Crack propagation of the FRP strengthened masonry walls

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Abstract:

Fiber reinforced polymer (FRP) composite materials are developed options for strengthening of masonry buildings. The application of FRP composites as externally bonded reinforcement in repairing and strengthening the masonry walls has becoming more attractive than the traditional methods which are based on steel elements.

FRP materials are being used in structural engineering in different shapes, such as bars and tendons for concrete or masonry elements; fabric and laminates for strengthening of the walls, beams, columns or other parts of structures.

Crack propagation and failure mode of civil structures due to different types of loading are very important parameters that must be evaluated to determine the behavior of these structures.

In this research, an experimental study has been conducted to evaluate crack propagation and failure mode of FRP strengthened masonry walls. Wall panels made of clay brick and strengthened using different type of FRP composites have been investigated and failure mode of them is analyzed.

Keywords: Masonry walls, FRP, Failure mode, crack propagation

1. Introduction:

Most of the existing unreinforced masonry (URM) walls have a low resistance against lateral loading and are vulnerable to earthquake and wind effects due to their low flexural capacity and relatively brittle mode of failure (Bocca, 2008). Thus, effective techniques are needed to strengthen these walls and structures against the above loading conditions.

Many techniques are available to strengthen and retrofit URM walls. The traditional techniques, such as the use of steel reinforcements and post tensioning, present complications in their application due to the excessive time required for application, the disruption of operation and the difficulties in handling of materials. In addition, the weight of materials, such as steel and concrete, significantly increases the mass of structural elements, resulting in the increase of inertial forces produced due to seismic loads and earthquakes.

An alternative method for strengthening and retrofitting the masonry structures is the use of fiber reinforced polymer (FRP) composites, adhered to the surface of the wall to resist lateral loads. The use of FRP composites has emerged as a promising retrofit solution and has grown very rapidly in recent years. FRP materials show high strength to weight ratio, high resistance to chemical and environmental corrosion, high fatigue resistance and can be formed to complex shapes (Seible et al., 1997). They are quick to apply and the cost of these materials has dropped significantly in recent years.

As the use of FRP composites is a new approach to strengthening and resistant design, there is little available test data and theoretical models to be used as a basis for the design of wall upgrades. For the definition of a state-of-the-art technique, there is a need of a collection of various significant case studies.
The aim of this study is to determine the flexural behavior of FRP strengthened masonry walls with different types and configurations of FRP composites.

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2. General setup for experimental study of masonry walls

2.1. Preparation of the masonry walls

The walls are with dimensions 1800mm×1800mm (height×length) supported at all four sides and loaded with UDL via airbag. The ultimate load was accepted to be the load at which the wall collapse in case of brittle failure or the load causing excessive deformations in case of ductile behavior. For this work the excessive deformation is accepted to be h/100 (h is height of the wall) for health and safety reasons.

The dimensions of tested walls in this research are smaller than the dimensions of real walls. However, the proposed work is about comparison of the out-of-plane behavior of different types and configurations of FRP strengthened masonry walls, and for similar dimensions of the walls, the out-of-plane behavior of them is evaluated.

Five specimen walls were constructed with clay bricks and mortar. Samples were constructed as a single layer brick masonry walls (1/2 brick thickness equal to 102mm thickness, Photo1).

Photo 1. General view of ½ brick thickness walls and airbag

The bricks were layered with a sand; cement; lime (6:1:1) mortar, which represents the type M4 according to UK National Annex to EC6. The cement used was Portland cement and the lime used was Hydraulic lime. Sand, cement and lime were mixed together with proper amount of water (to have a plastic consistency and uniform mortar) in the laboratory using a mixer. The thickness of bed joints between bricks rows was kept about 10mm.

All sample walls had dimensions of 1800mm×1800mm . The selection of the dimensions for samples was based on assumption of large scale modelling close to full-scale load bearing walls. The span of the reaction frame was about 1530mm, thus 135mm of the length and height of the walls in each edge was in contact with the frame. General recommendations for construction of the walls, indicated in the EC6 were applied.

2.2. Applying FRP composites to the walls

The FRP composites were attached to the masonry walls after 28 days from completion of construction of each wall, as to conform with BS EN ISO 14125:1998.

