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Flexural and Shear Strength of Reinforced Perforated Clay Brick Masonry Members

Ehab M. Lotfy, Hassan A. Mohamadien, Hussein Mokhtar Hassan

***Abstract*— Masonry is one of the oldest construction materials. For thousands of years masonry was the predominant building material until modern materials such as concrete and steel. In this research, experimental work has been done to study the flexural and shear behavior of reinforced perforated clay brick masonry beams subjected to flexural and shear. Ten beams with different shear span to depth ratio (a/d = 2,3,4 and 5) were tested, two control beams without flexural and shear reinforcement, two beams with only longitudinal tension and compression reinforcement and in the remaining six beams besides to the longitudinal tension and compression reinforcement, stirrups were provided with different spacing of 7.5, 15, and 22.5cm to study the effect of shear reinforcement ratio. The results present cracks patterns, deflections, flexural and shear strength of the tested beams. The failure modes varies from sudden flexural failure for beams without flexural and shear reinforcement to sudden shear failure for those without shear reinforcement. However, for beams with different shear reinforcement ratio, the mode of failure varied from shear failure to combined shear and flexural failure or flexural failure only depending on the shear reinforced ratio. Flexural, shear strength and ductility were significantly increased with adding longitudinal and shear reinforcement. The flexural strength increased to ten times for beams with flexural reinforcement compared with those without flexural reinforcement. Also it was noted that providing of shear reinforcement leads to enhance the flexural capacity of the beams and to increase shear strength, and ductility of the tested beams depending on the shear reinforcement ratio.**

***Index Terms*—Perforated clay brick, reinforced masonry, flexural strength, shear strength.**

I. INTRODUCTION

It is a well-established fact that clay has remained in use as universally available material of construction since thousands of years. When technology was not available, people resorted to clay, both sundried and baked in the form of bricks to construct the walls. The use of reinforced masonry is a desirable and now is a common construction practice. Reinforced masonry is used in lintels and retaining walls of basements as well as in fences. These masonry walls are subjected to out-of-plane bending relates to the resistance of walls subject to lateral loads from wind, earthquake, or earth pressures, and to eccentric load or direct loading due to gravity. Therefore attempts have been made to study the fundamental structural properties as well as flexural and shear behavior of beams manufactured from baked clay with post-reinforcement using grouting as bonding material[1].

Let it be known that the senior author has remained engaged in research for last more than twenty years [2].
This research intends to clarify the effect of flexural and web reinforcement on the ductility, flexural and shear strength. Experimental works were carried out on reinforced perforated clays brick masonry beams at ultimate level to shows how the flexural and web reinforcement ratio affect the ductility, ultimate flexural, shear strength and mode of failures of reinforced perforated clays brick masonry members. According to several authors, their design can be performed using the ultimate strength design method similar to that used for reinforced concrete beams [3.4]. In spite of Euro-code [5] provides the design of masonry beams under flexure and shear, by applying classic formulations used for homogeneous materials; very limited experimental and numerical information is available in the literature about the resisting mechanisms characterising the behavior of masonry beams under in-plane shear and bending. Based on experimental research carried out on masonry beams with variable depth to length ratios and variable tensile reinforcement ratios, Khalaf et al.[3] confirmed the assumption that plane sections remain plane during bending and obtained an ultimate compressive strain for masonry of about 0.003. According to Jang and Hart[6] and Adell et al.[7], uniform distribution of longitudinal reinforcement leads to the increasing of shear resistance by dowel action. Another important aspect regarding a section in bending is its compressive strength, which can play a significant role in the resisting moment [8].

II. TEST PROGRAM

Perforated clay bricks were assembled with mortar (water: cement: sand with ratio 1: 1: 3). The compressive strength of the assemblage masonry brick, f_m was 15 MPa. The assembled bricks formed a masonry bricks beams of a width; 120 mm, and total depth; 250 mm (effective depth, d = 210 mm) and length of 1800 mm. Flexural reinforcement has two bars of diameter 10 mm (f_y = 360 MPa) in tension side and one bar of diameter 8 mm (f_y = 240 MPa) in compression side which passed through the holes of perforated clay brick during assembling using mortar mentioned above. A triangle stirrups of diameter 6 mm (f_y = 240 MPa) were provided between courses through which the longitudinal reinforced bars were passed.

