Comparative Investigation of Strengthening Techniques of Masonry Panels using GFRP

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Abstract - *Unreinforced masonry (URM) accounts a huge proportion of structures around the world. All design philosophies in the world are exclusively formed for the design of RCC elements, where as there are very few of them for the design of masonry elements of a structure. The losses caused due to failure of URM are as close as the losses caused due to failure of RCC elements. Therefore, efficient and affordable strengthening techniques are urgently required for the strengthening of masonry elements. Among all the strengthening materials, Glass Fibre Reinforced Polymer (GFRP) has found to be a significant material which can provide tensile capacity to the brittle masonry elements. The aim of this experimental study is to provide a background to the physical and mechanical properties of GFRP in the form of unidirectional sheets and bars, and the strengthening techniques for masonry panels. Various strengthening techniques and configurations of GFRP sheets and bars are presented. Masonry wall panels (unstrengthened and strengthened) are modelled and analysed in a code viz. DIANA FEA and results are compared in terms of their shear capacities.*

Key words—Unreinforced Masonry, Glass Fibre Reinforced Polymer, strengthening, GFRP laminates (key words)

1. INTRODUCTION

Over the last few decades the world has seen a growing awareness amongst the structural engineers, the significance of the physical and in-service properties of GFRP. This material has emerged as an efficient competitor to other conventional materials used for the purpose of strengthening of structures. A huge number of structures comprising of masonry elements are in need of strengthening due to either structural degradation or change in the use of structure. The extraordinary properties of GFRP like high strength-to-weight ratio, lightweight, potentially high overall durability, corrosion resistance and tailorability enable it to be used in cases where the conventional strengthening materials may be found inefficient in terms of overall cost, durability and workability. Over last few years, the manufacturing technologies for production of GFRP composite have been revolutionised by sophisticated manufacting techniques. These technologies have enabled GFRP composites to be produced to high quality with minimal voids and precise fibre alignment.

The strengthening of existing masonry elements is fast growing especially after world war II. Due to the previously discussed properties of GFRP which are impeccable in nature, GFRP composite in the form of unidirectional sheets and bars has been used for this study. The strengthening of the wall panels is done in such ways that the shear strength of panels is enhanced. This is because, generally masonry panels fails from the joints made up of mortar which is bonded together with the brick blocks. The bond is solely responsible for the abrupt slip of brick blocks and mortar.

In this study, wall panels are modelled and analysed in DIANA FEA, which are later checked for in-plane compression, bending and shear capacities. Conclusively, the results obtained are compared with each other in terms of techniques of strengthening and change in the behaviour as compared to the unstregthened wall panel.

1.1 Objective of the study

The main goal of this study is to predict the behaviour of unreinforced masonry wall panels which are strengthened with GFRP sheet and bars enabling them to act it as a unit. Following are the objectives which are listed in accordance to reduce the distress of masonry walls, optimize the time and minimize the effort of worker.

i. To increase the diagonal stiffness of unreinforced brick masonry using GFRP by enhancing the ductility.
ii. To compare the performance of unstrengthened masonry wall panel model and strengthened masonry wall panel models using three techniques of strengthening.

2. SYSTEM DEVELOPMENT:

Strengthening of existing URM is done by using GFRP in two forms: GFRP laminates and GFRP bars. Externally bonded GFRP laminate strengthening is particularly preferred where there are severe access restraints or high cost associated with installation time. The objectives of the proposed study are presented in previous section which includes to increase the in-plane stiffness of brick masonary wall panels using GFRP by enhancing the ductility and reducing the sudden drift under lateral loads. The finite element model wall was developed and analysed in DIANA FEA. Another three model wall panels were developed with similar properties of materials strengthened with GFRP material, such that they act as a body. The three techniques used for strengthening are:

i. Laminating the surface of URM with GFRP strips of 4mm width horizontally.
ii. Laminating the surface of URM with GFRP strips of 4mm width vertically.
iii. Near Surface Mounting (NSM) the 12mm bars in the URM panels.

2.1 Failure mechanisms:

For GFRP-strengthened masonry panels under in-plane loads, the following failure mechanisms are possible:

i. failure by in-plane compression and bending (by FRP rupture or masonry crushing);
ii. failure by in-plane shear (by sliding shear or diagonal cracking);
iii. failure by FRP debonding.

