EXPERIMENTAL STUDY ON ADOBE WALLS WITH LONG TERM WATER EXPOSURE DUE TO FLOODS

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ABSTRACT

The sudden collapse of traditional adobe walls exposed to long term water action is addressed in this paper. Several solutions to avoid this dangerous behavior are tested experimentally. This is a common problem in Peru and many other countries. Heavy rains increase the rivers' flows and produce frequent floods that affect adobe houses built in riverside areas.

Six experimental techniques to protect adobe walls under floods were studied at the Structures Laboratory at the Catholic University of Peru. The techniques were simple, economical and had excellent results. The object was to protect the wall bases and lower layers to avoid the negative effects of water action. The study had two parts. In each of them four adobe walls were built on a concrete channel, which was filled with water simulating a flooding.

The first set had a traditional wall, and three other walls with different treatments against water action: a plain concrete plinth, stabilized adobe units, and an external wire mesh plastered with cement mortar. The second set also had a traditional wall, and three other walls with different treatments: a low resistance plain concrete plinth with large stones, clay brick units in the lower layers as plinth, and an improvement of the external wire mesh plastered with polished mortar. The traditional walls collapsed after 20 and 73 minutes in the first and second set respectively, while the other walls remained more than two weeks without danger of collapse. Therefore, the protection of adobe walls under floods is possible.

KEYWORDS: Adobe; Floods; Experimental techniques; Water action

INTRODUCTION

As result of our climatic diversity, Peru rural areas are periodically affected by intense rains that generate floods and river overflows. On the other hand, traditional adobe has a high vulnerability under prolonged contact with water product of these floods, which can cause the collapse of the structures (Figure 1). In this paper, two sets of experiments are reported, in which the water action of flooding was simulated on four adobe walls in each set. Eight walls were tested, two were traditional and the other six had some treatment or protection against water action. The solutions to protect the base of the adobe walls were all simple and economic. It is necessary to indicate that these solutions do not protect the adobes structures against the action of avalanches that drag large stones or rocks.

Figure1: Collapse of adobe houses under floods, Cusco Perú - 2010.

WATERPROOFED CHANNEL

A reinforced concrete channel with "U" section was used for the floods simulations, with an internal width of 280 mm. The channel fulfilled the requirements of impermeability and water tightness. It was divided into four sections of equal dimensions with independent channels as shown in Figure 2. In this way, the analyses of the variables of absorption, capillarity and performance along time of each wall were independent.

Figure 2: Channel used in the test of flooding. Test of water tightness.

CHARACTERISTICS OF THE MASONRY UNITS

For the first set of walls, traditional adobe units of 70x130x260 mm (height-thickness-length) were prepared in a factory; and for the second set the adobe units were prepared in the laboratory with dimensions 75x125x253mm. For improved wall SW, stabilized adobe units were prepared by adding 5% (in weight) of Portland cement type I to the dry soil. The CBW wall had industrial clay brick units in the bottom layers, having 91 mm height, 126 mm thickness and 231 mm length; also, these bricks feature 18 small holes in the bed area.

Table 1 shows the average results of the tests of suction and absorption for the different masonry units used in this research, as indicated in the Peruvian Brick Sample Code and Specifications (INDECOPI 2005). In the suction test, the masonry unit bottom 3 mm surface area is submerged into water for 1 minute, and the amount of water gained is measured, normalized to a surface area of 20000 mm^2 (200 cm^2) as indicated in the Peruvian Brick Code Peruvian Masonry Code (Sencico 2006, “Norma E.070” in Spanish). The Peruvian Adobe Code (Sencico 2000, “Norma E.080” in Spanish) does not have specifications for the above mentioned tests. For the traditional adobe units, these tests failed and the units disintegrated. In both tests, it is clear from Table 1 that the plastered adobe had a better performance than the stabilized adobes. These results indicated that a good behavior could be expected under water action if some treatment is used. Also, capillary rise was observed in the units after the suction tests. This rise was 17 to 20 mm for the traditional adobe units, 10 mm for the stabilized adobe units, 5 to 10 mm for the plastered adobe units, and 22 mm for the clay brick units. .

