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Axial behaviors of confined and unconfined brick masonry pillars

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Bricks are globally used in both load-bearing and non-load-bearing structures. In the rural areas of many countries, economic constraints are the primary reason for adopting brick masonry in load-bearing structures. In load-bearing structures, brick pillars and walls support the loads and transfer them to the footing. Generally, brick pillars fail due to crushing and are brittle in nature. The present work is aimed at preventing sudden brittle collapse of fly ash brick pillars. Accordingly, we experimentally tested a series of unconfined and confined brick pillars having various slenderness ratios. The testing program included unconfined, axially reinforced unconfined, and wire mesh confined brick pillars. To understand the compressive behaviors of these pillars, all column specimens were axially loaded till failure. Thus, the load-carrying capacities and failure behaviors of all brick pillars are outlined. Both unconfined and axially reinforced unconfined masonry pillars experienced sudden failure due to crushing. The strength of the wire mesh confined brick masonry pillar was higher than that of the unconfined brick masonry pillar and showed no sudden failure.

KEYWORDS
brick masonry, brick pillar, confined, failure, fly ash brick, load-bearing structure, slenderness ratio, unconfined

1 Introduction

Masonry construction efforts have been a mainstay of society since ancient times. The term "masonry" refers to the placement and bonding together of individual structural units. In particular, brick masonry continues to play a significant role to this day as a key component and primary contributor to affordable housing schemes in several developing nations. Nowadays, many varieties of structural units have been developed in terms of building masonry. In the context of the present study, these units are made by incorporating different waste materials (Zhang, 2013). Bricks are commonly used masonry units and are available in many types, such as fly ash, clay, engineering, and aerated bricks. The most accepted types of bricks used as masonry units are composed of burnt clay and fly ash.

The material properties of structural units can vary individually. Hence, it is mandatory to analyze the unit behaviors of all structural members. Many researchers have tested the monotonic loading behaviors of masonry elements. Masonry pillars were instrumental in the construction of many ancient monuments. Nevertheless, there are very few studies on masonry pillars with varying monotonic behaviors that also include tests on unconfined and confined masonry pillars. In a few cases, this problem was addressed using composite materials (Campione and Miraglia, 2003; Toutanji and Deng, 2002; Maalej et al., 2003; Spoelstra and Monti, 1999; Kwon and Spacone, 2002). Corradi et al. (2007) conducted tests on a confined brick masonry column and determined its ultimate load, stiffness, and ductility, which resulted in the finding that the obtuse-angled edges of the reinforcement column had nearly 50% higher compressive strength than the right-angled edges; the study also suggested that rounded columns were preferable for avoiding edge failure in bending resistance. Deng et al. (2020) examined the compressive strengths of masonry columns made of high-ductility fiber-reinforced concrete and observed that the cement-based mortar jacket masonry column achieved a high load-carrying capacity. Campione et al. (2016) investigated the impacts of inserting steel grids into mortar joints by evaluating the compressive behaviors of brick masonry columns under concentric and eccentric loads; these researchers found that internal confinement may be utilized to rebuild a new building using traditional methods. The durability of masonry mainly depends on the pattern, workmanship, and mortar quality of the composite units (Corinaldesi, 2009). Stresses may be created in the mortar joints and bricks in the brickwork or *vice versa*; bricks may cause lateral tension, and the seams in the masonry could also develop lateral tension (Sarangapani et al., 2005). This lateral force causes shearing between adjacent layers of the brickwork. The horizontal mortar bed joints between two layers of masonry have been reported to resist such shear (Dayaratnam, 1987). Ewing and Kowalsky (2004) studied the effects of clay brick masonry with confinement plates and reported that the confinement plates increased the compressive strength and deformation properties. Mcnary and Abrams (1985) conducted experiments encompassing uniaxial, biaxial, and triaxial tests on brick masonry and the interfaces between bricks and mortar. Sinha and de Vekey (1988) reported that the compressive strength of a double-brick-wide prism is marginally lower than that of a single-brick-wide prism; additionally, the mortar strength was found to affect the strength of masonry, which is greater for prisms with lower slenderness ratios. Oliveira et al. (2000) analyzed the stress–strain behaviors of clay bricks under cyclic loading by focusing on the rigidity degradation of the reloading branch. There are reported observations that the stiffening of mortar reaches a threshold strain value and is followed by softening of the bricks in the masonry; hence, masonry behaviors depend on a combination of the behaviors of bricks and mortar (Ozhan and Cagatay, 2014). The use of wire meshing reportedly provides confinement and enhances the seismic behaviors of stone masonry walls. This proposition has been substantiated through compression and out-of-plane tests on masonry wallets as well as small-scale shaking table testing on wall subassemblies (Pun, 2015). Many studies have investigated the compressive behaviors of masonry columns and prisms, but there is very limited research on confined fly ash brick pillars and tests of various slenderness ratios of these pillars. An enhanced method based on membrane equilibrium analysis has been developed to evaluate the structural responses of a masonry sail vault subjected to horizontal loads, such as seismic forces, in compression-only shells (Olivieri et al., 2025). In the present study, we tested a series of brick pillars with different slenderness ratios; the test structures included unconfined pillars, pillars with axial reinforcement, and confined masonry pillars.

