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Strength and Ductility in Retrofitted URM Walls by GFRP and CFRP

[1]M. Behrooyan, [1]H. Razaghi and [2]S.A. Alavi

[1]Department of Civil Engineering, Faculty of Technical,
Central Tehran Branch, Islamic Azad University, Iran
[2]Mazandaran University of Science and Technology, Iran

Abstract: In almost all masonry structures, walls are among the most vulnerable organs because of their capability in ductility and lack of strength due to low lending capacity and cracking failure mode. Thus, different strengthening techniques have attracted the researchers. Composite materials are one of the techniques which increase the essential factors: loading capacity and the wall ductility. In this article the results obtained from the nonlinear analysis finite element using the software ANSYS were compared with the results of the experiments carried on the unreinforced masonry wall strengthened with FRP and the correctness of the modal has been evaluated. Then the behavior of unreinforced masonry walls strengthened by FRP in several different arrangements using fibers carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) affected by the in-plane cyclic and gravity loads were analyzed. Results indicated the effective efficiency of FRP in increasing lateral loading capacity, ductility and in-plane behavior improvement.

Key words: Un-reinforced masonry wall · Strengthening · Cyclic loading · GFRP · CFRP

INTRODUCTION

Un-reinforced masonry buildings include a large number of buildings in the world which are designed according to the building codes [1]. Most of the buildings are built based on low quake loads and they are unable of energy dissipation in linear displacements during an earthquake [2]. Because of cracking failure mode and low bending capacity, un-reinforced masonry walls have low resistance to lateral loads [3]. This can be due to depauperation of designing, construction, serciceability condition or combinations of them [4]. There are many common methods for retrofitting of un-reinforced masonry walls which are vulnerable from an earthquake point of view, such as ferrocement, post tensioning, shotcrete, grout and epoxy injection, external reinforcement and so on [5]. Each of these methods has advantages and defects. Using composite fiber is one of the new methods of rehabilitation that has gained some popularity. Because of in-plane and out-plane stresses due to earthquake and wind loads, composite materials are a suitable solution for retrofitting of masonry walls [6]. Based on the fiber formation, FRP is generally divided in several groups. The three mostly used FRPs are carbon (CFRP), glass (GFRP) and aramid (AFRP). The initial performance of the fibers or reinforcements is carrying load along the composite length in order to provide resistance and stiffness in a line. Recently, several researchers have studied the use of FRP on un-reinforced masonry walls. In the cyclic static experiment by Schwegler (1994), in-plane lateral resistance of masonry walls had an increase of 1.7 [7]. Abrams and Lynch (2001) increased in-plane lateral resistance by factor of 3.0. Therefore, they concluded that masonry wall displacement had an increase by 1.7. Also, Zhao et.al, showed that diametrical layers of CFRP, increased the sample loading capacity significantly [8]. In this study, we will consider the behavior of an un-reinforced masonry wall, reinforced using polymeric fibers, affected by both gravity and cyclic statical loads, by the help of finite element ANSYS software and we study various reinforcement arrangements.

MATERIALS AND METHODS

Different models have been used by various researchers in order to study and investigate the in-filled panels under loading. The models were chosen based on the geometric conditions and the effective parameters [9]. Numerical modeling of the bricks walls are generally categorized in micro-modeling and macro-modeling.

Corresponding Author: Hossein Razaghi, Department of Civil Engineering, Faculty of Technical, Central Tehran Branch, Islamic Azad University, Iran.

