FEASIBILITY OF CONSTRUCTING MINIMUM HOUSES (SMALL)

USING STABILIZED SOILS

by

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ABSTRACT

This is an investigation of the feasibility of constructing low cost houses using stabilized soils.

Two types of soil stabilization were used for the present work. Gray clay was stabilized with lime and a sandy material, M-21; Boston Glacial Till was stabilized with cement.

"Daracone," a silicone manufactured by Dewey and Almy Chemical Company was used as a protective agent in part of the samples tested. Theoretical considerations and the experimental results obtained are included in this thesis.

SUMMARY

The objective of this investigation was to determine the adaptability of stabilized blocks for low cost house construction.

Two types of soil stabilization materials were used, cement and lime. The reason for their use is that they are relatively common and cheap in almost all localities.

Representative cylinders were made, part using gray clay stabilized with "Hercules" hydrated lime, and the rest using "Boston Glacial Till" stabilized with Portland cement. Half of each type of cylinders were silicone treated with "Daracone," a product manufactured by Dewey and Almy Chemical Company of Cambridge.

Three samples of each type of cylinder were subjected to accelerated weathering tests of wetting, drying, freezing, thawing, and to shrinkage, absorption and compressive strength measurements.

RESULTS

The results indicate:

1) Untreated soil cement cylinders stood up extremely well, with very little sign of deterioration, but with an absorption higher than treated soil cement.
2) Silicone treated soil cement cylinders also stood perfectly well the weathering tests, and the absorption capacity is relatively low.

3) Clay and lime stabilized cylinders if silicone treated stood the wetting and drying tests very well, but if untreated they failed rapidly.

4) Untreated and treated lime and clay cylinders showed very little deterioration after the freezing and thawing tests.

5) Absorption had little effect in the compressive strength of the cylinders, if they are oven dry before testing.

6) As the absorption increases the compressive strength of lime and clay cylinders decreases.

7) Silicone coatings had almost no effect in the compressive strength of either soil cement or lime and clay cylinders.

8) It is economically feasible to construct an earth house using lime or cement as stabilizers, but lime has to be protected in some manner against weathering.

INTRODUCTION

In undeveloped and in poor countries low cost housing is a complicated problem even though there are methods by which a small house can be constructed at a very low cost, using materials found in situ, or materials that can be bought very cheaply. Usually these materials have a great disadvantage, that is that they fall apart, when water is mixed with them. Adobe is a good example.

Therefore, if a cheap material can be found for the construction of these low cost houses, a great problem would be solved.

The very old technique used by the Romans of mixing lime with earth to obtain strength in their roads and the more recent investigations made by the "Portland Cement Association," using earth mixed with cement, suggests trying soil stabilization for the fabrication of blocks to build low cost houses.

It was decided to use lime and cement as stabilizers and to try different types of soil in order to study the behavior of these materials subjected to the tests to be performed.

Since it was not known how the stabilized blocks were going to resist water penetration or whether a low compressive strength could be obtained after wetting the samples for a long period of time, it was decided to paint part of the blocks with a substance that could close the porous exterior of the samples in order to decrease the moisture absorption and if possible increase its compressive strength.

Another problem encountered in the preliminary investigations of this work was the fabrication of the actual blocks. As transportation is the most costly item, the main interest was to find a machine that could produce these blocks and that could be moved easily. In choosing the machines the machine cost, the compressive strength it could transmit to the blocks, and the daily rate of production were considered. This last item was not too important since in undeveloped countries, hand labor is very cheap but was taken into consideration because mass production of low cost houses might become necessary and blocks needed at a fast rate.

Two machines were found that could satisfy the above conditions: "The Cinva Ram" and the "Landcrete." They will be described later.

OUTLINE OF PREVIOUS WORKS

As mentioned above, soil stabilization for roads is very old, and the behavior of materials has been investigated to some extent in the laboratory. Therefore, in the tests and conclusions drawn these prior investigations established several important basis.

More recently stabilized soils have been used in the fabrication of houses, but this is still in the experimental stage and not too much is known of the behavior of the materials. In Honduras, Arthur D. Little and Company, undertook the construction of several houses, using clay, stabilized with lime; the actual house was built without knowing too much about the laboratory results in the behavior of the materials. In Columbia the "Centro Interamericano de Vivienda y Planeamiento" and the "Instituto de Crédito Territorial de Colombia" constructed a house using soil cement. As in the case of Honduras, the house is just an experiment and it was also constructed without knowing too much about the laboratory behavior of the materials.

The machine used in both countries can be used with a great advantage. The CINVA RAM used in Colombia is the cheapest of the two. It was developed under the direction of its inventor, Engineer Raúl Ramírez, and its main purpose was to give rural workers, farmers and poor people, means of constructing their own house using this simple and inexpensive machine, which can be transported very easily, from place to place.

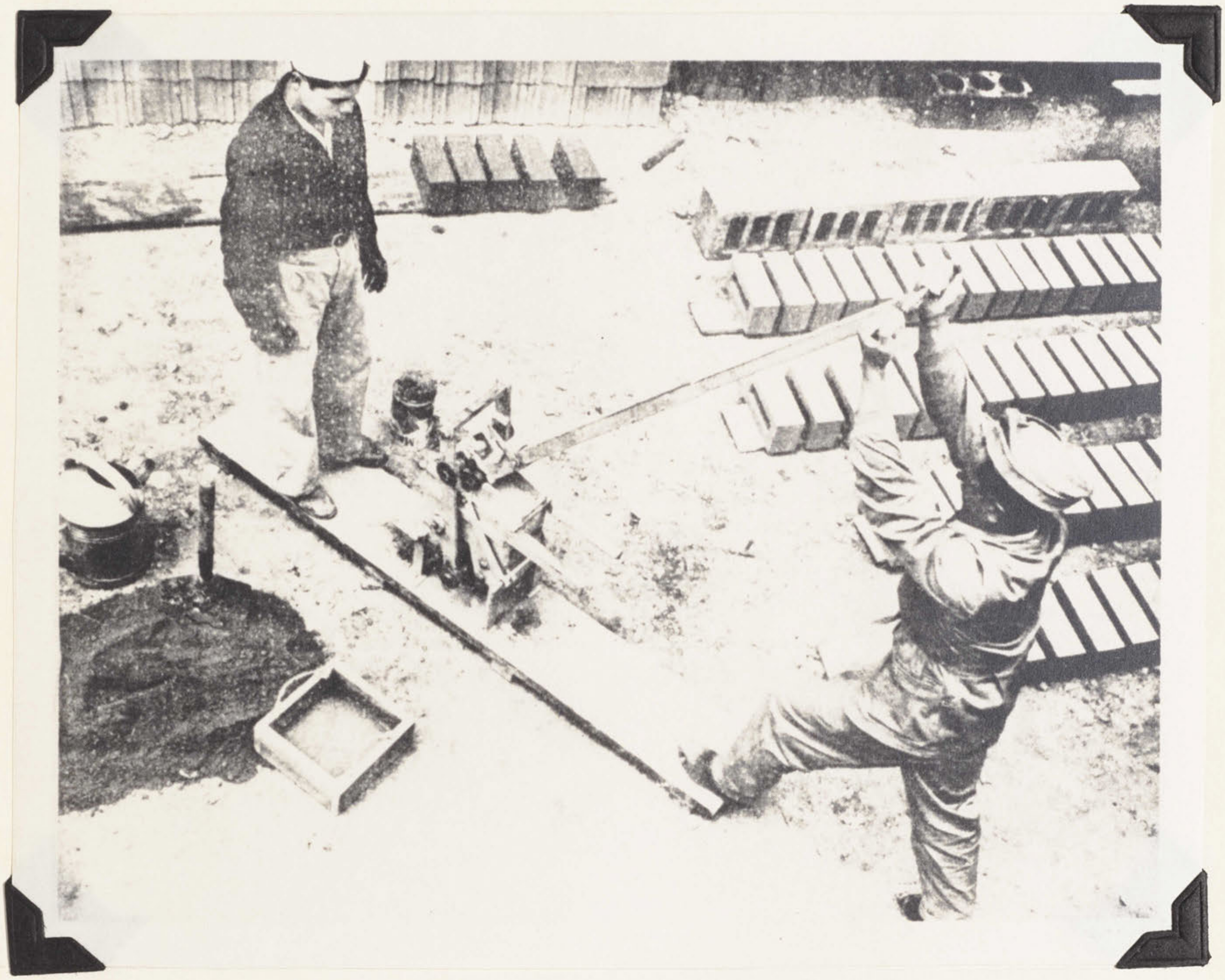


FIG. I

Basically the Cinva Ram consists of a metal box mold as shown in Figure I in which is placed the stabilized soil mixed with water to an optimum moisture content. Once the earth is in the mold, it is compressed by a piston that is hand operated. The compression force that can be obtained is 40,000 pounds.

