SHEAR AND OUT OF PLANE BENDING STRENGTH OF ADOBE WALLS EXTERNALLY REINFORCED WITH POLYPROPYLENE GRIDS.

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ABSTRACT :

Experimental studies were conducted using geogrids as seismic reinforcement for earthen buildings, including shaking table tests on complete modules and cyclic horizontal shear tests and out of plane bending tests on adobe walls. It has been concluded that the geogrid applied on both surfaces of the adobe wall, and plastered with mud is a compatible and highly efficient reinforcement that eliminates the seismic vulnerability of adobe constructions. The reinforcement embedded in the mud plaster mortar works in conjunction with the adobe wall forming a composite material where geogrid take the tensile stresses and the adobe takes the compression forces..

KEYWORDS: Geogrid, seismic reinforcement, adobe, composite material

1 INTRODUCTION

Between the many loses produced by earthquakes, the loss of earthen buildings is especially significant. Cases as the city of Bam in Southern Iran, almost completely destroyed by an earthquake in 2003, focused the attention on the problem of reducing the seismic vulnerability of earthen buildings and at the same time satisfying the minimum intervention criteria for economic reasons.
Structural interventions in earthen buildings have always had the problem of accomplishing engineering recommendation and at the same time being simple enough to be used by economically depressed people. Therefore, the structural intervention that provides life safety and assure the survival of the building must be executed in a way that produces minimal impact in the original building and its construction materials, they must be compatible with the earth material and simple enough for technical and economical reasons. In other words, the objective is to reach the maximum safety with minimum intervention.
Within this context, and industrial polymer geo-grid was used as external reinforcement for earthen buildings in a join research project between the Getty Conservation Institute and The Catholic University of Peru carried out in 2004-2005. Earthen model houses scaled ¾ of the original were externally reinforced with biaxial geo-grid at both sides of the wall and connected through it with nylon threads, The models were then subjected to several seismic simulation tests in one direction demonstrating the effectiveness of the polymer reinforcement in maintaining the stability of the building even in strong motions. This intervention technique promises to be a viable solution for new and existing earthen buildings.

2 GEOGRID ALTERNATIVE

In the year 2004, the Catholic University of Peru initiated a systematic experimental work in which several polymer grids were tested as possible seismic reinforcement for earthen buildings. After several static and dynamic tests were the variables were the type of grid and its reinforcement configuration, it was concluded that the biaxial geo-grid placed at both sides of the wall, connected through it with polystyrene threads and plastered with mud mortar, is a highly compatible and efficient reinforcement that eliminates the seismic vulnerability of earthen buildings. The next step was to investigate the mechanical characteristics of this new mud-grid composite material trough its behavior during horizontal in plane cyclic shear tests and out of plane bending tests.

3 SEISMIC SIMULATION TEST ON SQUARE HOUSES

3.1 Construction procedure

The reinforcing geo-grid requires standard properties of strength and stiffness. The grid tested (Fig. 1) is fabricated from high density extruded sheets punched with a precise and regular pattern of circular holes. The grid is then stretched in both directions at controlled temperature and tensile force in order to obtain a biaxial grid with square like openings, rigid joints and flexible ribs.

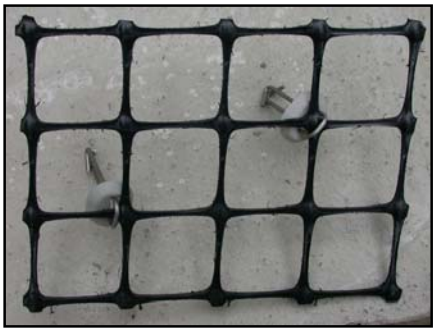

Figure 1. Biaxial geogrid.

For existing buildings, as a first step, the plaster of the wall must be removed before placing the grid on both sides of the wall. To fix the grid to the wall, it is necessary to drill 3/8" holes at vertical and horizontal distances of 40cm and tying both sides with polyester threads, it is not necessary to fill the holes after tying. Commercially available geo-grids come in rolls of 3 to 4m wide by 50 to 75m long, it must be placed on the walls in such a way that cover the wall surface continuously in the horizontal direction. Finally, the grid must be covered with a mud based plaster. For new buildings the polyester threads can be left embedded in the motar as the wall is built.
In order to compare the influence of the mortar, only half of the model house was plastered (Fig.2).