2.2 Flow chart of the study:

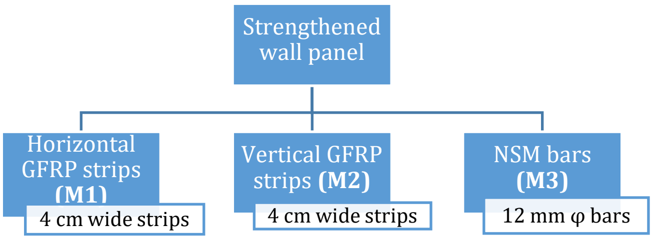

Figure - 2.1: Flowchart of Proposed Work

2.3 Analytical modelling:

The wall panels used for the study are of size 47 cm × 68 cm × 11 cm (Height × Width × Thickness) which are adopted from "Shear behaviour of masonry panels strengthened by FRP laminates", by M.R. Valluzzi, D. Tinazzi, C. Modena [19]. The adoption of dimensions is approximated because of the variation in brick size availability. The wall panels are modelled using four point 3D solid element in DIANA (Figure 2.2). Lamination of GFRP is applied with maximum size of wall panel in horizontal and vertical strips of 4 cm width at a spacing of 7 cm centre to centre in horizontal orientation (Figure 2.3) and 22 cm (Figure 2.4) centre to centre in vertical orientation. In case of wall panel strengthened with NSM bars, the bars used are of diameter 12 mm. Three bars are grooved at a distance of 22 cm centre to centre (Figure 2.5).

