Strengthening of Masonry Walls Using Textile Reinforced Mortar

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Abstract— Unreinforced masonry (URM) structures constitute the largest part of the current worldwide buildings. Many of these buildings are of historic and cultural significance. The need for retrofitting of these structures is urgent due to the poor seismic performance under moderate and high seismic demand. The main objective of this study is to investigate the out of plane behavior of URM walls retrofitted with the new rehabilitation technique of basalt textile reinforced mortar. Eight masonry walls were constructed and divided into two groups (First group consists of four horizontally spanning walls and second group consists of four vertically spanning walls). The test parameters considered in this study were wall thickness and spanning direction. The test results demonstrate the effectiveness of the proposed technique where remarkably increase in the flexure capacity by 264% and 406%. Also, improvement deformability and energy absorption were achieved for all retrofitted specimens.

INDEX TERMS— Unreinforced Masonry, flexural loading, Basalt textiles, Basalt textile reinforced mortar, BTRM, strengthening.

1. INTRODUCTION

URM structures poses about 70% of existing buildings all over the world most of them are of historic significance and their damage and collapse represents serious problem for culture [1]. These structures may be subjected to Out of Plane loading causing them to bend out of plane. The loads could be permeant loads such as earth pressure loads against retaining walls or temporary loads such as wind pressure or seismic loads. Many of these URM structures are not designed to bear these horizontal loads.[2]&[3]

Most of existing URM were designed and built before the establishment of modern building code requirements for seismic resistance. Therefore, the need to retrofit these masonry structures has become a priority either because of inadequate design criteria or because of increase in seismic load demands.[12]

Many retrofitting techniques for masonry structures has proven their effectiveness in increasing their flexural capacity, but have also many drawbacks. Traditional techniques are often time consuming to apply, high cost, add considerable mass to the structure, this added mass could change the dynamic properties of the structure, affect the atheistic appearance of the structures and most of them are irreversible techniques. These problems may be overcome by using more recent techniques such as fiber reinforced polymers (FRP) instead of conventional methods. Since 1980 fiber reinforced polymer (FRP) were widely used as strengthening material for URM due to its advantages such as high strength to weight ratio, high stiffness and ease of application [4]. However, FRP as a strengthening technique for masonry structures has some drawbacks such as weak behavior at high temperatures due to epoxy resins, difficulty of applying FRP on humid surfaces, high possibility of harm to the workers when applying epoxies, lack of vapor permeability as polymer isolate water inside masonry, high cost of resin, strength incompatibility between masonry and fibers and poor bond due to rough surfaces of masonry [5]. To overcome FRP drawbacks researchers started to develop new techniques to be used in strengthening. One of these techniques is textile reinforced mortar (TRM) also known as fabric reinforced cementitious matrix (FRCM). It is a composite material comprising fiber roving embedded in an inorganic matrix. The epoxy resin is now replaced with Cementitious mortar. The strengthening system is applied by immersing the fiber roving in cementitious mortar.

The study of TRM has advanced since mid-1990s with studies on the microstructures of bonding between composites and inorganic matrices. Before that the cement mortar was used with fibers but with different fiber configurations. These configurations were either sheets of fiber in one direction, randomly mixed fibers or spherical direction. These fibers configurations were found to be very poor when bind with cement mortar compared to resins. To enhance the bond between fibers and matrix these configurations were replaced with open mesh of fibers (woven fibers) which was named later as textiles[6]. TRM reduces the drawbacks of FRP as they are easy to install, have good performance at high temperature and low cost when compared to FRP. Different types of fibers were used in TRM system as a reinforcement for the mortar such as: glass, aramid and carbon fibers. Recently, basalt textiles were used as a reinforcement for the mortar in TRM systems due to its advantages such as: high performance, high heat resistant, low cost, ease of manufacturing as they are made from natural basalt rocks, environment friendly, strength compatibility with masonry.[7]&[8]

The objective of the presented experimental program is to investigate the out-of-plane behavior of URM walls

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retrofitted using basalt textile reinforced mortar (BTRM) system. Some factors expected to enhance the performance, increase the flexural capacity and to prove the compatibility of the new retrofitting technique with URM walls. The factors considered in this study were: spanning direction and wall thickness. The bonding mortar was used is polymer modified (PM) mortar. The test results were analyzed and the effect of different variables under consideration were evaluated.

