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# IMPROVING THE MOISTURE RESISTANCE OF ADOBE STRUCTURES

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## ABSTRACT

Mud plasters or stuccos are commonly used to improve the moisture resistance of adobe structures.

This study presents the results of a durability test program on mud plasters subjected to simulated rain. Different stabilizers were used, such as extracts from tuna leaves, a variety of cactus plants, banana leaves and stalks, locust bean tree pods and manure. Test results of mud plasters stabilized with an asphalt are presented for comparison.

Experimental results showed that drying shrinkage cracking is one of the most important factors that affect the disintegration of soil stuccos. A procedure was developed to obtain a crack resistant stucco composed of natural soil, coarse sand, straw, and a stabilizer extracted from the cactus plant. The stucco found to be water resistant.

## ACKNOWLEDGMENT

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## INTRODUCTION

Soil is probably the oldest and most universal building material. More than two-thirds of the people in many countries of the world continue to live in adobe houses. However, it is a general experience that adobe buildings do not resist well the destructive action of rain. Adobe walls are usually plastered with mud stucco in order to improve the moisture resistance, but these stuccos are seldom found to be durable.

In Peru, whereas the durability of recent adobe buildings to rain and earthquakes has been poor, there are several historical buildings which show that it should be possible to build durable adobe structures. The examples of durable adobe are the walls at Chan Chan and San Pedro de Racchi which are 700 to 800 years old. Unfortunately, the construction techniques developed by the Chimu, Incas, and later by the early Spaniards, have been lost.

During the last four decades, the devastating effects in terms of both the loss of adobe dwellings and human lives by earthquakes and rains in many countries of the world have cast a serious concern whether adobe dwellings are an adequate answer to the housing needs of most people in the Third World countries although construction with mud constitutes the only affordable solution.

## BACKGROUND AND OBJECTIVES

Many studies have been carried out with regard to protection of adobe structures against moisture (1,2,3)<sup>1</sup>. Most solutions require expensive industrial materials such as portland cement, lime, and asphalt. However, some extracts from plants have been traditionally used for protection against water. In Africa and South America latex from rubber plant (*Euphorbia Lacter*) is used as a waterproofing paint (4). In other areas, paints are made by boiling the stem and leaves of the banana plant. In Peru, a gluey fluid obtained from the cactus plant is mixed with lime and used for plastering adobe walls. In Northern Ghana, walls are plastered with mud stuccos mixed with manure and an extract obtained by boiling pods from locust bean tree (5). In the region of Nankansi (Ghana) mud stucco is polished with stones, which apparently reduces permeability to water.

The published literature does not contain scientific data on evaluation of the techniques and materials described above.

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<sup>1</sup>Number of references

Therefore, the objectives of the investigation on mud stuccos reported here was to undertake a laboratory evaluation of the various techniques and inexpensive natural materials that are being used traditionally for protection of adobe structures against rain.

## FIRST SERIES - EVALUATION OF VARIOUS STABILIZERS AND STUCCO APPLICATION TECHNIQUES

Three test series were carried out; the first involved evaluation of the soil additives or stabilizers; the second involved determination of the optimum composition of the cactus stabilizer; and the third involved the final evaluation of the optimum stucco on small walls.

### Soil Characteristics

Locally available soil, designated as PUC soil (campus of the Catholic University) which was extensively studied on previous research (6), was used for this investigation. It is a low-plasticity soil with the following Atterberg Limits: Plastic Limit = 15%, Liquid Limit = 27% and Plastic Index = 12%. The granulometric analysis of the soil is given in Table 1.

### Characteristics of Stabilizers

For the purposes of this study the term "stabilizer" is used for an additive that increases the resistance of plasters to rain.

Stabilizers were made from cactus plant (*Opuntia Ficus Indica*), pods of locust bean tree (*Ceratonia Silicua*), and stalks of banana (*Musa Paradisiaca*). An asphalt emulsion was also included for comparison.

The cactus stabilizer was obtained by soaking equal proportions by weight of the chopped plant in water for 5 days at normal temperature. At the end of this period, there was a substantial disintegration of the organic matter and a viscous fluid suitable for soil stabilization was obtained after removing solid matter.

To obtain a reasonable degree of disintegration, of the organic matter the banana stalks and pods of locust bean tree required boiling in water. Stalk and leaves of the banana plant, that has already given fruits, were chopped to small pieces (50 mm of maximum dimension) and boiled in a barrel filled up to 2/3 with this matter and the rest with water. The mix was boiled for 16 hours without obtaining a

viscous solution, as mentioned in the literature (5). Apparently the banana species selected in this research (*Musa Paradisiaca*) is not appropriate for stabilizing purposes. Locust bean tree pods were chopped to pieces approximately 20-mm long. Proportions of pods and water to be boiled were 1:10 by weight. A thick solution was obtained when the volume had reduced to approximately 2/3 of the initial volume, however, this study had to be discontinued because of the appearance of fungus and insects.

#### Fabrication of Stucco Specimens

Before testing the water resistance of stucco coatings on walls, it was decided to undertake a preliminary evaluation of them.

The specimens referred to as "stucco specimens" consisted of a layer of stucco cast in a wooden form so as to yield a panel of dimensions 20 by 400 by 400 mm. Since the wooden form was protected with a concrete-form releasing agent, its smooth surface offered minimum restraint during drying shrinkage. Therefore, only thin cracks appeared on the surface. The stucco consisted of a mix of soil, straw, stabilizer solution, and water if needed to obtain a standard consistency. A local grass was used as straw, added 2% by weight of the soil in all specimens. Preliminary studies had shown that drying shrinkage cracks in adobe were considerably reduced in the presence of straw.

