In-Plane Shear Behaviour of Unreinforced Brick Masonry Strengthened by Bio-Composite Fabrics

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Abstract--- Unreinforced Masonry structures are subjected to failure due to in plane and out plane loads from the wind and earthquakes. Therefore strengthening of Unreinforced Masonry structures (URM) is vital to make them seismic resistant. This paper describes an experimental investigation on the in-plane behaviour of the URM panels strengthened with composite fabrics namely glass fiber and jute fiber respectively. These URM panels were fabricated and provided with two different orientations of the said fibers. Diagonal compression test was conducted and the crack patterns were analyzed. The test results showed that strengthening URM with jute fiber can be used as an effective alternative for glass fiber for retrofitting.

I. INTRODUCTION

The use of Fiber Reinforced Polymers (FRP) as externally bonded strengthening material is showing a continual increase in the field of retrofitting because of its light weight, anti-corrosive, non-magnetic, and easy installation. FRP in retrofitting has a wide range of possibilities making it advantageous over the existing conventional techniques such as ferrocement, shot crete, external reinforcement, grout injections and centre core. Fiber Reinforced Polymer is a composite material generally comprising of aramid, glass, carbon and bio fibers such as sisal, jute embedded in a polymeric resin such as epoxy. Among several options, the fiber laminates are installed on the URM surface by using polymeric resin. These laminates are impregnated in the resin matrix and bonded on the URM surface and are cured. This process of installation of fiber laminates to the URM surface is called wet lay-up [1].

Unreinforced Masonry structures are susceptible to damage due to the lateral seismic loads. The shear behaviour of the Unreinforced Masonry structures (URM) is characterized by their resistance to in-plane loads which depends upon the masonry unit and the strength of the mortar. If the forces exceeds the shear capacity of these URM structures shear failure is likely to occur which is characterized by failure modes such as sliding shear, brittle cracking throughout the masonry unit, de-lamination and a combination of the said failure modes [2]. Therefore to improve the shear resistance these URM structures are strengthened with FRP.

Early investigations on the use of externally bonded FRP laminates or fabric as in-plane shear reinforcement of masonry walls has been reported. The experimental results and inferences showed that FRP provides effective resistance against seismic forces and also improved the shear strength of these structures considerably. Also the FRP laminates were effective in taking up high tensile loads thereby protecting the URM structures without collapse. In addition to this, the use of FRP laminates improved the ductility of the URM structures. URM walls are brittle in nature and fail due to rupture by shear in two ways- a diagonal splitting or as a step pattern sliding along the mortar joints. The characteristics of the failure depend upon the constituent materials such as mortar and bricks [3-7]. In order to improve its shear resisting capacity, this paper presents an experimental program on five URM panels in which four URM panels were strengthened with glass fiber and jute fiber fabric in diagonal and grid orientations respectively subjected to in-plane load. The crack patterns and the behaviour of each of the panels were studied.

II. EXPERIMENTAL PROGRAM

Materials

The Unreinforced Masonry wallets were made using wire cut bricks of dimensions 220 mm x 100 mm x 70 mm. Ordinary Portland Cement and natural sand were used in preparation of the masonry mortar. Suitable tests for the bricks, cement, sand and mortar were performed as per the IS Codes [9-12]. Jute fiber and glass fiber fabric impregnated in epoxy resin were installed on the surface of the URM wallets using the wet layup technique.

Construction of Masonry Wallets

Five square panels of side 510 mm and thickness 140mm. Wire-cut bricks of size 220 mm x 100 mm x 70 mm were used and were scaled down to a factor of 2. English bond was adopted for constructing the square panel. The mortar used in English bond is of mixed ratio 1:4 and the panels were white washed once they cured to observe the crack pattern. 6 mm plastering was adopted and the brick wallets were allowed to cure for a period of 7 days. Once the wallets were cured they were attached with Jute fiber and Glass fiber fabrics with the help of epoxy resin.

Manuscript received February 01, 2019

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It was estimated that at least 30% of surface area of panels was to be covered. Hence the thickness of fibers to be attached was derived accordingly. Two types of patterns were used to cover these panels: grid Pattern and diagonal pattern. The wallets were provided with single layer of glass fiber fabric and two layers of jute fibers.

Diagonal Compression Test

Diagonal compression test is done to study the in-plane behaviour of Unreinforced Masonry structures when subjected to seismic forces. Square panels were constructed and placed at an angle of 45° on the UTM with the help of top and bottom arrangements made of mild steel and tested diagonally for compression. Compression takes place vertically and tension occurs horizontally. Composite fibers were attached to the wallets with the help of epoxy resin and tested.

Fig.1: Testing of URM Wallet

The wallets were carefully lifted and placed in UTM in diagonal fashion as shown in the Fig.1. Sufficient arrangements were made for placing these panels in the UTM for diagonal compression test. The strain gauge readings were taken: three along horizontal and three along vertical direction respectively. Load was applied at a uniform rate and the strain gauge readings were taken for every 20 kN till the wallets collapsed.

Shear stress τ, and the shear modulus *G* were calculated as per the ASTM standard [8] which is as follows.

DS- Diagonal Shear; DLM- De-Lamination of FRP

Where,

P is the applied load and is the net area of the specimen which is calculated as follows:

Where,

w- width of the specimen h- height of the specimen

t- thickness of the specimen

n- % of unit gross area that is solid, expressed as a decimal. In this work n is taken as 1.

