CHAPTER #5.03

USAGE OF BAMBOO POWDER AS AN ADDITIVE IN ADOBE BRICKS AND BAMBOO CANES FRAME FOR THE REINFORCEMENT OF ADOBE STRUCTURE

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1. Introduction

1.1. Raw earth architectures

Every expression of vernacular architecture is able to gather and witness traditional techniques of construction from any time. During the centuries, these traditions achieve high levels of adaptation to the context, with solutions of considerable interest from a structural, bioclimatic, economic and environmental point of view. Among them, earth construction plays a leading role, as demonstrated by its high adaptability. In fact, they spread for thousands of years throughout the world in areas with very different environmental and social contexts. Many construction techniques rely on the use of raw earth. The best known, are adobe and rammed earth (called also *pisé* or *tapia*). Techniques based on earth and straw, are spread worldwide; for example the wattle and daub, or methods based on earth and wood, like the cob wall constructions (bague or freemason). In Latin America those techniques (called *quincha, bahareque, embarrado, cuje*..) use the bamboo as one of the main construction material. In this paper we refer to the technique of adobe. It consists of sun-dried bricks made of a mixture of clay, water and organic fibers, pressed into an open timber frame. Adobe buildings are widespread in Latin America and the Middle Eastern countries, but also in the Mediterranean Area. The main characteristic of adobe is to have high compression resistance, but no tension resistance. Therefore, one of the most critical points of adobe buildings, and in general of earthen structures, concerns their seismic behavior. In case of horizontal loads of a certain severity, the walls tend to crumble. This material, often considered as modest and brittle, has been regularly replaced by materials considered modern and safer. Nevertheless, understanding and analyzing the criticalities of raw earth should be the challenge to improve both materials and techniques, in order to design innovative solutions.

1.2. The research on bamboo as a constructing material

The properties of this material are botanical, anatomical, physical and mechanical. It grows in different climates and many species are also invasive; moreover, it is easy to be employed in any construction: lightweight to carry and it has an optimal tensile strength. The plant grows under the ground with a complex root system that forms a single body with the stems that protrude from the ground. The cutting of the culms is controlled and does not involve the death of the plants that every year regenerate, in contrast with what happens with trees. Despite its peculiarities, the bamboo is often known as the "poor man's timber", the symbol of the precariousness in which the most disadvantaged populations live. The research analyzes the possibility of increasing the tension resistance of earth bricks, by using bamboo powder from the waste of industrial processing as additive in the mixture of adobe. The use of bamboo is also hypothesized as an external reinforcement and a prototype structure, that uses bamboo as additives in the adobe mix and as external reinforcement. The research designed an external frame of bamboo to be applied to the existing and new adobe walls, which is able to provide support in case of earthquake. The research analyzes the possibility of delaying the collapse of the structures of adobe using bamboo as a completion.

2. Uniaxial compression tests on adobe with bamboo powder additive

2.1. Materials and methods

The bamboo species used in research is the Angustifolia Kunth, a type of giant bamboo that grows in several parts of the world at temperate latitudes. Angustifolia Kunth is endemic of Latin America, where it is called Guadua and where is one of the most common species used in the construction industry. The powder we employed, passed through a sieve of diameter φ = 4.75 mm, it is a waste of production from a Colombian company that produces furniture and structural elements in the building industry. For the tests, they were prepared 27 specimens of adobe with bamboo powder addictive from the "bamboo burr". The specimens are 8 × 8 × 8 cm. The tests conduced on specimens without any additive and with 20% of water of the weight of earth, and the tests from Gigliotti & Malara (2012). These tests were performed in the laboratory of Materials and Structures Testing of DIDA (Unifi). For the realization of the specimens, it was employed earth dried in oven at 60 °C for about 24 hours, minced with mechanical grinder and passed through a sieve of diameter φ = 4.75 mm (corresponding to ASTM sieve n°4). The sieve n°4 was also employed to sift the bamboo powder. The earth was kneaded with bamboo powder in proportions equal to 3%, 8% and 12% of the weight of the earth, and mixed with water at 30% and 40%. The mixture was manually processed and pressed into a timber mold, and removed after 2-3 days of drying. Thereafter the specimens were seasoned with air on a wooden panel for about a month. This process of slow drying reduces the possibility of cracking. The performed tests in monoaxial compression, were conducted in stress-controlled mode; the force is increased at a given rate and the correspondent piston's displacement is measured. The test specimen are loaded with a rounded head on a thick plate positioned on the upper surface of the specimen. The data on the displacements of the specimen along the direction parallel to the load were recorded through four displacement transducers placed on the four corners of the load plate.