It can be concluded that to produce these blocks no skill or experience is needed. The CINVA RAM weighs approximately 140 pounds making it transportable even by muleback. Its maintenance is very simple and it can be repaired very easily; the cost in Colombia is approximately $75. The net size of the block produced by the CINVA RAM currently being produced in Colombia is 11.5" x 5.5" x 3.5"; these dimensions make the CINVA RAM BLOCK, a good deal larger than ordinary common brick, thereby permitting more rapid construction of walls, especially by unskilled labor. Removable wood forms can be placed inside the metal box if smaller blocks are desired.

The Land Crete, a machine used in Honduras by Arthur D. Little, is a bigger machine and is capable of producing more blocks per day. The machine is sold at a price of $750 plus the shipment cost; small adapters have to be added in order to make half blocks and corner blocks. The machine's life has been conservatively calculated to be five years. The "Land Crete Company" states in its literature that an average of one thousand blocks can be made in an eight hour working day by a crew of six skilled workers. The machine normally works using gasoline for power but special changes can be made to use kerosene and even electricity, if available. This machine weighs more than the CINVA RAM and the basic cost is more, but the big advantage lies in the daily production rate. The machine would be very useful in a mass production of soil stabilized houses, where transportation is not too difficult.

Both machines can be used for any kind of soil stabilized blocks. One has the advantages in the production of individual soil stabilized houses and the other in the mass production of houses; i.e.: colonies for farmers, labor developments, etc.

Since at the beginning of the tests nothing was known about the behavior of the samples when subjected to freezing and thawing, wetting and drying, or water absorption, an investigation was carried out to find a paint that could decrease the water absorption of the samples.

"Daracone," a soluble Silicone, was used as a coating to protect the blocks from water and to decrease, to a great extent, the moisture penetration. It had previously been used in a somewhat similar application (Reference 9).

INADEQUACY OF PREVIOUS DATA

a) The actual constructions carried out in Honduras and Colombia are still experiments and few or no laboratory tests were made; therefore, little is known about compressed stabilized soil samples, using cement or lime subjected to the worst climate conditions that can be simulated in the laboratory.

b) Constructions in Colombia using soil cement were painted, but in the literature nothing is said about 1) behavior of unpainted blocks, 2) how they behave when subjected to wetting, 3) what effect water has in the compressive strength of the unpainted blocks.

c) The house built in Honduras, using clay stabilized with lime was painted; therefore, nothing can be said about: 1) the behavior of unpainted compressed lime-clay stabilization, 2) the effect that water or freezing has in the compressive strength of the mentioned blocks, 3) resistance to water penetration.

THEORETICAL CONSIDERATIONS

The idea of building a house using stabilized soils is that this construction is not for the man who can afford a brick home. It is for the man who cannot build a house at present prices of materials.

The idea is to use as much local material as possible existing where construction is taking place. The need for this type of construction is not new; rammed earth and adobe constructions are based on this principle. The addition of a little Portland Cement to a sandy material or lime to a clay-like material broadens the possibilities of the material's use in all climates.

Adobe and rammed earth constructions have a great disadvantage in tropical climates or in places where humidity is high. Walls built of these materials tend to soften if unprotected and eventually they will fall apart.

Soil Cement stabilization tests, carried out by the Portland Cement Association, show that addition of Portland Cement to soils for highway paving decreases the plasticity of the soils when wetted; this is the great advantage of soil cement over adobe or rammed earth. But in small or undeveloped countries cement is sometimes scarce, and it has to be imported. This was the case of Honduras; and since lime is a common material in this and other countries and it can be obtained very cheaply, lime was tried for stabilization.

The use of lime can decrease the cost even more, but since little laboratory work has been done, very little can be said with regard to the behavior of the material when subjected to weathering conditions.

A very important point that must be considered for soil stabilization is the selection of the soils to be mixed. The first factor is cohesion, since this will affect greatly the resistance and the quality of the stabilized block; cohesion is determined by the percentage of clay present.

Clay gives plasticity to soils; however, soils that have a great percentage of clay tend to develop cracks due to the shrinkage that occurs when the soil dries. On the other hand, an excess of sand and pieces of rock in the soil diminishes the tendency to crack but also lessens cohesion.

The excess of clay can be compensated by adding sand to the soil, but for sandy soils clay can be added.

However, to buy the material, to mix it, and to keep control of the mix, implies an increase in the cost of production of soil blocks. Consequently the convenience of using natural occurring soils, preferably those that have their elements in acceptable proportions, is obvious.

Tests conducted by the Portland Cement Association show that in general the cement requirements of a soil increase as the silt and clay increases; therefore the cost of each soil block will increase. Vice versa, gravely and sandy soils require less cement.

Experiments in Honduras by Arthur D. Little & Company showed that a cheap way of using clay-like soil was to stabilize them with lime (hydrated or quick lime).

Therefore in sites where clay is abundant, we can use lime for soil stabilization and where sandy materials are in abundance, cement can be used.

When cement is used, a complete stabilization of the soil requires between eight and fourteen percent by weight; this percentage is a direct function of the sand existing in the soil. The Portland Cement Association has developed some charts, which show the amount of cement necessary if the combined percentage of silt and clay existing in the soil is known; these charts are reproduced later.

In clay-like soils lime is desired for stabilization. The National Lime Association recommends between 3 percent and 5 percent by weight to get a complete stabilization.

In soil stabilized blocks, whether using lime or cement, water absorption may be detrimental to the compressive strength of the cylinders. It was decided to decrease the absorption of the cylinders by painting part of the samples with silicone.

PROCEDURE

Method of attack--The principal objective of these tests was to study the behavior of the different samples subjected to the worst conditions.

It was decided to perform our experiments in samples that could be used in actual constructions. The first trials were made with block molds 6x6x5 inches. This first attempt failed for several reasons. The clay was too sticky and after compressing the sample in the mold the block became stuck, and was difficult to press out. When the rammer was pushed down with hydraulic press, too much leakage occurred causing defective corners in the block. The pressure transmitted to the block was not uniform.

It was thendecided to use a cylindrical mold obtained from the Soil Mechanics Department. This mold produced cylinders 1.313 inches in diameter by 2.816 inches high. Even though this mold was smaller, it produced much better samples with more uniform pressure distribution through the cylinder.

The soils selected were from the Boston area. A clayey material common in this area to be stabilized with lime and a sandy material to be stabilized with cement were desired.

The Soil Mechanics Department was consulted. For the sandy material they recommended and provided M-21 "Boston Glacial Till," that had the advantages of being well graded and fairly common near this area. An unsuccessful attempt was made to obtain blue clay. Gray clay for the lime stabilization was obtained in Arlington, Massachusetts.

Preparation and Stabilization of Soil

(A) Both Boston Glacial Till and Gray Clay were passed through a No. 4 sieve to get rid of undesirable particles, after which they were air dried for forty-eight hours.

(B) Soil Cement Mixture--After the air-drying period the sandy M-21 soil was ready to be mixed with the cement. The mixture was established with the aid of a chart developed by the Portland Cement Association in its laboratory handbook and reproduced in figure #2.

From the Soil Mechanics laboratory the following data was obtained:

M-21 Boston Glacial Till

Sand........56 percent

Silt........35 percent

Clay........ 9 percent

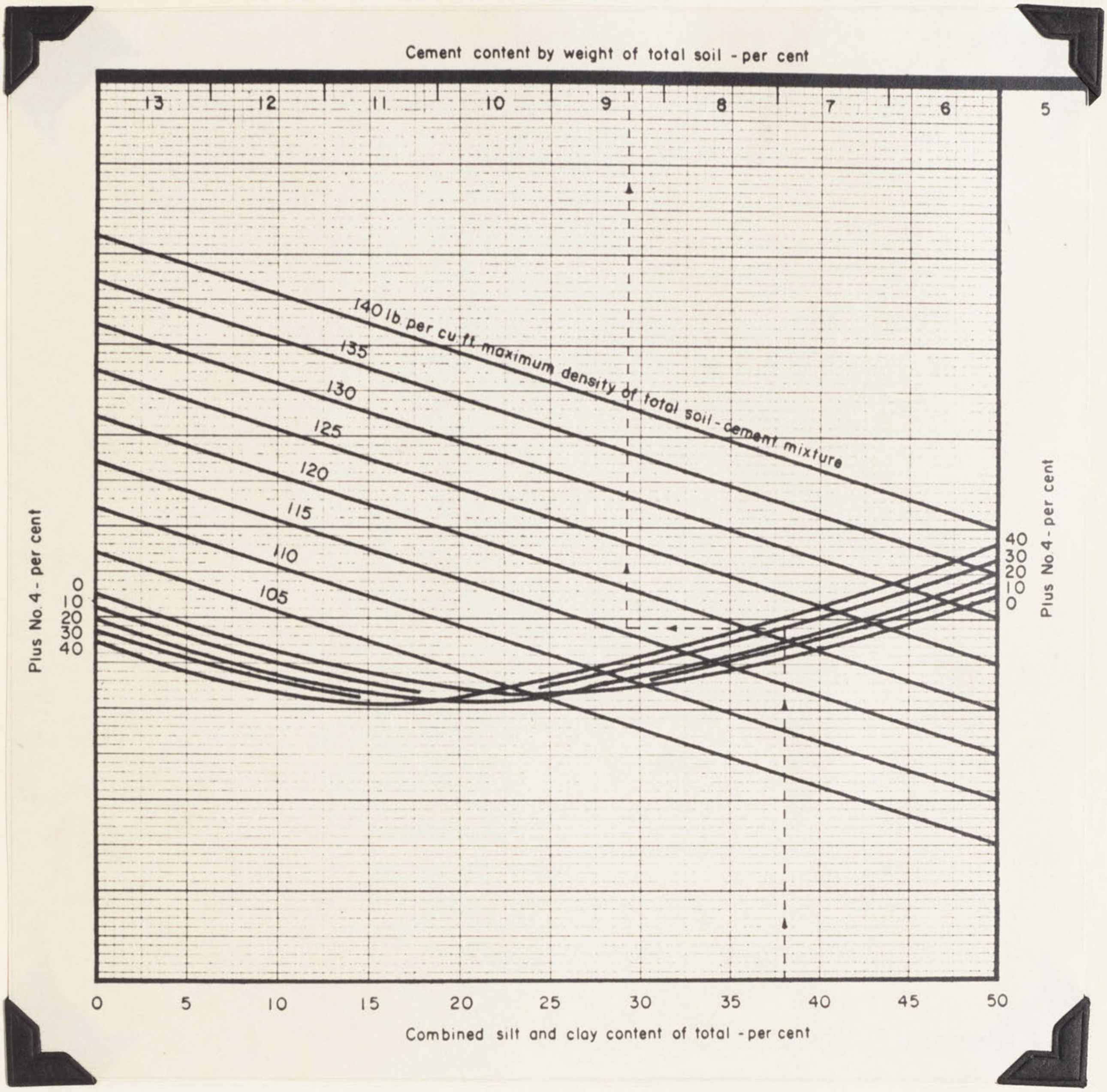


FIGURE 2

Combined silt and clay of total percent = 44 percent. From Figure 2 percent of cement by weight = 6.48 percent. From laboratory data after the mixture was done, density of total soil cement mixture = 124.5 $\#/Ft^3$. That checks with Figure 2.

After the soil cement mixture was completed, the water required for maximum compaction was determined. Ten pounds of mixture were weighed in an open pan. The soil was then thoroughly hand mixed with 550 cc of water in ten pounds of soil cement mixture. Preliminary investigations showed that maximum compaction was obtained with approximately 10.5 percent of moisture content.

Lime and Clay Stabilization. After the air dry period the Gray Clay was hand mixed with 4.5 percent by weight of "Hercules" hydrated lime.

Ten pounds of clay were weighed in an open pan and 0.45 pounds of lime added and hand mixed. This 10.45 pounds of mixture was mixed with 990 cc of water. Previous experiments showed that the maximum compaction was obtained using 10.45 pounds of clay and lime mixture with 990 cc of water. The water was added to allow a gradual increase in moisture.

Fabrication of Cylinders. The procedure followed in both types of cylinders was the same. After the mixture attained the desired moisture, the open pan was covered with a piece of wet cloth. Then some of this mixture was put in the cylinder to fill 1/3 of the volume, tapped 12 times, after which the next third was filled, and again tapped, finally the cylinder was filled and tapped, after which the cap was put on. The filled mold was compressed in a hydraulic press to 150 psi. After this pressure was obtained, the load was released slowly and the sample was taken out of the mold carefully.

Two long rectangular foils of tin were bent and inserted at both ends of the cylinders that were going to be tested for shrinkage.

Curing. After the cylinders were taken out of the mold, they were placed in the curing room at a temperature of 70°F. and 100 percent relative humidity for seven days.

Silicone treatments. Half of the soil cement samples and half of the lime clay samples were silicone treated. After the curing period, a coat of Daracone was applied to each; then after five hours a second coat of Daracone was applied and left to dry for ten hours.

Weighing and Measuring Cylinders. Following the silicone treatment all the cylinders that were going to be used for freezing and thawing and for wetting and drying tests, were carefully weighed and the ones that were going to be used for shrinkage were measured.

DESCRIPTION OF APPARATUS

Mold.--The mold which is shown in figure 3 was obtained from the Soil Mechanics Laboratory; it can withstand a load of approximately three thousand pounds. It consists of a cylinder to receive the samples, two rammers to produce equal pressure on top and bottom of the soil inside, and two additional cylinders to avoid tilting of the rammers. Once the mold is assembled, it is put in the hydraulic press.

Weighing and Measuring.--The molded cylinders were weighed on a scale of the type shown in figure 4. This is a balance type scale and it reads to one gram.

Since the lengths of the cylinders differed slightly, to establish a base measurement for their comparison, the length of a metallic rod was used to set the gage at a constant reading. Thus every reading taken from each of the cylinders gave the difference between their lengths and the rods; therefore the increase or decrease in length of a cylinder upon wetting or drying becomes the difference between the two length readings of that particular cylinder. The dial gage of the apparatus could be read to 0.0001 of an inch.

Oven.--The oven used is shown in figure 6. It was used for wetting and drying tests. It is a thermostat controlled type and it is capable of maintaining a temperature of approximately 40° C.

Water Absorption.--An open pan as shown in figure 8 was used for the water absorption test.

Compression Machine--The machine used in compacting the stabilized soil specimens and in testing the compressive strength is a Baldwing-Southark Hydraulic Press with a rated capacity of 200,000 pounds.

Figure 9 shows the machine with the caps used to obtain equal distribution of the load on top and bottom of the mold and the specimens.

Moist Room--The moist room used for curing and for freezing and thawing tests is maintained at 100 percent humid atmosphere and at a temperature approximately of 70° F.