Three different FRP composites were used to strengthen the URM walls and they are as follows:

- Glass Fiber Reinforced Polymer composites (GFRP) as wrapping,
- Carbon Fiber Reinforced Polymer composites (CFRP) as laminates,
- Basalt Fiber Reinforced Polymer composites (BFRP) as bars,

2.3. Configurations of FRP applications in this research

Different configurations of strengthening for masonry walls, used in this research, are as follows:

- Strengthening with one layer of GFRP wrapping on the tensile side of masonry wall,
- Strengthening with two parallel vertical CFRP laminates on the tensile side of masonry wall.
- Strengthening with two parallel vertical CFRP laminates and two parallel horizontal CFRP strips on the tensile side of the masonry wall (cross strengthening),
- Strengthening with two parallel vertical CFRP strips and seven parallel horizontal BFRP bars in the mortar joints on the tensile side of masonry wall.

The names and the relative configuration of strengthening of the walls are listed in Table 1.

Table 1. Names of the walls

No.	Thickness of the wall	Type and configuration of strengthening	Name of the wall (symbol)
1	½ brick thickness (102mm)	Control wall, without strengthening,	Wall 1
2	½ brick thickness (102mm)	Strengthened with one layer of GFRP in the whole surface,	Wall 2
3	½ brick thickness (102mm)	Strengthened with 2 parallel laminates of CFRP in vertical direction,	Wall 3
4	½ brick thickness (102mm)	Strengthened with 2 parallel laminates of CFRP in vertical direction and 2 parallel CFRP laminates in horizontal direction (cross),	Wall 4
5	½ brick thickness (102mm)	Strengthened with 2 parallel laminates of CFRP in vertical direction and 7 parallel BFRP bars in horizontal direction,	Wall 5

An airbag (photo 1) covering the whole surface of the wall was placed between the wall and the reaction support and strapped to the strong reaction frame (Photo 1). In each test, the airbag was filled with air using a foot pump to apply uniform out-of-plane pressure to the wall. During the whole process of loading, the pressure was recorded using a digital pressure gauge. The pressure was applied in increments of 0.5 kN/m². Two readings of pressure were recorded for each increment, one at the beginning and the other after 5 minutes.

3. Experimental test results for test over the masonry walls

The experimental study on the masonry walls produced results for the out-of-plane behavior of strengthened masonry walls under uniform pressure in terms of maximum strength, initiation of cracks and propagation of cracks. Initiation and propagation of cracks in masonry is monitored during loading.

3.1. Results for control wall (URM, wall 1)

No cracking was observed in the wall up to the pressure of 10kN/m². When the pressure exceeded 10kN/m², some small vertical cracks appeared in the middle of the wall. At pressure equal to 10.3kN/m², the wall suddenly failed with many cracks appearing in the middle of the wall (Photo 2), propagating towards the corners of the wall, showing the flexural failure.

The mode of failure for wall 1 was brittle and the ultimate load was about 10.3 kN/m².

Photo 2. Damage of the control wall (wall 1)

3.2. Results for GFRP wrapping strengthened masonry wall (wall 2)

During loading, when the pressure was about 19.4 kN/m² some noise was heard from the GFRP composites, which means that the delamination of the GFRP composites have started. At a pressure of 22.5 kN/m² delamination propagated from the middle toward the edges of the wall. Significant area of the GFRP wrapping was delaminated from the wall loaded near to the ultimate load, which was considered as warning sign for approaching the destruction of the wall.

The ultimate load was 31.5 kN/m² and at this pressure, the deflection of the wall was increasing without any further increase in the pressure.

The mode of failure was observed to be ductile and many small cracks appeared in the wall. Photo 3 shows delamination between the wall and GFRP composites, which appeared at the ultimate load.

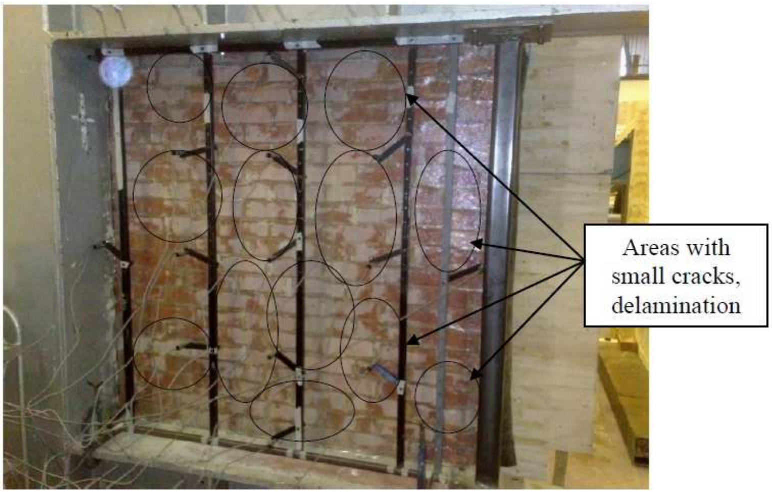

Photo 3. Damage of the wall 2

3.3. Results for CFRP-Vertical strengthened masonry wall (wall 3)

At a pressure of 23.5kN/m², a small vertical crack appeared in the middle of the wall and it developed toward the corners of the wall with increase in the load (Figure 1). When the pressure was about 25.5kN/m², cracks were visible easily. Finally, at a pressure of 32.5kN/m², the wall suddenly failed (Photo 4).

