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EARTHQUAKE-RESISTANT PROVISIONS FOR ADOBE CONSTRUCTION IN PERU

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SUMMARY

This paper presents a summary of research that served as basis for the Earthquake-Resistant Provisions for Adobe Construction in Peru, as well as the general characteristics of the code. Main points studied in pertinent investigations have been the critical importance of drying shrinkage of adobe mortar on masonry strength and the use of cane reinforcement to assure safety against collapse. The code has incorporated this results specifying a minimum of straw addition for drying shrinkage control and the obligatory use of cane reinforcement.

INTRODUCTION

Investigations in Peru have been dedicated to the study of the traditional techniques for adobe construction, characteristics of adobe materials that influence masonry strength, identification of predominant failure modes and, proposal of affordable solutions intended to improve the seismic behavior.

The object of the present work is to present and discuss the new earthquake-resistant provisions for adobe construction approved by the National Institute of Research and Standards for Housing (ININVI). The code was developed by members from the National Societies of Engineers and Architects, the National University of Engineering, the Ministry of Housing and Construction, ININVI and the Catholic University of Peru. This paper is mainly dedicated to the principles and experimental results that served as basis for the code.

EXPERIMENTAL STUDIES

Since the approval of the previous code in 1977, several research projects have been conducted (Refs. 1,2,3).

Vargas et al (Ref. 1) performed extensive testing to understand the influence of materials (soil, straw, additives) of adobe masonry on shear strength. The work intended to explain why masonries made with blocks of similar compressive strength may lead to quite different masonry shear strengths. The study came to the conclusion that shear strength depends primarily on microcracking of the mortar due to restrained drying shrinkage. Drying shrinkage, however, does not affect compressive strength to the same extend since drying conditions for blocks are less restrictive. Volumetric drying shrinkage depends largely on the plasticity of the clay and amount of coarse material present in the soil. Clay provides the dry strength but is also responsible of drying shrinkage. The most efficient way to control drying shrinkage was to use large amounts of straw (2-3% by weight) as had been observed in ancient Inca ruins. Fig. 1 shows the obtained improvement of diagonal compressive strength as a function of percentage of straw in the mortar. The influence of straw (in the mortar) in the behavior of walls (dimensions 0.15 x 2.4 x 2.4 m) under lateral force is shown in Fig. 2. Compressive tests of adobe cubes fabricated with large percentages of straw have exhibited a linear behavior up to unusual strains in the order of 0.10. Additionally, large amounts of straw when used for block and mortar fabrication reduce considerably the unit weight.

Ref. 2 covered the aspect of out-of-plane response of single-standing adobe walls of different slenderness (thickness/height ratios) and frequency content of the ground motion. Tests were performed on the shaking table. All specimens showed a rocking motion. In the most simple terms, the results of this work indicate that out-of-plane response is a problem only when the resisting cracking moment of the wall is smaller than the maximum moment than can be developed during the motion. This maximum moment is equal to the total weight times half of the thickness. From this condition a limiting height can be derived which is equal to:

$$h = \frac{f_r}{2\tau} \qquad (1)$$

where fr is the modulus of rupture and τ is the unit weight. If the height is larger than the limiting height the wall is likely to crack and collapse as shown in Photo 1. For values of the modulus of rupture ranging from 50 to 100 KPa, Eq. (1) gives limiting heights of 1.4 to 2.8 m.

A reinforcement mesh of cane has proved to be an efficient way to avoid the collapse of adobe house models tested in the shaking table of the Catholic University of Peru (Refs. 3,4). The specimens were house models of square shape of dimensions 3.25 x 3.25 (plan) x 2.40 m (height) x 0.30 m (thickness) (Fig. 3). Experimental results showed that even though strength can be improved by controlling drying shrinkage, failure is fragile unless cane reinforcement is used. Reinforced specimens could reach a minimum strength of 50 KPa after 6 runs of increasing amplitude of the simulated ground motion up to a maximum base acceleration of approximately 1.5 G (Ref. 4). In addition, it was observed that the reinforcement prevents out-of-plane overturning of the transverse walls. These tests were not completed at the time of the committee work.

TRANSLATION OF LABORATORY RESULTS TO THE CODE

General Characteristics of the Adobe House The Peruvian adobe code is mainly directed to constructions that may be built by the government or other agencies capable of enforcing quality control. It is, then, still restrained to a small percentage of the total number of adobe houses. Dissemination of results to rural or urban-marginal areas requires properly oriented implementation projects that accomplish housing needs through cooperative work with the community.

As a result of a limited experimental and analytical data and the intensive damage suffered if the past by adobe houses, the code allows only the construction of one-story houses, however, this and other limitations can be exceeded if properly justified by a professional. It is emphasized through the code that the construction should be compact, symmetric and, with small windows or openings. Roofing should be as light as possible. Cold weather demands, however, thick layers of mud for insulation. There exist a necessity to device affordable light roofs with adequate insulation.

Materials and Construction Dry strength of adobe blocks is provided by the clay component. Quality of the soil is indirectly controlled by the compressive strength of the block which has been specified as a minimum of 1.2 MPa. More desirable values are in the order of 1.5 to 2.0 MPa. It is recommended to eliminate all foreign matter from the soil; mix the mud as thoroughly and uniformly as possible, dry the adobe blocks in the shade; clean the blocks before laying, make uniform and complete mortar joints and, check the verticality of the wall.

