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EFFECTIVE SYSTEM FOR SEISMIC REINFORCEMENT OF ADOBE HOUSES

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SUMMARY

A reinforcement system for existing adobe houses is presented, as well as an adaptation for new houses, with the objective to prevent their collapse under severe earthquakes. The experimental research project was developed between 1994 and 1999, with the financial support of GTZ of Germany, the administration of CERESIS, and the execution of the Catholic University of Peru. Several reinforcement techniques were studied, and it was concluded that the most appropriate was to reinforce the walls with horizontal and vertical strips of wire mesh electrically welded, covered with cement mortar. The technique was applied successfully in six existing houses that were subjected to the earthquake of June 23, 2001 (Mw=8.4), that affected the south of Peru. Neighboring dwellings of non-reinforced adobe suffered heavy damage or collapsed. This motivated several reconstruction programs of new reinforced adobe houses in the Andean zone, in which the technique was improved. Shaking table tests on the system used in the new houses demonstrated that the reinforcement provided is effective for resisting severe earthquakes without collapse.

INTRODUCTION

The international decade for the reduction of natural disasters declared by United Nations (1990-2000), provided the idea for the development of a research joint project between the "Centro Regional de Sismología para América del Sur" (CERESIS) and the Pontificia Universidad Católica del Perú (PUCP), with the financial support of GTZ (the German institution for technical assistantship). In summary, the

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goal was to find a way to prevent the sudden collapse of traditional adobe houses during earthquakes, which usually cause human casualties and loss of properties (fig. 1). The main objective was to provide the adobe house with the enough seismic resistance, so that the habitants could get out before it collapsed.

Fig.1. Collapse of traditional adobe houses due to severe earthquakes in Peru.

The problem focused on the existing traditional adobe houses, which are nearly 2 million units according to the last National Housing Census of 1993, INEI [1]. These houses are vulnerable to earthquakes due to many reasons, as follows: low resistant materials, absence of seismic reinforcements, bad construction of the walls and roofs, lack of maintenance, etc.

A series of seismic simulation tests on shaking table were performed at the Structures Laboratory of PUCP, in order to study several reinforcing techniques. It was concluded that the most appropriate was to reinforce the walls with horizontal and vertical strips of wire mesh electrically welded, covered with cement mortar. This mesh is composed by 1 mm diameter wires, with ¾" spacing. The technique was applied successfully on six existing adobe houses that were subjected to the earthquake of June 23, 2001(Mw=8.4) that affected the south of Peru, while neighboring adobe houses without any reinforcement had severe damage or collapsed. This motivated that several reconstruction programs for new adobe houses use similar reinforcement in the Andean zones of Arequipa and surroundings.

REINFORCEMENT OF EXISTING ADOBE HOUSES

The experimental project on existing adobe houses was developed between 1994 and 1999, having the financial support of GTZ, the administration of CERESIS and the execution of the PUCP.

The first part consisted on a series of seismic simulation tests on shaking table, using isolated U-walls as well as house modules, searching for easy and economic ways to provide external reinforcement to the adobe walls, in order to prevent the collapse. The preliminary tests are described by Zegarra et. al. [2] (1996). Different types of reinforcements were used: wood tables, ropes, chicken wire mesh, and electrically welded wire mesh. It was concluded that for existing one-story houses, the objective could be achieved, by reinforcing the weak zones (fig. 2), which are the intersection of perpendicular walls, as well as the upper part of the walls. The electrically welded wire mesh is nailed in vertical and horizontal strips, simulating columns and beams, at both sides of the walls. Every 0.5m, both vertical meshes are connected by wires that pass through holes previously done on the walls. Later, these strips are covered with mortar of cement :sand 1:4, as shown in fig. 3 and described by Zegarra *et. al.* (1997) [3].

Fig. 2. Typical cracks on adobe houses due to out-of-plane seismic forces.