The specimens were divided into two groups A and B. The difference between groups A and B was only the shear span to depth ratio a/d, for group A (a/d = 2.0 and a/d = 5.0) and for group B (a/d = 3 and a/d = 4.0).

Table (1) shows the details of tested specimens; control

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Ehab M. Lotfy, Civil Engineering Department, Suez Canal University / Faculty of Engineering / Associate Professor, Ismaelia, Egypt, 0020552313892/ 00201149429507.
Hassan A. Mohamadien, Civil Engineering Department, Suez Canal University / Faculty of Engineering / Professor, Ismaelia, Egypt, 00201006077707.
Hussein Mokhtar Hassan, Civil Engineering Department, Suez Canal University / Faculty of Engineering / Lecturer, Ismaelia, Egypt, 00201113591660.

clay brick masonry beam without flexural and shear reinforcement (A_0 and B_0 Beams), (A and B beams) with only flexural reinforcement, (A1 and B1 Beams), (A2and B2 Beams) and (A3 and B3 Beams) with stirrup at spacing 7.5, 15, 22.5 cm respectively.

The specimens were tested under vertical static load up to failure. Deflection and cracking were recorded at different stages of loading. Fig. (1) shows the outlines of the tested beams.

Table (1): Layout of tested beam

Beam	a/d (left, right)	Ten. Reinf.	Comp. Reinf.	Stirrup diameter, spacing
Ao	2, 5	None	None	None
A	2, 5	2D10mm	1 D8 mm	None
A1	2, 5	2D10mm	1 D8 mm	D6 mm, 7.5cm
A2	2, 5	2D10mm	1 D8 mm	D6 mm, 15cm
A3	2, 5	2D10mm	1 D8 mm	D6 mm, 22.5cm
Bo	3, 4	None	None	None
B	3. 4	2D10mm	1 D8 mm	None
B1	3, 4	2D10mm	1 D8 mm	D6 mm, 7.5cm
B2	3, 4	2D10mm	1 D8 mm	D6 mm, 15cm
B3	3, 4	2D10mm	1 D8 mm	D6 mm, 22.5cm

III. TEST RESULTS

A. Behavior of Beams and Mode of Failure

For the control beams (A_0 and B_0 Beams) which had no flexural and shear reinforcement, it was observed that such beams failed suddenly at very small loads (2, 1.8 kN respectively). For (A and B beams) which had only Longitudinal tension and compression reinforcement and had no web reinforcing, shear cracks commenced at shear stress (0.3MPa, 0.25MPa) respectively and the shear cracks widened rapidly followed by a sudden shear failure as shown in fig.(1). For beams with web reinforcement (A1, B1 Beams), (A2, B2 Beams), and (A3, B3 Beams), tests indicated that increasing of web reinforcement ratio prevents diagonal tension failure and allow the full flexural capacity to be developed. The shape of failure varied from shear to flexural failure depending on the web reinforcing ratio. Fig.1 shows the different mode of failure for all beams.