2 Material properties

Ordinary Portland cement (OPC) 53 grade was used to prepare the brick masonry pillars. The fineness modulus of the cement was 311 m^2/kg, specific gravity was 3.16, initial and final setting times were, respectively, 30 min and 610 min, and cement consistency was 29%. Manufactured sand with specific gravity of 2.46, water absorption of 1.76%, and bulk density of 1,250 kg/m^3 was used for the mortar. The portable fly ash bricks were made as shown in Figure 1 using a combination of class F fly ash, cement, and quarry dust at proportions of 60%, 10%, and 30%, respectively.

To construct the brick pillars, we prepared mortar at the ratio of 1:5 of cement to manufactured sand according to the brickwork ratio. The grain of the manufactured sand varied from 4.75 mm to 600 µm and is categorized under zone II as per the construction standard IS: 383: 2016 (2016). Compared to river sand, manufactured sand is known to afford high strength (Ganesh and Jagadeesh, 2022); therefore, manufactured sand was adopted in this experimental work.

We used a wire mesh to enhance the resilience of the stone masonry (Bothara et al., 2023); hence, woven wire mesh was used for confinement in the prepared confined brick masonry pillars. The mesh was made of 250 grade steel, had hexagonal linkage spacing with 15 mm side dimensions, and had a wire thickness of 0.5 mm as measured by a Vernier caliper.

To ensure proper bonding between the mortar and axial steel rod, ribbed bars were used in this work. The steel reinforcement rods had a diameter of 10 mm and were placed in the middle of the structure in the axial direction to obtain a yield strength of 415 MPa and tensile strength of 552 MPa. The reinforced steel rebars were placed axially in the brick masonry pillars as shown in Figure 2.

3 Preparation of bricks

Portable sized fly ash bricks were cut from a non-modular fly ash brick block; the dimensions of the cut fly ash brick specimens were 100 × 50 × 50 mm. A cutting machine was used to cut the non-modular brick block, as shown in Figure 1. The compressive strengths of the non-modular brick block and portable bricks (cut specimens) were similar; these samples were tested using an average of five bricks per standard, as shown in Table 1.

4 Construction of brick masonry pillars

Three types of masonry pillars were constructed in this study, namely, unconfined brick masonry pillars, unconfined brick masonry pillars with axial reinforcement, and confined brick masonry pillars (unconfined brick masonry pillars + wire mesh). The brick pillar specimens were constructed in three different heights of 500 mm, 600 mm, and 700 mm and were cured for 28 days. The initially planned dimensions of the pillars were 130 mm × 130 mm; however, slight changes were observed in the cross-sectional dimensions after finishing. These actual dimensions and corresponding slenderness ratios are summarized in Table 2. The thickness of the mortar layer was 10–12 mm. Three samples of each brick pillar specimen were prepared for axial load testing. Figure 2 shows the details of these brick masonry pillars. To achieve proper bonding with the mortar, the bricks were moistened before installation. The compressive strength of the cement mortar cube was 8.76 N/mm^2.