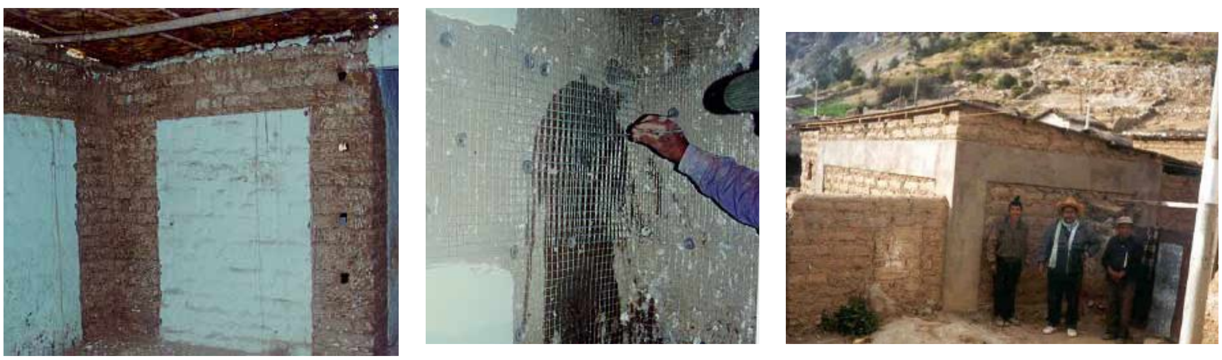

Fig. 3. Sequence of reinforcement on an existing house: Remove the existing cover and perforate the wall (left), connector wire and wire mesh installation (middle), and final cover (right).

The seismic forces increase with the amount of stories, therefore, in case of two-story houses, it is necessary to put the wire mesh over the whole surface of the first-story walls, and use strips of wire mesh for the second story walls, as shown in fig. 4.

Fig. 4. Reinforcement for existing 2-story houses.

In the second part of the project, towns with large amount of adobe houses were determined in 6 provinces of Perú: Tacna, Moquegua, Ica, Huaraz, Trujillo and Cusco, where 20 existing houses were selected for the application of the reinforcement technique. This part was done between September 1998 and January 1999, as described by Zegarra *et. al.* (1999) [4]. Later, the system was applied in a similar way to other Andean countries: Chile, Bolivia, Ecuador and Venezuela, as described by CERESIS web site [5].

SEISMIC BEHAVIOR OF THE REINFORCED HOUSES

The earthquake of June 23, 2001 (Mw=8.4) caused important damages, especially at traditional adobe constructions located in the south of Peru (Arequipa, Moquegua, Tacna). However, the 6 houses that were reinforced with the system proposed in this paper: three at Moquegua, two at Tacna and one in Arica (Chile), withstand the earthquake and the aftershocks without any damage, while neighbor houses had severe damage or collapsed (fig. 5), see Zegarra *et. al.* (2002) [6].

Fig.5. Reinforced house and unreinforced neighbor houses after the 2001 earthquake.

RECONSTRUCTION PROGRAMS OF ADOBE HOUSES

The COPASA-GTZ reconstruction program

The success of the reinforcement technique on adobe houses during the 2001 earthquake, motivated several reconstruction programs for new adobe houses in the Andean towns of Arequipa, according to GTZ [7]. The German government, through GTZ, and the Peruvian government, through CTAR-COPASA, financed the most important program building more than 350 new reinforced adobe houses for the people affected by the earthquake, and 16 demonstration modules. CTAR-COPASA is a mixed institution of the local regional government of Arequipa with assistantship of GTZ.

The architectural and electrical projects were performed by the “Servicio Nacional de Normalización, Capacitación e Investigación para la Industria de la Construcción” (SENCICO), a governmental institution dealing with the development of design and construction codes, the training of construction technicians, and also research for the building industry. The Arequipa branch of SENCICO did the coordination. The PUCP team, authors of this paper, elaborated the structural project.

The architecture of the house used for the reconstruction program consisted of a basic module that considered the type of existing houses in the zone, particularly, the idea that the rooms are multifunctional. Each room has 3.2m sides, and 2.2m height at the lowest part to 3.0m at the highest part.

