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EFFECT OF THE SCHEMES OF FIBER REINFORCED POLYMERIC LAMINATES ON THE OUT-OF-PLANE BEHAVIOR OF UNREINFORCED MASONRY WALLS

S. H. ALSAYED
Department of Civil Engineering, King Saud University
Riyadh, P. O. Box 800, Saudi Arabia
salsayed@ksu.edu.sa

ABSTRACT

Four un-reinforced concrete brick walls and four un-reinforced concrete block walls were cast and tested to investigate the effect of different schemes of glass fiber reinforced polymer (GFRP) strips on the behavior of the walls when subjected to out-of-plane loading. A total of seven different schemes were considered in the study. An 860 × 860 mm air bag with 70 tons capacity was used to apply a uniform out-of plane lateral load on the walls. The test results show that GFRP schemes have major influence on the out-of-plane response of the walls. The variation in the flexural capacity of the tested brick wall due to the change in the GFRP schemes was up to 60% of the reference specimen. The corresponding variations in the out-of-plane deflection and the surface strain were 64% and 40 %, respectively. The results also show that the variation in the flexural capacity of the block walls was up to 56%. The corresponding variations in the out-of-plane deflection and the surface strain were 124% and 295%, respectively. The failure was always of premature type, started at the support due to shear and proceeded by interlaminate de-lamination. The effect of the FRP schemes on the out-of-plane behavior of un-reinforced masonry wall would have been more pronounced had, the flexural capacity of the wall was attained.

KEYWORDS

Concrete walls, Unreinforced, Composite sheets, schemes, GFRP, flexural capacity

1 INTRODUCTION

Concrete hollow block and clay bricks are the main materials usually used for non- load bearing masonry construction. Availability of necessary raw materials, suitable technology and appropriate equipment for block/brick production and the likely savings due to faster erection have substantially changed the economics of their use as compared to other structural materials. These blocks/bricks are proportioned so that their sizes enable manual laying. Over the years many shapes of blocks/bricks have evolved to suit various specific situations, which resulted in a large array of block/bricks shapes to select from.

In modern reinforced concrete buildings, masonry walls are mainly used as infill walls. Therefore, they are not usually designed to carry any lateral loads. As a result, when a reinforced building is exposed to an earthquake or blast loading, masonry walls are the first structures that fail. In fact, failure of Un-reinforced Masonry Walls (UMW) due to blast and earthquake loading is now considered as the main cause for the loss of human lives and property. Therefore, there is an urgent need to increase the capacity and ductility of UMW such that they can resist the blast and earthquake loading. On the other hand, FRP laminates, as external reinforcement to structural elements, have great potential in providing the structural element with the needed strength and ductility and they also have many advantages over other available materials. However, their efficiency in enhancing strength and ductility of the walls is a function of the FRP schemes. Nevertheless, the interaction between the FRP schemes, wall size and degree of improvement in strength and ductility of the walls due to the FRP reinforcement is not very well established.

2 OBJECTIVES AND APPROACHES

The main objectives of this study are: (i) To investigate the interaction between different schemes of FRP laminates used to strengthen Un-reinforced Masonry Wall (UMW) and (ii) To calculate the increase in capacity and ductility of the UMW when subjected to out-of-plane loading. For this purpose two series of UMW were cast and tested. Different schemes were used to strengthen the walls with FRP sheets. Different slenderness ratios were considered in the investigation. All test specimens were tested using an inflated air bag load fixture. The applied load on each test specimen was incrementally increased until the failure point was reached. Comparison of the test results provided the data needed to fulfill the objectives of the investigation.

There are several conventional methods available to strengthen the UMW to improve their resistance to blast and earthquake stresses. In recent years, however, strengthening of UMW with FRP sheets has received quite a lot of attention from researchers and practitioners. But the effectiveness of the sheets in enhancing the capability of the UMW is dependent on the scheme of applying the FRP sheets and the ratio of the width to depth of the walls. Finding a preferable FRP configuration among different possible schemes may lead to better efficiency and cost reduction, in utilizing the FRP system to increase both the out-of-plane capacity and ductility of the UMW.