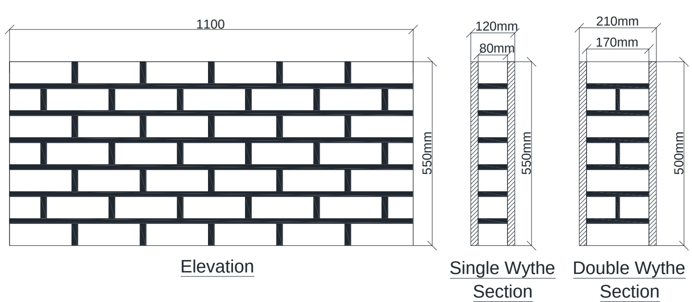
2. Experimental Program

2.1 Test Matrix

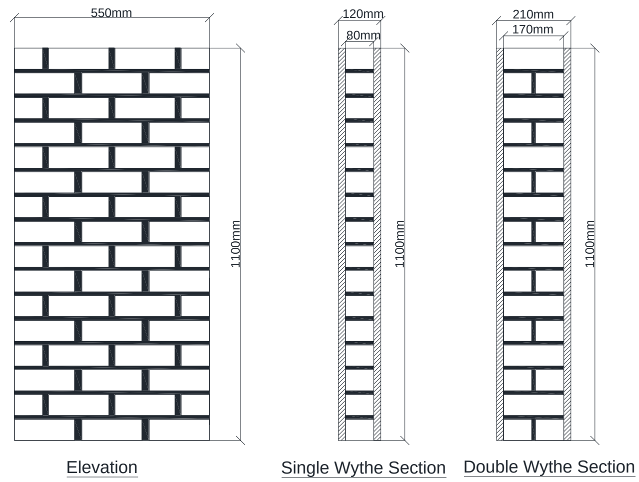
Eight unreinforced masonry walls were constructed, strengthened and tested under flexural loading. The specimens were divided into two groups. The first group was four specimens with loading span was perpendicular to the bed joint (vertically spanning). While the second group was four specimens with the loading span was parallel to the bed joint (horizontally spanning).

Solid clay bricks were used to construct these walls in running bond pattern. Four specimens were single wythe wall thickness and the other four were double wythe wall thickness. The nominal dimensions of the walls were 550×1100× 120mm for single wythe specimens and 550×1100× 210mm for double wythe specimens (this thickness includes 20mm mortar thickness added from each side) as shown in Figure 1.

Each group of specimens was distributed as follows: one single wythe control specimen, one double wythe control specimen, one single wythe specimen was strengthened with four layers of 5×5 mm textiles from one side (tension side only) and one double wythe specimen was strengthened with four layers of 5×5 mm textiles from one side (tension side only). The summarized test matrix is shown in Table 1.



a- Horizontally Spanning specimen nominal dimensions.



a- Vertically Spanning specimen nominal dimensions.

Figure 1: Nominal dimensions of the test specimens.

Table 1: Test Matrix.

No.	Loading Direction	Code	Wall Thickness	No of Layers
1	Vertical (perpendicular to bed joints)	V-C-S	Single	-------
2		V-C-D	Double	-------
3		V-S	Single	4
4		V-D	Double	4
5	Horizontal (parallel to bed joints)	H-C-S	Single	-------
6		H-C-D	Double	-------
7		H-S	Single	4
8		H-D	Double	4

*"C" refers to control specimens.

2.2 Material Properies

2.2.1 Masonry Properties

The masonry units used to construct all walls were solid clay bricks of average dimensions of 170 × 80 × 60 mm. The average compressive strength of the brick units and the masonry prisms (f'm) were 12.5MPa and 10MPa, respectively.

2.2.2 Mortar Properties

Two types of mortar were used in this investigation. The first type was masonry mortar that was used to construct all the wall specimens. The mortar chosen was Type-M confirming to ASTM C270-04a [9]. The second type was polymer modified mortar that was used in the application of the strengthening textiles to the walls. The mixing ratios of each mortar is explained in Table 2. Compressive strength and splitting tension tests were conducted to determine the mechanical propertied of the mortar. Three cubes of 50mm, for each test, were tested at the age of 28 days. The test results are summarized in Table3.

