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In-Plane Shear Behavior of FRP Strengthened Masonry Walls

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Abstract

Using Fiber Reinforced Polymer (FRP) is one of the recently developed techniques for structural retrofitting that includes various kinds of fibers such as Carbon Fiber Reinforced Polymer (CFRP), GFRP and AFRP which are included in continuous polymer matrix. Using FRPs can increase the ratio of strength and stiffness to weight, enhance the durability at various situations and convenience in installation.
A finite element method is introduced to model unreinforced masonry (URM) walls by using software, ANSYS. The masonry walls are strengthened with Carbon Fiber Reinforced Polymer sheets (CFRPs) and two different strengthening methods have been used with various thicknesses. The strengthened walls are affected by vertical loads and in-plane shear which can be found that the critical loads, the critical displacement, the ultimate loads, the ultimate displacements and the ductile coefficients of the masonry walls strengthened with CFRPs are improved remarkably.

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Keywords: MASONRY WALLS, STRENGTHENING METHOD, LATERAL LOAD, HISTORICAL BUILDINGS, CFRPS

1. Introduction

Most of the buildings throughout the world and typically in Iran are Unreinforced Masonry (URM) buildings. Generally, the seismic standard codes have not been observed for these buildings and recent seismic events have revealed that those are vulnerable to earthquakes.

FRP composite materials are recently developed as an option for strengthening of masonry buildings. The application of FRP composites as externally bonded reinforcement in repairing and strengthening masonry

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walls has becoming more attractive than traditional methods which are based on steel elements. Their excellent strength-to-weight ratio, easy installation and minimized damage for the existing structure make them the best option for strengthening buildings and structures.

At the present study, the modeling methods and in plane behavior of an URM building reinforced by FRP are investigated under mutual effect of vertical and shear loads by pushover analysis using finite element software, ANSYS.

2. In plane shear test on URM panel

It is required to empirically test a typical panel and to be modeled by presented method and then to be validated by comparing corresponding results. Therefore, the results of experimental tests conducted by Dr. M.R Maheri et.al at University of Shiraz are investigated [1].

Consider a typical 160×140 cm2 panel with thickness of a brick while the bricks are used saturated with dry surface and are cured during 28 days after the panel constructed. It shall be noted that fine aggregate within ASTM standard is used in mortar. Thus, the mortar can carry the loads sufficiently due to proper cohesion with adjacent bricks [2].

The main elements are reaction frame, strong floor, 30 ton vertical and horizontal hydraulic loading system.

At the present study, the Macro modeling is used which has been presented by Lourenco et. al (1997) at Minho university. Also some other researchers such as Kappos et. al and Giordano et. al (2002) have created Macro models on masonry buildings in greater dimensions by ANSYS and ABAQUS software which bricks, mortar and their interfaces are assumed as homogenous materials [3]. A three dimensional isoparametric element, Solid 65, is used to model URM panel. SOLID 65 is a three dimensional 8-node element having six corner nodes, and each node has three translational degrees of freedom. The materials are able to crack at tensile stresses and fail under compressive stresses at three perpendicular directions and also creep and plastic deformations. SHELL181, three dimensional 4-node shell element having six degrees of freedom at each node is used to model FRP shells. Therefore, only SHELL181 element which is a 4-node element is used to model composites and has the capability to transfer forces at panel and FRP interfaces [4].

Since the required force to separate the panel and FRP is rather high, the bonding at panel and FRP shell interface assumes ideally perfect [5]. Further details for types of modeling methods of masonry structures are presented at reference [6].

As it is shown in Table 1 and Fig. 1, the numerical curve shows stiffer condition than experimental curve and the load bearing capacity revealed 0.72 and 99.28 percent error and precision, respectively and also percentage of the error and precision at ultimate displacement are equal to 5.9 and 94.1, respectively; Consequently, the curves show good accordance in numerical and experimental results and it can be stated that the models are well calibrated.

