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Experimental investigation on the NSM retrofitted adobe walls under cyclic lateral loading

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ABSTRACT: In masonry structures, load bearing walls play a crucial role in the overall seismic performance and structural integrity. Thus, their retrofitting strategies typically involve retrofitting of their walls. One of the retrofitting technique can be using steel or composite materials in the form of near-surface-mounted (NSM) reinforcement. Despite being considered as masonry structures, there have been fewer investigations on seismic retrofitting of the adobe structures. In the current study, the efficiency of NSM steel rebars in improving the seismic performance of adobe wall is investigated through experimental investigations. The test specimens were comprised of four scaled-down (1/3) adobe walls measuring 1000 mm in length, 800 mm in height, and 200 in thickness. Retrofitting bars, in the form of two perpendicular NSM meshes, were applied on both sides of the walls. The specimens were tested under an incremental in-plane cyclic loading reversals applied simultaneously with a constant axial pre-compression of 0.1 MPa. Based on the obtained experimental results, NSM technique accompanied with the proposed anchorage system had a considerable effect in improving the lateral strength, lateral in-plane stiffness, and ductility of adobe wall specimens.

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1-INTRODUCTION

Much of the word architectural heritage in the regions with high seismic activity world has been built earthen materials. It is estimated that about 30% of the world's population lives in earthen buildings [1]. adobe structures are common in Iran and many other countries around the world. Insulation against sound and heat, cost-effectiveness, availability and low build time are positive features of adobe structures [2]. In developing countries, adobe structures include, in addition to architectural heritage, simple houses in rural and poor areas. However, there are concerns about the performance of this type of construction during earthquake actions. Damage to adobe structures in earthquakes in recent decades is evidence of the vulnerability of these structures. For example, in El Salvador's earthquake in 2001, more than one million people lost their homes and the most severe damage was to adobe houses [3]. In the Chile earthquake, about 370,000 homes were damaged and about 37% of them were adobe structures [4]. In the region of Maule, in Curicó, in particular, about 90% of the adobe structures were destroyed [4]. As a result, the definition of preventive techniques and low cost seismic retrofitting methods is a key aspect in maintaining these structures [5]. On the other hand, it is widely accepted that the performance of adobe structures depends considerably on the behavior of its walls. Therefore, strengthening walls in adobe structures can significantly improve their seismic response [6].

The conventional strengthening methods used in previous researches are divided into two groups of externally bonded and near surface mounted. In most existing studies, the externally bonded method has been used to retrofit adobe structures and this method has been effective in improving their seismic behavior. For example, Blondet et al. [7] used externally bonded synthetic rope to retrofit adobe structures. In another study, Hračov et al. [5] used externally bonded synthetic polyethylene and polypropylene mesh to repair and retrofit adobe walls. In addition, they used near surface mounted steel wire to strengthen the adobe walls, which increased the lateral strength up to 91%, indicating the superiority of the near surface mounted method compared to externally bonded mesh.

Near surface mounted method has many advantages over the externally bonded system. For example, this method has less effect on the appearance and beauty of the structure, and in this method, more strain in the reinforcing material created before the debonding and its maximum tensile strength can be used.

Despite extensive research on retrofitting/repairing of adobe structures, there is still insufficient knowledge about seismic behavior and their effective retrofitting methods. The

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Fig. 1. Test setup

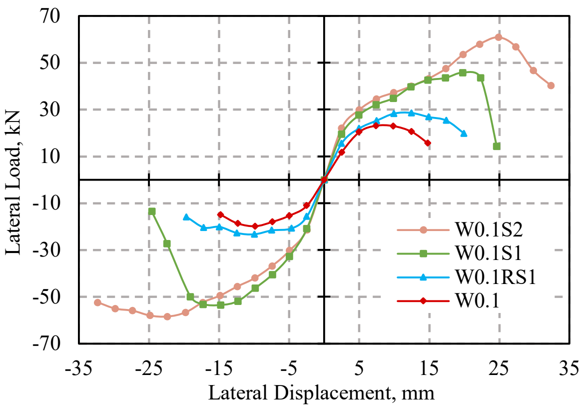

Fig. 2. The envelopes of hysteresis curves

current paper is part of a comprehensive laboratory research on seismic behavior and retrofitting of adobe walls at Yazd University. The main objective of this paper is to investigate the effect of retrofitting with near surface mounted steel rebars on the in-plane behavior of undamaged/damaged adobe walls. For this purpose, four adobe walls were tested under in-plane lateral cyclic loading and the results were compared to evaluate the retrofitting effect on lateral strength, displacement capacity, ductility and energy dissipation.

