reducing the arrow occurring in them, and improving the load displacement.

Fig.10: Relationship between Load and mid displacement for samples with fibers

5. Numerical Study:

A numerical model of the first model was built using the finite element program Abacus, where the brick sample was represented, pressure tested, and its deformed shape compared with that which we had in the experimental study. It is shown in the figure, where we notice from it in the figure the similarity in the behavior of the experimental sample and the numerical sample, as well as the collapse mechanism. The results in each of them are similar and are close in value to the collapse load for each of them.

Fig (11) Numerical Bricks Model

We also conducted a modelling exercise for the fiber-reinforced cement mortar cube, where there was also a similarity in its behavior to the experimental behavior that we had previously obtained, as well as the collapse mechanism and collapse load, which are shown in the following figure where we notice how the corners swell and become damaged.

Fig(12) Numerical mortar Cubic

After experimenting with modelling both the bricks and the mortar cube, the first model was modelled for both cases with the presence of fibers as well as without the presence of fibers. It was found that the experimental model matches the numerical model and this is shown in the following figure.

Fig (13) Model Number one

Fig (14) Model Without Fiber

We can see from the figure the separation mechanism that occurs, the similarity in it, and the fracture line that occurs between the numerical and experimental models.

Fig(15) Numerical model with fiber

We notice from the figure that the collapse mechanism changed after using fibers and making a larger number of brick units together.

6. Conclusion

It is evident from the results of the current study that for the same height-to-length ratio, the strength increases due to the presence of fibres, as this increase can reach more than two times, meaning that the fibres positively affected the load bearing of the brick wall, allowing it to reach greater levels of strength. That's for the two ratios (H/L = 0.25, 0.5). As for the deformations that occur in the case of the same ratio, the deformations decrease in the case of the presence of fibres than they were in the case of not using steel fibers. That is, the steel fibres, or the mortar reinforced with steel fibres, played an important role in reducing the deformations that occurred in the samples. In order to study the change in the ratio (H/L), we note that as the ratio increases, the force that the brick walls bear increases and the deformations decrease for both cases reinforced with steel fibres as well as those not reinforced with steel fibres, where the increase in strength ranged from two to three times. These results emphasise the importance of using steel fibres to reinforce the cement mortar used in brick walls because of the important role they play in increasing the cohesion of the brick units with each other and increasing the strength that they can bear, as well as reducing the resulting deformations. The subject needs more in-depth study. More attention is given to its benefits, especially when used to reinforce existing brick buildings. We can also note that by building a numerical model that matches the experimental results, it helps us in the process of expanding the experiments and models that can be built and increasing the possibility of understanding the behavior of such cases.

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