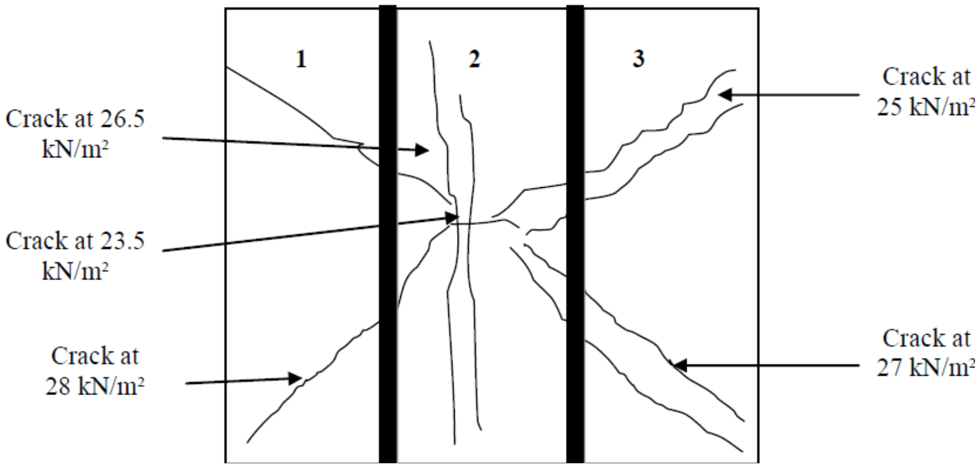

Figure 1. A scheme of the cracks before the collapse, Wall 3


Photo 4. Damage of the Wall 3

3.4. Results for CFRP-Cross strengthened masonry wall (wall 4)

A general scheme of cracks before collapse of the wall is presented in Figure 2. When pressure was about 6kN/m², first cracks appeared in the top-right corner of the wall (area 3). At a pressure of 24kN/m², a very small and vertical crack appeared in the middle of area 2. Small vertical cracks developed in the middle of areas 5 and 6 when the pressure was 27kN/m². At a pressure equal to 32kN/m² a very small vertical crack appeared in the middle of area 8 and diagonal cracks appeared in areas 1 and 3 at a pressure of 38kN/m². Diagonal cracks in areas 7 and 9 appeared at a pressure of 38.5kN/m².

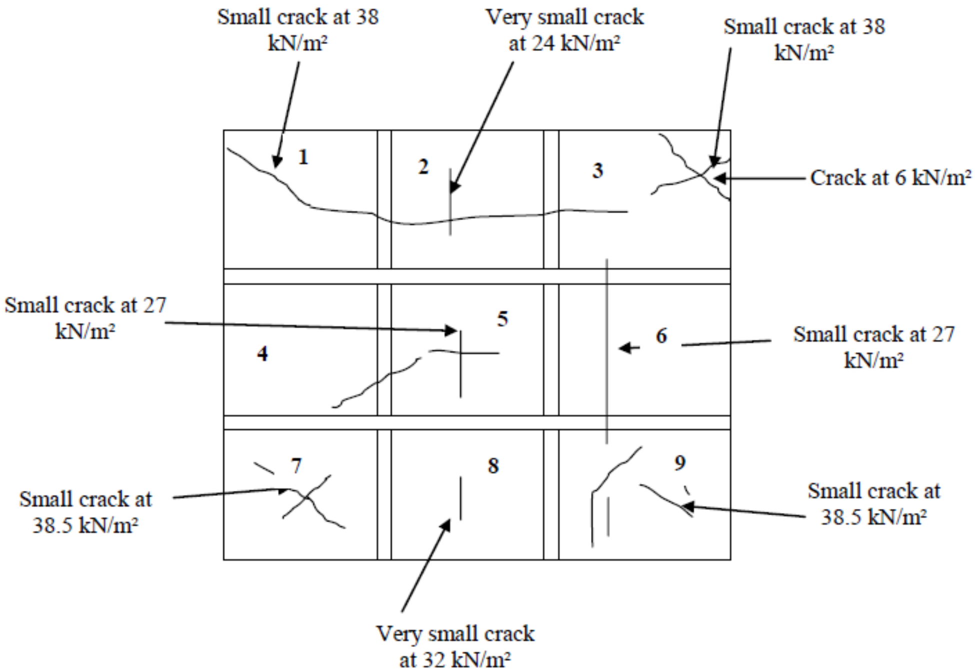

Figure 2. A scheme of the cracks before collapse, wall 4

At a pressure equal to 39.5 kN/m², the wall failed suddenly in a brittle mode. Photo 5 shows the cracks of the wall after destruction.