The solid components were proportioned by weight, and mixed using a soil mixer. Water or stabilizer was added in enough amount to obtain a given "standard consistency" in all the stucco mixtures. The consistency was measured with a modified Vicat needle (6) of the type which is used for the determination of consistency of cement pastes. This device, suitably adapted for use with mud mixtures, has a 10 mm steel ball welded at the tip of the needle. Consistency is defined as the depth of penetration of the ball in mm. A consistency corresponding to 10 mm penetration of the needle, was considered adequate to obtain workable stuccos without the use of excessive water which is essential for the control of drying shrinkage cracking.

To reduce permeability the stucco specimens were polished at ages of 5 to 7 days with a trowel, while spraying the surface with a small amount of water. The trowel was pressed hard against on the stucco in order to obtain a smooth, and compact, and less permeable surface. Additionally, the specimens were painted with the same stabilizer solution which is used for making the stucco. Fungus appeared on the surface during the first days but disappeared when the material became dry.

The effect of asphalt as a stabilizer was investigated by using two different emulsions containing 2 or 4% asphalt by weight of dry soil. Additionally, for comparison purposes, specimens of plain soil (without stabilizer), both with and without the surface polish were made.

### Test for Water Resistance

A severe or accelerated test was developed to evaluate the erosion resistance of stucco to the impact of water drops falling with pressure. In this test, the specimens were subjected to several cycles of a simulated rain test by using a lawn sprinkler connected to a hydraulic system. At the end of the tests the eroded material was collected in the trays kept below the specimens. Figure 1 shows the experimental setup of the simulated rain test.

The specimens were subjected to 20 cycles of 3 hours per day of simulated rain. The test was stopped if the accumulated eroded material exceeded 10% of the initial weight of the specimen, which was approximately 5 Kg. In addition to recording the weight loss at the end of the tests, the damage suffered by the specimens was also visually rated as light, moderate or severe. Tests were conducted inside an enclosure in order to avoid variations of the water flow because of wind. Figure 2 shows two test panels (S2 and S4) after the experiment.

The test results are shown in Table 2, and Figure 3, and are discussed below.

### Discussion of Results

Simulated rain test on specimens S1 (plain soil) (see Table 2) caused damage that could be clearly observed after only 30 minutes of exposure. At the end of the third cycle damage was visually rated as severe. The test was stopped at the end of the ninth cycle because the amount of eroded material had reached the specified limit of 10% of the weight of the specimen. At the end of the test, deep cavities of depth equal to the stucco thickness were observed.

In the case of specimens S2 (polished plain soil) polishing of the surface showed to be effective only during approximately the first four cycles. In the following cycles, erosion damaged the stucco in the same manner as in the case of S1 specimens.

With specimens S3, containing the banana stabilizer, after the first test cycle, about 50% of the polished surface of stuccos was found deteriorated. Damage concentrated in zones where drying shrinkage had caused microcracks. These cracks

were more susceptible to erosion in the subsequent tests.

With specimens S4, containing the cactus stabilizer, it was observed that water flowed easily due to the excellent finish which was smooth, compact, and shiny when wet. The finish was gradually lost due to erosion around zones of microcracks however the loss of material continued to remain low.

Except the 4%-asphalt specimens, the behavior of specimens stabilized with cactus (S4) was best. The washed material was only 28 grams against 650 for the control (S1) specimen. After 20 cycles of rain about 40% of the area looked still polished. Only in the case of 4%-asphalt addition (S6) or cactus stabilizer addition (S4), the results showed that after the first cycles the material loss per cycle tended to diminish (Fig. 3b).

### Conclusions from the First Test Series

(1) Simulated rain tests performed on stucco specimens indicated that drying shrinkage cracks created areas of weakness where subsequent damage occurred drying the rain. From this point of view, shrinkage cracking control is critically important.

(2) Test results indicated that stabilization almost to a level comparable to 4%-asphalt can be obtained by using the cactus stabilizer, which is much less expensive and more readily available in many areas.

(3) The experiments verified the effectiveness of the polishing technique on improving the resistance of the stucco to moisture erosion. This was especially effective in the specimens containing stabilizer. Apparently, polishing seals surface porosity and makes the surface impermeable to moisture.

### SECOND SERIES - FURTHER TESTS FOR IMPROVING THE DURABILITY OF STUCCO

On the basis of the results from the first test series, it was decided to carry out additional experimental work with the following objectives: (1) to determine the optimum concentration of the cactus stabilizer, (2) to investigate methods of controlling the cracking caused by drying shrinkage, and (3) to study the effectiveness of the technique of stone-polishing of the surface of stucco from the standpoint of impermeability.

### Optimum Concentration of the Cactus Stabilizer

Cactus stabilizer is made by soaking the chopped cactus plant in water for several days. The objective of this test was to study the influence of aging (number of days the plant is soaked in water) of the cactus stabilizer on the effectiveness of the product in improving the water resistance of stucco during the rain test.

Tests were carried out on stucco specimens of dimensions 400 x 400 x 20 mm and also on stucco applied on small walls. Tests characteristics were as follows:

#### (A) Tests on Stucco Specimens

Specimens consisted of stucco panels cast on a wooden frame of dimensions 400 by 400 by 20 mm. The mix contained PUC soil, straw (2% of weight of dry soil) and cactus solution (28% by weight of dry soil). Solutions aged to different periods were used. After casting stuccos were permitted to dry for 14 days. Three-hour tests of simulated rain were performed on triplicate specimens. Test results are shown in Table 3 and Figure 4.

