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Numerical Study of Masonry Walls Retrofitted by CFRP under Monotonic and Cyclic Loading

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ABSTRACT

Some factors such as poor quality of materials, lack of integrity in walls, lack of appropriate foundation, non-suitable horizontal and vertical bracing, having heavy roof in building, existence excessive openings in walls and etc. will cause the destruction of masonry structures against lateral loads. So after destructive earthquakes occur in different parts the world, researchers began to think of ways to retrofit these structures. In recent years use of fiber reinforced polymers (FRP) has been considered as a proper solution to improve the behavior of the lateral resistance and maintain stability system of masonry buildings and several factors affect the quality of this type of retrofitting. This paper is based on numerical modeling using finite element to investigate the effect of polymer fiber on the behavior of masonry walls and their productivity. Meanwhile masonry walls were retrofitted by using three different configurations and at the end force - displacement curves presented and compared with each other.

Keywords: masonry building, retrofitting, FRP, numerical modeling, force – displacement curve

1. Introduction

In the most of masonry buildings is not used from any of metal or concrete bracing against lateral loads during the earthquake. Masonry buildings are vulnerable because of low strength and brittleness walls against earthquakes. The high vulnerability of these structures is due to the unfavorable combination of mechanical properties. Masonry walls are very heavy and have very little tensile strength. Since the compressive strength of masonry is much greater than the tensile strength, more significant cracks occur in the tensile zone. Destruction and re-building of these structures is not an economic solution, but the behavior of these structures and their improvement techniques is the way should be plan for it.

Extent of performed research in the field of masonry buildings is not such as steel or concrete materials because of obsolescence and lacks of consumption in most countries in the world. However, in recent decades, experimental and numerical studies have been carried out on masonry buildings.

Benedetti and colleagues carried out 119 shaking table tests on 24 models from two-story houses. They concluded by means of simple techniques such as filling existing cracks in walls or horizontal metal strips the building performance can be improved in lateral excitation.

Corradi et al. studied the proposed system retrofitted by diametric compression tests. This system included scraping strips inside the wall and fills them with proper mortar. They conclude that this method can increase the stiffness of the shear the wall up to three times.

Ghobarah and Galal carried out experiments on five full-scale model brick wall. Out of plane loading was applied cyclic to walls. The walls were reinforced with horizontal and vertical FRP strips. Their retrofitting system provides a frame of FRP around the openings and Increase the strength and ductility of walls to 3 and 10 times, respectively.

Sathipran and colleagues carried out diametric compression test on masonry samples that were retrofitted with polypropylene mesh. They concluded that the system can increase the In-plane strength and ductility of the masonry walls to 2.5 and 45times, respectively. Yi and et al studied the three-dimensional finite element model of integrated elastic and non-integrated inelastic and they concluded non-integrated inelastic models are unable to model the behavior rocking and sliding of masonry parts, that considers as a most important failure modes.

Watanabe and Cao proposed a method for the analysis of masonry structures where the non-isotropic hyperbolic equations used to describe the properties of the blocks and and was used to model the behavior of the mortar between the blocks by viscoelastic element link. Numerical model also discussed to analysis of a retrofitting masonry building with wooden frames. Since the test is very expensive and time consuming therefore, by numerical studies and calibration the input parameters of the numerical model, we obtain a model that can evaluate Seismic Retrofitting of other structures. In coming study will examine the effects of different arrangements of polymer fibers on shear strength and energy absorption in the unreinforced masonry walls by using numerical methods.

2. Numerical modeling

2.1. Geometric and mechanical properties of materials

Walls used in this analysis have the dimensions 100 * 100 * 20 cm made of blocks with dimensions 20 * 20 * 10 cm. The arrangement of the blocks together such a way that vertical seams and gaps between the straight top and bottom rows are not in one direction and somehow create a continuous wall. Static and cyclic loading has been carried out in this study. So must use a suitable behavior model for masonry blocks to give an appropriate response both in compression and in tension under cyclic load. Therefore concrete damage plasticity model is used for modeling of brick material. CFRP fibers with a width of 10 cm were used for the retrofitting. Characteristics of the used materials are shown in tables 1 to 4.

Table 1 – Characteristics of polymer fibers

Characteristics of polymer fibers	
Tensile modulus of elasticity (MPa)	230000
Poisson's ratio	0.3
thickness (mm)	0.13
tensile strength (MPa)	3500
Ultimate tensile strain (%)	1.5

Table 2 – Elastic properties of block

Elastic properties of block	
modulus of elasticity **(**MPa**)**	3200
Poisson's ratio	0.18
density ($\frac{\mathrm{kg}}{\mathrm{m}^3}$)	1800

Table 3- plastic behavior of block in pressure

Pressure	
Plastic strain	stress (MPa)
0	7.26
0.00046	7.03
0.0029	6.58
0.0044	5.90
0.006	4.83
0.008	3.47

Table 4- plastic behavior of block in tension

tension	
Plastic strain	stress (MPa)
0	4.5
0.001	0.5
0.003	0.1

To model the behavior of mortar in normal direction, hard contact behavior and in tangential case, fixed friction coefficients were used. The friction coefficient to simulate the shear behavior of mortar is considered 0.6 and adhesion value is considered equal to 3.5 kilograms per square centimeter.