Figure 2.Model reinforced with geogrid, half plastered

3.2 Experimental results

The model was subjected to seven seismic motions with peak acceleration of 0.15g 0.30g 0.60g 0.80g 1.0g and two motions of 1.2g, the signal was derived from a record of the Peruvian earthquake of May 31st, 1970. The tests demonstrated that placing an external polymer grid on both sides and connected trough the thickness of the adobe wall is an effective way to avoid partial or total collapse of adobe buildings even for severe earthquakes.

If the grid is not cover with mud stucco, the initial strength is the same as the plain unreinforced wall and the grid starts working after the wall is cracked. The grid confines afterwards, the different pieces in which the wall is broken avoiding partial or total collapses. The mud plaster over the grid greatly increases the initial shear strength and the stiffness of the wall. By controlling the lateral displacements, it prevents the cracking of the wall in great extent (Fig. 3).

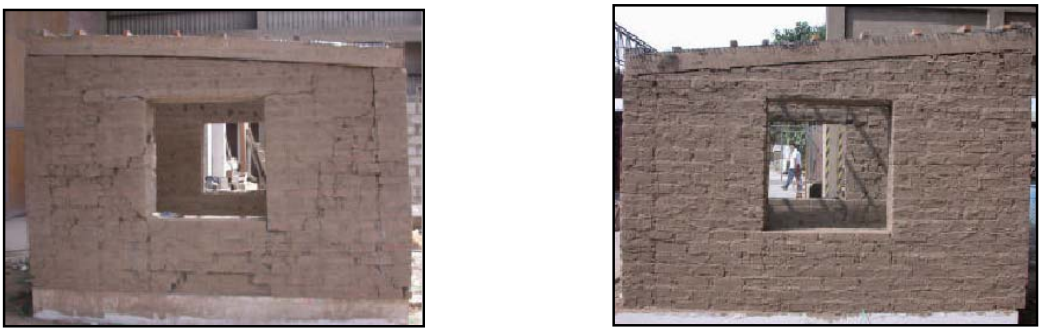

Figure 3.Non plastered side and plastered side after testing.

4 SEISMIC SIMULATION TESTS ON NUBIAN VAULT

As part of a project for the Health Ministry in the rural areas carried out by the non governmental organization Amares, we had the opportunity to test the effectiveness of this reinforcing technique in an earthen building of different architectural typology. Two Nubian Vaults models were subjected to the same series of dynamic simulation tests on the shaking table. Model 1 was a plain model and Model 2 was externally reinforced with the geo-grid but without plaster. The plaster was not placed on the walls surface because of weight limitations.
The test series was the same that the one used in the square model house. The direction of shaking was coincident with the transversal section of the vault.
The reinforced vault resisted greater seismic intensity motions than the unreinforced vault avoiding the collapse of the vault and providing inelastic deformation capacity to the earthen vault. The unreinforced vault collapsed at moderated seismic motions (Fig. 4).

Figure 4. Reinforced vault and non reinforced vault after test.

5 SHEAR STRENGTH OF ADOBE WALLS

From the earthquake resistant point of view, one of the main properties of the structural walls is the in plane shear strength that can be obtained from cyclic horizontal shear tests by dividing the horizontal force between

the net horizontal cross area of the wall. Three walls of the same architectural configuration were tested in different projects, Blondet et al, (2005) reported the comparative tests of a plain wall and a grid reinforced wall without plaster. A third wall was tested in 2007 with grid reinforcement and plastered with mud (Fig 5). The results show that the wall reinforced with geo-grid and plastered with mud, increase in the initial strength in 40% and the ultimate strength in 150% regarding the plain wall, whereas in the absence of plaster the reinforcement only provides displacement capacity regarding the plain wall. Also it was noticed a significant increase in the absorbed and dissipated energy with big capacity of horizontal displacement. At ultimate stages of testing, big portions of the plaster detached from the wall diminishing the horizontal force but nevertheless maintaining the displacement capacity as in the case of no plaster. (Fig. 6)

Figure 5. Cyclic shear test on reinforced adobe wall.