As can be seen in Figure 3, the age of cactus stabilizer is an important factor for adequate behavior of the stabilizer. Best results were obtained for ages between 14 and 25 days. Weight of the eroded material was reduced to almost nothing when the solution was 18 days old instead of 1 day old.

It was observed that characteristics of the cactus stabilizer changed with time. The stabilizer obtained at ages shorter than 14 days had light green color, a gluey consistency and was transparent and odorless. Between 14 and 25 days, the color of the solution changed to green, and it became thicker and darker, and had a strong smell of decomposed organic matter. During this period, the pulp of the plant dissolved completely, leaving only the skin as remanent. Subsequently, on further storage the solution turned into a dark viscous fluid. At approximately 60 days of soaking time, it became black, with a very strong smell of decomposed organic matter.

As has been mentioned, the optimum age of cactus stabilizer from the standpoint of erosion resistance of the stucco fell between 14 to 25 days. However, this study was performed during winter (15-20°C, 82-92% relative humidity). During summer (20-25°C, 76-88% relative humidity) it was observed that best results were obtained for shorter storage periods. In summer, the pulp dissolved between 7 and 14 days, and the decomposition process initiated approximately at 21 days.

### (B) Tests on Small Walls

Stucco was made from PUC soil, 2% straw and cactus solutions with different soaking times (7, 14, 21 and 28 days). The specimens consisted of 12-mm layer of stucco applied to a small adobe wall (0.60 by 0.60 by 0.15 m). Before plastering, the wall surface was cleaned free from dust and moistened with water.

Three-hour simulated rain tests were performed and the results are shown in Table 4 and Figure 4b.

These results indicated also that soaking time of cactus was an important factor in stucco's erosion resistance. As can be seen in Table 4, optimum results corresponded to a soaking time of approximately 18 days.

### (C) Conclusions from the Tests

Soaking time of cactus during fabrication of the stabilizer is a very important factor that influences stucco's resistance to erosion caused by rain. The optimum soaking time depends on environmental conditions (relative humidity and temperature).

For the environmental conditions at which these tests were performed (temperature of 15-20°C, 82-92% relative humidity), the optimum soaking time was 18 days. For times shorter or longer than the optimum time the stabilizer becomes less effective and even may not have any effect at all.

Published literature does not contain any data on the influence of aging of the cactus solution on the water resistance of stuccoes containing the stabilizer. This is probably the reason why the use of stabilizers has not been found to be equally effective by many investigations. To advance the art and science of producing durable adobe structures, scientific studies of this type are very essential.

### Shrinkage Cracking Control

Shrinkage cracking control of soil stucco was studied through (1) restraint of drying shrinkage by addition of coarse sand, (2) control of cracks growth by straw addition, (3) reduction of rate of drying by protecting the stucco against wind.

#### (A) Materials

Studies of cracking were performed on adobe masonry walls, 0.60 by 0.60 by 0.15 m. Four specimens of each type were tested. Wall surface was cleaned and sprayed with water to develop adequate bond with the stucco.

Particle sizes of coarse sand were limited between ASTM sieve N°4 and N°40. Amounts of sand used were 50, 100 and 200% by weight of dry PUC soil.

Straw type was "ichu", from Cuzco. It was cut in 100 mm-long pieces, and used in dry condition. The amount of straw was 2% by total weight of the dry soil-sand mixture. This quantity of straw is limited by the workability of the soil-water mixture.

#### (B) Test Procedures

Tests consisted of measuring cracks widths on specimens fabricated with different materials and techniques. Specimens were allowed sixty days for drying. To estimate cracking, two coordinate axes were drawn in the center of the plastered surface. Subsequently, the number of cracks that intersected the coordinate axes and the maximum crack width were recorded. Table 5 shows the results obtained.

#### (C) Discussion of Results

Addition of 50% coarse sand did not show any noticeable effect. Stucco cracked excessively, separating in segments and weakening the bond between stucco and wall surface.

Crack reduction on stuccos with 100 and 200% coarse sand were considerable; however, a lack of cohesion and inadequate workability were observed.

In the case of stucco with addition of straw only (2%) it was found that this quantity of straw could not control cracking properly. However, the same amount of straw led to effective control of cracking in mortar joints. Apparently, water in stucco is lost at a faster rate than in mortar joints; this effect increases cracking in stuccos.

Specimens of PUC soil with simultaneous addition of straw and sand presented only a small number of fine cracks (0.8 mm) and no workability problems were observed for the mix containing 50% sand and 2% straw.

For every type of stucco, cracking was less important in the case where wind protection was provided, as evidenced by the

reduction of number of cracks and maximum crack width (see Table 5). However, the improvement was not considered significant to justify protecting the stucco in real constructions.

#### (D) Conclusions

Main conclusions from this test are:

(1) Coarse sand addition was effective in cracking control; however large amounts (more than 50%) can cause lack of cohesion and workability problems.

(2) Straw addition was also effective in controlling the crack growth.

(3) Optimum results were obtained for simultaneous addition of sand and straw. Amounts of sand and straw shall be proportioned so as to obtain adequate workability. For PUC soil; best results corresponded to amounts of 50% sand and 2% straw.

(4) Cracking can be reduced by reducing the rate of loss of water by means of protecting the fresh stucco against wind. However, addition of straw and coarse sand seemed to be more effective.