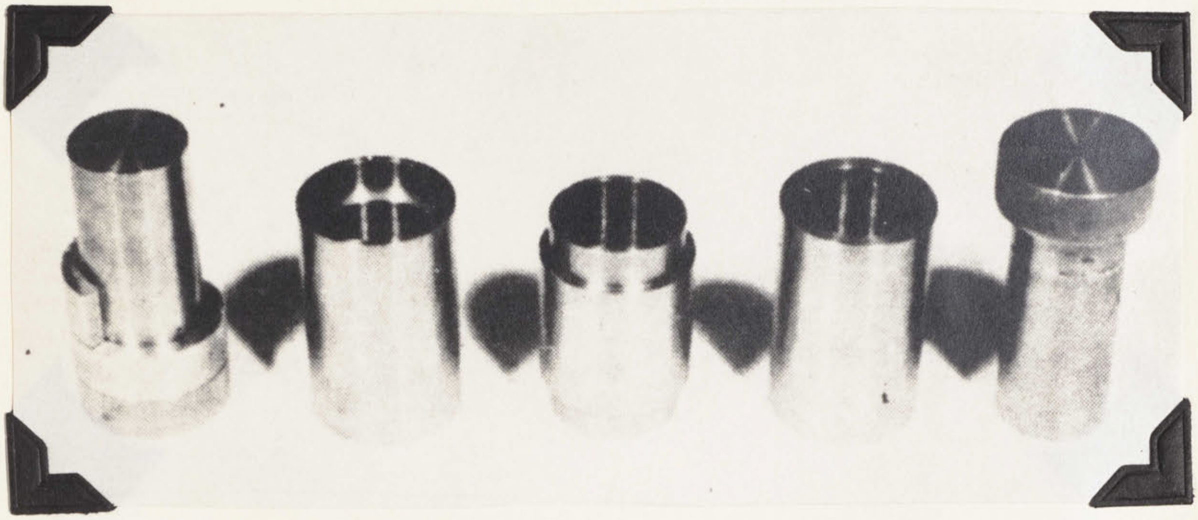


FIGURE 3

Mold

FIGURE 4
Balance Scale

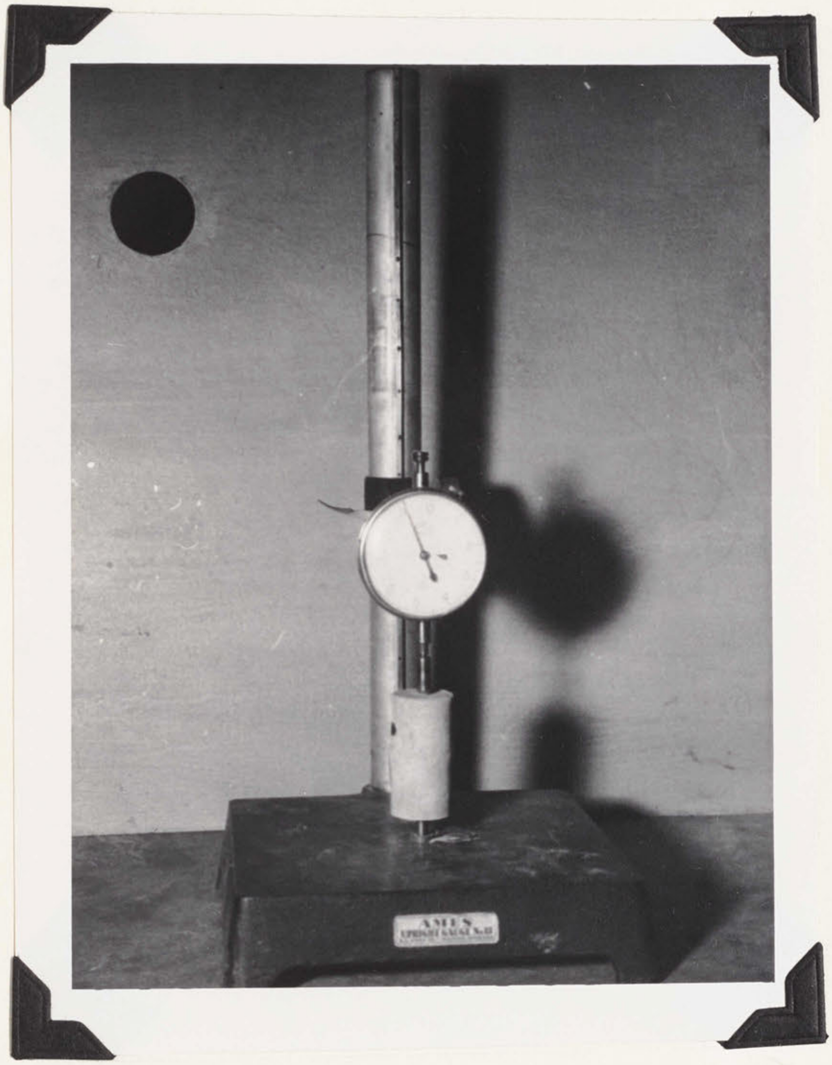


FIGURE 5

Apparatus for measuring changes in length.