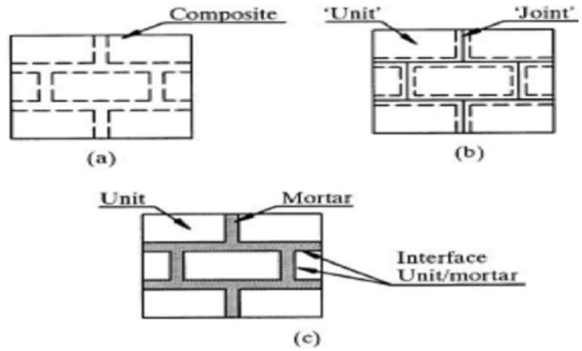

Fig. 1: Modeling of masonry wall by micro model

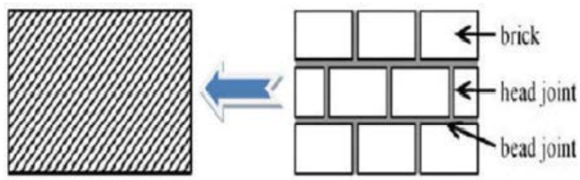

Fig. 2: Modeling of masonry wall by macro model

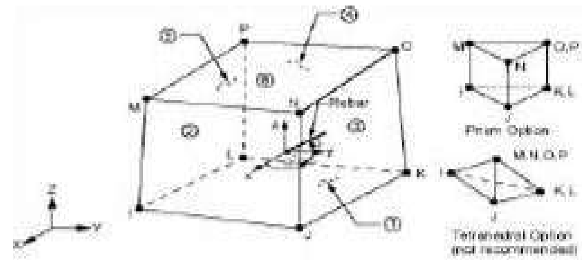

Fig. 3: SOLID65 element

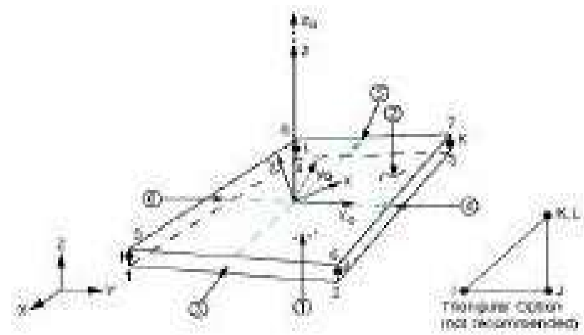

Fig. 4: SHELL181 element

In micro-modeling each components of the brick wall are modeled separately. Even though modeling in this method has considerable accuracy. But calculation and modeling of this is very complicated and it is not useful for large scale modeling.

In macro-modeling, brick wall is assumed as a homogenous and uniform material with equivalent mechanical properties [11]. Modeling in this method is very simple and calculation volume is also less than micro-modeling. Macro-modeling has been used in this study. This type of modeling studies the influence of infilled panels on the whole building, specially the influence of the panels on the quacking functions of a building. Fig. 2:Modeling of masonry wall by macro model SOLID65 (a three dimensional parametric element) was used for modeling of un-reinforced masonry walls. SOLID65 element is a kind of hexagonal and eight-nodal element with three degree of freedom in each node. Materials are able to crack in tensile stresses and failure in pressure stress in three orthogonal directions and they may crack in plastic deformations and creeping. The wall with an isotropic material, with equivalent material having the general elastic properties of the masonry panel is modeled [11].

Modeling of composites, because of their orthotropic materials, compared with isotropic materials such as steel, is very difficult and specific attention based on the material properties of fibers in each layer. For modeling FRP layers, non-linear structural elements SHELL181 were used, which is a 4-nodal 3-dimensional crust element having 6 degrees of freedom in each node. This element has an ability to imply every non-linear property, including strains.

Modeling Up to 255 layers IS permissible in this element and mean while information on the layer is inserted by crust sectional area.

As shown in fig. 4, the un-reinforced masonry wall is modeled 3-dimentionally using the ANSYS software. In all samples, a concrete beam is modeled on top of the wall for the uniform distribution of force on the total section-area of the wall and to prevent the direct force on the FRP surfaces.

Modeling Accuracy Evaluation: To evaluate the accuracy of modeling of finite elements for the un-reinforced masonry walls and the walls strengthened with FRP, experimental samples modeled by Elgawady et.al on masonry wall before reinforcement were collected in Switzerland and were used. The sample dimensions are given in table 1. Gravity load equal to 30KN was done using two pre-stressed bars and the samples were cyclically loaded as shown in fig. 5.

As seen in fig. 6 a good conformation exists between the modeling results obtained through finite element method using the software ANSYS and the experimental results.

Table 1: Dimensions and specification of the experimental specimen

Height (mm)	Length (mm)	Width (mm)	Elastic Modules (Mpa)	Compressive strength (Mpa)	Shear strength (Mpa)
710	1570	75	4500	5.7	0.16

Table 2: Dimensions and specifications of the simulated specimens

Item	Height (m)	Length (m)	Width (m)	Elastic Modules (Mpa)	Compressive strength (Mpa)	Tensile strength (Mpa)
Masonry Wall	2.8	4.0	0.2	1723	9.59	0.72

Table 3: Specifications of the FRP layers

Property --------------- FRP Type	E_1(GPa)	E_2(GPa)	v_{12}	G_{12}(GPa)	X_t(MPa)	Y_t(MPa)	S(MPa)	X_c(MPa)	Y_c (MPa)
CFRP	207	5	0.25	2.6	1035	41	69	689	117
GFRP	54	18	0.25	9	1035	28	41	1035	138