Table 1. Test specimens

Specimen	N.	Water Percentage	Additive	Additive %content*
I020	9	20%	None	0%
B330	9	30%	Bamboo powder	3%
B840	9	40%	Bamboo powder	8%
B1240	9	40%	Bamboo powder	12%
TGC**	5	19%	Calcined gypsum	15%

* dry weight percentage.

** Gigliotti & Malara, 2012

Table 2. Test specimens

Property	Symbol	Value
Specific Weight	Gs	2.4707 gr/cm3
Water Content	W	15.65%
Liquid Limit	Ll	23.09%
Plastic Limit	Lp	19.57%

Table 3. Comparison of the tensions of failure for adobe specimens

Specimen	Additive	σr [N/mm²]
I020	none	2.07
B330	3%	3.54
B830	8%	3.97
B1240	12%	4.61
TGC	Other*	2.4

* 19% of calcined Gypsum from Gigliotti & Malara (2012).

Table 4. The percentages of resistance's increase compared to resistance of the specimens without additive

Specimen	%
B330	70
B840	91
B1240	122
TGC*	15

* 19% of calcined Gypsum from Gigliotti & Malara (2012).

2.2. Tests

2.2.1. Preliminary analysis on the raw earth

To study earthen structures is necessary to investigate both the issues related to the soil mechanic and of the strength of materials. In order to hypothesize the shrinkage and the behavior during the tests. The earth used for the research is from an excavation about 4 meters deep in an area close to the little village of Guane, Barichara, Santander Department, Colombia. (Table 2)

2.2.2. Results

The tests on specimens with bamboo powder as additive, show different increases of the tension of failure σr respect to the values obtained by the specimens without any additive. Depending on the quantity of additive in the mixture. The test results are proposed in Table 3.

2.3. Conclusions

The use of bamboo powder as well as the calcined gypsum additive increases the compressive strength of the adobe. Heighten the quantity of additive there is an increase of the compression resistance; it is recorded according to the data presented in the following chart. (Table 4)
Bamboo powder is a material recycled from the waste of the industrial processing. Therefore, the use of such additive is an ecological solution and does not affect the final cost of the adobe bricks. Other than not affecting and reducing production costs, using this waste material allows you to enter a recycling and reuse process, thus sustainable.

3. Bamboo frame for the reinforcement of adobe walls

The research also tested the effectiveness of bamboo external frame for adobe walls, to install on existing and new structures. A grid of orthogonal bamboo canes, tied together by means of vegetal ropes, forms the designed reinforcement. The frames, juxtaposed on both sides of the adobe wall are anchored each other by transversal elements, in order to form an external cage that stands on independent foundations. In normal conditions, the bamboo grid does not collaborate with the bamboo wall, but the frame is activated in case of earthquake, avoiding the risk of crumble of the wall; in fact, the elastic bamboo grid dissipates the seismic energy. The reason why the reinforcement is installed on both sides of the wall is that the seismic force can have different directions. Nevertheless, the tests were performed considering the presence of the frame on only one side of the wall. In fact, the aim of these tests is to evaluate the resistance of the canes and the lashed connections under the wall's self weight on the most loaded side. If the wall were loaded on the opposite side, the second grid would be activated. The tests were performed considering that the two structures are independently anchored to the ground.