#### Stone-Polishing of the Surface of Stucco

To continue the studies on the polishing technique, tests were planned on stuccoes applied on small walls of dimensions 0.60 x 0.60 x 0.15 m. Thickness of stucco was 12 mm. Stucco mix was proportioned with the amounts of coarse sand and straw that had given optimum results in the study of shrinkage cracking control, i.e. 50 and 2%, respectively.

Based on the recommendations in published literature (5), the following procedure was used: (1) grind the surface of stucco with a coarse-texture granitic stone, (2) moisten and grind the surface with a smooth-textured basaltic stone. During preliminary trials, it was observed that the presence of coarse sand and straw in long pieces made it difficult to finish the surface. It was then decided to apply the stucco in two layers. The first layer, approximately 12 mm in thickness, consisted of a mix of PUC soil, coarse sand (50% of dry PUC soil) and ichu straw (2% of total dry material), and a top coat, approximately 3 mm in thickness, consisting of PUC soil and 50-mm long straw but without coarse sand addition. The top coat of more plastic soil facilitated the polishing of the surface, and additionally, helped to covered any microcracks present in the bottom coat.

It was observed in the laboratory that the effect of grinding the stucco with the coarse granitic stone was to obtain a smooth surface, while at the same time pores and cracks were sealed. It was found that subsequent grinding of the moistened surface by the basaltic stone provided a shiny and very smooth finish. Instead of water, cactus solution proved to be equally effective and was used in subsequent tests for the purpose of surface moistening during the grinding operation.

### THIRD SERIES - FINAL TEST OF A DURABLE STUCCO APPLIED TO A SMALL WALL

The conclusions from previous tests were used in the fabrication of final test specimens of stucco applied to small walls, 0.60 by 0.60 by 0.15 m. These walls were then subjected to the simulated rain test to study the resistance of the stucco to erosion by water.

#### Fabrication of Specimens

To apply the stucco, the wall surface was first painted with cactus solution and allowing 7 days of drying.

Stucco was applied in two coats: (1) a bottom coat of coarse-soil stucco, 12 mm in thickness and (2) a top coat of fine-soil stucco, 3 mm in thickness.

Coarse stucco was composed of PUC soil, coarse sand, cactus solution and straw (ichu type). The proportion of soil and sand was 1:0.5 and straw was added in a quantity of 2% of the total dry material. These proportions had yielded optimum results in regard to drying shrinkage cracking control. Straw was in 100-mm length pieces. Fine stucco consisted on PUC soil, straw and cactus solution. Fifty-milimeter long straw was used in this case, and coarse sand was not included. Stucco surface was polished with stones, as described under the second test series of this investigation. In all cases cactus of optimum composition was used, which corresponds to 18-day-soaking time.

Specimens of PUC soil and straw (2%), without the addition of cactus stabilizer and without polishing were also fabricated for comparison purposes.

#### Test Procedure

The specimens were subjected to 2 hours per day of continuous simulated rain during a 15-day test with equipment similar to that shown in Figure 1. Figure 5 presents the variation

of accumulated weight of eroded material versus time of exposure in hours. Again, it should be pointed out that the simulated rain test is an accelerated or severe test for measurement of relative resistance of various stuccos to impacting water. The results have no direct correlation with normal rainfall.

### Discussion of Results

The results showed that the stucco fabricated with soil, coarse sand, straw and cactus stabilizer (M2) is considerably more resistant to erosion by water than the control stucco, specimen M1 (plain soil stucco). This is due to the following reasons: (1) shrinkage cracking is adequately controlled by adding straw and sand to the soil, (2) addition of the cactus solution improves the impermeability and thus the resistance to erosion and, (3) polishing of the surface with stone further enhance the impermeability and water resistance.

Also, at the end of the test, the stucco stabilized with cactus was still in an easily repairable condition.

### CONCLUSIONS

(1) Drying shrinkage cracking, and high permeability are the most important factors that affect the disintegration of stuccos made from natural soil.

(2) A procedure has been developed to obtain a crack resistant stucco, composed of natural soil, coarse sand, straw, and an extract from the cactus plant. The stucco is also less permeable and more water resistant.

(3) A study showed that the effectiveness of the cactus extract depended greatly on its composition, which is controlled by the age and temperature of storage of the cactus-water mixture. Other natural materials, such as banana-stalks extract, locust bean pods extract, were not found effective; this may be due to the lack of scientific data on their optimum composition.

### RECOMMENDATIONS FOR FIELD PRACTICE

From the results of this study, the authors would like to make the following recommendations for plastering adobe walls with the mud stucco:

(1) Prepare the cactus extract by soaking chopped pieces of cactus until the soft (inside) part dissolves completely leaving only the skin as residue. The product is characterized by gluey consistency, green color, and strong

smell. Overaging changes the color to blackish, lowers the consistency of the fluid, and reduces its effectiveness.

(2) Remove dust from the wall surface, paint it with cactus solution in order to seal it and let it dry for a few days.

(3) Apply the stucco in two layers, a bottom layer about 12-mm in thickness and a top coat of a very thin layer approximately 3 mm in thickness. The bottom-layer stucco is made with soil, straw, and coarse sand in amounts that should be determined to maintain a balance between adequate workability and resistance to cracking on drying. The second layer contains straw in smaller pieces, approximately 50 mm-long and should not contain coarse sand. The second layer covers the microcracks of the bottom layer and provides a suitable surface adequate for polishing. Both stucco layers are mixed with cactus solution (no water is used).