Table 1: Suction and absorption tests

Type of Masonry Unit	Suction ($gr/min/200cm^2$)	Absorption
Stabilized adobe (SW)	80	16 %
Plastered adobe set 1 (PW1)	16	10 %
Clay brick units (CBW)	43	12.5%
Plastered adobe set 2 (PW2)	17	9.5 %

CHARACTERISTICS OF THE FIRST SET OF WALLS

The first set of four walls had a Traditional Wall (TW1) and three improved walls with different treatments against water action. The first treatment, Concrete Plinth Wall (CPW), used a plinth of plain concrete, instead of the traditional foundation of adobe walls made of stones. The second treatment, Stabilized Wall (SW), consisted in the use of stabilized adobe units with 5% cement in the bottom six layers exposed to flooding. In the third treatment, Plastered Wall (PW1), the units under water action were protected with a cement-sand (1:5 volume proportion) mortar cover applied over a henhouse mesh made of galvanized wires, connected to the wall. The main characteristics of the walls inside the channel are shown in Figure 3. With exception of the wall PW1 whose thickness increased due to the mortar plaster, all the walls had the same dimensions: 1.50m height, 1.65m length and 0.13m thickness. All the walls were constructed by the same masons. The vertical and horizontal joints of the walls had 15 mm thickness and the mortar was prepared with the same material used in the adobes.

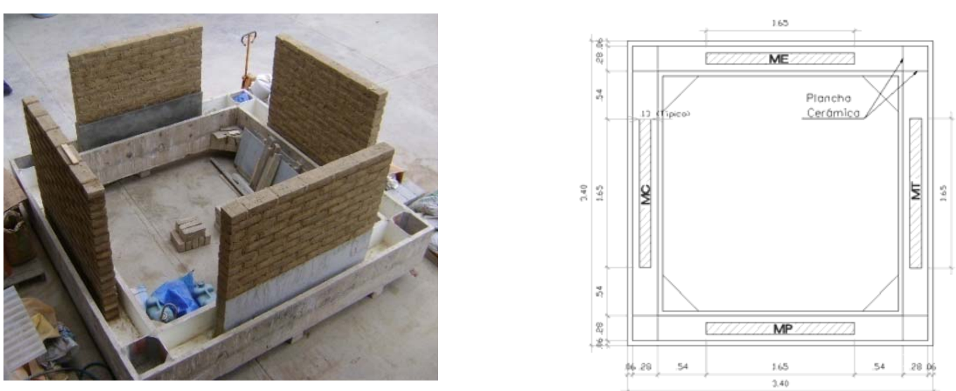

Figure 3: View of the four walls of the first set

The traditional wall (TW1) in Figure 4 does not have any improvement and the mortar was of the same material of which the adobe units were made. For the construction of the Concrete Plinth Wall CW1 shown in Figure 5, the plinth of plain concrete had f'c = 21 MPa. This foundation had 300 mm height over the water level and had the same thickness as the wall. The same traditional units and mortar were used (similar to TW1).