Table 2: Mixing ratios by volume of the used mortar.

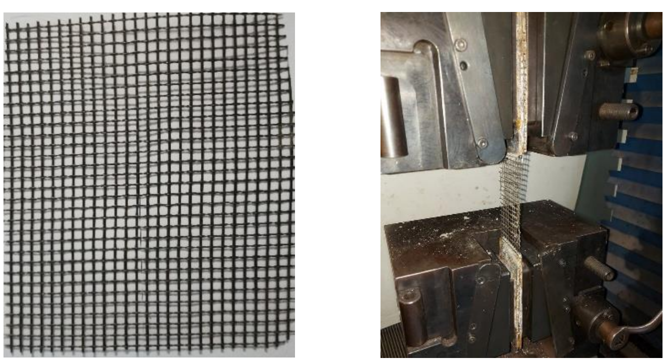
Mortar type	Cement	Sand	Hydrated lime	Latex	W/C ratio
Masonry mortar (Type-M)	1	3.75	0.25	-----	0.5
Polymer modified mortar	1	2.20	----	0.18	0.58

Table 3: Mechanical properties test results of the mortar.

Mortar type	Compressive strength. (MPa)	Splitting tension (MPa)
Masonry mortar (Type-M)	18.20	1.90
Polymer modified mortar	23.00	2.20

2.2.3 Basalt Textiles Properties

Basalt textiles mesh size opening configurations 5×5mm was used in this investigation as shown in Figure 2. Pin action tension test was conducted on the basalt textiles to determine its mechanical properties and results are shown in Table 4.



a) Textile mesh of size 5×5mm. b) Pin action tension test.

Figure 2: Basalt textiles and tension test.

Table 4: Basalt textiles mechanical properties.

Textile (mm)	Tensile strength (MPa)	Ultimate strain (mm/mm)	Modulus of elasticity (MPa)	Density (gm/m2)	Average thickness (mm)
5×5	855	0.0026	33	160	0.03

2.3 Specimens Preparation and Testing

2.3.1 Specimens Preparation

The specimens were constructed in running bond pattern at the same time by the same experienced mason. The specimens were cured using water spraying. All specimens were left at least 28 days before applying BTRM strengthening. The strengthening sequence was as follows: First, A splash cementitious coat was applied on the wall surfaces of all specimens, before applying the basalt textiles and polymer modified mortar, to produce a rough surface which improve the bond between PM mortar and the masonry wall. The splash coat layer was left to cure for 3 days. Second step, application of the BTRM, half of the PM mortar thickness (10mm) was applied. Then the basalt textiles were applied by immersing them layer by layer in the PM mortar to ensure the mortar enter between the openings of the textiles. Finally, another layer of PM mortar with 10mm thickness was applied on the top of the basalt textiles as a cover for the layers.

For specimens' sides with no reinforcement, one layer of PM mortar with 20mm thickness was applied on the top of the splash coat. Figure 3. shows the specimens preparation procedure.

a- Construction of specimens. b- Application of splash cementitious coat.

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c-Apply first layer of PM mortar.

d-Basalt textiles are applied.

e - Final layer of PM mortar is applied.

f- Specimens are ready for testing

Figure 3: Preparation procedure.

2.3.2 Specimens Testing

Wall specimens were tested under monotonic loading. All specimens were simply supported under three-point out-of-plane loading. The span between two supports for all specimens was 860mm. Load was applied using 100KN hydraulic jack reacting against the reaction of steel frame as shown in Figure 4. Two dial gauges were positioned in the middle of specimens to measure the mid-span deflection during the test. Electrical load cell with 100KN capacity was used to measure the test load.

Figure 4: Test setup of the flexural test for all specimens.

