Performance of solid masonry columns after strengthening

M Q Adnan¹, H H Hatem¹, H H Alghazali², W H Mahdi², A H Mahdi³, M W Mohammed¹, and M A Numan³

¹Senior Student, Civil Engineering, University of Kufa, Najaf, Iraq
²Lecturer, Ph.D., Civil Engineering Department, College of Engineering, University of Kufa, Najaf, Iraq
³Undergraduate student, Civil Engineering, University of Kufa, Najaf, Iraq

Corresponding author’s e-mail: hayderh.alghazali@uokufa.edu.iq

Abstract. Brick masonry is one of the widely used materials for the construction of walls and columns in buildings. In many cases, the built walls and columns fail due to excess lateral loads, environmental degradation, and increased loading requirements due to changes in occupancy. In this paper, an experimental was conducted to understand the performance of building columns made of solid clay bricks strengthening with fiberglass and ferrocement techniques materials. In total, six columns were constructed, two columns were control columns (unconfined), two columns were strengthened and confined with fiberglass mesh and plaster, and the other two columns were strengthened and confined with ferrocement. The experimental results showed that the maximum axial load of unconfined specimens can be increased if they are confined by fiberglass or ferrocement systems. Both systems can be used to repair uncollapsed columns which have been loaded close to failure or exposed to strength deterioration.

1. Introduction

Unreinforced clay brick masonry is a common type of construction that has been used for decades around the world. Clay brick is one of the oldest building materials and has been used since the early civilizations and is still relevant for new construction projects in modern architecture. It was used to build walls, pavements, and columns, and other elements in masonry construction. When combined with good building design, bricks can offer long-term life performance and provide healthy and comfortable environments. This type of construction is sensitive to some effects such as environmental degradation, foundation settlements, changing in loading demand, and damage from earthquakes. Nowadays, strengthening techniques are needed to use in the clay brick masonry to allow buildings to be preserved for future generations and to reinforce buildings that have been damaged. It has been found that strengthening of compression elements is among the extreme importance to prevent disastrous damage to historic vertical load-bearing structural elements [1]. Masonry columns are often strengthened by providing confinement using different techniques such as fiber-reinforced polymer (FRP) composite or ferrocement jackets. FRP materials offer numerous advantages for strengthening and stabilizing historic, mainly masonry structures, by virtue of their low weight, high effectiveness, and potential reversibility [2].

Within the building industry, the method of strengthening using FRP was mainly given first in concrete construction. Investigations by using the method of strengthening masonry walls with fiber-reinforced polymers were first realized by Schwegler [3] based on his results; the load-bearing walls of a six-story building were strengthened with carbon FRP laminates [4]. Di Ludovico M.et.al. [5]
presented an experimental work dealing with 12 square cross-sections listed faced tuff masonry columns subjected to uniaxial compression. In his work, three different confinement schemes were experimentally analyzed in order to evaluate and compare the effectiveness of the proposed strengthening techniques uniaxial glass FRP laminates (GFRP), uniaxial carbon FRP (CFRP) laminates, alkali-resistant fiberglass grid bonded with cement-based mortar. Experimental outcomes showed that the investigated confining systems were able to provide significant gain both in compressive strength and ductility of masonry members.

Ferrocement is a type of thin reinforced concrete wall commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh [6]. It offers appealing features for strengthening such as high tensile strength, high modulus of rupture, and low cost in maintenance and repair [7]. Shahzada K.et.al. [8] made a retrofitting of masonry columns. They used two sizes of columns 9 in. x 9 in. and 13.5 in. x 13.5 in. Retrofitted columns gave strength 1.5, 1.35 times more than the strength of 9 in. x 9 in. and 13.5 in. x 13.5 in. of un-retrofitted columns respectively. The columns became stronger due to retrofitting and showed ductile behavior during failure. Nandakumar, V.et.al [9] taken different types of steel wire mesh for casing ferrocement masonry column, and the strongest column with higher strength is calculated. In the present study, ferrocement and glass fiber reinforced polymer (GFRP) materials are used for strengthening the solid brick masonry columns. These materials have been used more recently for jacketing purposes so that the specimen is strengthened with a simple change in the cross-sectional size.

2. Materials

Solid clay bricks (Type-C) were used with dimensions of 240 mm (length) x 115 mm (width) x 75 mm (height). It was taken to the job site carefully to keep it from crashing. After that, several tests were conducted on the bricks according to the Iraqi Standard No.24/1988[10]. The average compressive strength of bricks is 15.03 N/mm². The average absorption of bricks is 22.1%. Test results are conforming to I.Q.S No.25/1988 [11].