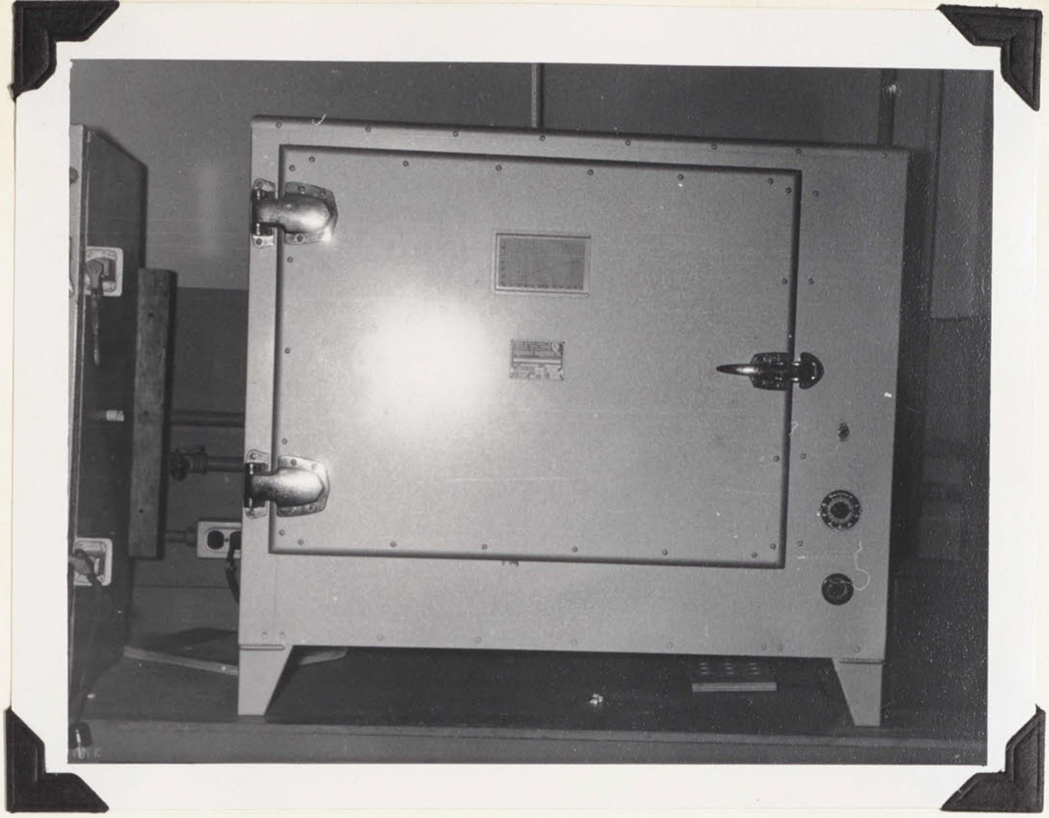


FIGURE 6
Oven

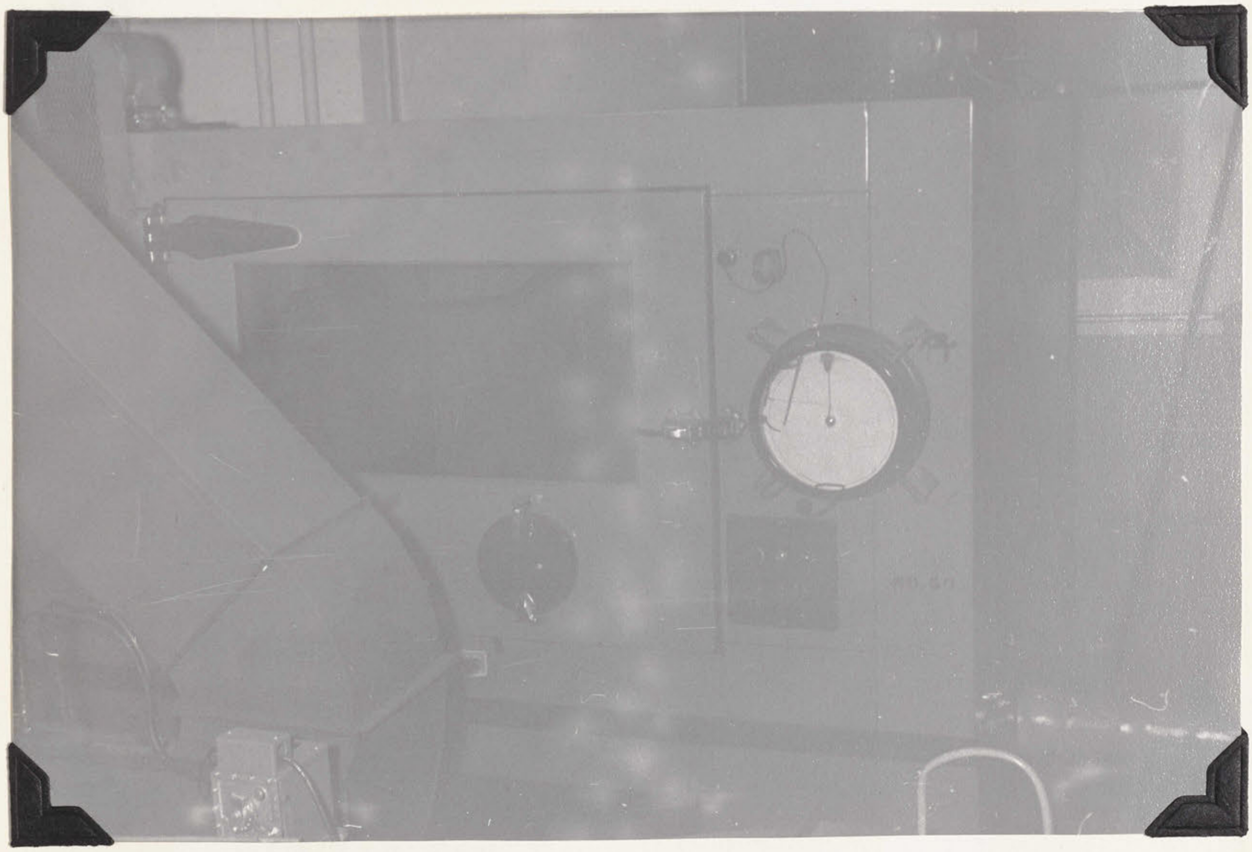


FIGURE 7
Freezing Box

FIGURE 8

Water Absorption Test

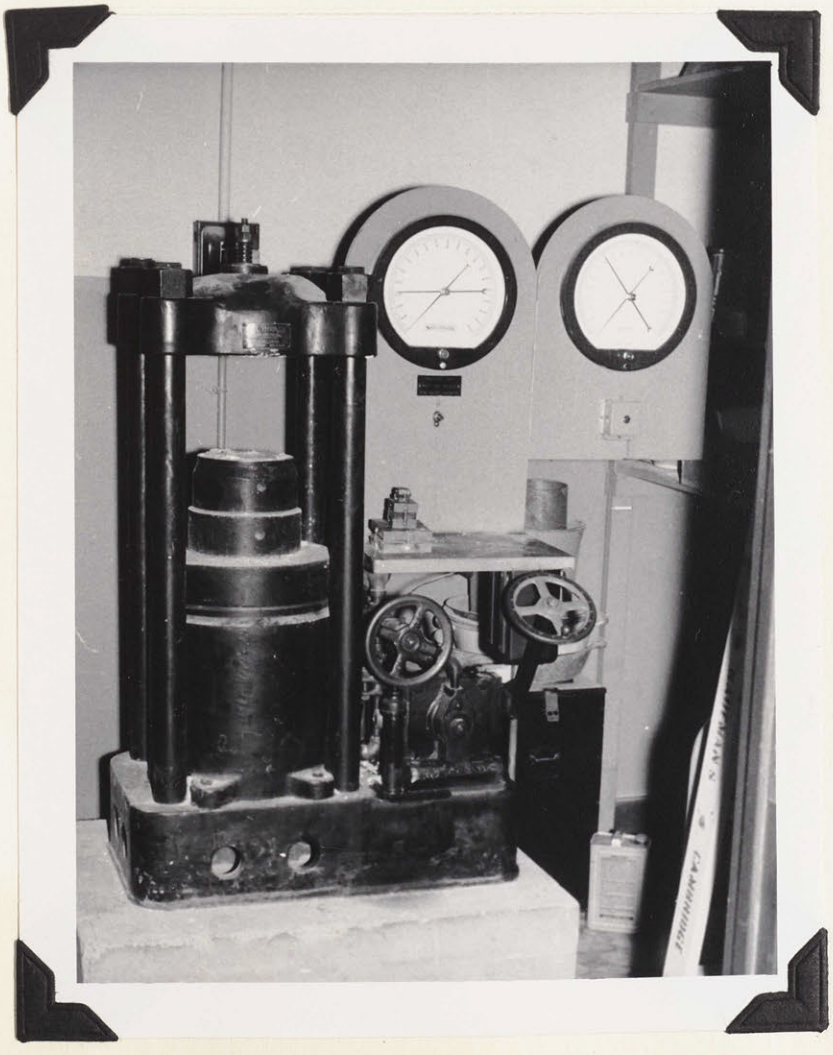


FIGURE 9

HYDRAULIC PRESS

Testing Procedure

The results of the tests performed are shown in the data sheets and are plotted in the graphs.

Test #I Wet, dry, and shrinkage test: This testing procedure was essentially the same as A.S.T.M. designation D-559, but with some modifications that reduced the number of specimens and the amount of daily routine in handling the specimens.

After the curing period three samples of each type of cylinder were weighed, the length measured and both values recorded. The samples were submerged in water for a period of five hours after which they were again weighed and the new length measured. The specimens were then put in an oven at 71° C (160° F.) for a period of 24 hours, removed, weighed and the new length recorded.

The above procedure constitutes one cycle of wetting and drying. Twelve cycles were required for the complete test. Visual observation was recorded, and the specimens that softened were removed.

Sometimes the test had to be suspended because of holidays or Sundays. During these periods the samples were left in the oven for a longer time.

At the end of the experiment the samples were put in the oven and dried.

The percentage loss in weight was determined by weighing the samples after each cycle and using the following formula:

$$\frac{\text{W dry initially} - \text{W dry at the cycle}}{\text{W dry initially}} \, 100.$$

The difference in length between the cylinder in either the wet or dry state and the rod is the difference between the dial readings of the cylinder and the rod. This difference in length is expressed as a change in length per unit length where the constant total length of the rod is taken as the base length to which the changes are referred, thus the dial reading of the cylinder in either the wet or dry state minus the dial reading of the rod, divided by the total length of the rod times 100 gives the percent change in length per unit length in either the wet or dry state.

The data and results of these tests are shown in data sheets I and II and in graphs 1A, 1B, 2A, 2B, and 2C.

Test II. Freezing Thawing and Shrinkage Tests

This test was also based in A.S.T.M. designation 0560-44 with some modifications.

After the curing period the specimens were weighed and the length measured. They were then put in the freezing box at -13°C (10° F) for a period of 24 hours after which they were removed, weighed, and the new length recorded.

They were then put in the moist room at a temperature of approximately 70° F. and 100 percent humidity for a period of 23 hours; the specimens were weighed and the new lengths recorded.

The above constituted one cycle of freezing and thawing;

the experiment was carried out for a period of six cycles. Visual observation was carefully kept. The percent loss in weight was relatively small, consequently it was neglected; and only the shrinkage was calculated using the same procedure as in the wetting and drying test.

Data and results for these tests are shown in data sheet No. III and in graphs 3A, 3B, 3C, and 3D.

Test III. Water Absorption Test

This test was done to determine the rate of absorption of each type of specimen submerged in water for a variable period of time intervals.

After the curing period the specimens were weighed, after which they were immersed in water for periods of fifteen minutes, thirty minutes, one hour, two hours, three hours, ten hours, twenty hours and twenty-four hours.

The cylinders were weighed after each interval of immersion. The cylinders that survived the test were oven dried at 110° C (220° F) for a period of twelve hours, after which they were tested for compression.

Data and results for this test are shown in data sheet No. IV and graphs No. 4A and 4B.

Test IV. Compressive Strength

Specimens were removed from the humid room after seven days. They were then placed in a room at 70° F and 50 percent relative humidity until tested. Tests were made after two, seven and twenty eight days.

Cylinders were placed in the hydraulic machine and a load of approximately 1,000 pounds per minute applied until breaking point was reached. The load required and the angle of failure were observed.

The data and results of these tests are shown in data sheet No. V and graphs 5A and 5B.

DATA SHEET NO. I

<u>Wet and Dry Test</u>

Percent loss in weight vrs. cycles.

Treated Soil Cement		Untreated Soil Cement		Treated Lime		Untreated Lime	
Cycles	Percent loss in Weight	Cycles	Percent loss in Weight	Cycles	Percent loss in Weight	Cycles	Percent loss in Weight
1	8.90	1	5.20	1	27.10	1	32.00
2	9.00	2	5.20	2	31.21	2	48.87
3	8.90	3	5.21	3	36.00	3	
4	9.00	4	5.21	4	38.50	4	
5	9.62	5	5.21	5	39.40	5	
6	10.00	6	5.21	6	41.21	6	
7	10.41	7	5.21	7	43.40	7	
8	11.19	8	5.21	8	43.60	8	
9	11.15	9	5.21	9	45.41	9	
10	11.21	10	5.21	10	46.44	10	FAILURE
11	11.15	11	5.21	11	46.70	11	
12	11.10	12	5.21	12	47.23	12	

RESULTS PLOTTED IN GRAPHS I_A AND I_B

DATA SHEET NO. II

WET, DRY AND SHRINKAGE TEST

Percent Change in Length per Unit Length Vrs. Cycles

Treated Soil Cement		Untreated Soil Cement		Treated Lime-Clay		Untreated Lime-Clay	
Cycles	ΔL 10^{-2} inch/inch	Cycles	ΔL 10^{-2} inch/inch	Cycles	ΔL 10^{-2} inch/inch	Cycles	ΔL 10^{-2} inch/inch
0	0	0	0	0	0	0	0
½	-2.9	½	-8.2	½	-1.0	½	-18.0
1	-21.0	1	-16.0	1	-6.0	1	-16.2
1½	-2.2	1½	-9.2	1½	-0.3	1½	-17.0
2	-19.2	2	-21.2	2	-9.1	2	FAILURE
2½	-6.0	2½	-4.4	2½	-1.0		
3	-18.0	3	-22.8	3	-9.0		
3½	- 6.0	3½	-10.0	3½	-3.2		
4	-17.2	4	-24.4	4	-11.0		
4½	- 6.0	4½	-10.4	4½	-3.1		
5	-17.6	5	-15.2	5	-10.0		
5½	- 6.0	5½	- 4.2	5½	- 4.1		
6	-18.0	6	-18.0	6	-11.0		
6½	- 5.2	6½	- 3.2	6½	- 2.2		
7	-16.8	7	- 7.2	7	-11.0		
7½	- 4.0	7½	- 4.0	7½	- 1.2		
8	-19.6	8	-10.6	8	-10.1		
8½	- 2.8	8½	- 4.0	8½	- 2.3		
9	-19.6	9	-11.6	9	-10.0		
9½	- 2.4	9½	- 2.0	9½	- 1.1		
10	-18.0	10	-14.0	10	-10.0		
10½	- 2.4	10½	- 1.2	10½	- 2.2		
11	-18.8	11	-16.0	11	-10.0		
11½	- 4.0	11½	- 2.4	11½	- 1.1		
12	-18.0	12	-13.2	12	-10.0		