Figure 4: Traditional Wall set 1– TW1

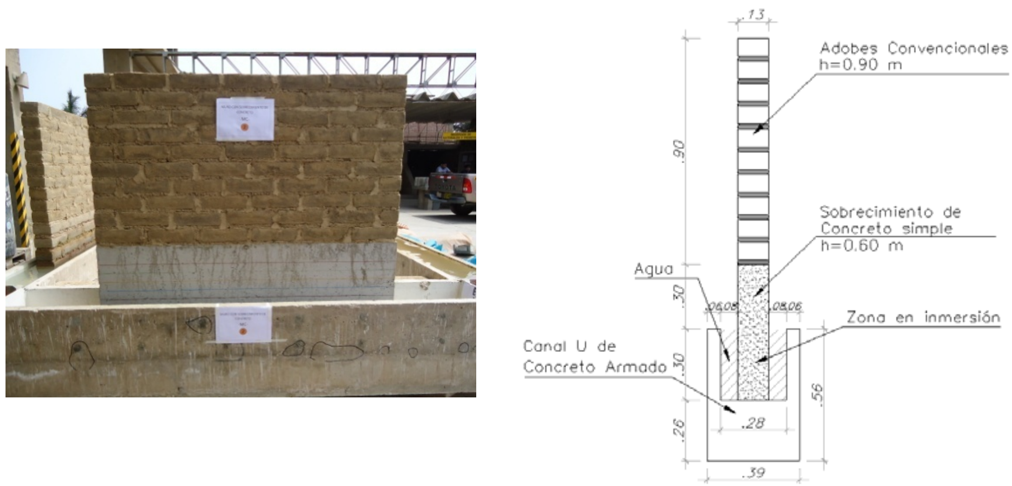

Figure 5: Concrete Plinth Wall – CW1

In the stabilized wall SW (Figure 6), from the base of the channel up to a height of 300 mm over the water level, six layers of stabilized adobes with 5% of cement (in weight), were used. The mud mortar was stabilized with the same proportion of cement, whereas the following layers had traditional adobe units and traditional mortar, similar to TW1. The plastered wall PW1 (Figure 7) was constructed totally with traditional adobes and mortar mud (similar to TW1). Later, it was plastered with a cement-sand mortar mix of 15 mm thickness, from the base up to a height of 300mm above the water level, over a henhouse wire mesh.