The thickness of the wall is 0.4m and the roof has a small slope. The module has two rooms, with 36 square meters of plan area, and includes main door and windows, roof with wood beams, covered with metal sheets or with micro concrete tiles, tide to the beams in order to secure them against seismic vibrations.

The basic module architecture is shown in fig. 6, in which the vertical strips of wire mesh covered with mortar may be appreciated. The module was conceived in such a way that could be adapted to different areas and that future modules for expansion could be added by duplicating this basic module.

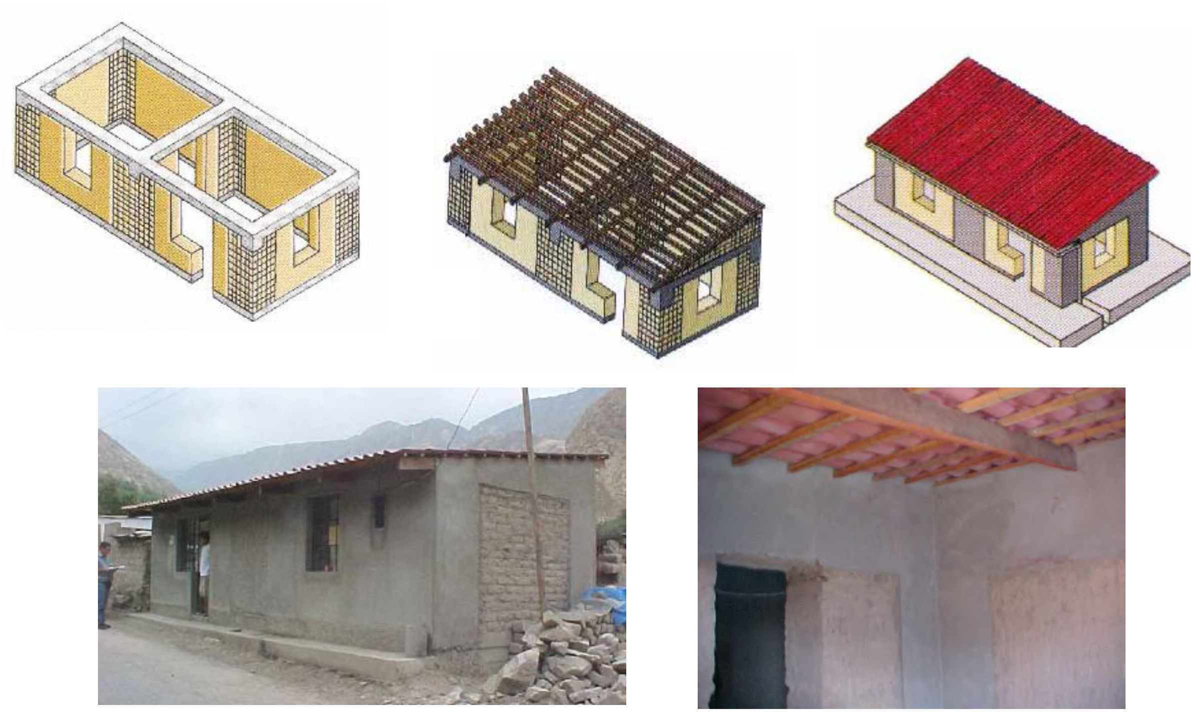

Fig. 6. Views of the new reinforced houses built in Arequipa.

Some of the structural improvements, designed at PUCP, are indicated in fig. 7, and include the following: 1) use of plain concrete for the foundation; 2) the construction procedure, like the wetting of the adobe units before placement, the use of a marked stick to control the 2 cm joint width, the installation of the connector at the vertical joints covered with cement mortar; and, 3) the collar beam of poor concrete (f´c=10 MPa), used as lintel in doors and windows, reinforced with two #3 bars.

Fig. 7. Some structural improvements in the new adobe houses: wire connector in joint (left), collar beam (middle), and shear key (right).