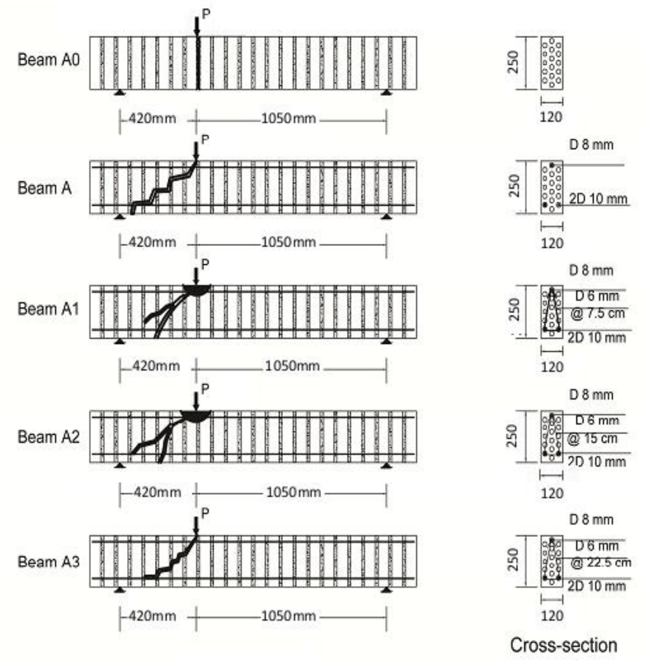

Figure (1-a): layout and mode of failure of tested beams (group A)

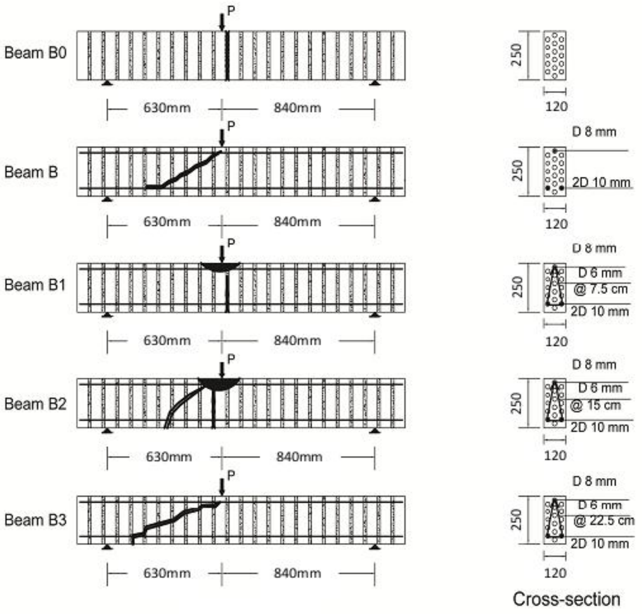

Figure (1-b): layout and mode of failure of tested beams (group B)

B. Ductility and Flexural Strength

The flexural behavior of reinforced clay brick masonry beams is very similar to that of reinforced concrete beams. The design of reinforced masonry should follow as closely as possible the current practice used for the design of reinforced concrete [9,10] using limit state design. The calculated ultimate moment, M_u for the tested reinforced beams is based on a maximum compressive strain of 0.003 as specified in the Canadian code [11] and it was found to be (M_u=11 kN.m) which is closely to ultimate bending moment of the tested beams. The measured deflection at the location of loading point for different stages of loading was plotted against the corresponding bending moment for all beams up to failure. It was observed that a brittle and sudden failure occurred for beams without flexural and web reinforcement. Means while for beams with flexural reinforcement only (A1, B1 Beams), exhibited an enhancement in flexural strength and ductility. They failed eventually in sudden shear. Moreover, for beams provided with web reinforcement, the ductility increased significantly with the ratio increasing of web reinforcement. Fig (2) shows the relation between the measured deflections against corresponded bending moment for different beams of group A and group B. Also fig. (3) shows the ultimate flexural strength for all beams of group A and group B. It can be seen that the flexural strength increased ten times for beam with flexural reinforcement compared with beams without flexural reinforcement and increased about twenty times for those with flexural and shear reinforcement; spacing 7.5 cm compared with for that without reinforcement. Table 2 shows the test results of ultimate moment and ultimate deflection of the tested beams.