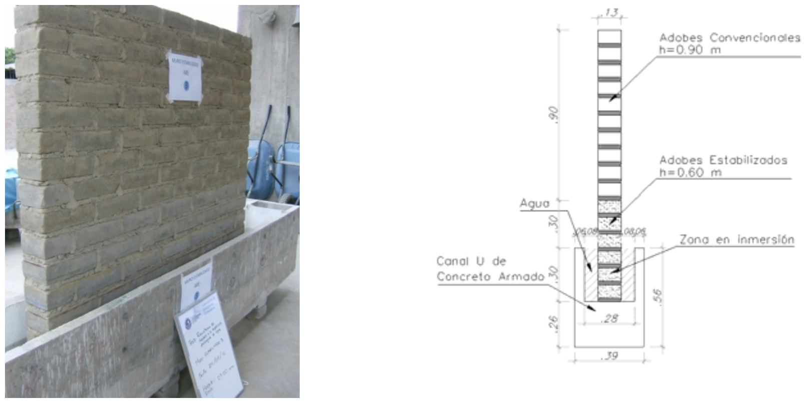

Figure 6: Stabilized Wall - SW

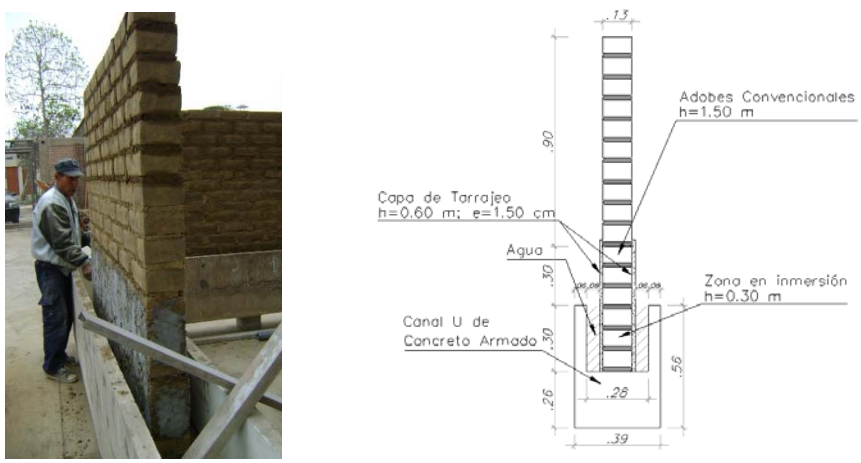

Figure 7: Plastered Wall set1 – PW1

CHARACTERISTICS OF THE SECOND SET OF WALLS

The second set of four walls had a Traditional Wall (TW2) and three other improvements in the wall treatment against water action. The CBW wall had the bottom six layers of clay brick units, as a brick plinth of 600 mm height, which is twice the area in contact with water. The mortar mix was cement-sand 1:4 volume proportion. The following 10 layers were of traditional adobe units, similar to TW2. The CW2 wall had a plinth of low resistance plain concrete; it had 600 mm height in which concrete was poured in layers, with 75 mm (3") previously washed stones placed in each layer. The last wall PW2 was built similar to the TW2, but a mortar cement plaster was applied afterwards over a welded wire mesh, to a height of 600mm and 20 mm thickness over the perimeter. The wire mesh was placed on both sides of the wall and it was connected to the wall with smaller wires in the vertical joints every 250mm. Finally, the plaster surface was polished by using cement powder with water.

Figure 8 displays the characteristics of the four walls of this second set. Also their position inside the concrete channel is shown.

