Seismic Design Criteria for Adobe Buildings Reinforced with Geogrids

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SUMMARY
Existing earthen buildings are about half of the housing inventory in the world. In many places were these buildings are located, strong earthquakes are also very frequent, causing every time considerable material damage and irreparable loss of lives and cultural property. In spite of its seismic vulnerability, vernacular earthen houses, however, are still being used by millions of people in many countries because of cultural, climatic and economic reasons. In the search for widely available and compatible materials, biaxial geogrids placed on both surfaces of the adobe wall, connected throughout it and plastered with earthen mortar, appears as a promising solution for reinforcing new and existing earthen buildings without changing its appearance and providing excellent seismic resistance, avoiding collapse. This has been corroborated by static and dynamic simulation test carried out at the Catholic University of Peru.

Keywords: seismic behaviour, earthen buildings, seismic resistance, geogrid reinforcement

1. INTRODUCTION

1.1 Seismic Vulnerability of Earthen Buildings.

The main structural elements of earthen building are the walls, and their seismic vulnerability is due to its high mass therefore producing high inertial forces and its very low tensile strength giving as a result a brittle type of failure, with a sudden collapse (Figure 1).

Figure 1. Destruction of adobe houses Pisco, Peru. 5/08/2007 (Photo: Eric Hulburd)

1.2 Seismic Reinforcement fort Earthen Buildings

In the last 30 years, there have been several attempts to solve the problem of the low seismic resistance of vernacular earthen buildings. They have addressed both, the new and the existing earthen buildings using natural (wood and cane) and industrial materials (steel bars, steel mesh and cement).

In both cases, the most effective solution found so far, is to provide the building with uniform reinforcement, horizontal and vertical elements placed at a certain distance ranging from 0.40 to .70 meters or the use of a steel mesh with or without cement mortar plaster.

For new buildings, the most common solution is to incorporate an internal mesh of vertical whole canes every 50cm and horizontal split canes every 3 or 4 layers firmly tied at the corners and wall intersections and at the crown wooden beam (Vargas 1978). The main inconvenience of this solution is that natural materials cannot be applied in cases where massive construction is undertaken such as in the aftermath of an earthquake.

For existing buildings two solutions have proven to be effective: completely reinforce the building with an external welded wire mesh anchored to the foundation and top beam (IAEE 1986) and partially reinforce the buildings with an external steel mesh covering both sides and tying them through the adobe walls (Zegarra et al. 1997), this solution would require a sand cement mortar plaster for the sake of protection of the steel mesh. Both solutions can also be applied to new buildings. There are however some inconveniences in the use of these solutions, first, it implies materials, wire mesh and cement that are much too expensive for their use in vernacular housing, second, the sand cement plaster have the inconvenience of incompatible stiffness with the adobe walls, and third, for buildings of cultural value, a sand cement stucco on an adobe wall, will change its plastic appearance.

Structural interventions in earthen buildings have always had the problem of accomplishing engineering recommendations 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, the reinforcement used must be compatible with the earth material and simple enough for technical and economic reasons. In other words, the objective is to reach the maximum safety with a minimum intervention.

Within this context, and industrial polymer geo-grid was used as external reinforcement for earthen buildings in static and dynamic experimental research projects at Catholic University of Peru carried out since 2004. 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. Cyclic shear and out of plane bending tests were also carried out in order to determine mathematical relationships between load and deformation that would lead to simple design procedures.

2. THE GEOGRID ALTERNATIVE

2.1 Reinforcing Material

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 reinforcing geo-grid requires standard properties of strength and stiffness. The grid tested as reinforcement (Figure 2) 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 2. Biaxial geogrid.

2.2 Construction Procedure

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 mortar as the wall is built (Figure 3).

Figure 3. Construction process of geogrid reinforcement

3. SEISMIC SIMULATION TEST ON SQUARE HOUSES

In order to compare the influence of the mortar, only half of the model house was plastered (Figure 4).

Figure 4.Model reinforced with geogrid, half plastered

3.1 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 (Figure 5 and 6).

Figure 5.Non plastered side

Figure 6.Plastered side after testing.

4. 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 (Figure 7). 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. (Figure 8)

Figure 7. Cyclic shear test on reinforced adobe wall.

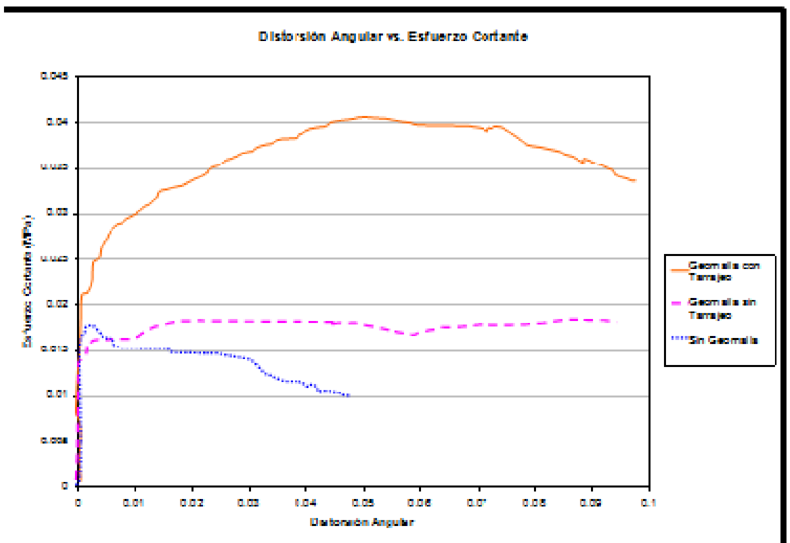

Figure 8. Comparative evolvement curves of plain, reinforced without plaster and reinforced and plastered walls in shear test.

5. SEISMIC DESIGN CRITERIA

In order to seismically reinforce adobe walls it is necessary to cover the maximum shear strength that is 0.04MPa associated to an angular distortion of 0.025. The reinforcement has to resist the shear force equivalent to the maximum shear strength times the thickness of the wall, in this case (0.04Mpa x t) being t the thickness of the wall.

In this way a simple design procedure is stated to allow adobe walls to resist earthquake forces beyond the elastic range.

6. 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 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 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.

- All seismic simulation tests performed, varying the reinforcement configuration, grid type and orientation of the house regarding the direction of shaking, 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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