Shear strain was calculated by,

Where,

- shortening of length in vertical direction
- elongation of length in horizontal direction

g- gauge length

Shear modulus G was obtained by,

Where,

- Shear stress for a load of 1/3 of the maximum load
- shear strain for a load of 1/3 of the maximum load

III. RESULTS AND DISCUSSION

The experimental test results are tabulated as shown in Table I.

Table I: Shear Strength & Modes of Failure

Wallet Specs	No Layers	Max Load (kN)	Shear Strength (MPa)	Shear Modulus (MPa)	Mode of Failure
URM	-	112.5	1.114	170.93	DS-Splitting
URM-GF-D	1	121	1.198	720	DS-DLM
URM-GF-G	1	132.5	1.312	182.07	DS-DLM
URM-JF-D	2	118	1.168	650.96	DS
URM-JF-G	2	122	1.208	132.34	DS

DS- Diagonal Shear; DLM- De-Lamination of FRP

Fig. 2: Comparison of shear strengths of URMs

Table II: Shear Strength Ratio

Wallet specification	% increase in shear strength
URM-GF-G URM-JF-G	92%
URM-GF-D URM-JF-D	97%

URM-Unreinforced Masonry
URM-GF-D-Unreinforced Masonry-Glass Fiber-Diagonal
URM-GF-G-Unreinforced Masonry-Glass Fiber-Grid
URM-JF-D-Unreinforced Masonry-Jute Fiber-Diagonal
URM-JF-G-Unreinforced Masonry-Jute Fiber-Grid

The graph of the shear strength of the different URM wallets is shown in the Fig.2. It can be seen from the graph that URM-GF-G has the highest shear strength of all the wallets tested in this experiment. The ratio of shear strength between the glass fiber and the jute fiber with their respective orientations is shown in the Table II. It was found that the jute fibers were able to provide a 92% of strength of the glass fibers in grid orientation and 97% of the strength of glass fibers in the diagonal orientation. This indicates when URM can be strengthened with jute fibers in the place of glass fibers achieving nearly equal strength of the glass fibers.

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Also, when URM strengthened with FRP in the grid orientation can withstand the in-plane loads under seismic conditions effectively compared to the diagonal orientation.

A. Failure modes

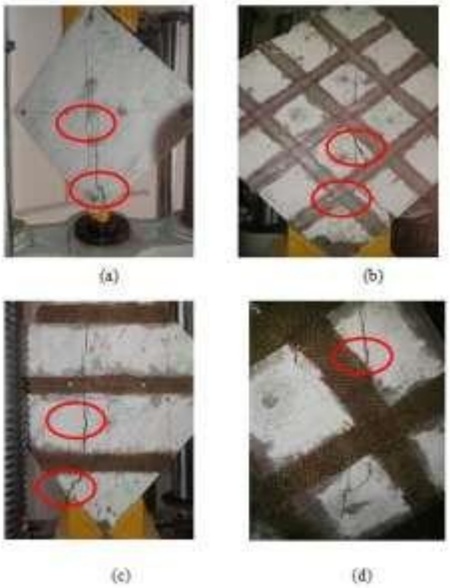

Fig.3: Failure modes of the URM panels

The failure modes of the URM panels are shown in the Fig.3. During the experiment the URM showed a brittle failure. The URM failed with a crack development through the centre and splitting diagonally which can be seen from the Fig.3.(a). In the URM-GF-D wallet the load was taken up by the fibers until the maximum load and a diagonal cracking pattern was observed. While the URM-GF-G wallet failed with due to diagonal shear which can be seen from the formation of the crack. Only minimal cracks were observed and the cracks but the glass fiber fabric delaminated at some places which is shown in the Fig.3.(b).

In the URM-JF-D wallet, the crack travelled from bottom to top with maximum crack width at the bottom which can be seen from the Fig.3.(c). Whereas in the case of URM-JF-G wallet the cracks were comparatively lower and the specimen bulged in the middle indicating that the in-plane load is taken by the jute fiber laminate which is evident from the Fig.3.(d). Cracks with maximum width were seen on the bottom phase of the wallet. Unlike glass fibers, the jute fibers didn't delaminate which is due to the higher stiffness of glass fibers compared to the jute fibers. However, structural integrity was maintained and both the glass fiber and the jute fiber laminates provided sufficient resistance to the in-plane loads and kept the specimens intact without complete collapse.

IV. CONCLUSION

From the experimental program the following conclusions can be drawn.

1. The URM wallet without fiber laminates had a brittle failure and the strengthened wallets did not have such a sudden failure. So, when the masonry units are strengthened with FRP, can provide sufficient warning to the inhabitants before it fails.
2. The grid orientation is more effective than the diagonal orientation and also offers more uniform stress distribution for area coverage of 30% in both the glass and jute fiber laminates.
3. The stiffness of FRP is more compared to jute and hence some de-lamination was observed and the glass fiber laminate was cut at some places.
4. With the double layer of jute fibers, about 95% of the strength of glass fibers was achieved which proves that the jute fiber can be an effective replacement for glass fibers.
5. Jute fibers are naturally available fibers which are bio-degradable and recyclable and also relatively cheaper compared to the other synthetic fibers.

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