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Experimental investigation on the seismic behavior of adobe walls retrofitted with palm meshes

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ABSTRACT: Use of adobe materials is considered as a common construction practice in rural and historic cities of developing countries including Iran. Compared to other conventional building materials, adobe offers some advantages such as eco-friendly features, local availability, easy application, cost-efficiency, and high thermal and sound insulation. However, the weak seismic performance of adobe buildings under past earthquakes has led to extensive economic losses and casualties. Therefore, retrofitting of such buildings and development of guidelines for their seismic design seem vital if they are intended to resist strong ground motions. In addition, retrofitting of adobe buildings with natural and traditional materials would be more desirable. Due to the critical role of walls as the main load bearing element in adobe buildings, their retrofitting would be of high priority. Towards this, the current study was aimed at utilizing palm fibers as a natural and sustainable material in lateral retrofitting of adobe walls. In total, six adobe wall panels, with dimensions of 1000×900×200 mm, including one control and five retrofitted specimens were tested under the combination of a constant vertical load and incremental lateral displacement reversals. The retrofitting technique involved external application of palm meshes plastered with a straw-mud mortar. The experimental parameters comprise dimensions of meshes, number of anchors on both sides of the walls, and arrangement of meshes. The results indicated that using externally bonded fiber meshes can lead to retaining the overall integrity and change the shear failure mode to a rocking/toe crushing. Further, the lateral strength, ductility factor, and energy dissipation capacity of walls were improved remarkably.

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1. INTRODUCTION

Soil is one of the most important materials of historical buildings, which has significant cultural value in most civilizations. Thus, these buildings should be protected for future generations. In recent years, soil materials such as adobe have been considered as an eco-friendly building material in advanced countries [1]. Other advantages of soil, in comparison with other common building materials, can be named as high insulating, humidity adjustment, local availability, low cost. In addition, soil constructions usually would not require highly skilled labor. From structural point of view, this material has acceptable compressive strength but low tensile strength [2]. As a result, soil structures have been able to acceptably sustain gravity loads, while vulnerable under lateral loads as evidenced by recent earthquakes, including El Salvador (2001), Peru (2001), Bam in Iran (2003), China (2008), Chile (2010) and Nepal (2011)[3]. Unfortunately, many of the adobe masonry structures around the world are built in areas with high seismic risk, and therefore it is necessary to strengthen them and maintain their integrity to withstand seismic-induced forces [4].

Pioneer investigations dates back to 1980s, when Meli et al. [5] conducted a study on the seismic behavior of adobe structures., Their experiment was comprised of 1: 2.5 scaled-down masonry houses tested on a shaking table. Based on their results, strengthening of masonry houses using welded wire mesh was found to be an efficient method in this research. Bakhshi et al. [6] tested two models of four-crag hinged roof adobe construction: a test sample and a sample of 2: 3 steel mesh reinforced on a shaking table. An unsupported sample due to the lack of integrity of the structure, by creating vertical cracks in the walls and failure in the corners, led to the instability of the structure.On the plate, these cracks were directed to the bottom of the wall and the slipping mode was observed in the lower horizontal portions of the specimen. Hračov et al. [2] tested eight specimens of 240 mm thick adobe walls with two different adobe blocks under cyclic loading to evaluate the seismic behavior of adobe walls. They strengthened the walls using external polyethylene and polypropylene meshes and also used NSM steel cables. Both methods retained the overall wall integrity and increased lateral strength significantly.

In this paper, the results of lateral cyclic loading of six adobe wall specimens measuring 200 mm × 900 × 1000 mm were investigated under a constant vertical compressive