3 LITERATURE REVIEW AND BACKGROUND

Retrofitting masonry walls with FRP should increase the out-of-plane flexural strength of the system and minimize the damage by producing a greater ductility of the wall and therefore greater energy absorption. Further, the external reinforcing fibers should confine the blasted wall and limit shattering and fragment generation. Properly designed fabric overlays should limit the injury from broken fragments to small areas.

Several studies have been carried out to investigate the increase in strength capacity and ductility of the UMW due to FRP strengthening but the data is scarce and not well documented. Tests of URM beam specimens by Ehsani et al. [1] have demonstrated that, by the use of proper thickness of FRP laminas or fabrics, it is possible to achieve the full capacity of the masonry at failure and to obtain large deformation capacity before the ultimate capacity of the strengthened system is reached. One of the early studies on the use of non-metallic reinforcement for strengthening of masonry walls was that of Croci et al. [2], who tested shear wall specimens with vertical or inclined reinforcement made of low modulus polypropylene braids (which do not fall in the class of high strength FRP composites). A few years later, Sweidan [3] demonstrated, through analytical development, the high effectiveness of a FRP post-tensioning system for pre-stressing masonry. Detailed concepts and analytical results on the applicability and effectiveness of FRP tendons to apply circumferential prestressing to the historic masonry structures are given by Triantaflllou and Fardis [4]. Hamid et al. [5] also tested the effectiveness of E-glass chopped strands as an external reinforcing material to improve the compressive, tensile and flexural strength of one-third scale hollow masonry. Test results indicated that the load capacity of the strengthened masonry was much higher than the control specimens. Reinhorn and Madan [6] conducted an experimental evaluation of un-reinforced masonry walls strengthened by the Tyfo W Fiber wrap system and noticed that the system was effective and observed that the failure of the externally reinforced specimens under in- plane loading occurred in three stages: (1) de-bonding in the center region of the walls; (2) breaking of fibers and, finally, (3) shear failure of the masonry walls.

Triantafillou [7] presented a systematic numerical analysis procedure for the short-term strength of masonry walls strengthened with externally bonded fiber-reinforced polymer (FRP) laminates under out-of-plane bending, in-plane bending, and in-plane shear. Based on the results of testing 12 wall specimens it was also noted that, when out-of-plane bending response dominates, the increase in the bending capacity is quite high.

Ehsani et al. [1] presented a new approach for seismic retrofitting of un-reinforced masonry structures. Six masonry beams with a composite fabric added to their tension side were tested in flexure. These tests showed that both the strength and ductility of the tested specimens were significantly improved. The failure modes were observed to be either premature tension failure of the fibers or compression failure of the masonry units. Ehsani and Saadatmanesh [8] also investigated the in-plane shear behavior of unreinforced masonry walls strengthened with fiber-reinforced plastic overlays. They noted that external FRP retrofit systems did not appear to significantly increase the in-plane shear strength of that type of wall system. Further, it was found that the fiber orientation had a major influence on the stiffness of the retrofitted system. Al-Shaar and Husein [9] performed a seismic analysis and shake-table seismic testing using USCERL's Tri-axial Earthquake and Shock Simulator on masonry walls retrofitted with Hexcell-Fyfe Tyfo composite systems. The results of the testing indicated that applying the overlay materials to one side of the unreinforced masonry walls enhances its seismic resistance.

Schwegler [10] was the first to propose and study the use of carbon fiber reinforced polymer (CFRP) laminates as a seismic strengthening material for the elements of masonry structures. He demonstrated the effectiveness of this technique through full-scale, both in-plane and out-of-plane cyclic testing of one-story masonry walls. Analytical model for the in- plane behavior of CFRP-strengthened walls within the framework of stress field theory was also developed in that study. The feasibility of enhancing the strength and ductility capacity of URM walls using carbon fabrics overlay was also demonstrated by Laursen et al. [11]. The tests carried out revealed that the application of carbon fabrics has changed the brittle shear failure mode of original wall to flexural failure and the deformation capacity of the wall was almost doubled.. Thus the overall findings of the work proved the effectiveness of retrofitting URM walls using carbon fabric overlays.