2-TEST PROGRAM

The present study was conducted on the basis of testing four adobe wall specimens with considering the variable parameters of initial damage and reinforcement ratio. The adobe blocks used in construction of wall panels measured about 200×200×45. The walls were made from mud mortar in 1:1 ratio of clay and sand. The compressive strength of adobe was 4.43 MPa while the compressive strength of the mud mortar was obtained to be 3.31 MPa.

Prior to application of the NSM steel retrofits on the damaged wall, the control wall was repaired with cement based mortar. The NSM reinforcements were applied vertically and horizontally in both sides of the strengthened or repaired walls. To preclude undesirable debonding failure, both ends of rebars comprised 90° hooks. The retrofitting scheme involved cutting slots into the wall surface to place the NSM rebars. Then, holes were then drilled at positions of the ends of the rebars, and the intersection of the vertical and horizontal slots. Afterwards, the vertical rebars were put into the slots. In order to prevent buckling of vertical reinforcement, vertical rebars at both sides were connected together using a galvanized wire passed through the holes. Finally, the horizontal rebars were placed into their location and all holes and slots were filled using a non-shrinkage cementitious grout with a minimum compressive strength of 35 MPa. The steel rebars had a tensile strength of 420 MPa and an elastic modulus of 203 GPa.

Fig. 1 provide an illustration of the test setup. The lower part of the wall was fitted as a grip on a special base attached to the rigid floor, and on top of the wall, the roller support was provided. In order to simulate the gravity load on adobe walls, a vertical load (equal to 0.1 MPa vertical stress) was applied using al hydraulic jack. The increasing lateral displacement reversals were applied at 700 mm height using a dynamic actuator possessing a capacity of 100 kN.

3-RESULTS AND DISCUSSION

The hysteresis curves of adobe walls were obtained and their envelopes were compared in Fig. 2. In the overall comparison of the curves, a significant improvement in lateral behavior can be observed in strengthened wall specimens. The NSM repairing scheme was not only capable of restoring the strength of damaged walls, but also enable to improve their structural performance compared to the as-built specimen. The highest ductility factor, energy dissipation and displacement capacity were observed in W0.1S2.

4-SUMMARY AND CONCLUSIONS

In this research, retrofitting of adobe walls in two undamaged and damaged conditions using near surface mounted of steel rebars with end hook was evaluated. Based on the experiments, the following conclusions were made:

1- Strengthening the undamaged specimens using near surface mounted steel reabrs was able to increase the lateral load bearing capacity about 3 times of the control specimen. Using this method in damaged and severely cracked wall could restore the lateral loading capacity to a higher level compared to the control wall.

2- The maximum displacement capacity of the control wall was 13.8 mm (the drift of 2%), which is an acceptable value. Displacement capacity in the repaired wall increased by 35% and in strengthened walls increased up to 235%.

3- The proposed strengthening method was able to maintain the integrity of the adobe wall to a remarkable lateral displacement and prevented opening of the cracks. By increasing in the number of steel rebars, the failure mode in the adobe wall was limited to local crushing at the lower corners of the wall.

4- There was no visible slip and debonding between the strengthening rebars and the wall. This indicates the effectiveness of the proposed anchorage system.

5- The ductility factor of retrofitted specimens increased from 30 to 65% relative to the control specimen.

6- Energy dissipation in the retrofitted specimens increased up to 5 times compared to the control. Among the retrofitted specimens, the repaired wall had the least amount of energy dissipation which was twice the energy dissipation of the control specimen.

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