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Fig. 1: Palm rope mesh

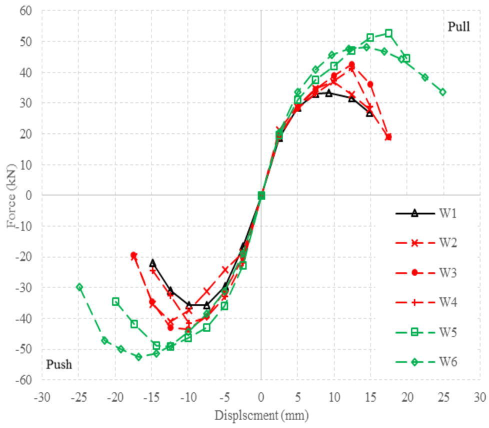

Fig. 3: The envelopes of hysteresis curves

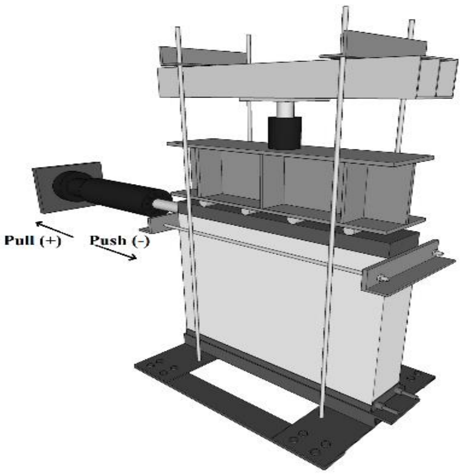

Fig. 2: Test setup

stress of 0.3 MPa and an incremental displacement loading reversals. The experimental program was aimed at evaluating the effect of external strengthening with palm rope mesh.

2. TEST PROGRAM

The present study was conducted on the basis of testing six adobe wall specimens with considering the variable parameters of grid mesh reinforcement, mesh arrangement, and number of transverse anchors. The wall samples were made of handmade adobe blocks of 200 × 200 × 45 mm in dimensions. The walls were made from mud mortar in 1: 1 ratio of clay and sand. The compressive strength of adobe was 4.43 while the compressive strength of the mud mortar was obtained to be 3.31 MPa.

For strengthening of the adobe wall samples, a woven mesh of the palm rope was used as shown in Fig. 1. The palm rope with a diameter of 5 mm was made in the city of Bafq. Mesh gratings had dimensions of 50 and 100 millimeters and were used in two configurations of rhombus and squares. The external strengthening mesh was plastered with straw-clay mortar, which were responsible to adhere the mesh to the wall, to tighten the grid mesh and protect the meshes. The palm rope strings had a tensile strength of 0.22 kN and an elastic modulus of 0.43 GPa.

Fig. 2 provide a schematic 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 0.3 MPa vertical stress on adobe wall) was applied using al hydraulic jack. The increasing lateral displacement reversals were applied at 800 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. 3. In the overall comparison of the curves, an improvement in behavior can be observed by decreasing mesh size (increasing mesh strength) and changing the grid mesh arrangement from square to rhombus (W5: small grid, square, W6: small grid, rhombus). The highest ductility factor, energy dissipation and tolerable drift were also observed in W6 and W5, respectively.

4. SUMMARY AND CONCLUSIONS

This paper presents a part of the results of a broad research project at Yazd University on the evaluation of the behavior and retrofitting of adobe walls. In this research, the role of woven warp of palm rope, which is an environmentally friendly traditional material, has been evaluated to improve the behavior of traditional adobe walls under lateral loads. Parameters for assessing behavior were overall integrity, lateral strength, lateral drifts, ductility factor, and energy dissipation capability. Based on the obtained results, the following remarks can be drawn:

1. The proposed external strengthening method using woven warp of palm rope improved the integrity of the wall samples and increased the ability to withstand the larger drifts. Also, with the proper distribution of cracks in the wall, the postponement of a sudden drop in resistance was observed in strengthened wall samples. Stronger meshes showed significantly better results.

2. After retrofitting intervention, the shear strength of

adobe walls increased up to 105% relative to the control sample3. The ductility factor of the control specimen was about 3, which is an acceptable value for this inexpensive, and environmentally friendly material. Nonetheless, this value increased to about 4 after strengthening.

4. Energy dissipation capability of the strengthened specimens was determined to be three times of the control specimen. The strengthened specimens could retain their energy dissipation ability and lateral strength up to an acceptable drift of 0.03.

5. The failure modes of the adobe walls were dominated by diagonal shear and toe crushing. Nonetheless, W6, which was strengthened with a stronger mesh and rhombus configuration indicated insignificant diagonal cracking up to the failure.

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