(4) When the stucco has dried, grind the surface first with a rough-textured granite stone and thereafter moisten it with the cactus solution and polish it with a smooth-textured basaltic stone until the surface looks total impermeable.

(5) Paint the finished surface with the cactus solution.

Table 1 Granulometric Distribution of PUC Soil

ASTM Mesh #	4	10	20	40	100	200
Opening (mm)	4.76	2.00	0.84	0.43	0.15	0.075
% Retained Accumulated	0.00	1.30	3.40	9.40	24.00	34.00

Table 2 Results of Rain Tests on Stucco Specimens

Stucco	Number of Cycles	Eroded Material (gr)	Damage
S1 Plain Soil	9	613	Severe
S2 Plain Polished Soil	10	653	Severe
S3 Soil with Banana Stabilizer	20	288	Moderate
S4 Soil with Cactus Stabilizer	20	28	Light
S5 Soil with Asphalt (2%)	20	60	Light
S6 Soil with Asphalt (4%)	20	15	Light

Table 3 Influence of Aging of Cactus Solution on the Water Resistance of the Stucco Containing the Stabilizer  
(Tests on Stucco Specimens)

Aging Period (days)	Eroded Mass (gr)	Concentration, Color, and Odor of the Solution
1	162.0	Odorless. Light green color. Transparent. Relative Density = 0.97.
3	51.6	Gluey consistency. Relative Density = 0.98.
5	13.3	Similar as on the 3rd. day.
7	9.0	Similar as on the 3rd. day.
14	4.5	Odor of decomposed organic matter. Thicker consistency. The pulpe of leaves has dissolved. Color is darker. Relative Density = 0.98.
18	0.8	Similar as on the 14th day. Relative Density = 0.99.
25	2.2	Similar as on the 14th day. Strong odor of decomposed organic matter.
35	34.4	Strong odor, but thinner consistency.
60	72.3	Black liquid. Very strong odor of rotten organic matter.

Table 4 Influence of Aging of the Cactus Solution on the Water Resistance of the Stucco Containing the Stabilizer  
(Tests of Stucco Applied to Small Walls)

Soaking Time (days)	Weight of Eroded Material (gr)
7	440
14	302
18	160
25	287

Table 5 Effect of Straw and Sand Additions on Controlling the Cracks due to Drying Shrinkage

Ichu Straw (%)	Coarse Sand (%)	Wind Protection (Yes/No)	Number of Cracks	Max. Crack Width (mm)	Observations
-	50	N	-	8.0	Excessive cracking. No adhesion between wall and stucco.
-	100	N	23	2.0	Cracking without loss of adhesion.
-	200	N	6	0.8	Small cracks. Loss of cohesion in mortar.
2	-	N	34	2.0	Cracking without loss of cohesion.
2	50	N	14	0.8	No adhesion problems.
2	-	Y	27	1.3	Slower drying process, but many small cracks.
2	50	Y	10	0.6	Very small cracking, and no loss of adhesion due to slower drying process.