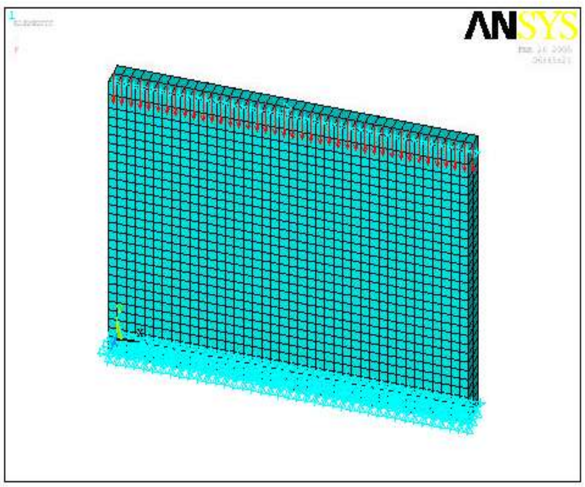

Fig. 5: Masonry wall model and how loading

Specimens Selection: The masonry wall has 2.8m height, 0.4m length and 0.2m width. This wall is indeed an upright beam, which holds the bending moment and shearing forces due to lateral loads on the floor or the diaphragm and is also affected by gravity loads. Therefore the bordering conditions of the wall was modeled as anchored in the bottom and free at the top. This means while the loading surface of the wall is 4m, the gravity load on such a wall is 30kg/cm. In all specimens, loading mode was applied with controlled displacement so that a predetermined displacement history can be done in the system.

Masonry Material Specification: Masonry material specification (with 1:3 ratio of sand to cement) used in modeling of un-reinforced masonry walls is given in table 2.

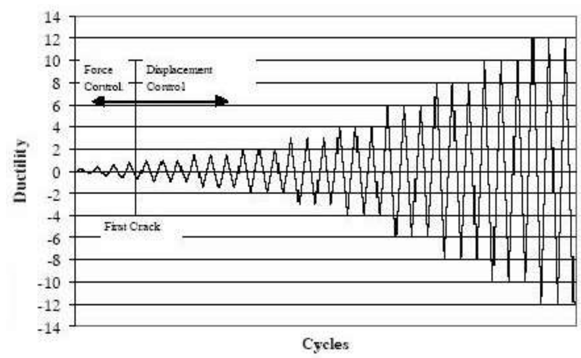

Fig. 6: Loading sequence for cyclic loading

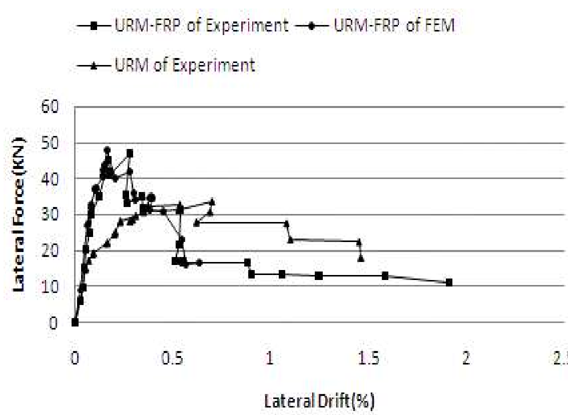

Fig. 7: Comparing of modeling and experimental results

Composite Material Specification: Specification of composite material CFRP, GFRP used in modeling of reinforced by FRP samples, studied in this paper is given in table 3.

Based on the description of failure modes of un-reinforced masonry walls, different FRP patterns that can be presented to cope with the failures are

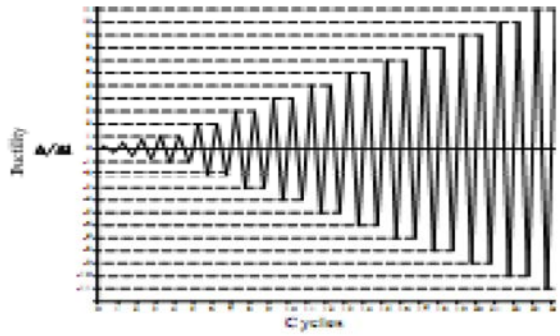

Fig. 8: load-displacement history

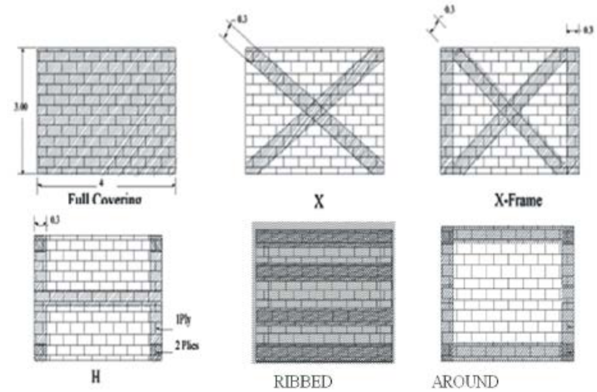

Fig. 9: Different FRP Patterns for strengthening wall

Masonary Wall Reinforcement Patterns: shown in fig. 8.It should be noted that reinforcement was done by 1mm thickness and the fiber angle is zero and 90° and the width of the FRP strips in reinforcement patterns is 30cm.

