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Experimental investigation on the axial capacity enhancement of brick masonry column by ferrocement overlay

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Abstract

Masonry is an indispensable construction component, serving as either load-bearing or infill material in reinforced concrete or steel-framed buildings. In rural areas of Bangladesh, brick masonry columns are very commonly used as load-bearing walls. Usually brick masonry columns are capable of withstanding axial loads but they are weak in carrying lateral loads. Due to the increase in population density in rural areas, vertical extension of existing buildings featuring load-bearing masonry columns are essential. As a result, the capacity of these masonry columns will need to be increased. An experimental investigation has been carried out to evaluate the enhancement of axial capacity and the deformation ability due to addition of ferrocement overlay around the brick masonry columns. Eight categories of specimen have been made, each with a length of 610 mm and the following cross-sections: 230×230 mm2, 225×225 mm2, and 114×114 mm2. The specimens have been strengthened by ferrocement overlay, leaving one specimen from each category as a control specimen. Ferrocement overlay involved the use of single, double, triple, and quadruple layers of wire mesh, with the cross-sectional dimensions of the specimens increasing by at least 50mm (25mm on either side). Monotonic loading has been used to investigate axial capacity of both the control and strengthened specimens. The study revealed that the capacity of the brick masonry column was increased by a maximum of 35% when three layers of wire mesh have been used in the ferrocement overlay. The average increase in axial capacity and deformation ability has been found to be 26% and 31% respectively.

Keywords: Strengthening, axial capacity, deformation ability, ferrocement overlay, brick masonry.

1. Introduction

Masonry structures have long been favored in the construction sector due to their strength, aesthetic appeal, and cost-effectiveness (Smith, 2015). In low-rise buildings, brick masonry has been extensively used as load-bearing elements. However there have a number of causes those leads to make structures weaker such as inferior construction, settlement of foundation, deterioration of strength of the construction material due to aging, etc. (Olsen, 2008). With the increase in the population and urbanization accelerating, the demand for vertical expansion is being increased. In those cases, there are two ways to get rid of this kind of situation, one is dismantling of the existing structure and then make a new one for the desired population. The other and viable option is to strengthen the old structure and make things easy for accommodating the desired population. Traditional methods such as RC jacketing, grouting cracks and voids, stitching with metallic or brick elements, post-tensioning with steel ties, shotcrete jacketing, ferrocement, and center core retrofitting are available for retrofitting existing masonry structures (Saatcioglu & Razvi, 1992). Among these techniques, ferrocement jacketing has emerged as a promising method due to its less cost, effectiveness and utility. Ferrocement is the first known form of reinforced concrete which was first used two centuries ago in Italy and France, mainly for construction of boats (Lalaj et al., 2015). Several researchers studied the effect of ferrocement overlay application around RC columns, Masonry columns, Masonry walls, RC beams, etc. (Soman and Mohan, 2018; Kazemi and Morshed, 2005; Ranjith et al., 2017; Rampello et al., 2012). By applying ferrocement layers, the load-bearing capacity and structural performance of existing masonry columns can be significantly enhanced (Ranjith et al., 2017). Unreinforced masonry (URM) columns experience transverse expansion when subjected to compressive loads. Due to the varying stiffness of the two materials and the strong bonding behavior between them, the lateral deformation of the mortar is often greater than that of the brick units. This leads to axial compression and bilateral stress on the brick units, resulting in the rapid development and propagation of vertical cracks (Rampello, et al., 2012). To restrict the transverse expansion of masonry and improve its strength and deformability, various reinforcing techniques have been applied to masonry columns (Abdullah and Takiguchi, 2003).