Table 1.Comparing numerical and experimental results for lateral load-displacement of G3

Ultimate Load (KN)	*Ultimate Load(KN)*	*Ultimate Displacement(mm)*	*Ultimate Displacement (mm)*
Experimental	Numerical	Experimental	Numerical
140	139	1.000	**0.941**

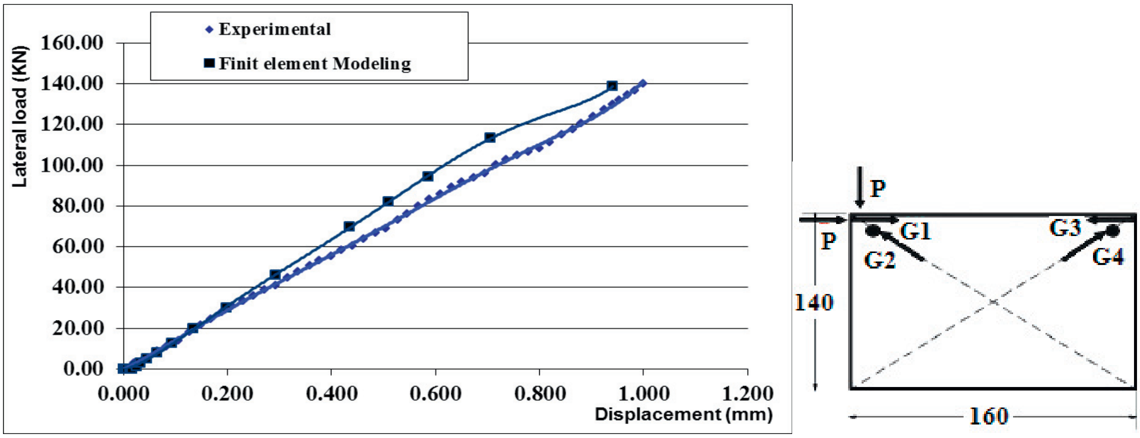

Fig. 1. Load-Displacement curve for G3 lateral displacement transducer

3. Properties of composite materials

The properties of composite materials of CFRP applied in modeling of masonry specimens reinforced by FRP are presented in table 2.

Table 2. Mechanical properties of FRP shells [7]

Materials	*Ex (GPa)*	*Ey (GPa)*	*vxy*	*vyz*	*Gxy (GPa)*	*Xt (GPa)*	*Yt (GPa)*	*Sxy (GPa)*	*Ultimate strain*	*Thickness (mm)*
CFRP shell	373	2.35	0.25	0.35	1.56	2940	55.9	70	0.8	0.165

4. Reinforcing patterns of masonry panel

Different reinforcing patterns of URM panels with FRP based on failure modes are presented in Fig. 2 which can be applied to counter such types of failure. It shall be noted that 2 and 4 mm FRP sheets with carbon fiber angle of 0 and 90 degrees are used on both sides and the width of FRP sheets are considered 20 cm at reinforcing pattern of vertical and wrapping sheets.

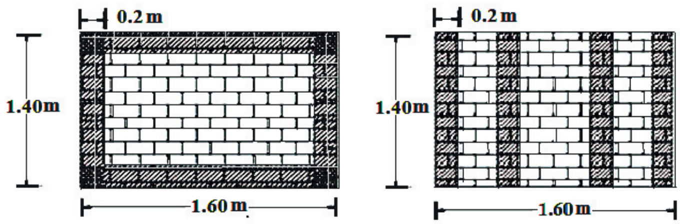

Fig. 2. Different reinforcing patterns of the panel by FRP sheets

Four CFRP vertical strips, 20 cm wide and 140 cm high (the height of the panel up to bottom of the beam) have been used to retrofit the specimens. At this type of retrofitting, three various thicknesses of 2 and 4 mm

CFRP have been modeled to investigate the influence of composite thickness on nonlinear behavior of the panel. Also, the bonding of the panel and the FRP shells are assumed ideally perfect [7].

Also, retrofitted panels with double side horizontal and vertical wrapping strips are used. The width of the wrapping strips is 20 cm. The size of the CFRP element considered to be 5 cm, the fiber angle is zero and 90 and the bonding of the panel and the CFRP shells are assumed ideally perfect and double side strip. CFRP composites having two different thicknesses of 2 and 4 mm are analyzed to investigate the influence of composite thickness. The results are shown in Fig. 3 and table 3.