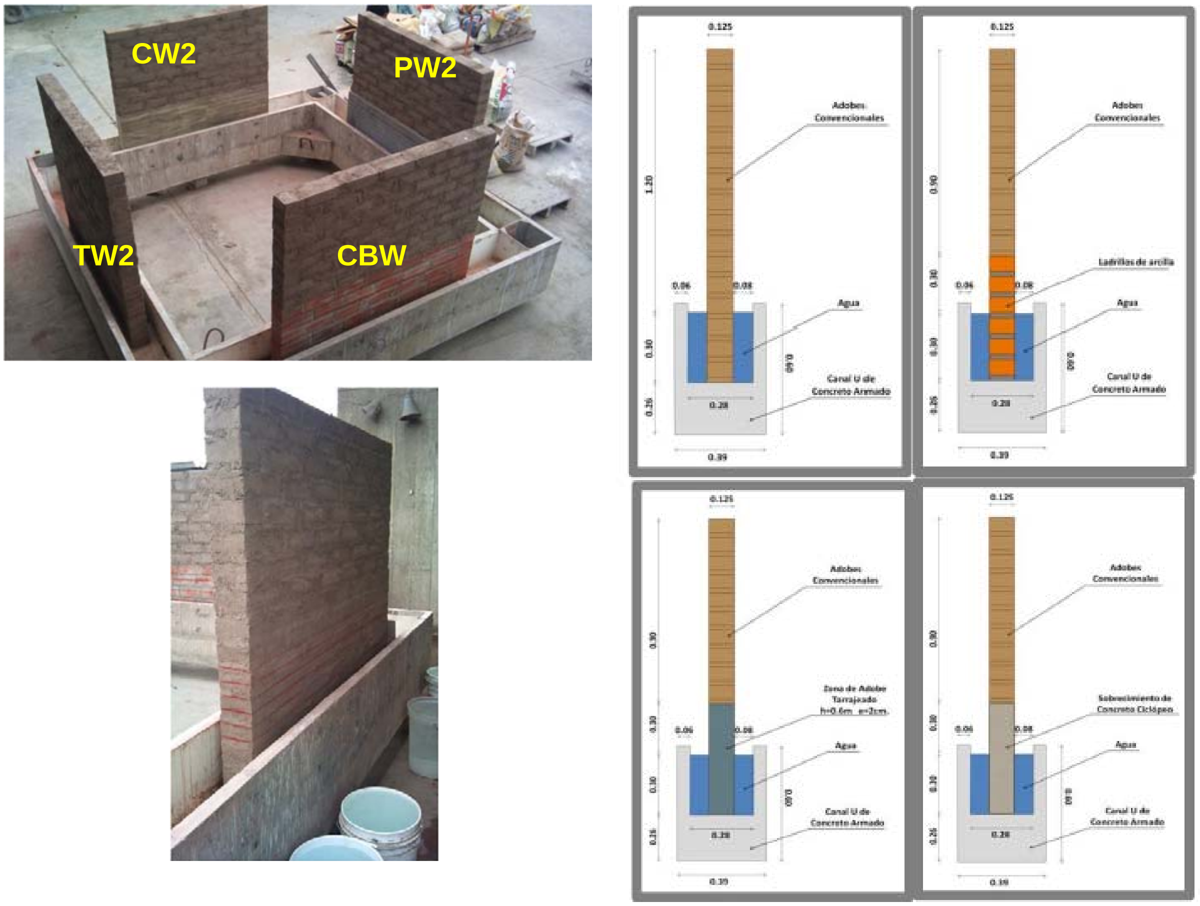

Figure 8: Walls of set2 – in the drawings TW2 (upper left), CBW (upper right), CW2 (lower left), and PW2 (lower right).

SIMULATED FLOOD TEST IN THE WALLS

The test procedure is described as follows. For both sets of walls, the flood simulation was performed 28 days after construction. To measure the amount of water absorbed by each wall, a ruler was used in each part of the channel, with divisions every 10 mm, over a total height of 300 mm. To measure the water rise across every wall by capillarity, horizontal marks were done every 50mm on the walls. The four parts of the channel were filled almost simultaneously with water simulating a flooding and controlling the water volume.

Two time periods were defined: the Short Period of Flooding (SPF) from the beginning of the test until 72 hours of flood; and the Long Period of Flooding (LPF), from the end of the SPF until 16 days of flood. During SPF, the wall base changes from natural humidity to a saturation condition. If a wall does not resist this period, it means that the wall does not resist the flood. The SPF time tries to represent a flood caused by the water rise of rivers, in which the water amount is rather constant. During LPF the wall base is already saturated and has resisted such aggressive environment. If a wall collapses during this period, it can be concluded that it is resistant to the flooding, but because of this effect, it suffers severe erosion that is not repairable, and therefore the treatment is considered as not adequate. This LPF time tries to represent the gradual water evaporation and the drainage of the flooding. Any wall that remains standing after this period will be considered to have had a successful treatment or improvement.

During the SPF, absorption and capillarity measurements were taken every hour, and every 24 hours the water volume lost by absorption of the walls and evaporation was replaced. During this period a video was recorded to register the instant of collapse of any wall. During the LPF, absorption and capillarity measurements were taken every 24 hours. Every week, the water volume lost by absorption of the walls and evaporation was replaced in order to keep the water rise by capillarity. During this period the times of measurement and water replacement were widely separated, and no video was recorded. Only photos and daily measurements were taken. At the end of the test, the walls were demolished from the top layer. A photographic record was taken of one unit every two layers, to study its consistency to touch and to observe the core humidity after splitting the unit in half.

BEHAVIOR OF THE WALLS UNDER THE FLOODING SIMULATION

The traditional adobe walls collapsed after 20 and 73 minutes, while the other six remained stable without danger of collapse. For the first set of walls, TW1 resisted less than the short period of flooding. The adobe units at the base disintegrated and immediately the wall overturned as can be seen in Figure 9. The other three walls of set 1, CW1, SW and PW1 resisted 16 days of flooding and they are shown in Figure 10.

Figure 9: Overturned wall TW1 and condition of the adobes in the base.

Figure 10: Three walls of set 1 that resisted the flooding simulation test

For the second set of walls, TW2 resisted 73 minutes of flood, also less than the short period of flooding. The other three walls of set 2, CW2, CBW and PW2 resisted all the 24 days of flooding before being demolished, as shown in Figure 11. Figure 12 shows the condition of adobe units of walls PW1 and SW of set 1, and the brick units of CBW of set 2.

Figure 11: Three walls of set 2 that resisted the flooding simulation test

Figure 12: Inspection of masonry units in the base after demolition of the walls.