5 Experimental studies

5.1 Test setup

The axial load test was performed on all brick masonry pillars using a universal testing machine (UTM) with a maximum force

FIGURE 1
Preparation of the portable fly ash bricks.

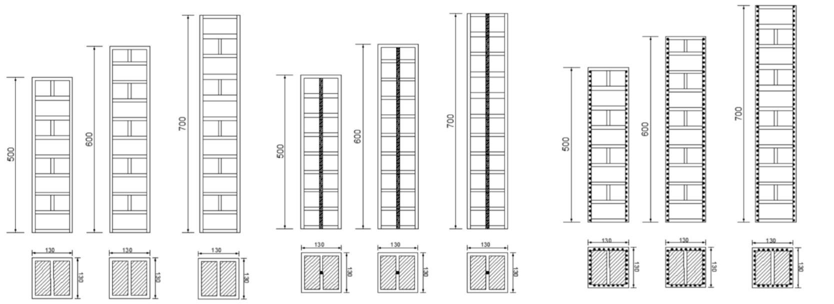

FIGURE 2
Brick masonry pillar types evaluated in this work.

TABLE 1 **Dimensions and properties of the fly ash bricks.**

S.No.	Brick type	Brick dimensions (mm)	Average compressive strength of brick (N/mm^2)	Average water content (%)	Flexural strength (N/mm^2)
1	Non-modular fly ash brick	230 × 110 × 70	9.35	15.20	2.15
2	Portable sized fly ash brick	100 × 50 × 50	9.57	13.82	2.50

capacity of 1,000 kN. The UTM is also equipped with a facility to measure displacement. The tests were conducted in displacement mode at a loading rate of 0.5 mm/min. Two linear variable differential transducers (LVDTs) were used to measure the axial and lateral displacements, where one LVDT was affixed at the base of the pillar to measure axial displacement and the other LVDT was affixed at the mid-height level of the pillar to measure lateral displacement. The pillar specimens were painted with a white distemper and marked with lines to observe the crack patterns.

5.2 Failure behavior of the unconfined brick masonry pillar

The unconfined plain brick masonry pillars showed brittle failure. All the short, medium, and long masonry pillars failed by crushing. The critical failure location was observed to be the base of the column; the brick part was crushed initially, followed by crushing of the mortar and delamination of plastering. Vertical cracks were also observed in the medium and long masonry

TABLE 2 **Details of the brick masonry pillar specimens.**

S.No.	Specimen designation	Actual cross-sectional area (mm^2)	Height (mm)	Slenderness ratio (height/Least lateral dimension)
1	S (short pillar)	130 × 131	500	3.84
2	SR (short reinforced pillar)	130 × 131	500	3.81
3	SWM (short wire mesh pillar)	131 × 131	500	3.81
4	M (medium pillar)	130 × 130	600	4.61
5	MR (medium reinforced pillar)	130 × 131	600	4.61
6	MWM (medium wire mesh pillar)	130 × 131	600	4.61
7	L (long pillar)	130 × 130	700	5.38
8	LR (long reinforced pillar)	130 × 131	700	5.38
9	LWM (long wire mesh pillar)	131 × 131	700	5.34

a) b) c)

FIGURE 3
Failure patterns of brick columns with varying heights: **(a)** short unconfined pillar (S-pillar); **(b)** medium unconfined pillar (M-pillar); **(c)** long unconfined pillar (L-pillar).

pillars, which formed just before the ultimate load. The failure modes of the short, medium, and long masonry pillars are shown in Figure 3.