Masonry Shear Strength The importance of mortar is emphasized since it is a critical aspect. A 1% straw by weight is mandatory for drying shrinkage prevention. Straw should be any durable strong natural fiber cut in pieces of approximately 50-mm length. This amount corresponds to approximately the maximum that can be mixed by hand. If mixers are available higher amounts can be used. The recommended 1% straw is equivalent to proportions of 1 volume of soil to 1/2 volume of straw. In order to reduce mortar water absorption from the blocks, it is recommended that they should be wetted for 10 to 15 minutes.

The specified shear strength was safely assumed as 25 KPa since there was only limited information at that time. This value seems overconservative compared with the recent data from Ref. 3., which gives values larger than 50 KPa. These last values have been, however, calculated from laboratory specimens which are usually not representative of actual constructions.

Bending Strength Modulus of rupture of the masonry is assumed to be 40 KPa. Unfortunately, there is little information that supports this value which corresponds to masonry fabricated with mortar with no straw addition and tested under static loading. There is no data about the influence of straw on bending strength. To avoid a bending failure different limits of heights and, widths of walls between supports are given. For example, a 0.30m thick wall has a maximum height and width of 2.3 m and 2.5 m, respectively, while a 0.40-m thick wall has maximum heigth and width of 3 and 3.4 m. These values seem overconservative, specially for the thinner walls.

Design Philosophy The design philosophy is to allow the structure fail by shear, while out-of-plane overturning of the walls is avoided. In order to prevent a fragile shear failure, the use of cane reinforcement is mandatory. Unfortunately, it requires much more workmanship than unreinforced masonry. According to Eq. (1) to reach limiting heights of 2.4 m, a common wall height, the value of the modulus of rupture should in the order of 86 KPa, which is quite high for adobe masonry. It is likely that straw addition will increase bending strength to these ranges but there is no experimental information available. The code was assumed that cane reinforcement will prevent also the out-of-plane overturning of walls. Wall construction complicates a great deal when reinforcement is used, however, is affordable and guarantees prevention of collapse.

CONCLUSIONS

The Peruvian adobe provisions for earthquake-resistant construction has incorporated ancient traditions as the use of mortars with large amounts of straw. The good behavior associated at this technique has been experimentally verified. Cane reinforcement has been specified to prevent the collapse of walls by shear and out-of-plane overturning.

The code specifies a conservative value of shear strength. Reduction of this value would still need further studies.

The adequate behavior that can be obtained using the code regulations require more workmanship than usual. So, the acceptability by the users will not be immediate and would need implementation work which address all social-economical and technical aspects.

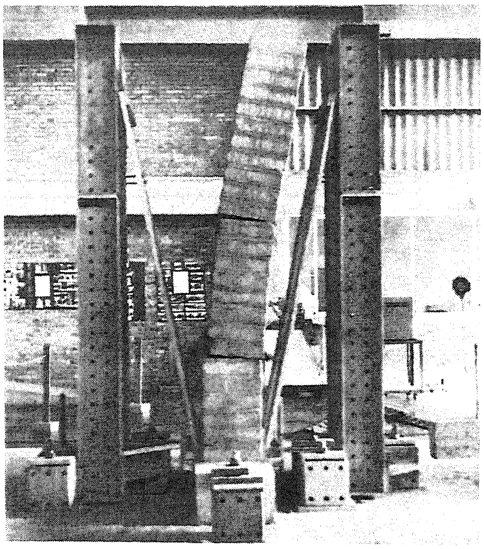

Photo 1 Cracking and Overturning of Wall 0.40 x 1.20 x 2.80 m.

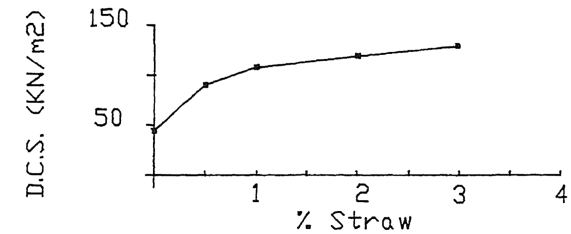

Fig. 1 Straw Influence on Shear

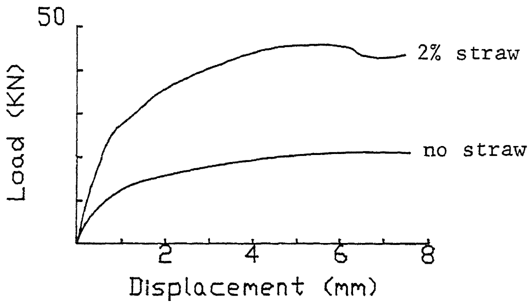

Fig. 2 Lateral Loading Test

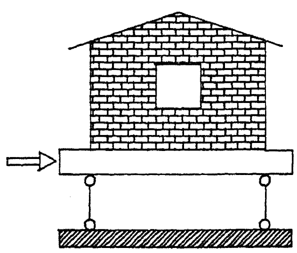

Fig. 3 Shaking Table Test

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