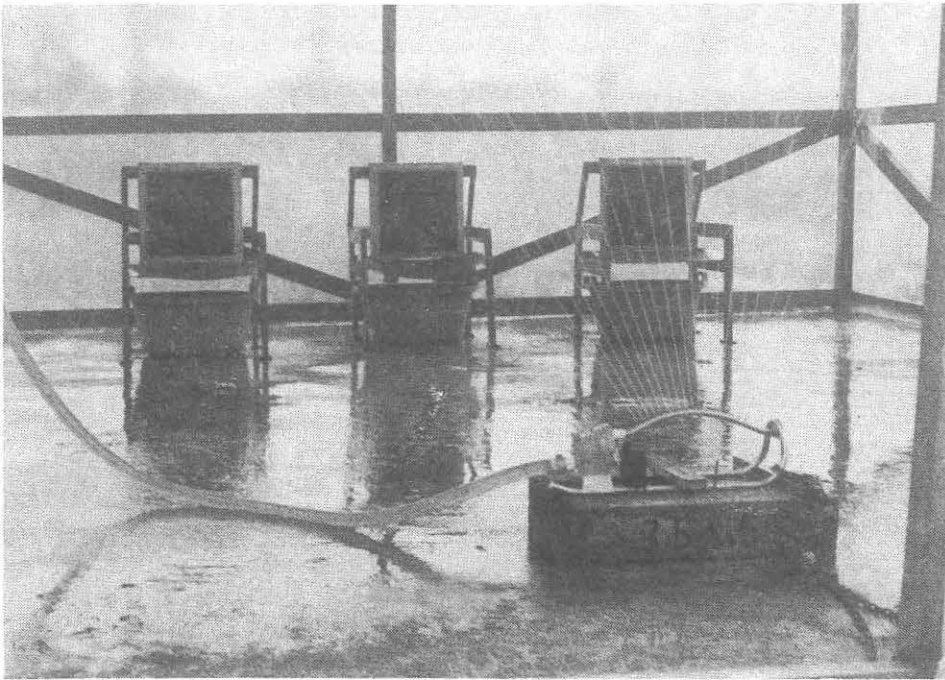


Figure 1 Test Setup

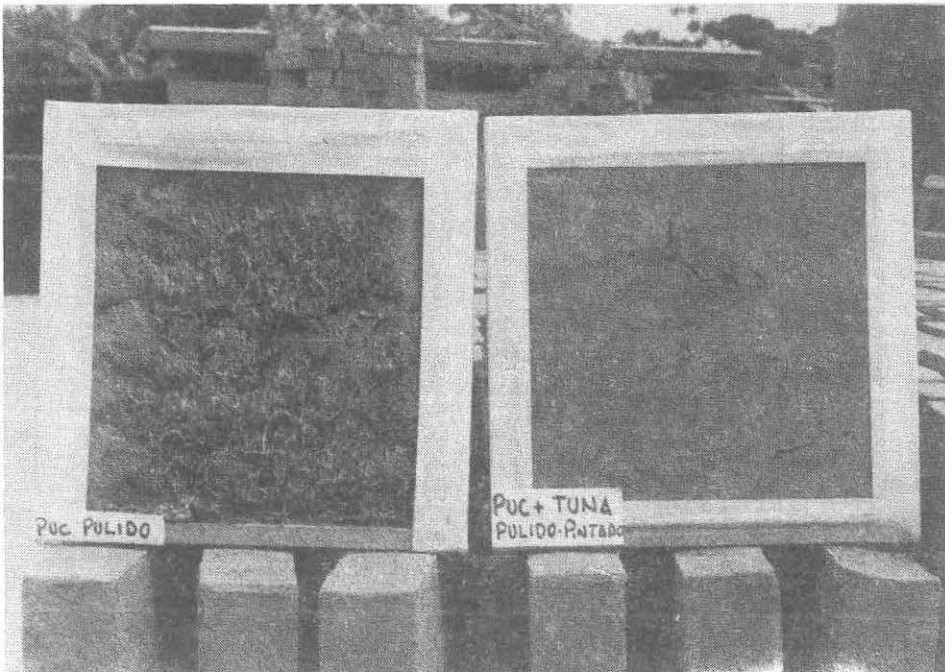
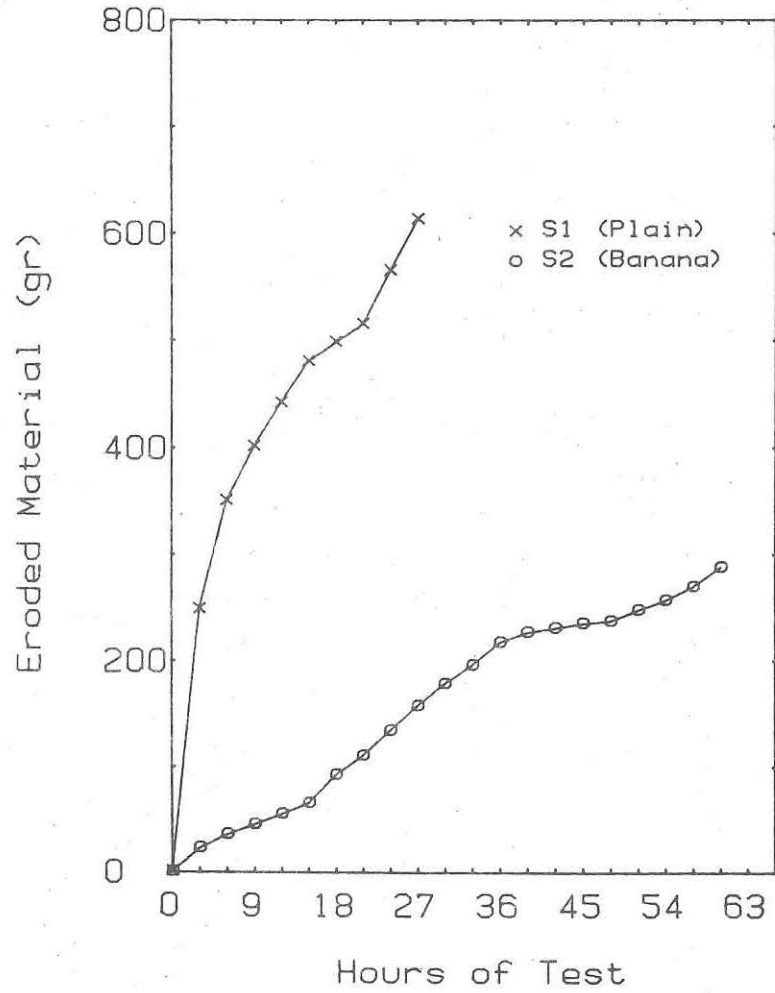
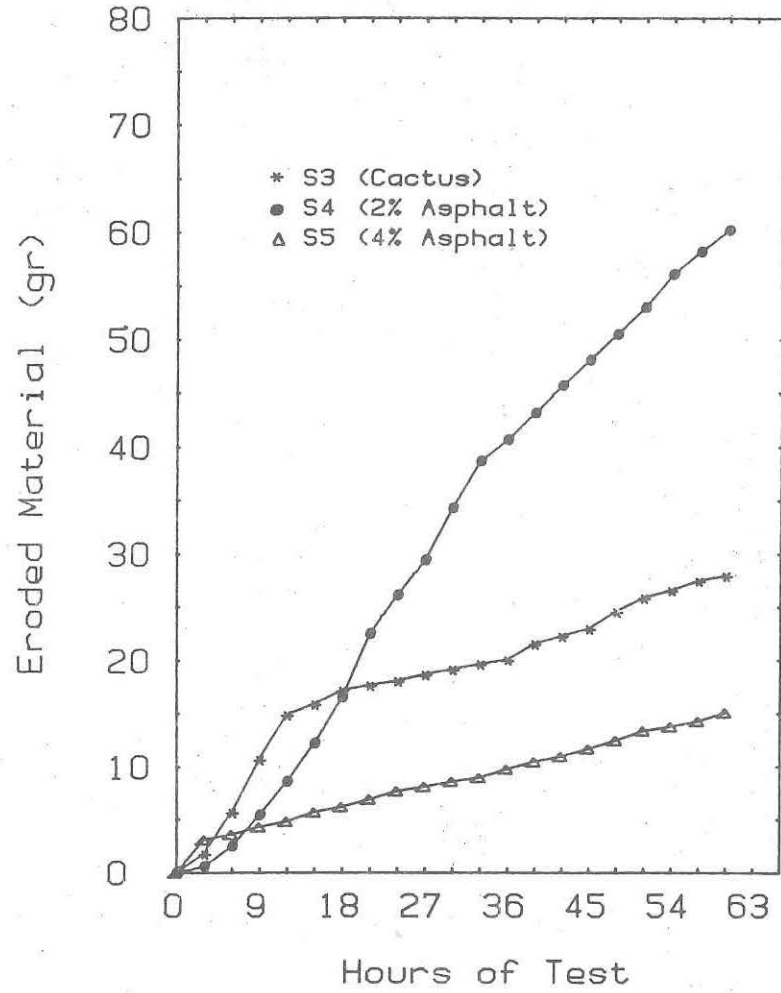