Type (I) Portland cement was used supplied from the General Company for Iraqi Cement (Al-Assad Company in Najaf). The physical properties of cement conform to the Iraqi standard No.5/1984 [12] as shown in Table 1. Natural sand with a maximum aggregate size of 10 mm and fines modulus of 2.23 was used in the study with specifications coincide with the Iraqi standard No.45/1980 [13] grading zone (3) as shown in Table 2.

| Physical Properties                                      | Test Results | I.Q.S. No. 5/1984[12] |
|----------------------------------------------------------|--------------|-----------------------|
| Fineness using Blain method (m²/ kg)                      | 322          | ≥ 230                 |
| Setting time (using Vicat’s instruments)                  |              |                       |
| Initial (minute)                                         | 95           | ≥ 45                  |
| Final (hour)                                             | 4:25         | ≤ 10                  |
| Compressive strength for cement Cubes of (70.7×70.7×70.7mm) at: 3-days (MPa) | 17.5         | ≥ 15                  |
|                                                        | 7-days (MPa) | 26.2                  | ≥ 23                  |
Table 2. Sieve analysis of natural sand.

| Sieve Size | %Passing | L.Q.S. No.45/1980 [13] |
|------------|----------|------------------------|
| 10 mm      | 100      | 100                    |
| 4.75 mm    | 97.2     | 90-100                 |
| 2.36 mm    | 89.1     | 85-100                 |
| 1.18 mm    | 80.2     | 75-100                 |
| 600 micron | 73.8     | 60-79                  |
| 300 micron | 32.4     | 12-40                  |
| 150 micron | 4.5      | 0-10                   |

Two types of strengthening materials (steel wire mesh, fiberglass mesh) with a 1 x 1 cm; holes (see Figure 1) were used in combination with cement-sand mortar.

![Steel wire mesh](image1.png) ![Fiberglass mesh](image2.png)

(a) Steel wire mesh  (b) Fiberglass mesh

Figure 1. Strengthening materials used in the study.

3. Experimental program

3.1. Preparation of masonry specimens

The research program aims to study the effectiveness of strengthening and performance of solid brick masonry columns. The study was performed on test six samples of brick masonry columns prepared with nominal dimensions (width x depth x height) of approximately 240mm x 240mm x 955 mm, respectively. Test specimens included two reference unconfined masonry columns (without any strengthening technique) designated as (Control-1 and control-2). Every two samples of the other four columns represented confined masonry columns by using ferrocement and Fiberglass mesh strengthening techniques designated as (FC-1 and FC-2) and (GF-1and GF-2), respectively.

All masonry specimens tracked the same sequence of steps in the construction; the solid bricks were submerged in tap water for a minimum of 1-hour prior to their use to achieve bonding between bricks and mortar. Cement-sand mortar with recommended mix proportion of 1:3 and water-cement ratio of 0.6 was used in the masonry work of brick columns. The mortar was mixed at a steady rate until the mixture became homogeneous. Immediately after mixing the mortar, column fabrication took place. A lubricated plywood plate was used as a base to construct a brick column. The first mortar layer was used to ensure that the first layer of bricks would bond together. Each layer of mortar was leveled
utilizing a wooden frame that 1.5 cm thick as shown in Figure 2-a. The mortar was placed and then spread using a trowel.

Two saturated bricks were placed inside the edges of the wooden frame. Column depth was selected since the summation of the two brick widths and the vertical joint between them was approximately 240 mm. Before proceeding, the horizontal levelness of the first bricklayer was verified using a suitable level measuring tool. The remaining bricklayers were placed in an alternate header bond configuration according to the same procedure used in the first layer (see Figure 2-b). The top surface of the bricklayers was gently pressed in multiple locations until the layer becomes flat. Excess mortar exposed by pressing was removed and discarded. Generally, after the placement of the 10th bricklayer, the vertical alignment was verified using a vertical level. To characterize the masonry mortar material properties, nine masonry mortar cubes were made using steel molds with dimensions of 70.7 x 70.7 x 70.7 mm. Cubes were taken and tested for compressive strength with an average of 20 MPa. Also, tensile strength was done for mortar using cylinder molds of 200 x 100 mm. Test results showed that the average tensile strength equals 1.9 MPa.