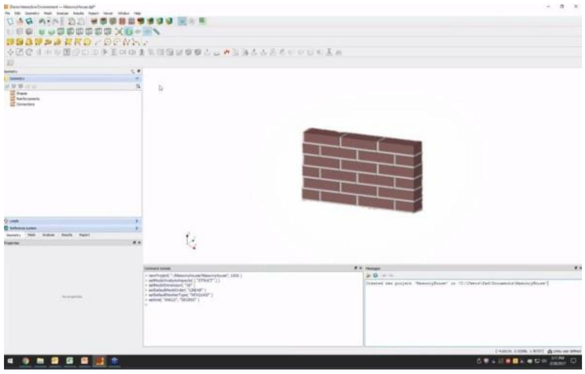

Figure - 2.2: Control wall panel (M) modelled in DIANA

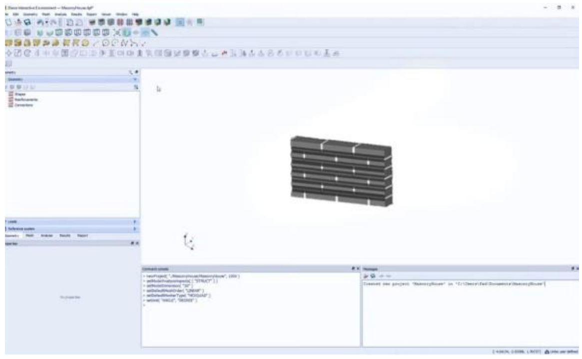

Figure - 2.3: Wall panel with horizontal GFRP strips

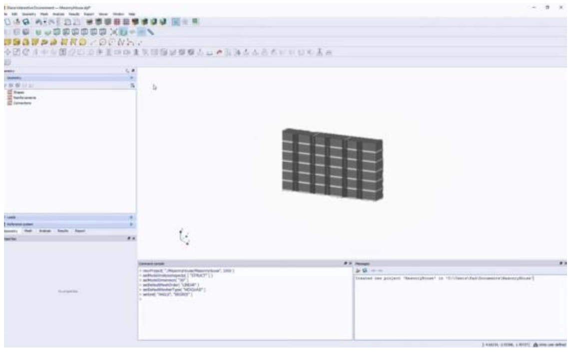

Figure - 2.4: Wall panel with vertical GFRP strips

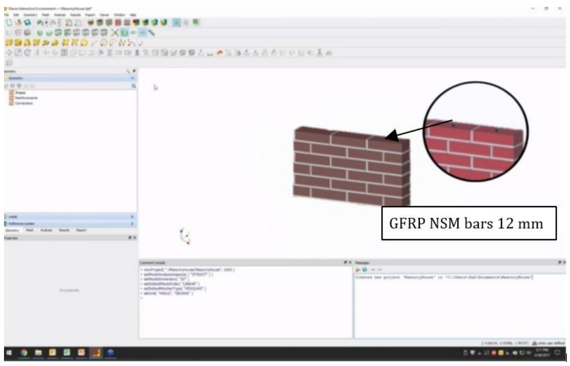

Figure - 2.5 Wall panel with GFRP NSM bars

2.4 Material Modelling:

The FRP laminates involved in the experimental work consist glass glass fibre polymer (unidirectional fibers) embedded in epoxy resin, according with the wet lay-up technique. Ideally the composite of epoxy resin, GFRP and wall panel should act as one unit, which is not possible practically because however strong the GFRP-wall panel bond is, the GFRP dislocates from its original position during test due to removal of superficial layer on the bricks. This demerit of experimental testing is eliminated in the analysis done in DIANA FEA. This can be done by adding a layer of a material which resembles GFRP properties over the wall panel as per the discussed orientations ensuring the model to work as one unit.

In case of NSM strengthening, 3 cylinders of diameter 12 mm and 47 cm height is selected and the material properties are altered with the properties of GFRP bars, which will be a software equivalent of drilling a hole and penetrating the bar. The geometrical parameters and material parameters which are considered for the study are listed below.

Table - 2.1: Geometrical and material parameters

Parameter	**Data**	**Units**
1. Wall Panel		
Height	47	cm
Width	68	cm
Thickness	11	cm
2. Brick		
Brick thickness	7	cm
Brick width	11	cm
Brick length	22	cm
Compressive strength	8.83	MPa
3. GFRP		
Density	2600	kg/m^3
Equivalent thickness (strips)	0.115	mm
Characteristic tensile strength	1700	MPa
Tensile modulus of elasticity	65	GPa
Ultimate strain	2.8	%
4. Mortar		
Flexural strength	1.48*	MPa
Compressive strength	6.03	MPa

**adopted from [19].*

2.5 Loading condition:

All the modelled wall panels are slightly away from a square shape due to use of non-modular bricks. The loading condition used is along the longer diagonal of the panel. A triangular cut at the ends of corners of the longer diagonal is must for even application the compressive load (Figure 3.8). The load application method used in Diana is trial and error basis. A load interval of 5 kN is adopted and checked for every increase in load. The parameters recorded are cracking load, failure load, failure mode and crack pattern for each model. The results and their analysis is given in the next section.

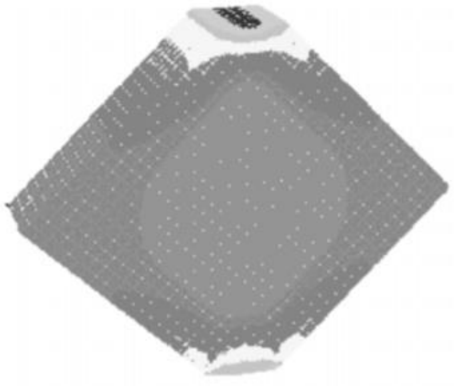

Figure 2.6 Cut down corners of the wall panel

3. RESULTS AND DISCUSSION

The objective of this study is to increase the diagonal stiffness of unreinforced brick masonary using GFRP by enhancing the ductility and to compare the performance of unstrengthened masonary wall panel model and strengthened masonary wall panel model using three techniques of strengthening. Three techniques of strengthening used are horizontal and vertical orientation of GFRP strips and NSM bars. Comparison of three techniques is carried out on the code which are finally related to the control wall panel. The analytical work carried out with reference to these objectives is presented in the previous chapter. The results of the same are presented and discussed in details in the following sections.

In all the cases, failure mechanism consisted in sudden loss of collaboration between reinforcement panels, due to rupture of the GFRP strips. Horizontally specimens showed spread-cracks patterns, whereas a clear splitting crack appeared in all the vertically reinforced panels. The ultimate strength increase was considerable in almost all cases; while only panel reinforced by NSM bars was seriously affected by de-bonding of brick units.

3.1 Graphical representations of stress-strain behavior

The stress – strain behavior of all the panels are plotted which will make the future understanding easy.