2.2. elements used in the numerical model

In this article two different elements for blocks and polymer fibers is used to model the masonry walls. Masonry blocks were mesh with hexagonal solid elements. This is the kind of continuous, three-dimensional element with eight nodes that each node has 3 degrees of freedom along the principal axes and has the ability to accept any type of mass and rotational load as well as linear and planar loads with different intensity. In this element shape functions derived from reduced integration methods were used for force and displacement distributions and other parameters.

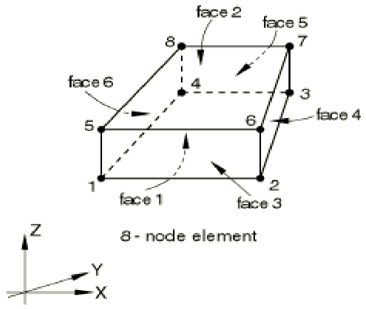

Figure 1 - solid element used for masonry blocks

For meshing FRP strips was used a kind of shell elements. This element is a three-dimensional element with four nodes and very low thickness that each node has 6 degrees of freedom and has the ability to consider the nonlinear strain. As like as last case, shape functions derived from reduced integration methods were used for force and displacement distribution and other parameters.

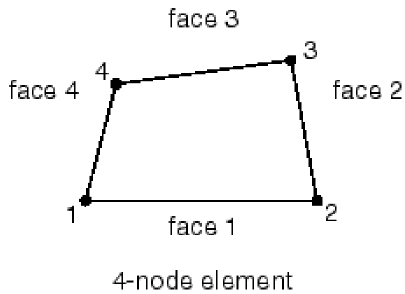

Figure 2 - The shell element used for polymer fiber strip

It should be noted that 2000 solid elements and 30 shell elements per unit length for FRP is used in finite element model mesh. The finite element model can be used to model the contact between the wall members. General contact mode is used to model the contact between the contact surfaces. Figure 3 shows the finite element model without fiber.

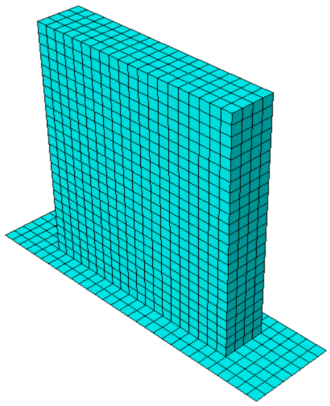

Figure 3 - Finite element model of masonry wall without fiber

2.3. loading conditions and fiber configuration

In this article the rigid beam on top of wall with the dimensions 100 * 20 * 20 cm was used to apply vertical and lateral loads. Initially, vertical compressive load of 12 kg/ cm^2 was applied gradually and then proportional lateral displacements were applied to wall. These displacements were considered in monotonic state to increase linearly up to 3 cm and in cyclic mode with maximum amplitude of 2 cm (Fig. 4). Also, pressure load on the wall is considered in order to simulate the ceiling's effect and modeling conditions closer to the actual situation. The fibers with a width of 10 cm used for reinforcement in different arrangement on the wall. In the first case fibers was used in the form of X, in the second case, the frame around the wall and in third case overall on the outer surface of the wall were used. This action has been done only on the one outer surface of the wall. Finally, the results of the force - displacement graphs are compared with each other.

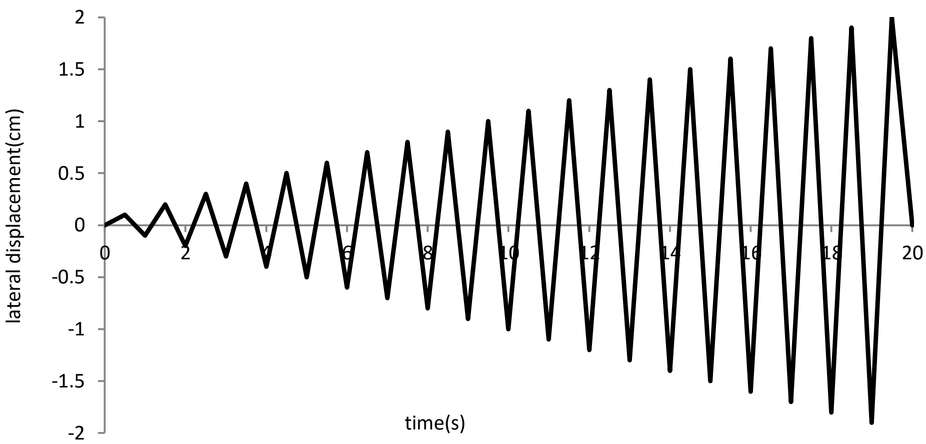

Figure 4 - Lateral displacement variation with time in cyclic loading