RESULTS PLOTTED IN GRAPHS
2A, 2B, and 2C

DATA SHEET NO. III

FREEZING AND THAWING SHRINKAGE TEST

Percent Change in Length vrs. Cycles

Treated Soil Cement		Untreated Soil Cement		Treated Lime-Clay		Untreated Lime-Clay	
Cycles	ΔL 10^{-2} $\frac{inch}{inch}$	Cycles	ΔL 10^{-2} $\frac{inch}{inch}$	Cycles	ΔL 10^{-2} $\frac{inch}{inch}$	Cycles	ΔL 10^{-2} $\frac{inch}{inch}$
0	0	0	0	0	0	0	0
½	-8.9	½	-11.8	½	- 8.6	½	- 7.4
1	-1.1	1	- 0.7	1	+ 1.8	1	+ 1.2
1½	-8.7	1½	-10.9	1½	- 8.2	1½	- 7.4
2	-1.6	2	- 1.0	2	+ 4.6	2	+ 3.3
2½	-8.0	2½	- 9.9	2½	- 6.7	2½	- 8.0
3	-0.7	3	- 0.8	3	+ 3.0	3	+ 4.8
3½	-7.2	3½	- 9.6	3½	- 5.7	3½	- 4.8
4	-0.5	4	-0.7	4	+ 6.3	4	+ 6.0
4½	-6.8	4½	-10.0	4½	- 5.6	4½	- 3.4
5	+0.6	5	- 0.8	5	+ 6.1	5	+ 7.0
5½	-8.1	5½	- 9.7	5½	- 4.5	5½	- 2.0
6	-0.8	6	- 0.2	6	+ 5.7	6	+ 6.0

RESULTS PLOTTED IN GRAPHS
3A, 3B, 3C, and 3D

DATA SHEET IV

ABSORPTION TEST

Percent Absorption vrs. Time of Immersion (hours)

Treated Soil Cement		Untreated Soil Cement		Treated Lime Clay		Untreated Lime Clay	
Percent Absorption	Time of Immersion	Percent Absorption	Time of Immersion	Percent Absorption	Time of Immersion	Percent Absorbtion	Time of Immersion
0	0	0	0	0	0	0	0
0.8	1/4	11.8	1/4	4.2	1/4		1/4
1.6	1/2	13.2	1/2	5.4	1/2		1/2
2.5	1	15.0	1	6.5	1		1
3.2	2	15.0	2	7.5	2		2
3.4	3	14.8	3	7.0	3		3
3.4	10	14.8	10	7.0	10	FAILURE	10
3.4	20	14.8	20	7.0	20		20
3.4	24	14.8	24	7.0	24		24

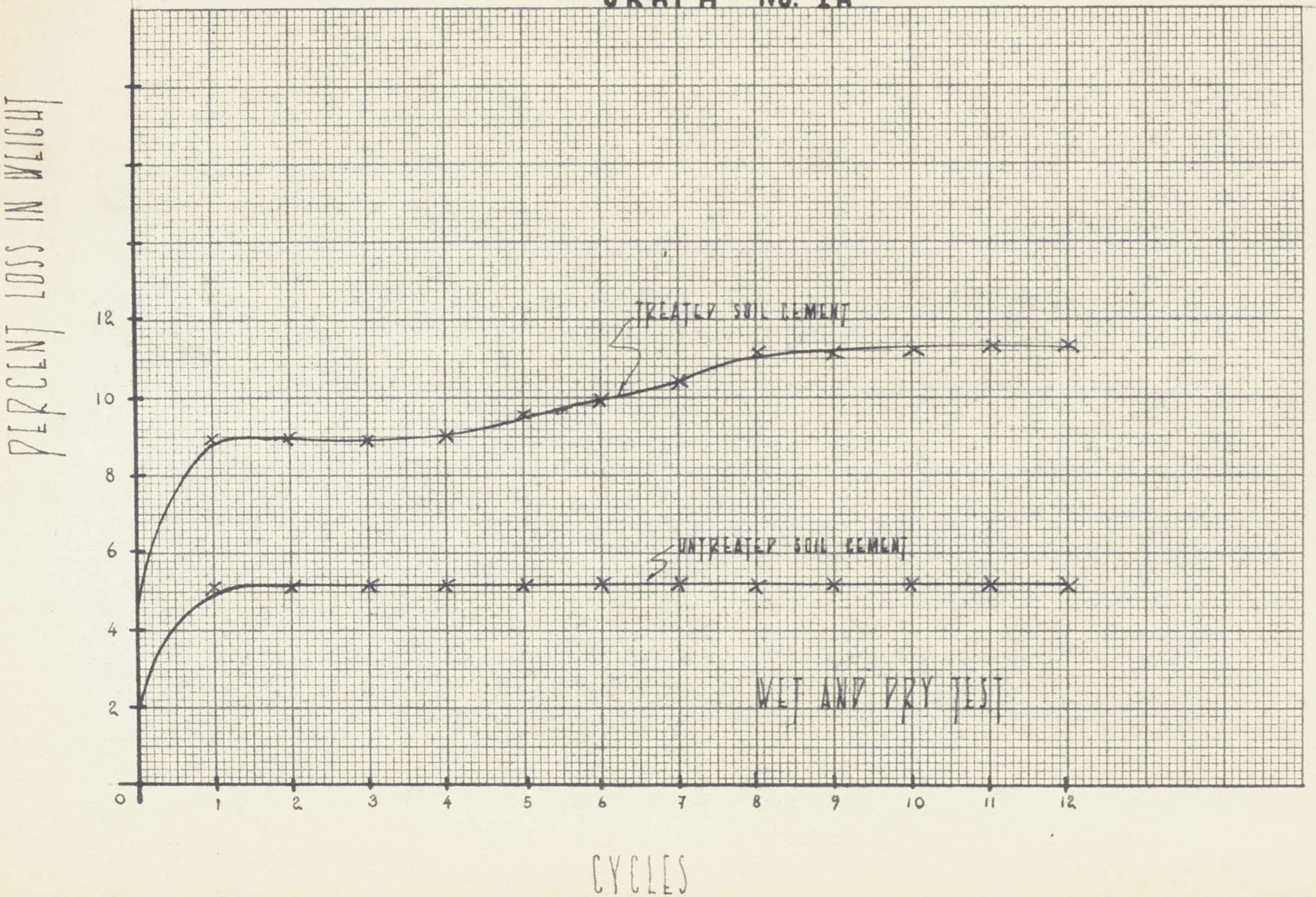
DATA SHEET NO. V

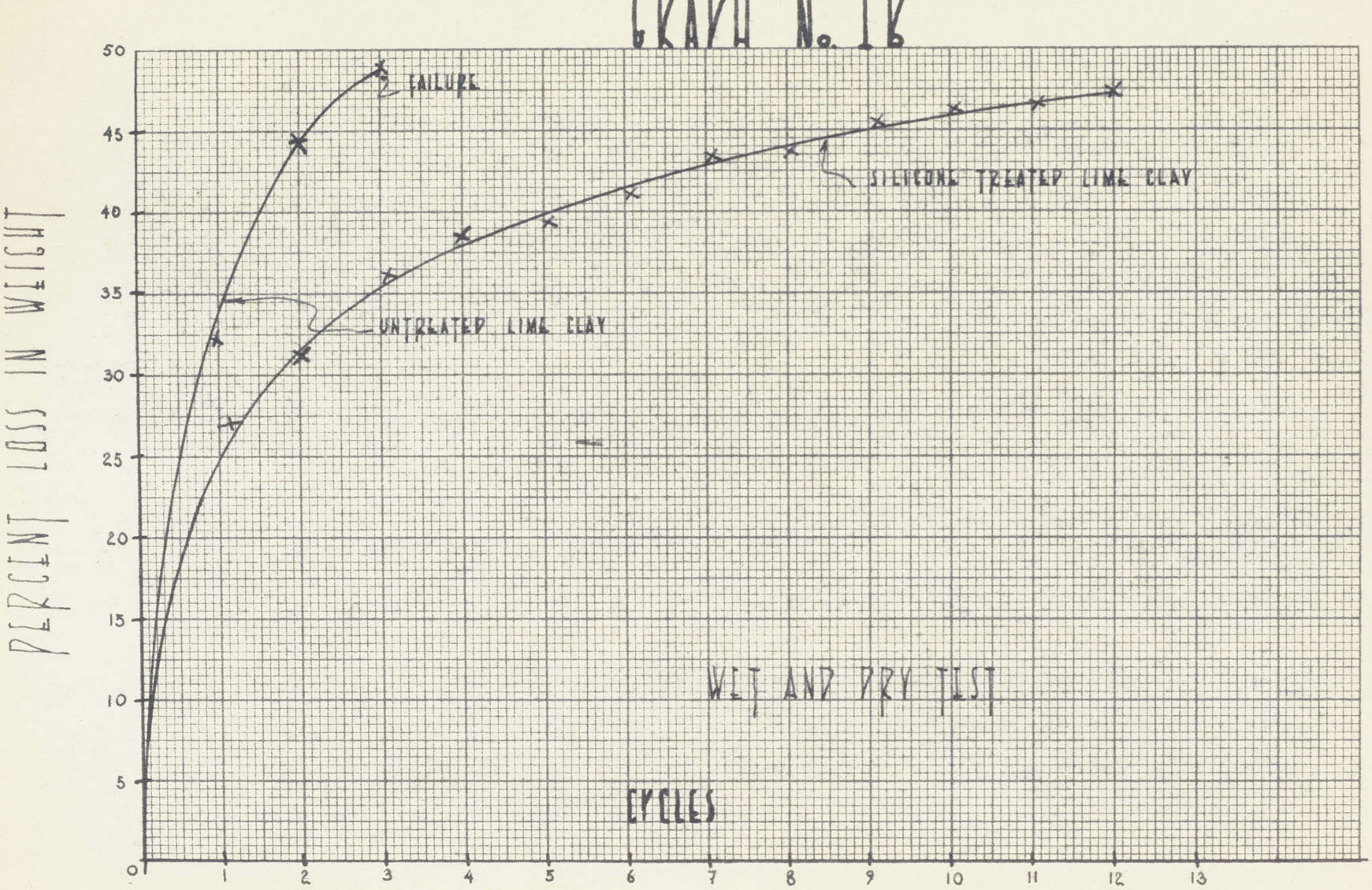
COMPRESSIVE STRENGTH TEST

Compressive Strength vrs. Time (days)