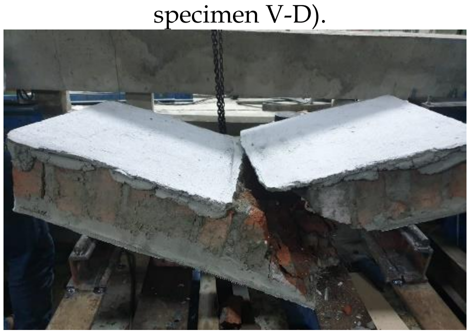
3. Test Results

3.1 Failure Modes

Three mode of failures appeared in this investigation. The first failure mode was tension failure which appeared in all specimens except for specimens H-D and V-D. This failure mode can be summarized as follows: when increase loading microcracks start to initiate in the mortar at the tension side, then basalt textiles start to bear the load till rupture occurs to basalt (the specimen fail immediately after textiles rupture). Same occur to the control specimens but differ that approximately only one straight crack pattern at the mid-span from the tension side. Figure 5.a. show the first failure mode. The second and third failure modes takes the same sequence of the first mode but the difference is that the failure is not at the tension side. The second mode is compression failure which appeared in V-D specimen, while the third mode is shear failure and it appeared in specimen H-D. Figures 5.b. and 5.c. shows the compression and shear failure modes.

a-First failure mode (tension failure).

b- Second failure mode (compression failure for specimen V-D).

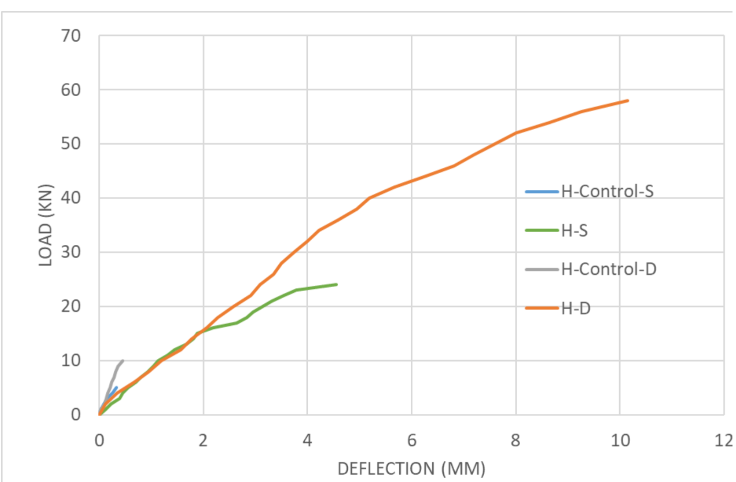


c- Third failure mode (shear failure for specimen H-D).

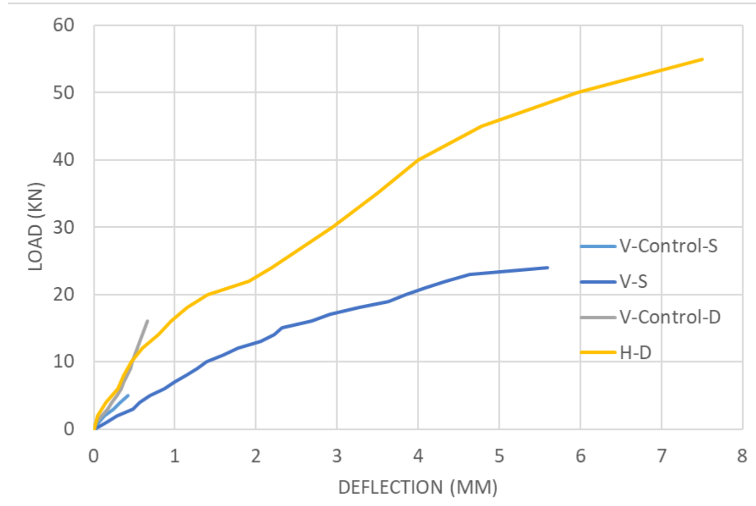
Figure 5: Failure modes.

3.2 Load Against Mid-span Deflection

The load against mid-pan deflection were recorded during testing for all walls as shown in Figure 6. Ductility is an important indicator to indicate the ability of element to sustain large in elastic deformation and to absorb energy. This property is important in design structures on seismic loads. The energy absorption can be used to describe the ductility of the walls. The walls behavior is linearly without yielding. E.A can be defined as the area under load against mid-span deflection curve. Detailed test results and energy absorption are described in Table 5.



a- Horizontally spanning walls.



b-Vertically spanning walls.

Figure 6: Load against mid-span deflection.

Table 5: Test Results.