At the end of the collar beam, at the intersection with an orthogonal wall, a plain concrete shear key was included to avoid sliding of the beam during seismic movements. The purpose of this beam is to connect the walls, and in case the collapse of the unreinforced part of the walls occurs, this beam can still carry the roof weight, supported on the corners of the house that have wire mesh reinforcement.

Based on the architectural and structural plan drawings of SENCICO and PUCP, a technical Manual to aid the reconstruction work was elaborated by CTAR-COPASA [8]. This manual explains step-by-step the activities involved in the construction of a reinforced house. It features how to select an adequate site for the house, the trace of the walls, how to select the soil for the adobe units, how to elaborate the units, the placement of the adobe units, the location of the connectors, how to prepare, cut and place the wire mesh, how to build the collar beam, the roof and its cover, how to place the doors and windows, how to cover the wire with mortar, etc.

Seismic Simulation test on proposed module

In order to validate the technique experimentally, GTZ-COPASA in 2002, performed seismic simulation tests on shaking table on adobe modules of one room, at the Structures Laboratory of PUCP. This module was done by the workers of COPASA, with materials driven from the zone of Arequipa, and following the specifications included in the construction Manual. The module was designed to have a similar density of walls as the real houses, and was subjected to soft, moderate, severe, and catastrophic earthquakes, established by the Peruvian Seismic Code of 1997 of SENCICO [9].

The module withstand without any damage the mild earthquake, with unimportant damage the moderate earthquake, and with moderate damage the severe earthquake. Only for the catastrophic earthquake the module nearly reached collapse, generated by the shear friction failure of the plain concrete key located at the upper corners.

A conclusion driven from this test was that the seismic behavior of the proposed system for reinforced adobe houses could be still improved, in order to withstand even catastrophic earthquakes. The new features could include vertical dowels to connect the foundation with the wire mesh strips, reducing the rocking observed, and on the other hand, reinforcing the upper key with vertical dowels, to control the shear friction failure observed (fig. 8).

Fig. 8. Behavior of the module during the catastrophic earthquake simulation test (left), after the test (middle), and failure of the plain concrete shear key (right).

The PNUD-SENCICO reconstruction program

SENCICO (Arequipa branch) during 2002 and 2003 have developed the reconstruction of several adobe houses in the Andean zone of the province of Arequipa, with the financial support of the Italian Government and the Program of United Nations for Development (PNUD). This project also had the support of the local Municipality of Arequipa and the National University of San Agustín, according to SENCICO [10].

In this program, almost 100 adobe houses have been constructed, following the module plans initially developed by the COPASA-SENCICO-PUCP team. Most of these houses have the roof with a single slope, and only a few have a two-sloped roof. The roof cover is of metal sheets. In fig. 9 some of the houses of this project are shown, in which it can be observed the correct location of the visible electrical installations by the outer side of walls and roof, in order to keep the structure intact.

Fig. 9. New adobe house built by PNUD-SENCICO.

CONCLUSIONS

Using simple and economic techniques, this project has demonstrated that it is possible to provide reinforcement to existing and new adobe houses, to reduce the destructive effects of severe earthquakes, protecting the lives of low-income people.

For existing houses, it is necessary that before they are reinforced with the proposed system, they comply the limitations indicated at CERESIS [5]; for example, the walls must have their bases undamaged by the humidity, the roofs should not deteriorated, etc.

For new houses, it is recommended a correct location, for example, to avoid zones subjected to landslides or near slopes, and to not build besides a neighbor unreinforced house with damaged walls.

Although COPASA and SENCICO in Perú have divulgated this technique by building five hundred houses in the Andean towns of Arequipa, with the support of the German and Italian governments, the efforts are still small for millions of existing adobe houses in seismic areas over the world. It is necessary the support of governments and all kind of institutions so that techniques like the one presented in this article be divulgated. The reduction of the vulnerability of adobe houses is a need for our countries in which the poorest people live.

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Specially, we have to mention the work done by Mr. Alberto Giesecke, CERESIS Director, who had the initial idea to do research on how to provide seismic safety to the adobe houses, home of the poorest people.

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