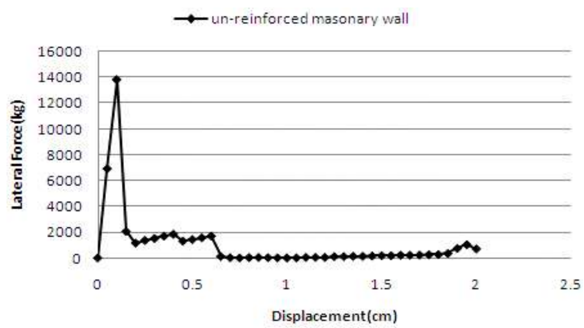

Fig. 10: Displacement-Lateral Loading curves in un-reinforced masonry wall

RESULTS AND DISCUSSION

Results Obtained by Analysis of Model Un-Reinforced Masonry Wall: Curves in fig. 9 show the amount of lateral forces against displacement of un-reinforced masonry wall.

Results Obtained by Analysis of Models Reinforced by CFRP: Curves in fig. 10 show the amount of lateral forces against displacement of walls reinforced with CFRP. Results indicated that loading capacity, with the coefficient 1.82 to 1.01, based on the type of reinforcement, increased for S-C-C and S-C-R models, respectively. Also, the ductility increased by a coefficient of 5.2 to 1.8 for the S-C-C and S-C-R models.

Results Obtained by Analysis of Models Reinforced by GFRP: Curves in fig. 11 show the amount of lateral force against displacement of walls reinforced with GFRP. The results indicate that loading capacity increased by a coefficient of 1.8 to 1.02 depending on the form of reinforcement for S-G-C and S-G-R samples. Also, ductility increases by a coefficient of 4.8 to 1.7 for S-G-X-F and S-G-R Models, respectively.

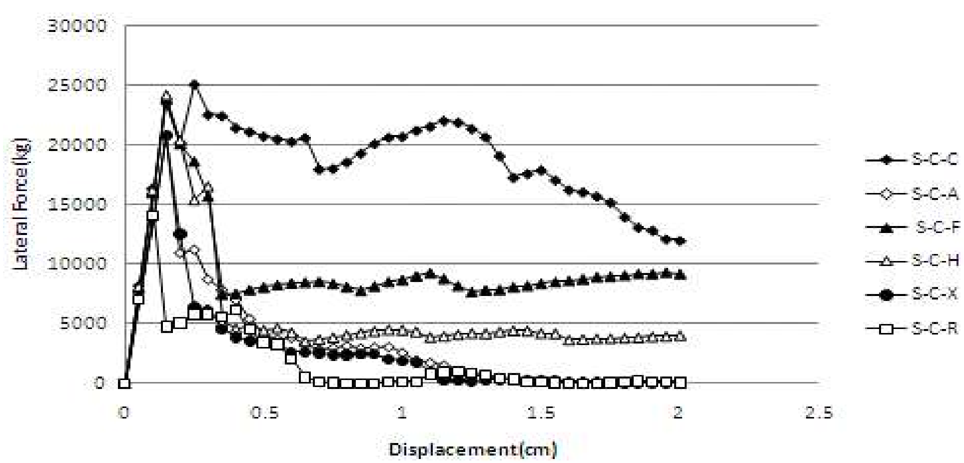

Fig. 11: Displacement - Lateral loading curves in walls reinforced by CFRP

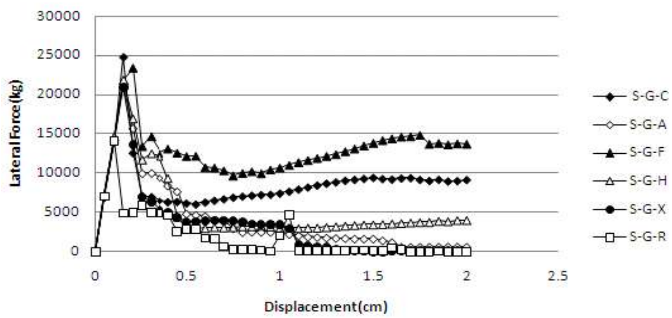

Fig. 12: Displacement - Lateral loading curves in walls reinforced by GFRP

CONCLUSION

- CFRP coatings increase lateral resistance of the simulated walls between 82%-1.55% and GFRP strips increase lateral resistance between 80%-2.16%.
- Using high strain fiber increases wall ductility and energy dissipation and also causes to delay of failure modes of masonry wall.
- FRP coating as reinforcement (R) which is composed of carbon and glass had the weakest behavior among different types of reinforcements.
- FRP coating which had been used as two vertical plus two diametric FRP strips (X-Frame), had the most optimized behavior, which significantly increased lateral resistance and ductility.
- Generally, FRP coatings which are applied in two horizontal and vertical directions on the wall, can delay all failure modes of masonary walls.

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