RESULTS OF THE FLOODING SIMULATION TESTS

In order to compare the results of all the treatments that had good behavior in the flooding simulation tests, the following factors were considered: 1) degree of absorption and capillarity; 2) humidity of the masonry units at the end of the test; and 3) consistency of the adobes of the base at the end of the test. These factors were normalized respect to best technique in order to get a comparison damage index under flooding (see next paragraph).

In Fig.13 the water absorption (in liters) of the walls and the capillary rise (in cm) during the 16 days of test of set 1 are shown. A rapid absorption of water during the short period of flood is clear, whereas during the long period of flood the slopes of the graphs for walls SW, PW1 and CW1, are in a proportion 3:2:1 respectively. Regarding the capillarity, the rise for CW1 was of only 9cm without reaching the adobe layers and became stable after 48 hours. At the end of the test, the capillary rise proportion was 1.65: 1: 0 for walls SW, PW1 and CW1, respectively. In Fig. 14, the water absorption and the capillarity rise during the 24 days of test of set 2 are shown.

Also a rapid absorption of water during the short period of flood is clearly similar for the three walls. Regarding the capillarity, the maximum rise was only 55mm for CBW and for CW2 it was nearly 330mm by day 20. At the end of the test, the capillary rise proportion was 2: 3: 7 for walls CBW, PW2 and CW2, respectively.

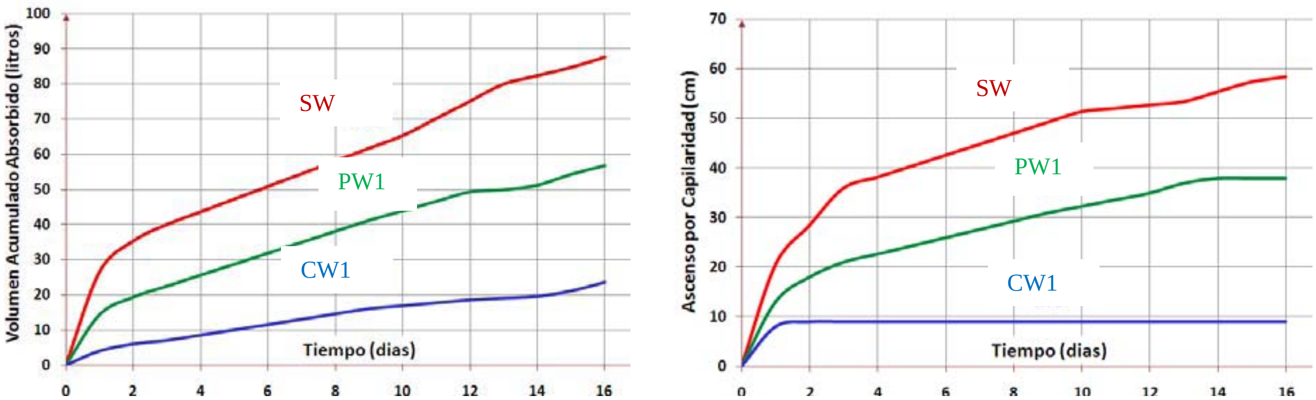

Figure 13: Results for set 1 of walls, absorption (left) and capillarity (right)