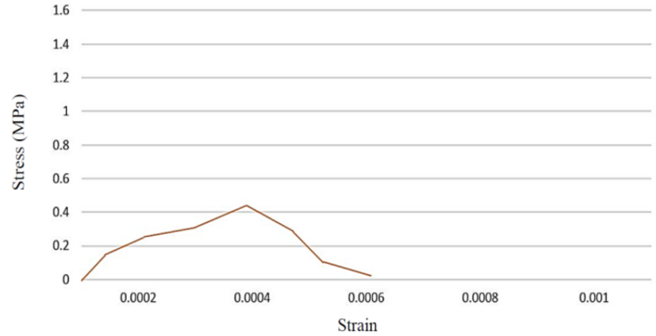

Figure - 3.1: Stress-Strain diagram of URM control panel (M)

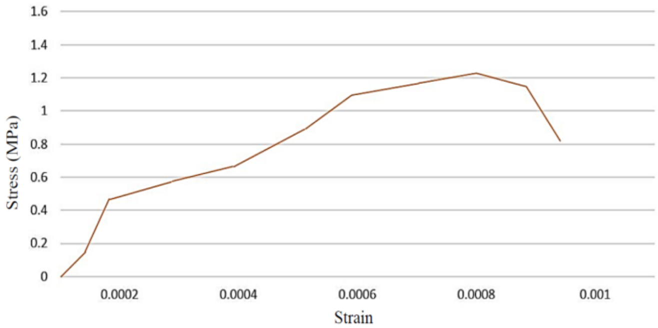

Figure - 3.2: Stress-Strain diagram of horizontally reinforced panel (M1)

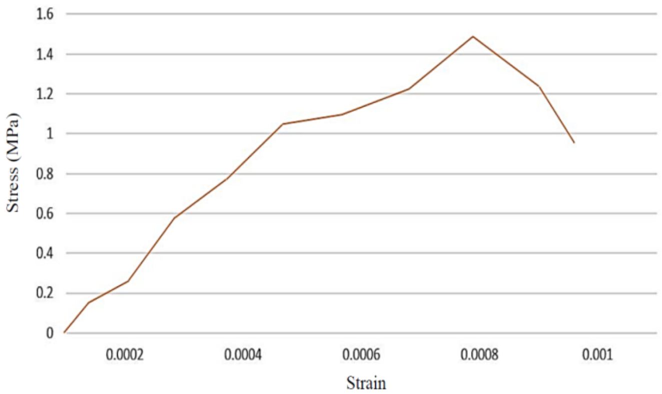

Figure - 3.3: Stress-Strain diagram of vertically reinforced panel (M2)

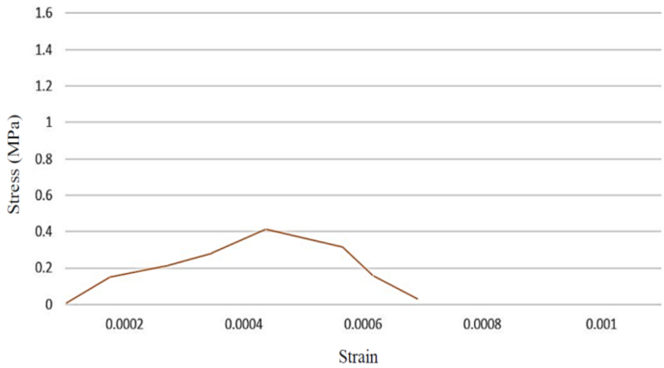

Figure - 4.4: Stress-Strain diagram of panel reinforced with NSM (M3)

Table - 4.1: Experimental tests results

Panel type	Cracking load	Failure load	Crack pattern
M (URM panel)	3.9 kN	0.18	-
M1 (horizontally reinforced panel)	10.9	7.2	Spread crack
M2 (vertically reinforced panel)	13.6	8.6	Split crack
M3 (NSM bars)	3.6	0.19	Spread crack

4.3 Conclusions

The contribution of GFRP strips on the behavior of clay brick walls has been investigated; the results of the present study indicated that vertical reinforced panel offers the best resistance against failure but the type of failure is sudden because the split crack occurs along the direction of applied force within a fraction of second. This aspect of serviceability is mild in case of horizontally reinforced wall panel but offers a resistance slightly less than that of vertically reinforced panel.

The results of NSM bars reinforced panel indicates a slightly higher resistance than the control panel but, it also showed that before the stress in the bars is reached the brick units are debonded and the wall panel fails to sustain. Alternative anchoring methods appear to be a key issue to evaluate during further experimentations in order to prevent loss of effectiveness due to de-bond.

Conclusively, we can say that, NSM technique is not alone efficient, and it can be combined with vertical strip reinforcement for the best results.

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