The above discussion indicates that others have found external reinforcement of structural systems with fiber composites, including masonry, an effective means of enhancing the strength of these systems. This paper summarizes an investigation of the use of FRP materials as a retrofitting technique for concrete masonry wall systems to increase their resistance to lateral out-of-plane blast loads.

4 EXPERIMENTAL PROGRAM

To arrive at the objectives of the investigation two series of UMW were constructed and tested. The first series consisted of four clay brick walls and the second consisted of four concrete block walls. Each wall was strengthened with one of the selected schemes of FRP sheets. All specimens were subjected to the same loading configuration until failure..

5 TESTING PROGRAM

5.1 Brick Walls

Four masonry brick walls were constructed with 200 × 100× 50 mm bricks and type I masonry cement mortar. All walls had a thickness of 100 mm. The designations given to the brick walls along with other details are presented in Table 1. To facilitate handling during transferring to the testing machine and to prevent any sudden movement during handling operations, the walls were constructed on steel channels and were braced with specially designed steel frame.

Table 1: Bick wall designations

Wall Name	Width (mm)	Length (mm)	Ratio h/L	Strengthening Scheme No.
BRW-A	1600	800	2	2
BRW-B	2000	1000	2	3
BRW-C	1000	800	1.25	4
BRW-D	2000	1000	2.0	5

L: Length of Wall, h: width of Wall

5.1.1 Brick wall materials

5.1.1.1 GFRP sheets

The GFRP composite materials used in series-1 tests were Fyfe- glass SHE-51A with Tyco S epoxy.

5.1.1.2 Epoxy

The epoxy used to bond the GFRP sheets to the surface of the wall consisted of two components (resin and hardener) with mixing ratio of 2.9:1 by weight, respectively. The glass transition temperature of adhesive (Tyfo S) was 84.75°C, its moisture absorption was 0.44% and its tensile strength was 82.72MPa.

5.2 Block Walls

In series II specimens, four 1740 × 1460 mm block walls designated as BLW-1, BLW-2, BLW-3, and BLW-4, were constructed using 400 × 200 × 100 mm concrete block units. All walls in this series had identical dimensions. Each wall was strengthened on its tension side with GFRP sheets (in a strip form) using one of the four schemes selected for this series of specimens. Thus, the only difference among the four block walls was the GFRP scheme used to strengthen the wall. After preparation, to prevent any sudden movement during handling operations, the walls were braced with specially designed steel frames.

5.2.1 Block wall materials

5.2.1.1 GFRP sheets

The GFRP composite system used in series II tests was SikaWrap Hex 100G sheets with SikaDur 300-Hex Adhesive.

5.2.1.2 Epoxy

The epoxy used to bond the SikaWrap GFRP sheets to the surface of the block walls also consists of two components (resin and hardener) with mixing ratio of 1:4 by weight. The glass transition temperature of adhesive (SikaDur Hex-300) was 88°C, its moisture absorption was 0.89% and its tensile strength was 71.59 MPa.

5.3 TEST setup

After being constructed, the walls (brick and block walls) were allowed to cure in controlled laboratory air for a minimum of 28 days under room temperature (23°C ±2). Following that, the surfaces of the walls were leveled using mortar to improve the contact area between the surface and the GFRP sheets. In this preparation, attention was given to cleaning the joints and removing excessive mortar from the wall surface. To clean the residual dust from the prepared surfaces, a light water was applied after brushing. The water was applied 48 hours prior to application of the composite overlay.

Based on ASTM Standard Test Methods of Testing Wall Panels for Construction, an 860×860mm air-bag with 70 tons capacity was used to evaluate the lateral strength of the retrofitted reinforced masonry wall systems. This assembly uses air to apply uniform out-of-plane lateral loads to walls positioned horizontally.