Naaman (2000) described the distinctive physical and mechanical properties of ferrocement. Ferrocement has high tensile strength and stiffness due to the confinement with two-dimensional reinforcement of the mesh system and undergo large deformations before cracking or high deflections before collapse. Khan and Monem (2007) studied the composite behavior of brick masonry column encased with ferrocement having one, two and three layers of wire mesh with some bonding agent on the surface. Results indicated a significant strength enhancement of those column. A similar kind of findings were reported by Ahmed and Chowdhury (1998) but in their study no bonding agent was used. Shah (2011) and Kaish et al., (2012) carried out study on ferrocement jacketing of brick masonry columns. An increase of 19% and 21% reported for the first crack load and ultimate load respectively compared to the control specimen (Shah, 2011). Both concentric and eccentric loading were applied on the control and ferrocement jacketed column and, significant strength gain was reported (Kaish et al., 2012). In this paper, the authors present the usage of ferrocement jacketing as an effective method to enhance the axial capacity and deformation ability of unreinforced brick masonry columns.

2. Experimental program

The experimental program included 36 clay brick masonry columns that were evaluated under an axial compression load while taking into account four different kinds of bricks. These categories included first class and second-class clay bricks, which were used in the combustion of coal and gas, respectively. The nominal dimensions of the control specimens were b = 114 mm, h = 114 mm, and L = 610 mm. The aspect ratio L/b was 5.35 prior to the strengthening process, but it was decreased to 3.71 thereafter. With initial aspect ratio L/b = 2.65, another set of control specimens had the following measurements: b = 230 mm, h = 230 mm, and L = 610 mm. This aspect ratio dropped to 2.17 after the strengthening process, as seen in Figure 1. One specimen from each group acted as the control specimen for the experiment, while the remaining specimens underwent strengthening applying ferrocement overlay. Table 1 provides a detailed breakdown of the reinforced brick masonry columns' metrics. By doing this, the brick masonry columns were pre-wetted prior to surface preparation, which included removing dust and other foreign objects and chipping the surface to make it rough before inserting a rowel plug. A single layer of wire mesh was positioned where it would be required and then tightened adequately. A rich mortar having 1:2 mixing ratio made with locally available coarse sand (FM =2.65) and Portland composite cement maintaining a w/c ratio of 0.55 is sprayed around the surface of the column to a thickness of 25mm. The study also looked into the effects of using several wire mesh layers in one particular group (M1BS). Five specimens were thoughtfully created for this group, one as a control with no wire mesh and the other four with numerous layers of wire mesh, single, double, triple, and quadruple layers, respectively. All specimens underwent a curing process by frequently sprinkling water on their surfaces for a continuous period of 28 days adhering to completion of a 24-hour setting time of concrete.

Table 1
Description of specimens

Types of brick	Class	Column Designation	Number of specimens	Cross Section (mm^2)	Remarks
Coal burned	1st class	H1BS	1	114×114	Control specimen
		H1FS	3	164×164	Strengthened specimen
		H1BL	1	230×230	Control specimen
		H1FL	3	280×280	Strengthened specimen
	2nd class	H2BS	1	114×114	Control specimen
		H2FS	3	164×164	Strengthened specimen
		H2BL	1	230×230	Control specimen
		H2FL	3	280×280	Strengthened specimen
Gas burned	1st class	M1BS*	1	114×114	Control specimen
		M1FS	3	164×164	Strengthened specimen
		M1BL	1	230×230	Control specimen
		M1FL	3	280×280	Strengthened specimen
	2nd class	M2BS	1	114×114	Control specimen
		M2FS	3	164×164	Strengthened specimen
		M2BL	1	230×230	Control specimen
		M2FL	3	280×280	Strengthened specimen

* Effect of multiple layers of wire mesh studied for this particular group.

3. Properties of the materials used

The properties of the bricks utilized in this study are presented in Table 2. To create the brick masonry, Portland composite cement was employed, characterized by an initial setting time of 90 minutes and a final setting time of 350 minutes. River bed sand, locally available, was chosen for the brick masonry mortar, possessing a Fineness Modulus (FM) of 1.51.