Specimens	Code	Pfailure (KN)	Δfailure (mm)	E.A. (KN/mm)
Vertically Spanning	V-C-S	5.70	0.43	1.24
	V-C-D	16.40	0.65	4.62
	V-S	28.80	5.59	87.99
	V-D	55.00	7.50	292.09
Horizontally Spanning	H-C-S	5.60	0.33	1.07
	H-C-D	14.80	0.57	3.85
	H-S	28.00	4.56	74.46
	H-D	58.00	10.15	353.14

4. Discussion of Results

4.1 Effect of Textiles Strengthening

The retrofitted specimens showed highly increase in the flexural capacity when compared to the control specimens. Single wythe specimens showed increase in the flexural capacity, maximum deflection and energy absorption by 400% to 406%, 12 to 13 times and 68 to 69 times when compared to control specimen. While double wythe specimens showed increase in the flexural capacity by 236% to 291%, 11 to 17 times and 63 to 91 times, respectively when compared to control specimen. It's clearly noticed that this technique showed high efficiency in strengthening the URM wall.

4.2 Effect of Wall Thickness

In case of single wythe specimens, the strengthening increased their capacities and they failed in tension. The textiles yielded their ultimate tensile strength till rupture. While the double wythe specimens, due to their high strength, using the same strengthening of four layers of 5×5mm textiles caused them to fail in compression and shear before they reach their ultimate tensile strength. So, the four layers for the double wythe specimens is considered over-reinforcement. Due to double wythe failure modes the increase in flexural capacity didn't reach high as expected.

The double wythe specimens showed increase in flexural capacity, maximum deflection and energy absorption by 91% to 107%, 35% to 122% and 232% to 375%, respectively when compared to single wythe specimens.

4.3 Effect of Loading Span Direction

The spanning direction showed insignificant contribution on the walls results. This is clearly due to the plastering mortar which bear all the load in tension and compression and minimize the contribution of the masonry.

5. Basis of Flexural Desgin

The theoretical flexural capacity of URM walls strengthened by using BTRM can be determined using analytical model of ACI-549.4R-13 [10]. The masonry stress-strain distribution over the section is idealized as a uniform stress block with parameters (β1) and (γ). The experimental and theoretical flexural capacities are explained in Table 6. It was noticed that there is nearly no deviation between the theoretical and experimental results. This demonstrates the high efficiency of this retrofitting technique. Equation [I] introduces the ACI model as follows:

$$M_{th} = A_f \cdot f_f \left(d - \frac{\beta 1\, c}{2}\right), \text{ Where } c = \frac{Af.\varepsilon fu.Ef}{\beta 1.\gamma.fm'.b} \qquad [I]$$

The terms can be described as follows:

- (A_f) is the area of the textiles.
- (f_f) is the ultimate fiber stress.
- (γ) and (β1) terms are parameters which define the rectangular stress block in the masonry equivalent to the actual non-linear distribution stress and can be assumed equal to 0.70[10].
- (εf) is the ultimate fiber strain from Table 4.

Table 6: Experimental and theoretical flexural capacities.

Specimens	Code	M_{exp} (KN.m)	M_{th} (KN.m)	M_{exp} / M_{th}
Vertically Spanning	V-S	6.192	5.986	1.034
	V-D	11.825	11.204	1.055
Horizontally Spanning	H-S	6.020	5.874	1.025
	H-D	12.470	11.653	1.070

6. Summary and Conclusions

The aim of this investigation is to study using the new technique of BTRM for strengthening of the URM walls. Out-of-plane bending tests were carried out on masonry walls with loading direction parallel and perpendicular to the bed joints. PM mortar was used as a bonding material. The variables considered in this study were span direction and wall thickness. Based on the results obtained and discussed above the following conclusion can be drawn:

1- The proposed technique of retrofitting of URM walls with BTRM have proven its high efficiency.
2- This technique has advantages of low cost, ease of application, overcoming FRP problems and possibility of usage with historical buildings.
3- Retrofitting of URM walls using BTRM remarkably improved the flexural capacity, deformability, energy absorption of the masonry walls.
4- The flexural capacity remarkably improved by 403% on average for single wythe specimens and 264% on average for double wythe specimens.
5- The loading direction have no contribution on the wall capacities.
6- Wall thickness have high contribution on the wall capacities, double wythe walls have higher flexural capacity than single wythe by 99% on average.

7. Refrences

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