5.3 Failure behavior of the unconfined brick masonry pillar with axial reinforcement

The axially reinforced unconfined brick masonry pillars showed brittle failure. All the short, medium, and long masonry pillars failed by crushing at the base. In the short specimen, an initial vertical crack was observed at the base of the pillar that propagated to the top before crushing was observed. In the medium and long masonry pillars, initial vertical cracks were observed at the base of the pillar before progressing to crushing. Overall, the failure behavior was characterized by the appearance of vertical cracks, followed by crushing and subsequent delamination of the plaster. We observed the falling of crushed brick pillar particles in all columns. The failure modes of the axially reinforced short, medium, and long masonry pillars are shown in Figure 4.

5.4 Failure behavior of the confined brick masonry pillar

The confined brick masonry pillar, wherein the brick masonry is wrapped in two layers of woven wire mesh, typically has higher load-carrying capacity than both

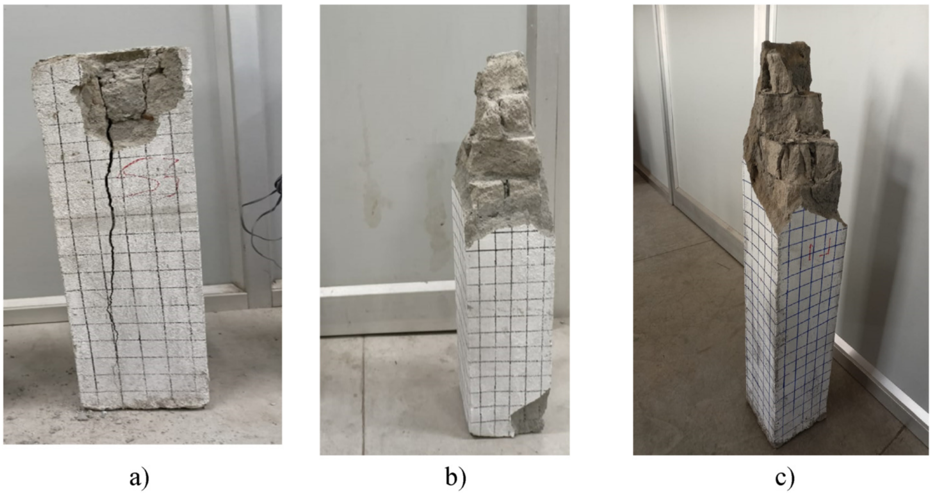

FIGURE 4
Failure patterns of unconfined brick masonry pillars with axial reinforcement: **(a)** short reinforced brick pillar (SR-pillar); **(b)** medium reinforced brick pillar (MR-pillar); **(c)** long reinforced brick pillar (LR-pillar).