Photo 5. Damage of the wall 4

3.5. Results for the wall strengthened by BFRP (horizontal bars) and CFRP vertical laminates (wall 5)

The cracks observed before the collapse of the wall are presented in Figure 3. First crack appeared in the middle of the wall when the pressure was about 36kN/m². At a pressure of 38kN/m², some small and diagonal cracks appeared in the middle of area 2 and between BFRP bars 2-3 and 4-5 from top edge of the wall. At a pressure of 42kN/m² diagonal cracks developed from the middle of the wall toward the corners and finally when the pressure increased to 45.5kN/m², the wall failed in a brittle mode of destruction (Photo 6).

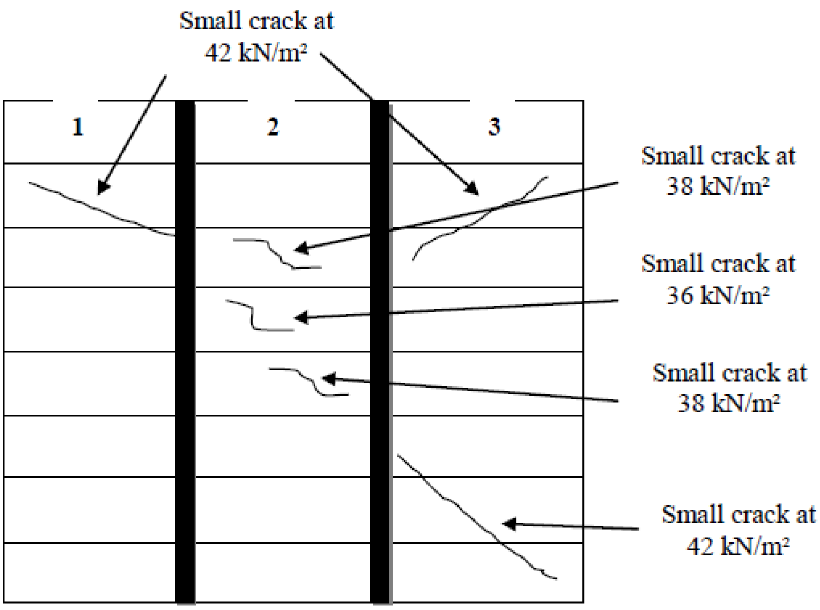

Figure 3. A scheme of the cracks before collapse of wall 5

Photo 6. Damage of the wall 5

4. Analysis of the results for masonry walls

The ultimate loads and modes of failure for all walls are presented in Table 2.

Table 2. Ultimate load and type of collapse for walls

Wall number	Ultimate load (kN/m²)	Type of failure
Wall 1	10.3	Brittle
Wall 2	31.5	Ductile
Wall 3	32.5	Brittle
Wall 4	39.5	Brittle
Wall 5	45.5	Brittle

All FRP composites significantly increased the flexural strength of the walls. Failure modes for all tested walls were due to bending with some local shear cracks in some walls.

The results pointed out that wall 2 (GFRP wrap strengthened masonry wall) presented ductile bending behaviour, while the other types and configurations of strengthening provided a brittle mode of failure. BFRP horizontal bars and CFRP vertical laminates together performed better than other configuration of strengthening, in term of increasing the ultimate load (wall 5). This is due to attachment of the BFRP bars to the wall in relatively small distances (220mm) and in the horizontal direction.

5. Conclusions

The main results of this study are summarized as follows:

- All types of used FRP strengthening are increasing at least 3 times the out-of-plane capacity of ½ brick thick URM walls.

- Highest ductility in terms of maximum deflection at ultimate load is observed for wall 2 with GFRP wrapping. This wall recovered significant part of its initial shape after unloading.

- Strengthening of masonry walls using horizontal BFRP bars and vertical CFRP laminates is most effective method between the investigated methods in aspect of increasing the ultimate load.

6. References

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