After fabrication, all columns were wrapped with wet canvase to cure for a minimum of 14 hours (see Figure 2-c). All specimens were watered daily for 7 days. After the curing time was complete, the specimens were uncovered and stored in the same location until the ferrocement and fiberglass matrix jackets were installed.

Ferrocement jackets were used to confine two columns. Also, another two columns were confined using Fiberglass jackets. The procedure used to apply the strengthening jackets to the column specimens followed the sequence of steps described herein and as follows: one confinement layer of steel wire mesh or fiberglass mesh was used. The matrix preparation of strengthening jackets included cutting the strengthening materials as sheets with length equals to column height. Prior to plaster application, the column was sprayed with water to ensure a proper bond between the bricks and the matrix.

Immediately after the application of the first plaster layer, the strengthening materials sheets were applied. The sheets were positioned around the column (see Figure 3-a&b) with an overlap in the transverse direction of the column. The sheets were lightly pressed into the first layer of plaster using a trowel or by hand to ensure a proper bond. After positioning the sheets, they were covered with a thick layer of plaster as shown in Figure 3-c.
3.2. Test setup and procedure

All columns were tested using structural hydraulic testing framed system machine, with 2,000 kN capacity at the structural laboratory of the Civil Engineering Department, University of Kufa, Iraq. Columns were painted with white color to observe the crack development as shown in Figure 4-a. The test column was gently pick-up and places into test position. End conditions for each of the test specimens were kept similar. To ensure a uniform load distribution and avoiding stress concentration, thick steel plates with dimensions 400 mm x 400 mm x 15 mm were placed at both column’s ends. The specimen was instrumented with electrical resistance gage attached in a direction parallel to loading to measure the axial displacement. The test setup is as shown in Figure 4-b. All test columns followed the same testing procedure. After adjusting the vertical alignment, the load was applied gradually by a hydraulic jack. Columns were subjected to a concentric uniaxial compression load with a loading rate equals to 5 kN/min. A preload of 5 kN was applied to seat the loading system then unloaded to zero. During the test operating, measurements of loads, corresponding displacements, and cracks were monitored and documented up to failure load. The tests were terminated after a significant drop in applied load, or when a portion of the columns began to dislodge.

![Figure 3. Column strengthening.](image)

![Figure 4. Columns painting and test setup.](image)
4. Test Results and Discussions

All the column specimens were tested under concentric uniaxial compression until failure. The experimentally collected data was applied load and vertical displacement. The collected data were used as a basis of comparison to estimate the efficacy of confinement systems used in this study. Failure modes of tested column specimens are presented in Figure 5. In general, all specimens had a similar behavior up their maximum axial loads as shown in Figure 6. During testing, vertical hairline cracks started to form at 65 to 80 % of their maximum failure load. For unconfined specimen (control 1 &2), the tested columns failed in a brittle manner due to the spalling of plaster and bricks crashing. Prior to the peak load, vertical visible cracks formed on all column faces. Horizontal cracks also formed at the mid-height of the column. Once the peak load was reached, the cracks widened significantly and became apparent on all column faces and a large chunk of plaster fell out. It was observed that most cracks of exposed brick did not match with plaster cracks. The cracks of confined specimens with fiberglass mesh (GF-1 & GF-2) were different in appearance from those of unconfined specimens. Vertical visible cracks appeared on the surface of the composite at the column corners and end of the glass fiber overlap prior to the peak load. Horizontal cracks also formed mid-height of the tested column. After the peak load was reached, the vertical cracks along the overlap increased significantly, indicating that the composite was beginning to debond due to the developed tensile stresses. The exterior matrix layer (plaster and fiberglass mesh) began to detach from the column caused the load applied to the column to decrease rapidly, similar to the failure of unconfined columns. The confined specimens with ferrocement (FC-1 & FC-2) developed few cracks in the test specimens. The cracks were mainly vertical and occurred at the top one-third of the tested specimens. Once the peak load was reached, these vertical cracks began to widen and increase in length and ferrocement layer was detached from the specimen caused the load capacity to decrease until the load began to plateau.

![Figure 5. Failure modes of tested columns.](image-url)
Figure 6. The load-displacement curve of tested columns.