Table (2): Test results of tested beams

Beams	Ultimate Load (kN)	Ultimate Moment (kN.mm)	Max. Deflection (mm)
A0	2.000	600	0.55
A	2.200	6500	3.67
A3	32.000	9600	6.5
A2	33.000	9900	10
A1	40.000	12000	14
B0	1.800	648	0.75
B	11.000	3900	4.2
B3	25.000	9200	8
B2	32.000	11500	14
B1	34.000	12200	18.7

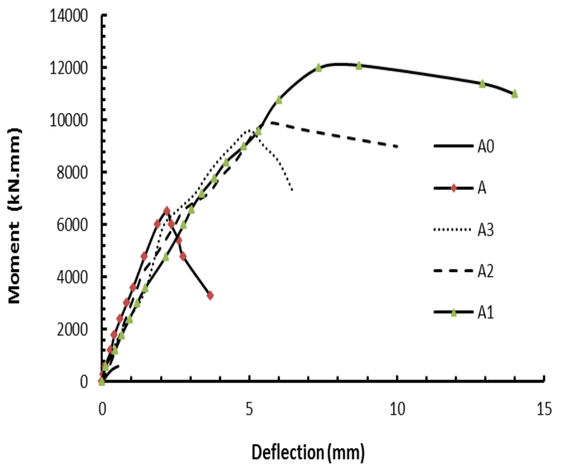

Fig (2-a): Moment - Deflection relationship for group A

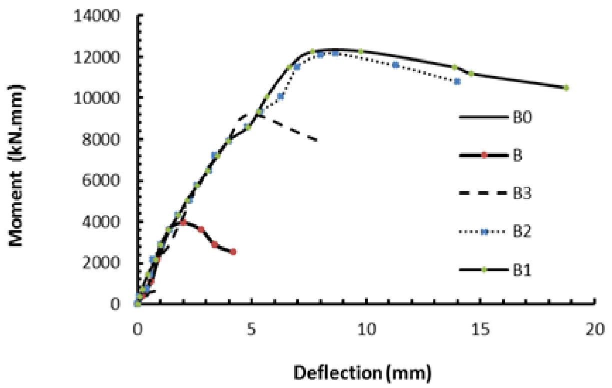

Fig (2-b): Moment - Deflection relationship for group B

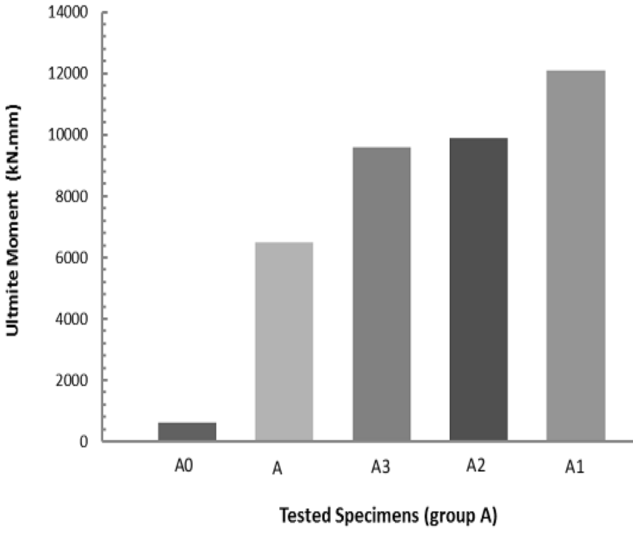

Fig (3-a): Ultimate Flexural Strength of A beams

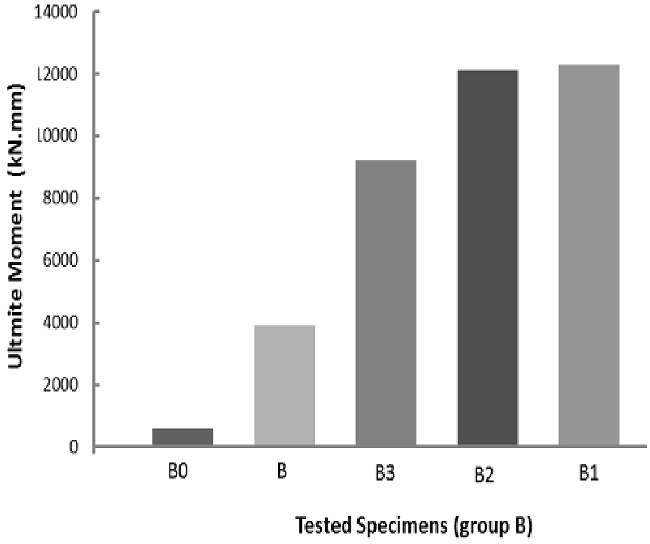

Fig (3-b): Ultimate Flexural Strength of B beams

C. Shear Strength

From the test results, the shear behavior of the tested beams is similar to that of reinforced concrete beams. For beams without web reinforcement (A and B Beams), once the shear crack commenced, it immediately widened and propagated towards compression zone causing sudden shear failure. For beams with web reinforcement, the behavior and mode of failure were different depending on the web reinforced ratio. Fig.(4) shows the relationship between shear stress and web reinforcement ratio for the tested beams. It can be seen that the shear stress is significant effect with increasing web reinforcement ratio.