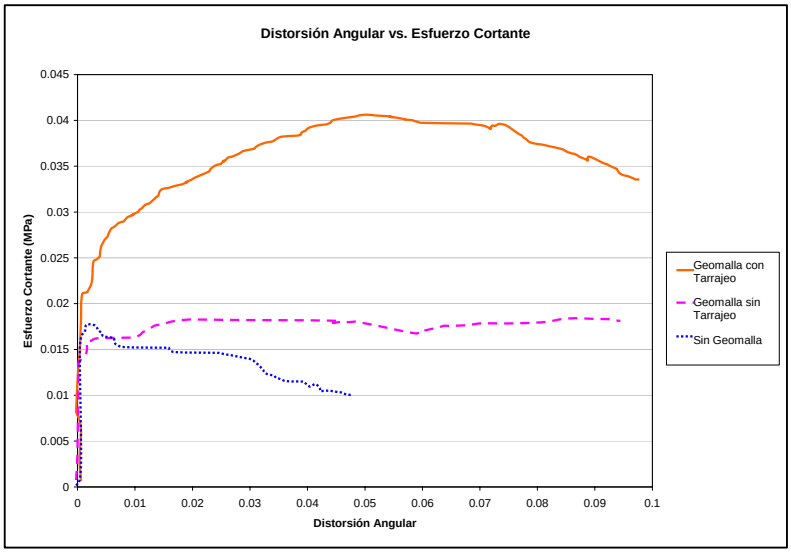

Figure 6. Comparative evolvement curves of plain, unreinforced and reinforced walls in shear test.

6 OUT OF PLANE BENDING RESISTANCE OF ADOBE WALLS

Another important structural property of the wall is the out of plan bending capacity that can be obtained by out of plane horizontal force tests. Three 0.80 x 1.60m walls with a thickness of 0.25m were subjected to loading and unloading test. The walls were horizontally supported at the bottom and top creating a simply supported bending type of behavior. The tests corroborated that the grid embedded in the plaster mortar creates a composite material where the adobe wall takes de compression forces and the grid the tension forces (Fig. 7), and that they work jointly until ultimate stages of the testing. The reinforced panel can undergo 25 times more the horizontal displacement that the plain panel (Fig. 8) also there is an important increase in the bending capacity.

Figure 7. Out of plane bending test on reinforced adobe wall.

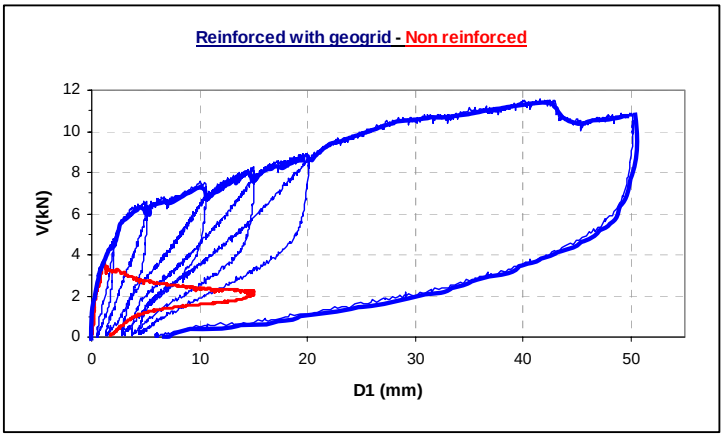

Figure 8. Comparative curves of plain and reinforced walls in bending.

7 CONCLUSIONS

- The geo-grid reinforcement placed externally on the wall surface is very effective in drastically reducing the seismic vulnerability of the earthen buildings with different architectural typologies.
- The biaxial geo-grid by its compatibility with natural soil, high tensile strength, stiffness and durability is suitable to be used as external seismic reinforcement on earthen buildings.
- The geo-grid embedded in the mud plaster creates a composite material providing tensile resistant and displacement capacity to the whole earthen structure. It is now possible to develop mathematical expressions to compute the shear and bending stresses.
- This technique, although can be applied to both existing and new adobe buildings. In case of existing buildings the plaster has to be removed and placed again after the reinforcing procedure.
- By providing a mean to satisfy the safety conditions of actual construction codes, this technique can help to legitimize earth as a construction material and allow the tradition of building with earth to continue in the future in earthquake prone countries.
- Many other seismic simulation tests have been performed varying the reinforcement configuration, grid type and orientation of the house regarding the direction of shaking. All of them have demonstrated that uniform and compatible external reinforcement placed continuously on the walls drastically reduces the seismic vulnerability of earthen buildings and even eliminates it.

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