Table 3 summarized test results of the tested column under concentric uniaxial compression load. The average maximum load of the unconfined specimen was 129 kN. For confined specimens with fiberglass mesh, the average ultimate load was 150 kN. However, the ferrocement confined specimens carried a maximum load of 200 kN. From Table 3, it can be concluded that confined specimens with fiberglass mesh and ferrocement exhibited 16% and 55%, respectively, increase in the maximum axial load compared to unconfined specimens. Also, confined specimens showed increase in vertical displacement about 37% and 13%; respectively, compared to unconfined specimens.

Table 3. Test results of tested columns

| Column Name | Description                     | Column No. | Maximum Compressive Load (kN) | Maximum displacement (mm) |
|-------------|---------------------------------|------------|-------------------------------|---------------------------|
| Control     | Brick masonry columns without  | 1          | 110                           | 7.78                      |
|             | strengthening                    | 2          | 148                           | 5.84                      |
| GF          | Brick masonry columns strengthening with fiberglass mesh | 1          | 160                           | 9.19                      |
|             |                                 | 2          | 140                           | 8.755                     |
|             |                                 | 1          | 190                           | 8.675                     |
| FC          | Brick masonry columns strengthening with ferrocement mesh | 2          | 210                           | 6.75                      |

5. Conclusion
In this paper, an experimental program was carried out on six solid clay brick columns strengthened with two different systems. Column specimens were tested under concentric uniaxial compression
The influence of fiberglass and ferrocement on the performance of the column specimens was investigated and discussed. From this study, it can be concluded that the maximum axial load of unconfined specimens can be increased if they are confined by fiberglass mesh or ferrocement system. Ferocement system showed a good improvement than fiberglass mesh in increase the load capacity of column specimens. Both systems can be used to repair uncollapsed columns which have been loaded close to failure or exposed to strength deterioration.

Acknowledgments
The authors would like to thank the University of Kufa, the college of Engineering, the Civil Engineering department, and the laboratory staff for their help in the experimental program of this study.

6. References
[1] Jemison, S E. 2018 “Compressive behaviour of masonry columns confined with steel reinforced grout (SRG) composite, Masters Theses, Missouri university of science and technology, pp.1

[2] Bruggi, M.; Milani, G.; Taliercio, A. “Design of the optimal fiber-reinforcement for masonry structures via topology optimization”, Int. J. Solids Struct. 2013, 50, 2087–2106.

[3] Schwegler, G. (1994); “Verstärken von Mauerwerk mit Faserverbund werkstoffen in seismisch gefährdeten Zonen, Eidgenössische Materialprüfungs- und Forschungsanstalt”, Nr. 229

[4] Schwegler, G. (1996); “Verstärkung von Mauerwerkbauten mit CFK – Lamellen, Sonderdruck kaus ”, Schweizer Ingenieur und Architekten, Nr. 44

[5] Marco Di Ludovico, M., Fusco E., Prota A., Manfredi G. (2008), “Experimental Behaviour of Masonry Columns Confined Using Advanced Materials”, The 14thWorld Conference on Earthquake Engineering. October 12-17, 2008, Beijng, China.

[6] ACI Committee 549, “State-of-the-art report on ferrocement”, ACI549-R97, in Manual of Concrete Practice, ACI, Detroit, 1997, pp. 26

[7] Shah, A. A. (2011) “Applications of Ferrocement in Strengthening of Unreinforced Masonry Columns” International Journal of Geology, Issue 1, Volume 5, 2011.

[8] Shahzada, K., Alam, B., Javed, M., Ali Z., Khan, H., Ali Shah, S. Retrofitting of Brick Masonry Columns by Ferocementing. International Journal of Advanced Structures and Geotechnical Engineering.ISSN 2319-5347, Vol. 01, No. 02, October 2012.

[9] Nandakumar, V., Revathi, K., Revathi, M.P. Study of Ferro cement in Strengthening of Brick Masonry Columns. International Journal of Engineering Development and Research, IJEDR 2019 Volume 7, Issue 1 ISSN: 2321-9939.

[10] Iraqi Specification No.24, “Methods of Sampling and Testing Clay Building Bricks” Baghdad, 1988.

[11] Iraqi Specification No.25, “Clay Building Bricks” Baghdad, 1988. Updating No.1/1993.

[12] Iraqi Specification No.5, “Portland Cement” Baghdad, 1984.Updating No.1, 2/2010, updating No.3, 4/2015 and updating No.5, 6/2016.

[13] Iraqi Specification No.45, “Aggregates from Natural Sources for Concrete and Building Construction”, Baghdad, 1984. Updating No.1/2015 and No.2/2016.