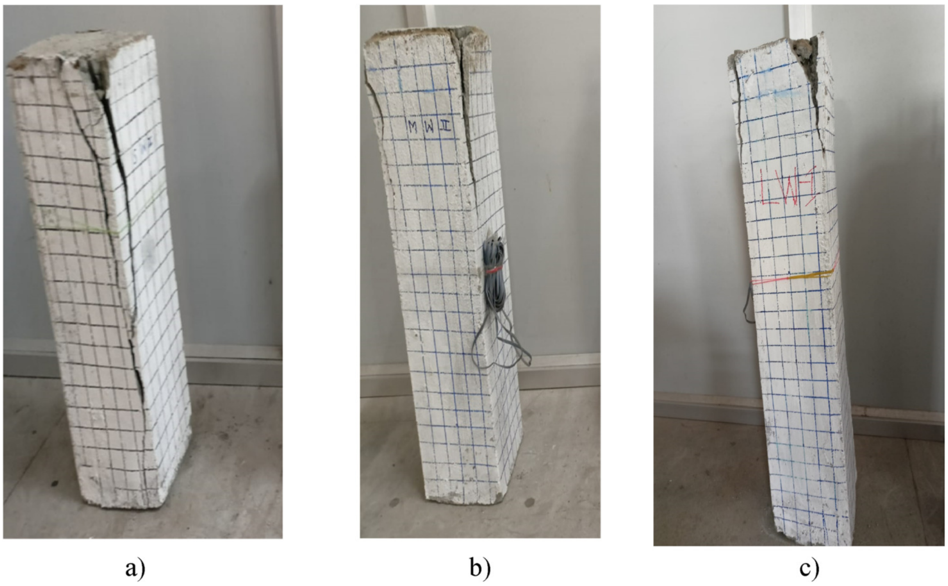

FIGURE 5
Failure patterns of confined brick masonry pillars: **(a)** short confined pillar (SWM-pillar); **(b)** medium confined pillar (MWM-pillar); **(c)** long confined pillar (LWM-pillar).

reinforced and unreinforced unconfined masonry pillars. Here, the crushing failure occurs at the top surface and corner support portions, with vertical cracks on all columns. However, delamination was observed only at the base of the specimen, and the falling of crushed brick pillar particles was prevented by the woven wire mesh. The strength and stiffness of the wire mesh confined brick masonry pillars are higher than those of the unconfined and axially reinforced brick masonry pillars because of the confinement pressure. Figure 5 illustrates the failure modes of the short, medium, and long confined brick masonry pillars.

5.5 Load–deflection behaviors

The load–deflection behaviors of the unconfined, axially reinforced and unconfined, and confined brick masonry pillars are shown in Figures 6a–c. The load–deflection capabilities of the pillars are very smooth, but small peaks are observed in the

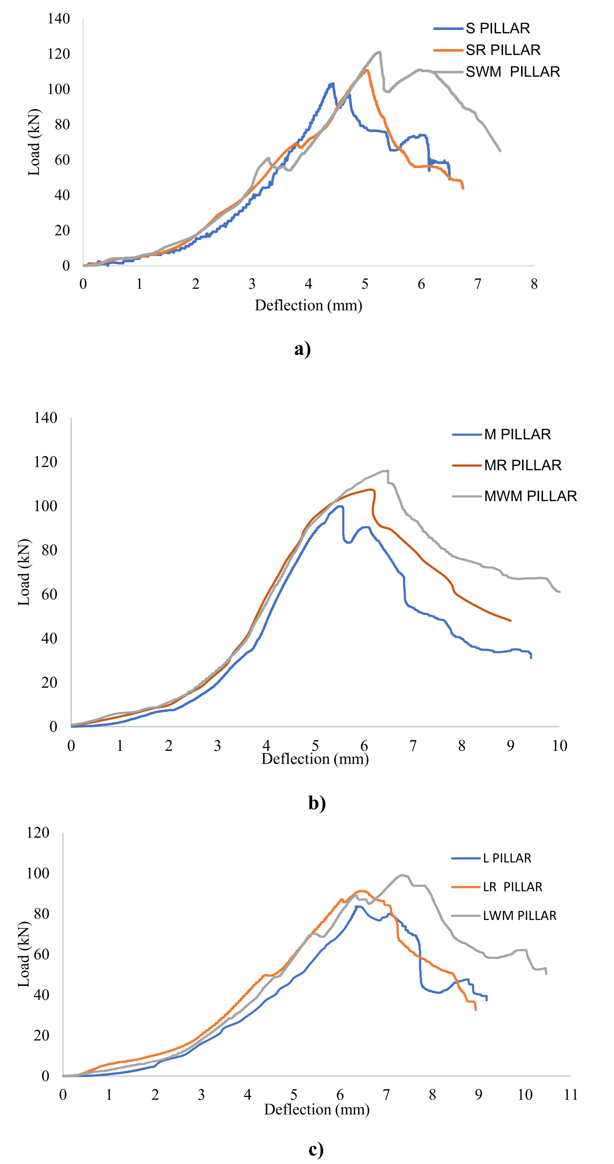

FIGURE 6
Load–deflection curves of the **(a)** short, **(b)** medium, and **(c)** long unconfined, axially reinforced unconfined, and confined brick masonry pillars.

load–deflection curves that indicate crushing of bricks or mortar. The strength and stiffness values of the axially reinforced and confined brick masonry pillars are higher than those of the unconfined brick masonry pillars.