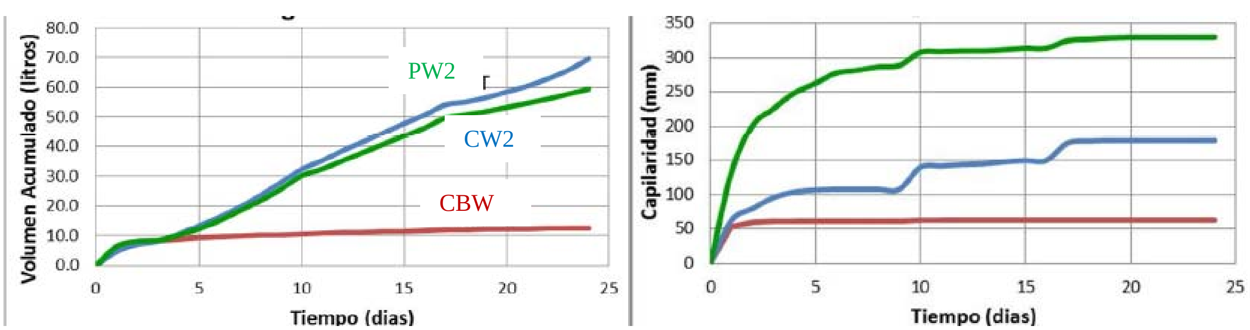

Figure 14: Results for set 2 of walls, absorption (left) and capillarity (right)

After finishing the tests, the walls had all their 15 layers carefully dismantled. For set 1 of walls, the first 8 layers of SW and the first 6 layers of PW1 were humid, whereas all the units of CW1 were dry. Therefore, the humidity ratio can be set as 4:3:0 for walls SW, PW1 and CW1, respectively. For set 2 of walls, the first 3 layers of CBW and the first 4 layers of PW2 were saturated, while the first 350mm, equivalent to 3 and a half layers, of CW2 were saturated. Therefore, the humidity ratio is 3:4:3.5 for the walls CBW, PW2 and CW2, respectively.

The consistency of the units was defined as the touch feeling. In this way, the adobe units at the base for walls SW and PW1 had partial instability, whereas CW1's adobes were dry. Therefore the proportion can be set as 1:1:0 for the set 1 walls SW, PW1 and CW1, respectively. Similarly, for set 2 walls, the units of CBW and PW2 were unstable and the units of CW2 were dry. Therefore the proportion can be set as 0:1:0 for the walls CBW, PW2 and CW2, respectively.

DAMAGE COMPARISON INDEX UNDER FLOODS AND COSTS

According to the relevance of the 4 previously analyzed factors in producing damage to the walls under flooding, a percentage factor was assigned and then added to define the damage comparison index (called DCI) of the walls. The results are shown in Table 2 for the walls of set 1, in addition the cost of the walls per unit area is shown. Table 3 has similar data for the walls of set 2.

Table 2: Damage Comparison Index (DCI) for set 1 and Costs

	Capillarity Factor	Absorption Factor	Humidity Factor	Consistency Factor	DCI	Cost USD/m^2
Percent	10	30	10	50	100	
TW1	It collapsed 20 minutes after beginning of the flood					11.84
SW	1.65	3	4	1	197	13.60
PW1	1	2	3	1	150	16.69
CW1	0	1	0	0	30	22.15

Table 3: Damage Comparison Index (DCI) for set 2 and Costs

	Capillarity Factor	Absorption Factor	Humidity Factor	Consistency Factor	DCI	Cost USD/m^2
Percent	10	30	10	50	100	
TW2	It collapsed 73 minutes after beginning of the flood					13.67
CBW	2	1.11	3	0	83.3	22.42
PW2	3	1.0	4	1	150	23.12
CW2	7	1.21	3.5	0	141	21.86

CONCLUSIONS AND COMMENTS

The flooding simulation tests demonstrated the high vulnerability of the traditional adobe units to the water action in both sets. Therefore, it is recommended to avoid the use of traditional adobe in flooding areas. The best result for long term flood in set 1 was the use of a plinth of plain concrete without damaging any adobe unit. However, this technique treatment doubled the cost of the wall of traditional adobe. In the set 2 walls, the best result was obtained using the clay brick units. This technique is even better because it is cheaper than the use of plain concrete.

The solutions using plaster PW1 and PW2 are applicable to existing housing units. The polished finishing used in PW2 improved respect to PW1 the capillarity rise from 380 mm (PW1) to only 96 mm (PW2). On the other hand, the use of stabilized adobe SW, plinths of plain concrete CW1 and CW2, and clay brick plinth CBW may be applied to new housing units.

ACKNOWLEDGEMENTS

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