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Investigating the effect of vertical load on the behavior of adobe walls under cyclic lateral loading

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ABSTRACT: Adobe constructions are vulnerable to lateral loading and their failure in the past earthquakes has caused severe casualties and structural damages. Nonetheless, numerous adobe buildings are still being used in seismic-prone regions worldwide, including Iran, many are of historical background. Therefore, evaluation of their lateral behavior and retrofitting stands of high priority and can lead to preserving these national assets. In this study, the cyclic lateral behavior of adobe walls made of adobe units and mud mortar was investigated under different constant axial loads. The experimental specimens were comprised of four adobe wall panels measuring 1000 mm in length, 900 mm in height, and 200 mm in thickness. The main experimental parameter was the magnitude of axial compression applied on the wall. The experimental results were compared in terms of load-displacement hysteretic curves, cracking pattern, failure mode, stiffness degradation, cumulative energy dissipation, and hysteretic damping. With increasing axial stress from 0.1 to 0.7 MPa, the failure mode was changed from shear to shear-compression. Also, with increasing axial stress, lateral resistance increased, but the corresponding displacement decreased.

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1-INTRODUCTION

Soil has been extensively used as an affordable and inexpensive material in many countries. Most of the world's architectural heritages in regions of high seismicity have been built with 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. At present, about two-thirds of the buildings in Iran's historic textures consist of adobe structures [1]. Therefore, it is important to recognize the behavior of such buildings. Adobe structures usually consist of two elements of ceiling and wall. The ceilings have the role of transferring gravity loads to the wall. In addition to bearing vertical loads, walls act as the main lateral load carrying systems. Due to high variations of the behavior of adobe structures, the lack of a specific standard for such structures and local properties of materials, laboratory studies are the preferred method for evaluating and studying adobe structures [2].

Wu et al. [2] examined the hysteresis behavior of adobe walls, 1300 mm in height and 1650, 1750, and 2000 mm in length under cyclic loads. For this purpose, wall samples were loaded under vertical pre-compression of 0, 0.047 and 0.094 MPa combined with lateral cyclic load reversals. The adobe units used for the construction of walls posesses dimensions of 50 x 90 x 200 mm and a compressive strength of 1.66 MPa.

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The results showed that with increasing the ratio of height to length, the fracture mode was changed from the diagonal shear to slip while the ductility index increased. Varum et al. [3] examined the overall behavior of adobe buildings by conducting experiments on full scale samples.

Silveira et al. [4] tested a real scale I-section wall tested under the combined action of 19.4 kPa vertical pre-compression stress and in-plane lateral cyclic loading . The wall had a height of 3.07, a length of 3.5, a wingspan of 1.7 and a thickness of 0.29 m. The adobe units used in construction were collected from an old structure and had a size of 240 × 240 × 120 mm. Based on their results, the wall failure mode was diagonal tension. Capozucca [5] obtained adobe samples of 17 x 50 x 100 mm from an old structure. The adobe dimensions were scaled down to 1:3. The constructed walls were tested under different ratios of the main normal stresses. The observed cracks were developed in the middle of the sample and mortar-adobe interface.

A review of previous studies on the behavior of adobe walls shows that limited studies have been conducted to investigate the effect of vertical load on the in-plane cycle behavior of adobe walls. In addition, adobe units used in past research are different from the traditional adobes used in Iranian buildings in terms of dimensions and constituent materials. While conventional adobes used in Iran have been made from clayey soil fibers and limes were used in construction