Table 2
Properties of bricks

Types of brick	Class	Size (mm)	Weight (gm)	Absorption (%)	Compressive Strength (MPa)	Tensile Strength (MPa)
Coal burned	1st class	230×110×65	2923	14.23	11.80	1.19
	2nd class	230×110×65	2702	17.36	8.83	0.97
Gas burned	1st class	225×110×65	3380	9.56	23.89	2.63
	2nd class	225×110×65	3275	15.20	18.43	1.78

(a) (b) (c)

Fig. 1. (a) Brick masonry column (b) strengthened brick masonry column and (c) experimental setup.

However, for the rich mortar used in the ferrocement overlay process, river bed sand with a Fineness Modulus (FM) of 2.65 was utilized. In the brickwork, a mortar ratio of 1:4 was employed, resulting in a compressive strength of 16.35 MPa for the mortar. On the other hand, the rich mortar employed for ferrocement overlay exhibited a significantly higher compressive strength of 31.78 MPa.

4. Experimental setup

The specimens were tested using a Universal Testing Machine (UTM) with a capacity of 2000 kN. The specimens were inserted in the UTM by using two rubber pads one at the top and other at the bottom end of the specimen in a manner so that the load can be transferred through the centroid of the specimen and there will be no eccentricity. The experimental setup is shown in Figure 1(c). Specimens were loaded under a monotonically increasing vertical load until failure. During testing the cracking load, failure pattern and axial deformation were observed for each specimen and duly recorded.

5. Results and discussion

The first cracking loads of different columns are presented in Table 3. As anticipated, the average first cracking loads were lower for each type of control brick masonry column. However, when the columns were strengthened using ferrocement jacketing, their average first cracking loads demonstrated a substantial increase compared to the control specimens within their respective groups.

The enhancement percentages for single layer ferrocement jacketed full brick columns are about 94%, 88%, 93%, and 90% in series M1FL, M2FL, H1FL and H2FL respectively. For single layer ferrocement jacketed half brick columns are about 174%, 171%, 173%, and 168% in series M1FS, M2FS, H1FS and H2FS respectively. When the strengthening was done with multiple layers of wire mesh in that case the maximum enhancement of cracking load found to be 188% for three layers of wire mesh. The ultimate strength of the columns is also presented in Table 3.

As projected, the ultimate strength of the strengthened columns was increased significantly. The enhancement percentages for single layer ferrocement jacketed full brick columns are about 25%, 26%, 25%, and 23% in series M1FL, M2FL, H1FL and H2FL respectively. For single layer ferrocement jacketed half brick columns are about 29%, 28%, 28%, and 26% in series M1FS, M2FS, H1FS and H2FS respectively. When the strengthening was done with multiple layers of wire mesh in that case the maximum enhancement of ultimate strength found to be 36% for three layers of wire mesh.

Table 3
Summary of test results

Designation	Avg. first cracking load (kN)	Avg. first cracking strength (MPa)	Avg. first cracking strength enhancement (%)	Avg. failure load (kN)	Avg. failure load enhancement (%)	Avg. ultimate strength (MPa)	Avg. ultimate strength enhancement (%)	Avg. deformation (mm)	Ductility enhancement (%)
H1BS	53.00	4.08	--	80	--	6.16	--	3.90	--
H1FS	166.00	6.02	47.72	218	172.50	7.89	28.08	5.15	41
H1BL	156	2.95	--	240	--	4.74	--	4.50	--
H1FL	338	4.31	46.19	463	92.92	5.91	24.68	5.89	31
H2BS	44	3.39	--	68	--	5.23	--	4.00	--
H2FS	37	4.97	46.85	182	167.65	6.61	26.32	5.30	33
H2BL	136	2.57	--	216	--	4.08	--	4.40	--
H2FL	291	3.71	44.38	410	89.81	5.01	22.79	5.80	32
M1BS	61	4.69	--	96	--	7.39	--	4.30	--
M1FS	200	7.26	54.63	263	173.96	9.53	28.90	5.46	27
M1BL	188	3.71	--	304	--	6.00	--	4.70	--
M1FL	437	5.78	55.60	590	94.08	7.52	25.40	6.08	29
M2BS	55	4.23	--	84	--	6.46	--	4.55	--
M2FS	176	6.39	50.92	228	171.43	8.27	28.01	5.80	28
M2BL	149	2.94	--	244	--	4.82	--	4.90	--
M2FL	330	4.36	48.26	459	88.11	6.07	25.90	6.60	35