Wall specimens were simply supported in the horizontal testing frame at the top and bottom using I-beam supports. Five load cells were used to measure the loading at several points under the wall. Four load cells were at the edge of the specimen while the fifth was at the center. Each wall specimen was lifted and moved to the testing apparatus in a balanced manner by an overhead crane. The balanced lifting of the walls was necessary to avoid premature failure in the mortar joints. Five linear voltage displacement transducers (LVDTs) were used to monitor the response of the wall specimens to the applied lateral loads. In addition, strain gages were used to measure the strain in GFRP attached to the wall. The air bag pressure was measured electronically using a pressure transducer. All readings of strains, deflection, and bag pressure were recorded by a computerized data acquisition system at 2sec intervals.

5.3.1 Testing procedure

The testing of each wall consisted of the following steps:

1. Small air-pressure loads were applied to the specimen to ensure a complete contact of the specimen with the two upper and lower supports.
2. Once uniform support contact was achieved, the air pressure was released and an initial reading was recorded.
3. Uniform increases in air pressure were applied.
4. Throughout the test, the wall specimen was visually inspected for any distress and initiation of cracks. Attention was also focused on monitoring the air bag for any over inflated areas in which bubbles might form.
5. Air pressure was increased uniformly until failure of the wall was attained.

6 TEST RESULTS AND DISCUSSION

6.1 Brick Walls

The experimental data presented here for concrete brick walls were obtained from testing the 4 walls with different slenderness ratios and different FRP schemes. A summary of the maximum load carried by each wall along with the corresponding mid-span deflection and strain at the surface of FRP strip is presented in Table 2 and in Figs. 1 to 2. Unfortunately, all specimens failed due to de-lamination of the sheets preceded by shear failure in the vicinity of the support area, and therefore, none of the walls achieved its flexural capacity. This seems to add some difficulty to clearly single out the effect of the FRP schemes on the behavior of the walls. The test results clearly show that strengthening of un-reinforced brick walls by externally bonded FRP sheets significantly increases the out-of-plane flexural strength of the wall. Prior to strengthening, the walls were not even able to stand their own weight. The results also indicate that although wall A was strengthened with two strips whereas wall B with three strips (both walls had the same slenderness ratio), the first scored higher flexural capacity and lower out-of-plane deflection and surface strain at failure. This may be attributed to the fact that wall A had larger test span which implies higher deflection at lower load and thus shear and de-lamination occurred at a lower load. However, by using a better FRP scheme with wall D (identical to wall B except for the FRP schemes) the failure load of wall D increased by 24% over that of wall B. Also the out-of plane deflection and surface strain of wall D reduced by 10% and 35% respectively. On the other hand, reducing the slenderness ratio from 2 to 1.25 (wall C) and improving the FRP scheme led to great improvement in the flexural capacity. The increase in the flexural capacity of wall C over that of Wall A is 60%. The corresponding reduction in out-of-plane deflection and the surface strain is 64% and 40% respectively. Fig. 2 also shows that although wall B and Wall D had different FRP schemes, their flexural rigidities were almost the same. This may attributed to the fact that failure in both wall occurred before attaining their actual capacity. Furthermore, the wall with slenderness ratio of 1.25 scored the highest flexural rigidity than the other three walls. It is noteworthy to indicate here that, as explained earlier, since failure of the walls was due to shear and de-lamination of the sheets, it was not possible to correctly compute the effect of different GFRP schemes on the ductility of the walls. Therefore, further study on the out-of-plane walls is recommended. In the new study, special attention should be given to the size of the specimens such that failure would occur due to rupturing of the sheets.