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Fig. 1. Test setup

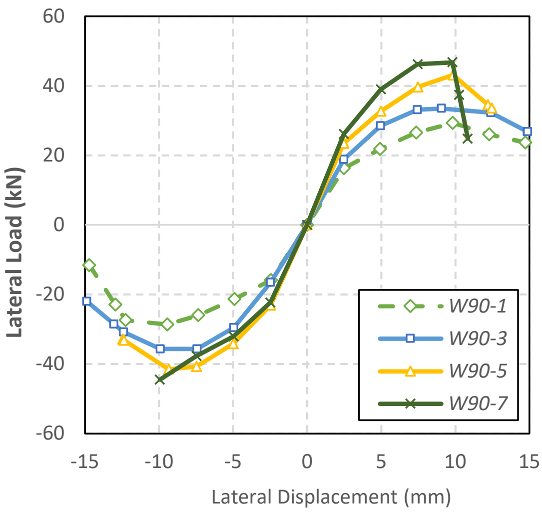

Fig. 2. The envelopes of hysteresis curves

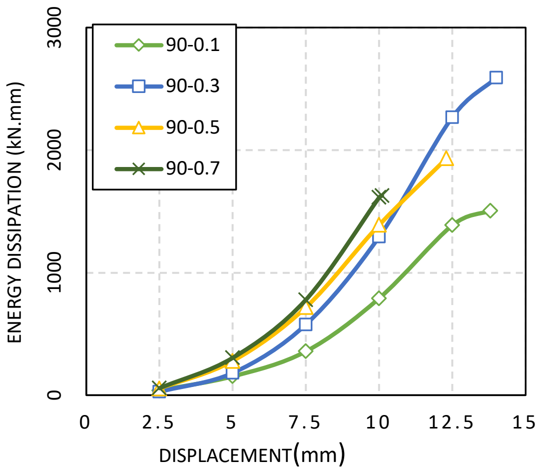

Fig. 3. Cumulative Energy Dissipation Curves

of adobes in some of previous studies. In this research, considering the probable vertical stresses on the walls of the adobe, the cyclic behavior and failure modes of adobe walls are investigated under the constant vertical stresses of 0.1, 0.3, 0.5 and 0.7 MPa.

2-TEST PROGRAM

The experimental program was comprised of four adobe wall samples scaled down to 1:3. All wall panels were 1.0 meter long, 900 mm high and 200 mm thick. These wall samples were tested under constant vertical stresses of 0.1, 0.3, 0.5 and 0.7 MPa and lateral loading reversals. The adobe blocks used in construction of wall panels measured about 200×200×45 mm. The walls were made of mud mortar mixed with a clay to sand ratio of 1:1. The compressive strength of adobe was 3.61 MPa while the compressive strength of the mud mortar was obtained to be 3.31 MPa. The construction of samples was done by local craftsmen with enough experience in the field of adobe work. The bond pattern of adobes was carried out following the details of the work used in the construction of the old walls. In erecting the wall panels, the thickness of the mortar joints was attempted to be approximately 10 mm.

Fig. 1 provides 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, while a roller support was provided on top of the wall. The vertical load was applied using hydraulic jack. The increasing lateral displacement reversals were applied at 800 mm height using a dynamic actuator possessing a capacity of 100 kN. Lateral loading was performed using a frequency of 0.1 Hz and a displacement increase of 2.5 mm after each three cycles.

3-RESULTS AND DISCUSSION

Fig. 2 compares envelopes of the hysteresis curves of adobe walls. With increasing vertical stresses, the lateral strength of adobe walls increased, while the displacement corresponding to the failure of the samples decreased. As seen in the figure, the maximum lateral resistance of the wall samples is obtained in the lateral displacement of 7.5 to 10 mm, which corresponds to a drift of about 1%.

In Fig. 3, cumulative dissipation energy curves of the tested walls are compared together. However, in the initial cycles, energy dissipation was found higher in samples with higher axial compression. But, the ultimate energy dissipation capacity of the wall loaded under 0.3 MPa axial compression were larger. In this specimen, while considerable friction slippage resulted in energy loss, the compressive stress was not high enough to lead to a premature compression failure.

4-SUMMARY AND CONCLUSIONS

In this research, an experimental invetigation was conducted to evaluate the impact of axial compression on the lateral behavior of adobe walls. For this purpose, four wall panels were tested under the vertical pre-compression stresses of 0.1, 0.3, 0.5 and 0.7 MPa, combined with cyclic lateral loading. Based on the obtained results, the following conclusions were made:

1- With increasing axial compression, the lateral load capacity of the wall panels increased. The maximum increase, under vertical stress of 0.7 MPa compared to 0.1

MPa, was about 57%.

2- With increasing axial stress, the failure mode was changed from shear-slip to shear-compression.

3- With increasing axial stress, the maximum tolerable lateral deformation was reduced.

4- The maximum lateral load capacity of the wall samples was obtained at a drift of about 1%.

5- The lateral stiffness of the adobe walls was enhanced with increasing axial stress.

6- The highest energy dissipation was observed in the wall under 0.3 MPa axial stress. The least energy dissipation was related to the wall specimen with the least stress.

7- The highest cyclic damping ratio was observed in the wall specimen with the axial stress of 0.3 MPa and was about 0.24.

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