Figure 2 Specimens S1 (Plain Soil) and S4 (Soil with Cactus Solution) after Test



(a)



(b)

Figure 3 Results of Rain Tests on Stucco Specimens

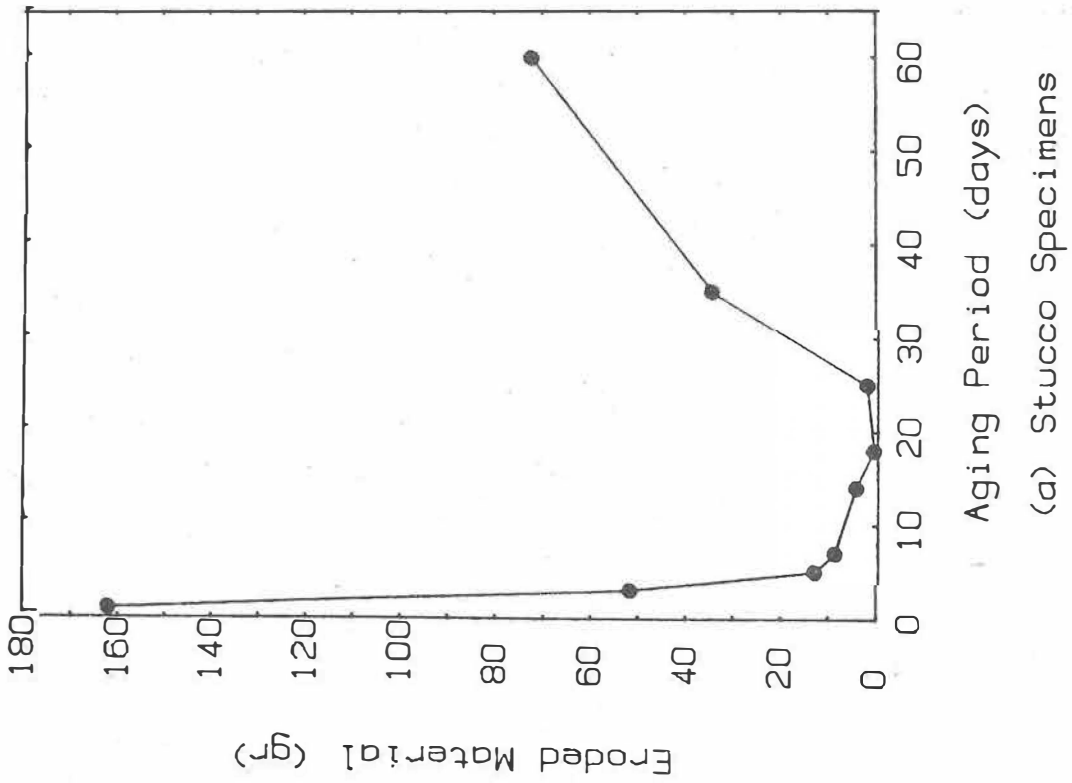
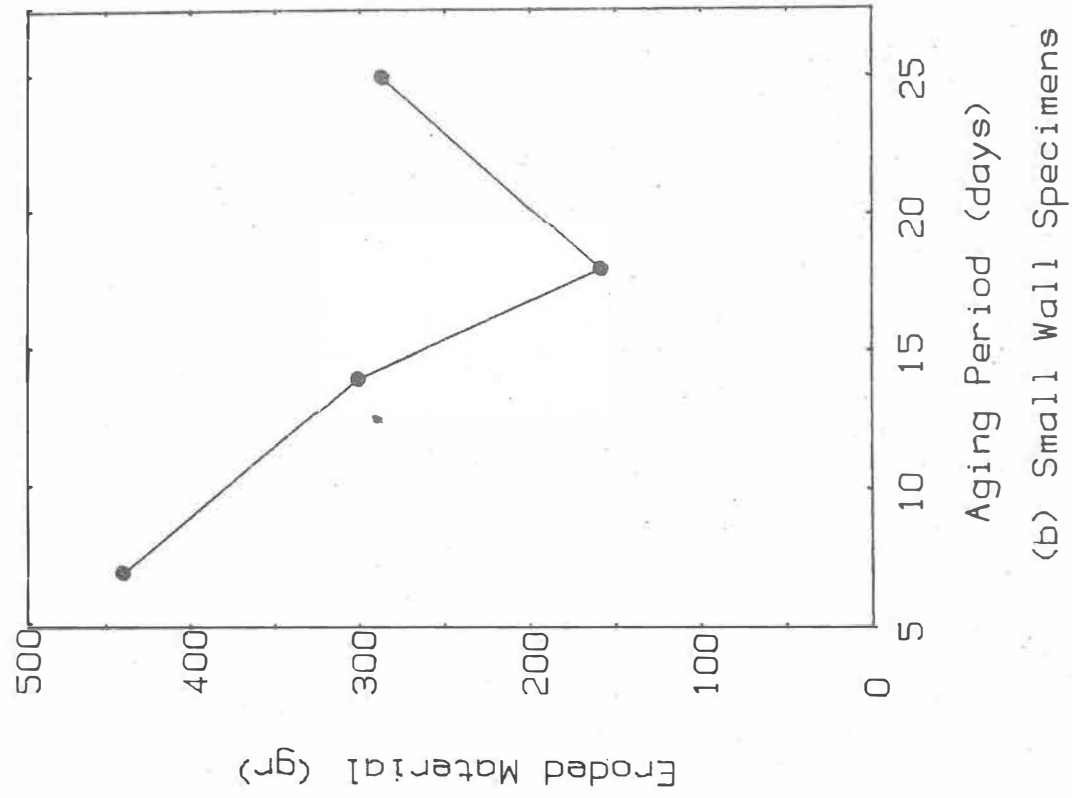