Table 2: Max. flexural capacity, central deflection and mid-span surface

Brick Wall	Wall Dimensions (mm)	Scheme	Max Load Capacity (kN)	Max Deflection at Mid-Span (mm)	Average Strain in Fiber In Long Dir (mm/mm)	Average Strain in Fiber In Short Dir (mm/mm)
BRW-A	1600 x 800	2 Horizontal GFRP strips, 120mm	45.24	32.085	10138	- - -
BRW-B	2000 x 1000	3 Horizontal GFRP strips, 120mm	34.31	46.135	15636	- - -
BRW-C	1000 x 800	2 Dir GFRP Strips, 120mm	71.99	11.6	6110	229
BRW-D	2000 x 1000	2 Dir GFRP Strips, 150mm	42.54	41.465	10187	453

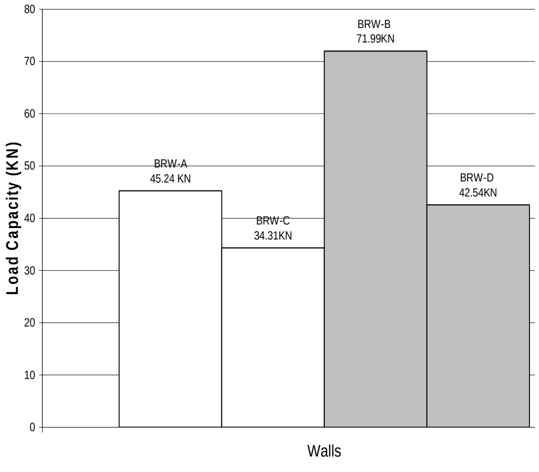

Fig. 1: Maximum flexural capacity of the brick walls

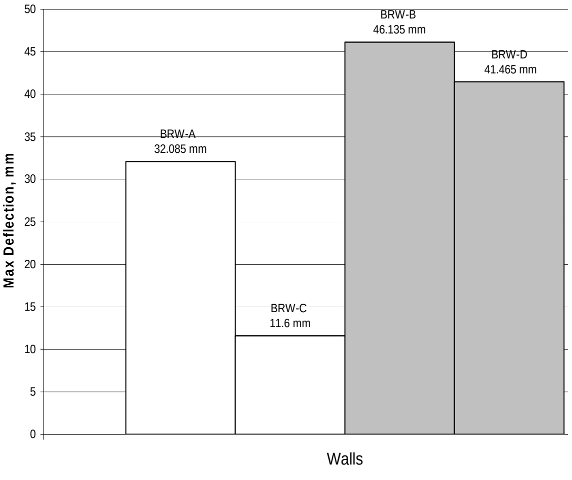

Fig. 2: Maximum central out-of-plane deflection at maximum load

6.2 Block Walls

The experimental data and result analysis of the concrete block walls obtained from testing the 4 walls with different GFRP schemes has been discussed in this section. A summary of the maximum load carried by each wall along with the corresponding mid-span deflection and strain at the surface of FRP strip is presented in Table 3 and in Figs. 3 and 4. Once again, all specimens failed due to de-lamination of the sheets preceded by shear failure in the vicinity of the support area. Unlike brick walls, block walls was able to carry some of the out-of-plane loading even without GFRP strengthening. At the start of loading the load deflection relationship (not shown here) was almost identical for all walls. This may be ascribed to the fact that at the start of loading most of the applied load was carried by the walls themselves and the contribution of the GFRP sheets in carrying part of the load was almost nil. However, at the onset of mortar crack the GFRP sheets start to work and compensate for the weakness of the walls due to the propagation of the cracks. At this stage of loading the response of the walls to the loading, vary with the type of GFRP scheme used to strengthen the wall. The load deflection relationship curves constituted of two parts. The first part represents the wall response to the applied load before cracking (pre-cracking stage) and the second part represents the post cracking stage where the GFRP sheets (strips) caries major part of the applied load. Therefore, the second part of the curves is greatly affected by the GFRP schemes used to strengthen the walls. Exception from that is the load-deflection relationship curve for Wall BLW-1 where its curve was composed of one segment (linear line) until the failure point. It seems that covering the whole wall with the GFRP sheet delayed the crack formation until the point where interlamination between the wall and the sheet occur. Wall BLW-1 scored the highest flexural strength where the applied load was 312 MPa and the corresponding mid-span deflection and strain on the GFRP surface were 6.94 mm and 3232 micro strain, respectively. Relative to BLW-1, due to the change in the GFRP schemes the maximum pressures in BLW-2, 3 and 4 were reduced by 38%, 56% and 40%, respectively. The corresponding increase in the maximum mid-span surface strains in BLW-2, 3 and 4, for the same reason, are 114%, 195% and 117%, respectively. These results clearly show that FRP scheme has a significant influence on the out-of-plane behavior of the walls. The influence is expected to be more pronounced had the walls failed due to FRP rupture. However, further study is needed to explore such a case.