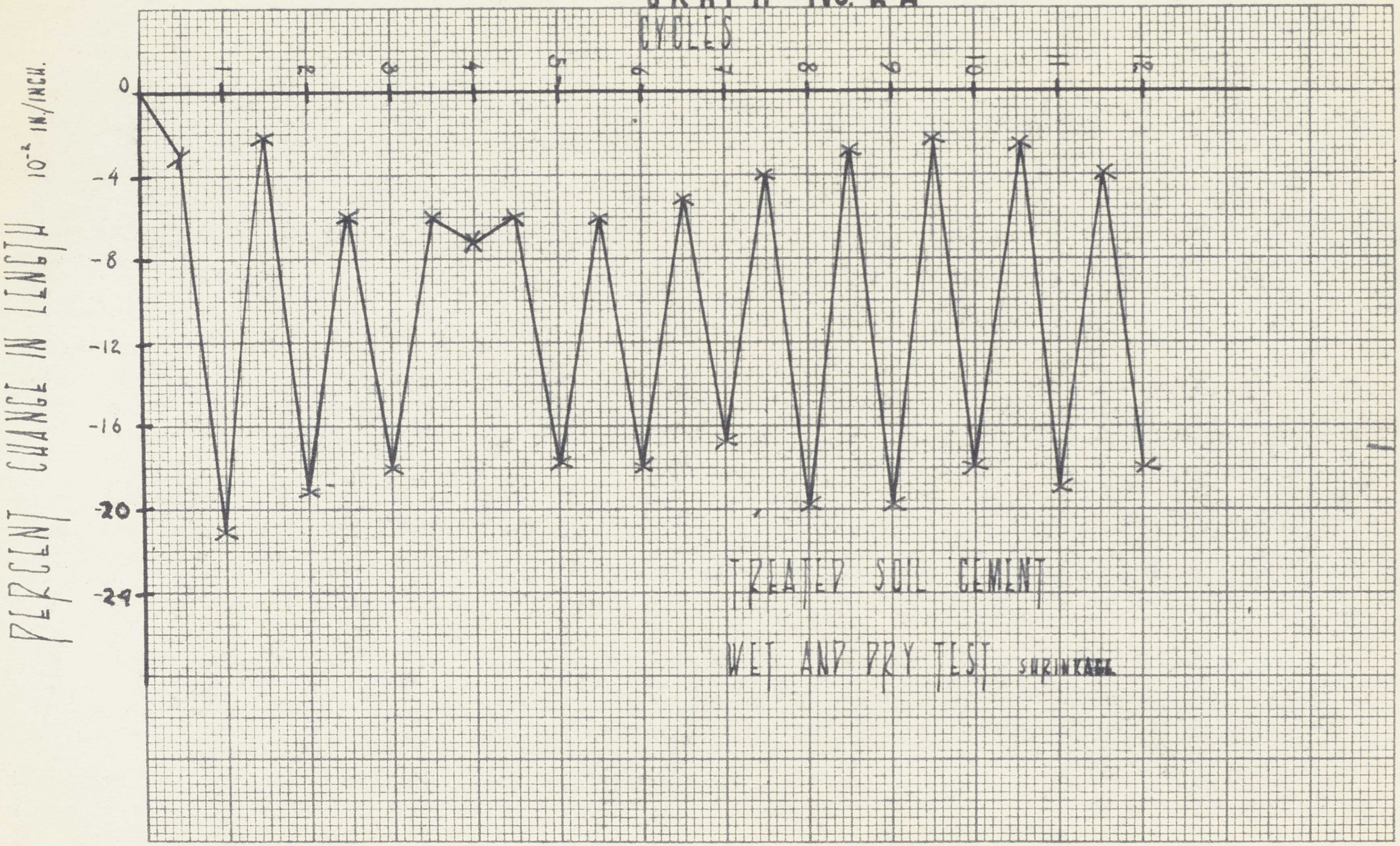
Treated Soil Cement		Untreated Soil Cement		Treated Lime Clay		Untreated Lime Clay	
Days	Psi	Days	Psi	Days	Psi	Days	Psi
2	410	2	422	2	105	2	115
7	550	7	593	7	275	7	305
28	703	28	748	28	580	28	603

GRAPH No. IA

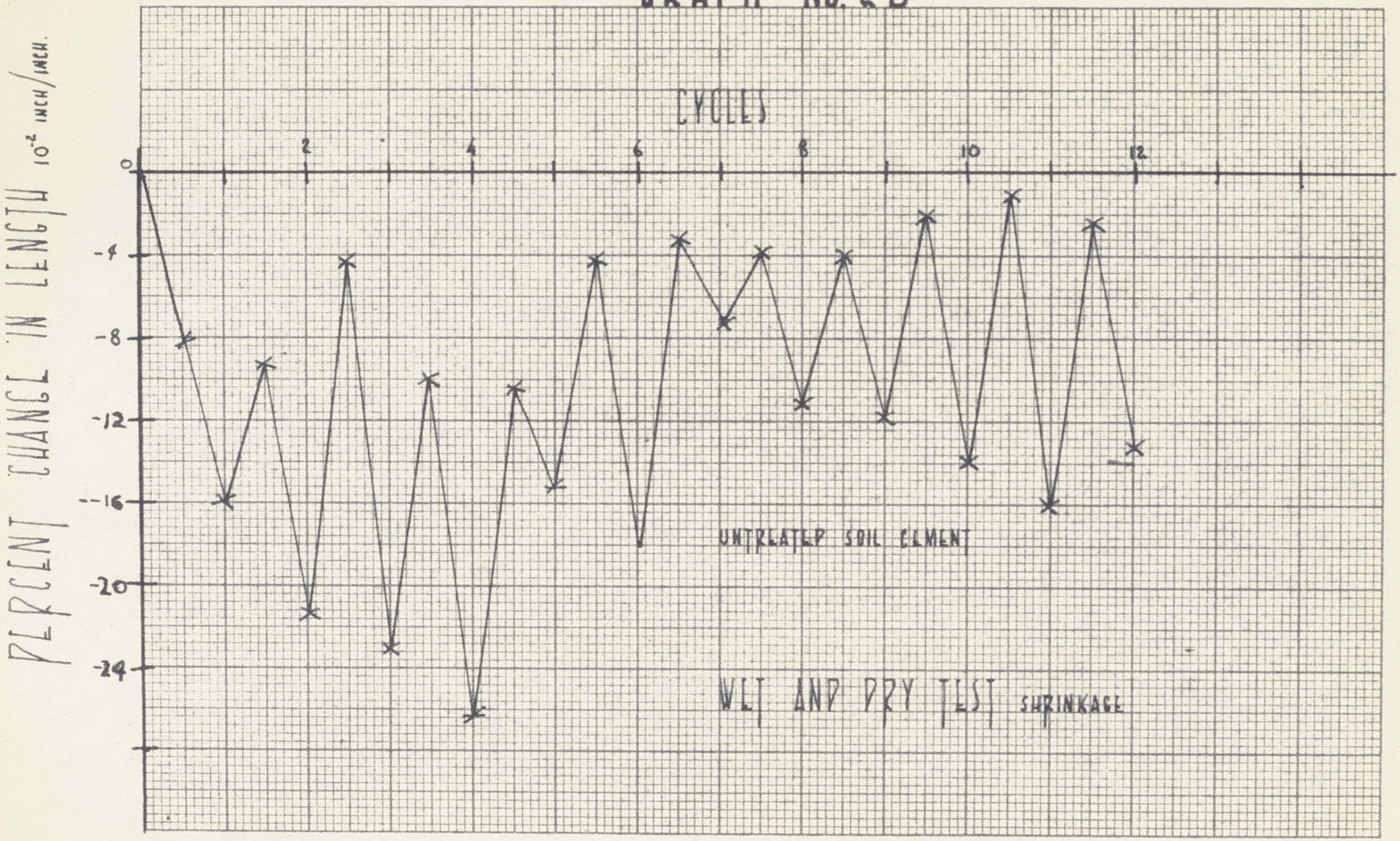

PERCENT LOSS IN WEIGHT
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
11
12
TREATED SOIL CEMENT
UNTREATED SOIL CEMENT
WET AND DRY TEST
CYCLES