Figure 4 Effect of Concentration of Cactus Solution on Erosion Resistance

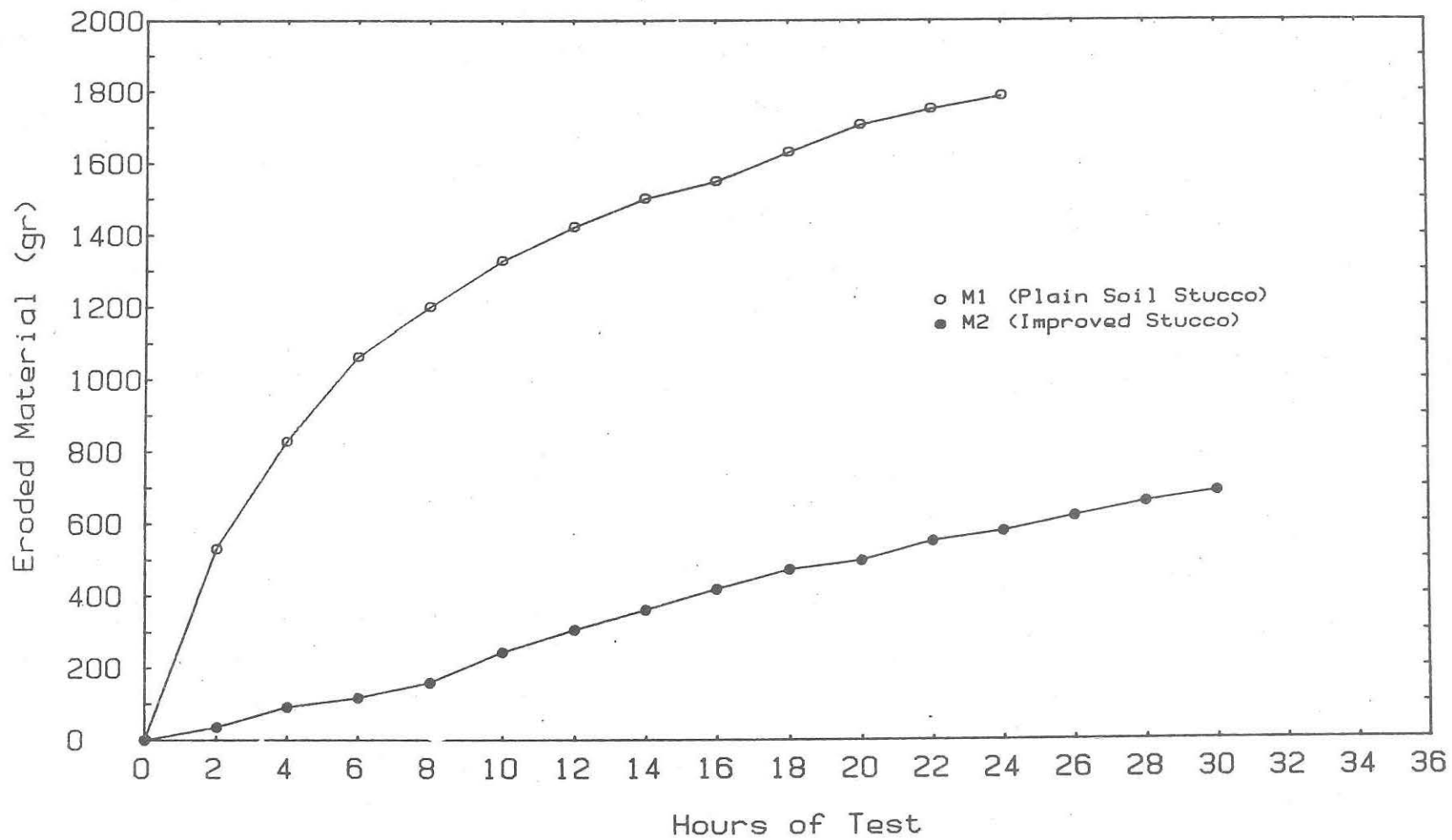


Figure 5 Results of Rain Tests on Small Wall Specimens

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