3.1 Materials and methods

Laboratory tests were done on the adobe panel, on the bamboo frame and on the adobe wall reinforced with the frame. These structures were tested in horizontal position. The tests performed are static tests, that do not intended to quantify the failure resistance of the structure, but only to assess the collaboration of the two materials in the situation in which the adobe panel is subjected to out of plane stresses. The line of interaction of the load is perpendicular to the rows of bricks. The load was applied manually with the consecutive addition of weights of 5 kg each. The distributed load, perpendicular to the surface of the wall, is positioned along the central part of the same on a metal bar of 4 cm in width. The surface of the metal bar on the panel side was coated with polyethylene to adapt to the surface irregularities of the adobe wall. The measuring apparatus consists of graduated rulers integrated in the wall. A fixed horizontal line, constituted by a nylon wire hold in tension between the two supports, is the parameter on which is measured the vertical displacement of the specimen at the point of application of the load.

3.2 Adobe Wall

In order to perform the tests, they were made by hand 1200 bricks of dimensions 10 × 10 × 2,5 cm (scale 1:4). This procedure of production is analogous to the one described in the paragraph 2.1. For the realization of the bricks, no additives were used in the mixture. The bricks were afterwards assembled in scaled walls (scale 1:4) of dimensions 60 × 60 × 10 cm. The bricks are disposed in rows of 6 elements, fixed with mortar of sieved earth ASTM 10 (φ = 2.00 mm), mixed with water in proportion of 2.5 liters of water every 7 kg of earth. After a few days, the formwork is disassembled, and the wall seasoned for a month.

3.3 Bamboo Frame

The bamboo used is Phyllostachys viridiglaucescens, an Italian species that grows in Camaiore, Lucca. The preservative treatment is with the method of vertical diffusion for transpiration of the foliage, using a solution of borax and boric acid. The mechanical characterization of the bamboo culms is in Table 5.

Table 5. Characterization of the culms of Phyllostachys viridiglaucescens*

Property	Unit	N. of specim. tested	Value
Diameter min	mm	/	46.0
Diameter max	mm	/	67.0
Thickness min	mm	/	4.1
Thickness max	mm	/	7.2
Area min	mm²	/	578.2
Area max	mm²	/	1347.0
MC	% (dev.st.)	12	24.9 (5.8)
σc	MPa(dev.st.)	12	56.8 (7.6)
Ec	MPa(dev.st.)	12	3100 (520)
σt	MPa(dev.st.)	4	159.0 (13.0)
Et	MPa(dev.st.)	4	22500 (8000)

* Mechanical characterization of bamboo culms carried out by Fabiani, M. (2014).

Since the guadua culms used for structural uses in Colombia have diameters between 8 and 12 cm, a scaled diameter comprised beetween 2 and 3 cm was chosen. The canes were chosen with less imperfections. The length of the canes is about 1 m. The bamboo structure consists of 4 horizontal and 4 vertical canes joined together at 90 degrees angles. The spacing between the canes is about 19 cm, which corresponds to a real spacing of 75-80 cm (scale model 1:4). The lashing are made following the traditional technique of lashing with ropes (uniones amarradas in Hidalgo López, 1980). In particular, the square lashing, optimal for joining two perpendicular elements was chosen. This type of joint, as it is completely external to the culm, avoids to drill the bamboo fiber; it is simple to perform, and is realized with readily available on-site materials. The analysis of the mechanical behavior of the lashes showed that it has a static behavior similar to that of a hinge. The resistance of this type of unions is linked to the mechanical characteristics of the material used for lashings. The rope used is the Cabuya, a processed product extracted from the fibers of Furcraea Andean plant, traditionally used in the Eje cafetero region (Colombia). The tension of failure in traction was measured of the order of about σr = 54 Mpa.