Table 3: Summary of the maximum flexural load and the corresponding mid span deflection and strain for the block wall

Wall #	Wall Dimensions	Pressure (MPa)	Load (KN)	Mid-span Deflection (mm)	GFRP Strain at Mid-span (mm/mm)
BLW-1	1400×1650	311.8	151.72	6.94	3232
BLW-2	1400×1650	194.5	145.36	20.79	6911
BLW-3	1400×1650	135.7	50.93	15.54	9533
BLW-4	1400×1650	188.1	84.29	15.21	6999

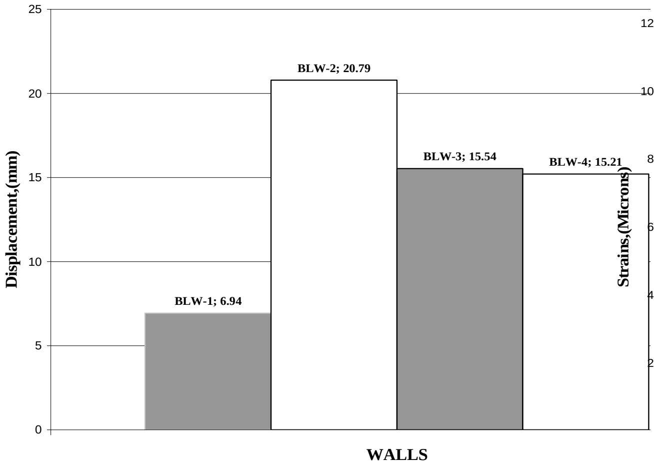

Fig. 3: Maximum measured out-of-plane displacement of concrete block walls

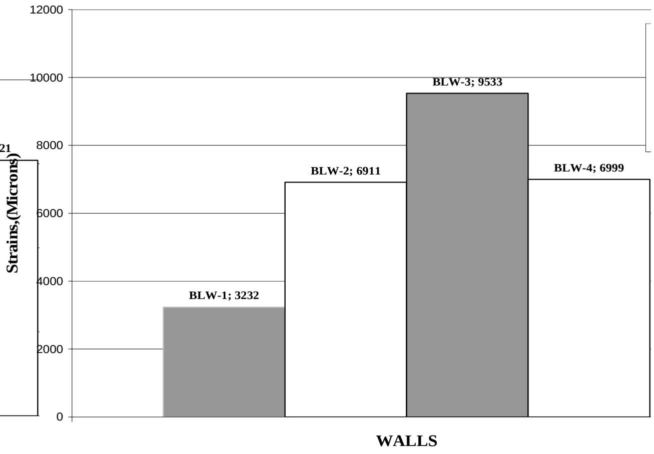

Fig. 4: Maximum measured Mid-span strain of concrete block walls

7 CONCLUSIONS

Based on the results of the tests carried out as part of this study program the following conclusions may be drawn:

1- Strengthening concrete brick or block walls with FRP sheets (strips) has significant influence in increasing their out-of-plane flexural capacity.

2- FRP schemes play a major role in the out-of-plane flexural capacity, deflection and surface strains of the walls.

3- All test specimens in this study could not develop their maximum flexural capacity as failure occurs due to shear at the supports and de-bonding of the FRP sheets.

4- Further study is needed to investigate the effect of strengthening FRP schemes on out-of-plane behavior of un-reinforced masonry walls for the case where flexural failure of the walls occur due to rupture of the composite sheets.

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