Table 3.Numerical results of masonry panel with/without retrofitting by double side vertical and wrapped strips having thicknesses of 2 and 4 mm

Type of retrofitting		*Ultimate Load*		*Ultimate displacement*	
	Numerical object	Numerical result (KN)	Improvement (%)	Numerical result (KN)	Improvement (%)
	S0	139	-----------------	0.941	-----------------
Double side vertical strips	S-CFRP-0-90-2 mm	189	35.97%	1.092	16.04%
	S-CFRP-0-90-4 mm	212.46	52.84%	1.076	14.34%
Double side wrapped strips	S-CFRP-0-90-2 mm	211	51.79%	1.36	42.4%
	S-CFRP-0-90-4 mm	225	61.87%	1.09	15.83%

According to table 3, the double side vertical strips of CFRP composites having different thicknesses cause an increase in lateral bearing capacity and ductility of the masonry panel. Also, a positive performance at nonlinear behavior of the panel observes due to increase in thickness.

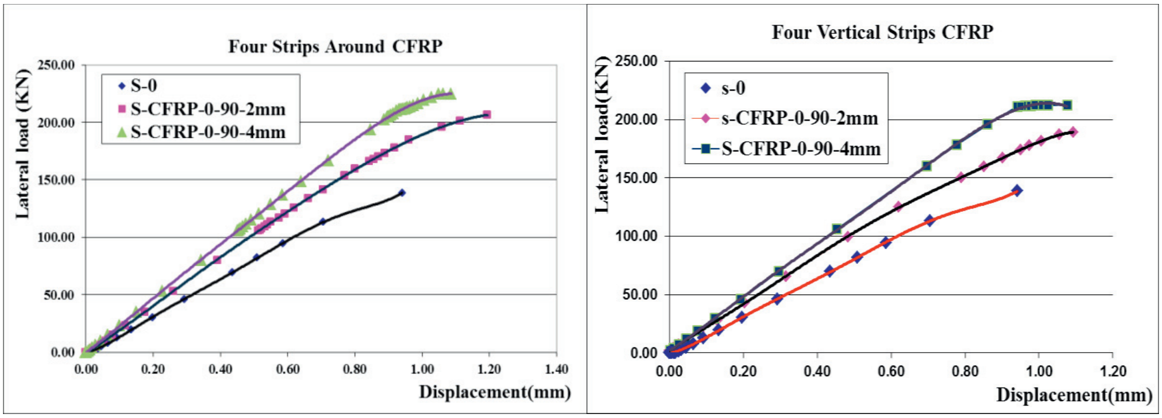

Fig. 3.(a) Load-Displacement curve at point G3 for retrofitted panels with double side horizontal and vertical CFRP wrapped strips having the thicknesses of 2 and 4 mm and non-retrofitted panel; (b) Lateral load-Displacement curve at point G3 for double side vertical strips of CFRP retrofitted panel

According to table 3, the double side wrapped strips of CFRP composites having different thicknesses cause an increase in lateral bearing capacity and ductility of the masonry panel.

The Lateral load-Displacement curves for the masonry panel retrofitted with two types of methods by CFRP composite having the thickness of 2 mm have been compared and the following results are obtained.

As it is shown in fig. 3, the application of CFRP can improve and increase the ductility and lateral bearing capacity. The four horizontal and vertical strips around show a rather good performance and improve the bearing capacity up to 51.79% and cause an increase in ductility amounted to 42.14% and also apply less CFRP, therefore, it can be considered to have the optimum performance among the methods. The behavior of the retrofitted panels with vertical CFRP strips reveals that the ultimate lateral load is increased up to 35.97%. Moreover, the displacement of the panel is increased amounted to 16.09% which cause an increase in ductility up to 16.09%. In fact, the stiffness of the masonry panel is increased and the ductility has been improved.

5. Conclusion

- The numerical modeling curve shows more stiffness than experimental curves and the bearing capacity revealed 0.72 and 99.28 percent error and precision, respectively due to calibration of the finite element model using ANSYS comparing to experimental results from Dr.Maheri et.al at University of Shiraz and also percentage of the error and precision at ultimate displacement are equal to 5.9 and 94.1, respectively which shows good accordance in numerical and experimental results. Comparing both analytical and experimental curves revealed that ultimate load of experimental specimen is equal to 140 KN while the ultimate load at analytical model is equal to 139 KN and also the ultimate displacement of the experimental specimen is equal to 1 mm though the analytical value is amounted to 0.941 mm which shows more stiffness in analytical model than experimental one.
- The ductility and energy dissipation of the panel increases by using fibers with high failure strain capacity which can postpone the whole failure modes of the masonry panels.
- All strengthening methods of CFRP composites having different thicknesses cause an increase in lateral bearing capacity and ductility of the masonry panel. Also, a positive performance at nonlinear behavior of the panel observes due to increase in thickness.

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