3.4. Tests on the flexural test on the adobe panel reinforced with bamboo frame

The adobe walls were loaded until their collapse, that happened with an ultimate load of Fu = 220 kg. The test results are shown in the load – displacement (σ-ε) diagram (Figure 1).

The bamboo frame was not brought to its breakpoint, as the available instrumentation for the test was not able to apply an adequate load until the failure. The tests demonstrate how bamboo is able to withstand, without damage, to loads that determine the collapse of the adobe structure. Besides, once removed the load, the structure goes back to its initial configuration with minimum deformation left. Concluding, the results verified that the presence of the bamboo frame improves the stability of the adobe panel, if the panel exceeds the tension of failure. The bamboo structure under normal conditions of use does not cooperate with the adobe wall, but it is triggered in caseof horizontal loads, avoiding the collapse of the wall (Figure 2).

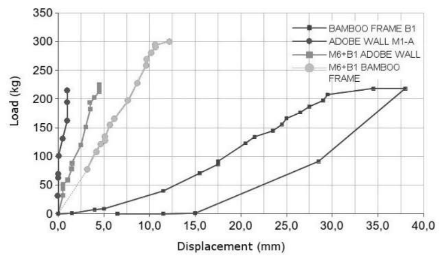

Figure 1. Load displacement diagram results

3.5. Conclusions

Figure 2 shows the load-displacement diagram results. Here, is possible to do a direct comparison among the bending tests of the different solutions (the adobe wall, the bamboo frame and composed structure). The adobe panel and the bamboo frame have a very different behavior. On one side, the adobe wall has not yield point and reaches abruptly the collapse (see test M1, Figure 2), on the other side, the bamboo tends to significantly deform. The specimen B1 in Figure 2 is an example of the above described behavior. Despite the different behavior of the two materials under loading, they have performed a good collaboration. As exhibited by the test specimen M6-B1 in Figure 2, the tests on the reinforced adobe wall demonstrated the ability of the bamboo frame to support the adobe panel, and prevent its collapse. When the adobe structure exceeds the tension of failure and fails, the adjacent bamboo frame prevents the crumbling of the already damaged parts. The comparison of the test specimens with and without reinforcement evidences the efficiency of the proposed solution, as shown in Figure 2.

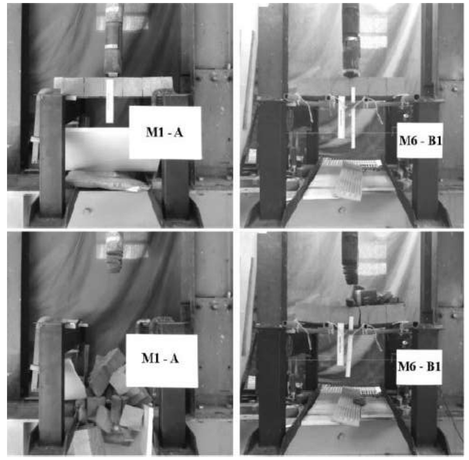

Figure 2. Comparison between de unreinforced wall (M1) and the wall reinforced with the bamboo frame (M6-B1)

4. Conclusions

The research has demonstrated the ability to increase the resistance of the adobe structures using various products from bamboo cane. Bamboo powder is a waste of industrial processing. Produced in large quantities, it can be used as additive in the mixture for adobe bricks. In small weight percentage (3% of weight of the used earth) the tested specimens' compressive strength increases up to 20%. Bamboo cane frames are external reinforcement in new and existing adobe structures. In presence of several horizontal stresses that could cause the collapse of the adobe structure, the bamboo frame is crucial to prevent the collapse. In addiction, the great flexibility of the element in bamboo absorbs seismic energy incident on the structure by reducing a further increasing of deformation of the adjacent adobe wall. The advantages of the use of such products are several. Among them, the bamboo is able to increase the resistance of existing and new construction to prevent their collapse in case of exceptional events. Nevertheless it is a renewable resource.

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