In this analysis, we observed that the axial load capacity decreased as the heights of both confined and unconfined brick masonry pillars increased. The slenderness ratio played a significant role in axial loading, and the failure pattern varied according to height. Among all the specimens, the woven wire mesh imparted the maximum strength during axial loading. Once the load reached the maximum value, the pillar shortened and expanded laterally; the wire mesh then prevented lateral expansion, thereby increasing the load-carrying capacity. In the woven wire mesh confined pillars, failure occurred only at the edges of the specimens. Furthermore, no sudden collapse was observed for the confined brick masonry pillars.

6 Behaviors of the masonry column under axial loading

To understand the failure behaviors, all masonry pillars explored in this study were subjected to axial loading until failure. All columns were stable and showed no cracks or plaster delamination up to the ultimate load. A summary of our test results is provided in Table 3. Once the load reached the ultimate value, hairline cracks became visible at both the base and top of each specimen; subsequently, the load was decreased, causing the cracks to propagate. Three failure modes were observed in this study: the first failure mode was crushing at one end of the column, the second mode of failure was vertical cracking, and the third mode of failure was plaster delamination. Since the compressive strength of the brick is higher than the strength of the mortar, failure occurred in the bricks. Tawfik et al. (2014) calculated the ductility factor as the ratio of the displacements corresponding to 85% of the ultimate loads on the ascending and descending portions of the load–displacement curve.

7 Conclusion

Many ancient structures, including and especially monuments, have pillars made of bricks. The structural performances of these pillars are critical as their stability and load-carrying capacity significantly influence the overall integrity of the structure. In this context, the present study explores the behaviors of confined and unconfined brick masonry pillars. Our study yielded the following significant findings:

1. The primary mode of failure of the unconfined, axially reinforced and unconfined, and confined brick masonry pillars was crushing, and no delamination of the plaster was observed in the confined brick masonry pillars.
2. The average strength enhancement of the axially reinforced unconfined brick masonry pillars is 7.33%–9.26% compared to that of unconfined brick masonry pillars.
3. The average strength enhancement of confined brick masonry pillars is 17.04%–18.60% compared to that of unconfined brick masonry pillars.
4. The strength of a masonry pillar is reduced when its height is increased.

The strength of a masonry pillar depends on the individual strengths of its mortar and brick components. Ideally, the compressive strengths of both the mortar and bricks should be similar to prevent early failure of the masonry pillar structure.

Confined brick masonry pillars can be confidently used in regions prone to seismicity as they are not susceptible to sudden failure. However, additional research efforts are needed to

TABLE 3 Compressive stress and ductility of the brick masonry pillars.

S.No.	Specimen designation	Ultimate compressive load (kN)	Area of the cross section (mm^2)	Compressive stress (N/mm^2)	Ductility
1	S	103.14	17,030	6.056	1.12
2	SR	110.70	17,030	6.500	1.16
3	SWM	120.97	17,161	7.049	1.31
4	M	99.87	16,900	5.909	1.22
5	MR	107.19	17,030	6.294	1.29
6	MWM	116.89	17,030	6.864	1.33
7	L	83.50	16,900	4.941	1.22
8	LR	91.23	17,030	5.357	1.28
9	LWM	99.03	17,161	5.771	1.36

investigate the effects of cyclic and reverse cyclic loading conditions to simulate realistic earthquakes as well as evaluate the energy dissipation, stiffness degradation, and ductility characteristics of such pillars.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, and any further inquiries may be directed to the corresponding author.

Author contributions

KP: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. AP: Conceptualization, Investigation, Methodology, Validation, Visualization, Writing – review and editing.

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