Fig. (5) shows the relationship between shear stress and shear span to depth ratio, a/d for the tested beams. It can be seen that shear stress has significant effect with shear span to depth ratio, where shear stress decrease greatly for $a/d < 3$, and decrease moderately for $a/d \geq 3$.

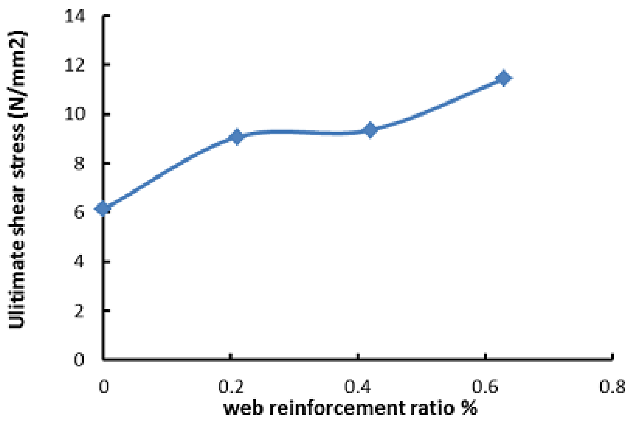

Fig (4): Shear stress and web reinforcement ratio

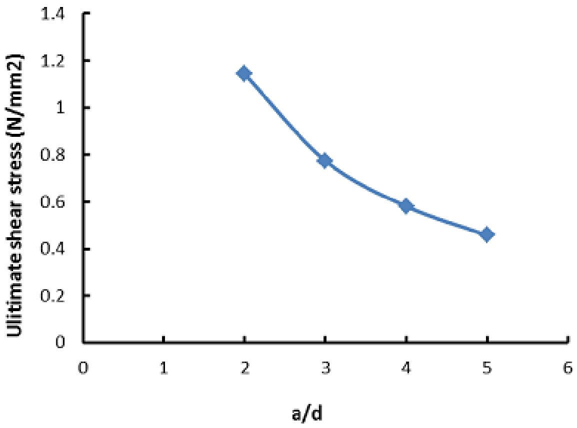

Fig (5): Shear stress and shear span to depth ratio a/d

IV. CONCLUSIONS

From the experimental study on the efficiency of flexural and web reinforcement on the perforated clay brick masonry beams, the following conclusions can be drawn.

1) Mode of failure of specimens is affected by flexural reinforcement and web reinforcement ratio.
2) Ductility increased significantly with the increasing of web reinforcement ratio
3) The flexural strength of flexural reinforcement beams increased ten times compared with that without flexural reinforcement
4) The efficiency of flexural reinforcement increases with adding web reinforcement ratio.
5) The flexural strength of beams with flexural and shear reinforcement; spacing 7.5 cm increased about twenty times compared with that without flexural reinforcement
6) Ultimate shear strength of specimens is affected strongly by web reinforcement ratio.
7) Ultimate Shear strength has significant effect with shear span to depth ratio, where shear stress decrease greatly for a/d < 3, and decrease moderately for a/d ≥ 3.

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