Figure 2 shows the effect of multiple layers of wire mesh on the first cracking strength of the column. It is seen that cracking strength increases with the increase of number of layers of wire mesh up to three layers but the trend of strength enhancement changes after that.

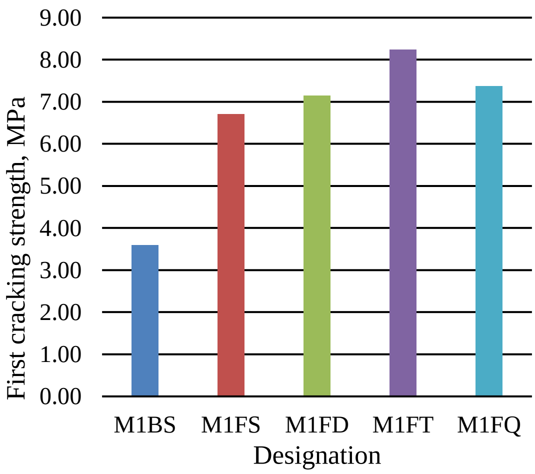

Fig. 2. Effect of multiple layers of wire mesh on the cracking strength

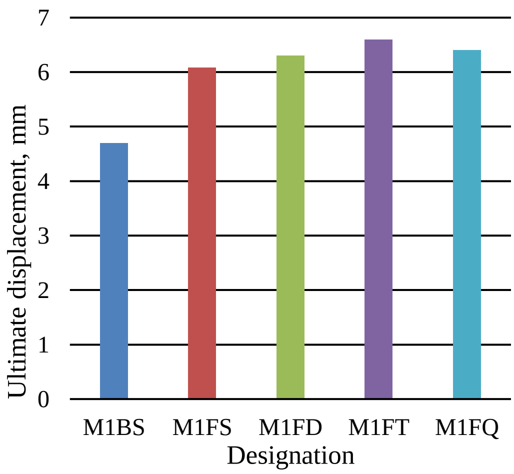

Fig. 3. Effect of multiple layers of wire mesh on the displacement.

Figure 3 shows the effect of multiple layers of wire mesh on the displacement of the columns. It is seen that columns undergoes large deformation with the increase of number of layers of wire mesh up to three layers but the trend changes after that as in the case of strength enhancement. This similarity implies a dependable reaction to the employed strengthening approach. The enhanced load carrying capacity observed in the Table 3 indicates that the strengthened columns possessed an increased ability to withstand applied loads. This improvement in axial capacity is a positive outcome, as it signifies the effectiveness of the strengthening method in enhancing the structural performance of the columns. Furthermore, Figure 3 depicts a substantial increase in the deformation ability of the strengthened columns compared to their non-strengthened counterparts. This elevated ductility is a desirable attribute as it allows the columns to undergo larger deformations while maintaining structural integrity.

6. Conclusion

Strengthening using Ferrocement overlay has shown to be a viable and efficient way to reinforce different kinds of brick masonry columns. The investigation showed that the brick masonry columns' performance significantly improved after going through the strengthening process. The first cracking strength averaged a surprising 49% improvement, demonstrating the approach's significant advantages. Further highlighting the efficiency of ferrocement overlay strengthening, the ultimate strength of the strengthened columns showed an average increase of 27% in comparison to the control specimens. Notably, in comparison to the control specimens, the strengthened columns showed an average increase in deformation ability of 32%, clearly demonstrating their improved ductility. These results demonstrate the applicability and viability of ferrocement overlay as a proven method for strengthening and enhancing the load-bearing capacity.

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