GRAPH No. IB
PERCENT LOSS IN WEIGHT
CYCLES
FAILURE
SILICONE TREATED LIME CLAY
UNTREATED LIME CLAY
WET AND DRY TEST
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13

GRAPH No. 2A

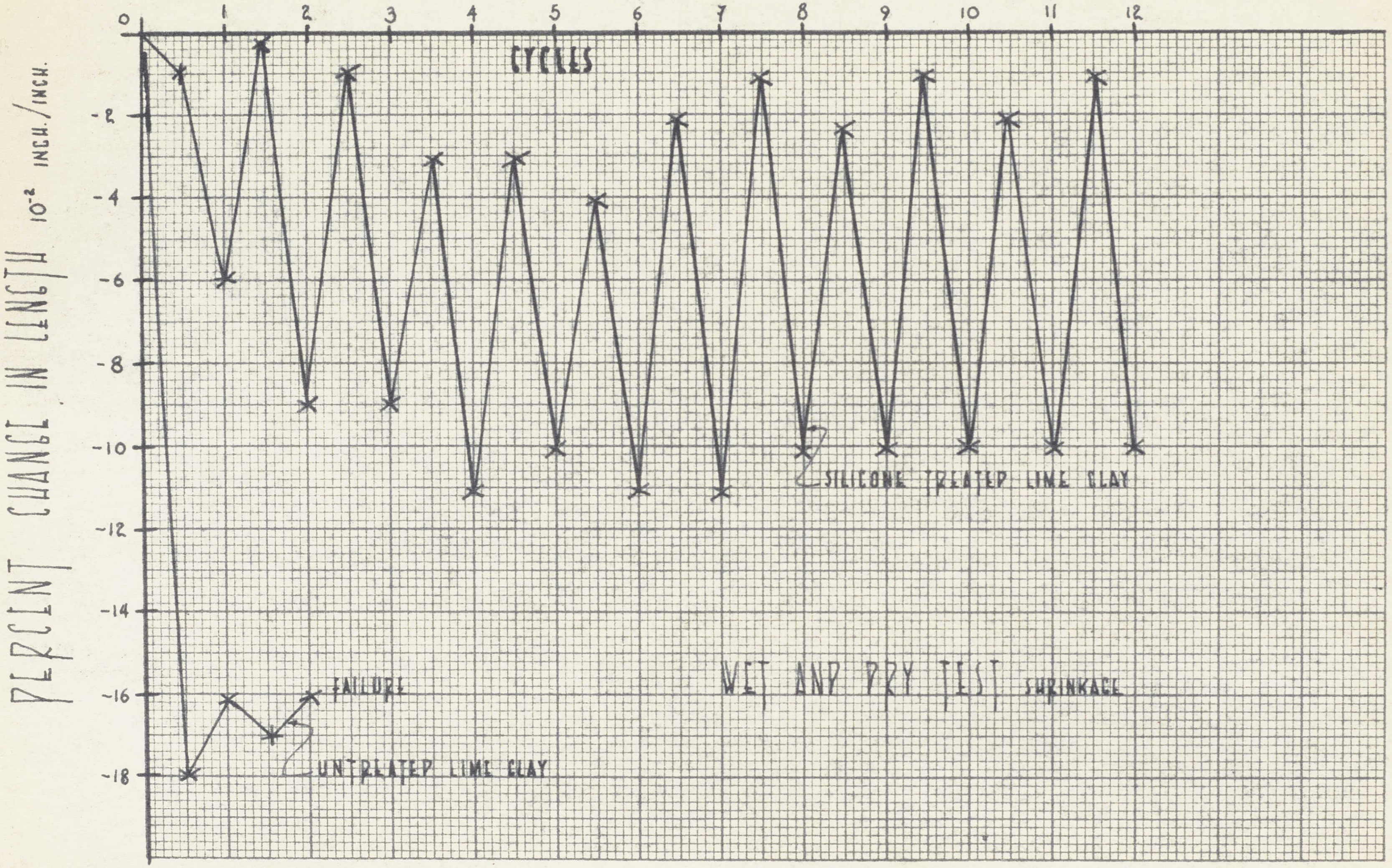

CYCLES
1
2
3
4
5
6
7
8
9
10
11
12
0
-4
-8
-12
-16
-20
-24
PERCENT CHANGE IN LENGTH 10⁻² IN/INCH.
TREATED SOIL CEMENT
WET AND DRY TEST SHRINKAGE

GRAPH No. 2B



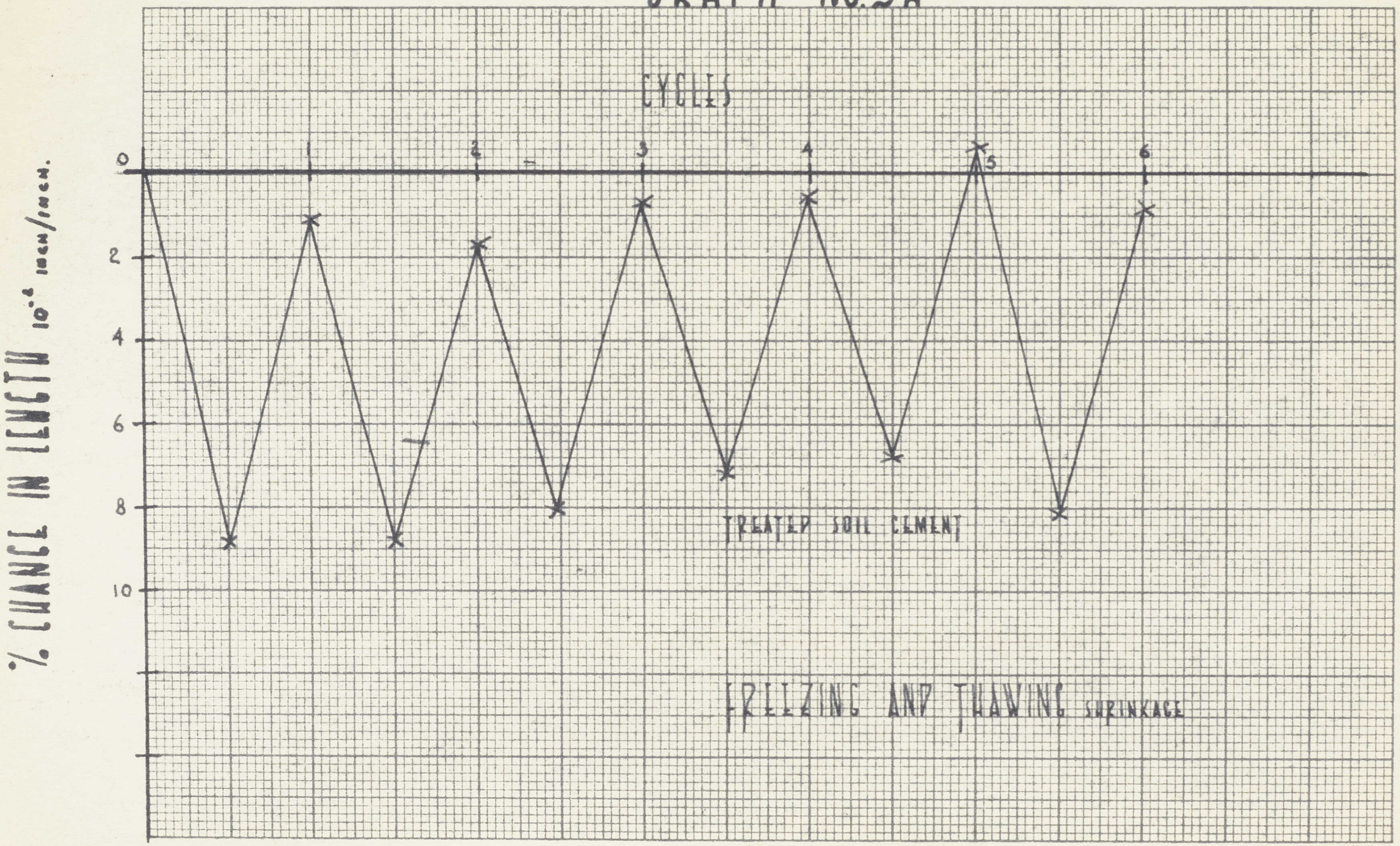
CYCLES
2
4
6
8
10
12
0
-4
-8
-12
-16
-20
-24
PERCENT CHANGE IN LENGTH 10^{-2} INCH/INCH.
UNTREATED SOIL ELEMENT
WET AND DRY TEST SHRINKAGE

GRAPH No. 2C

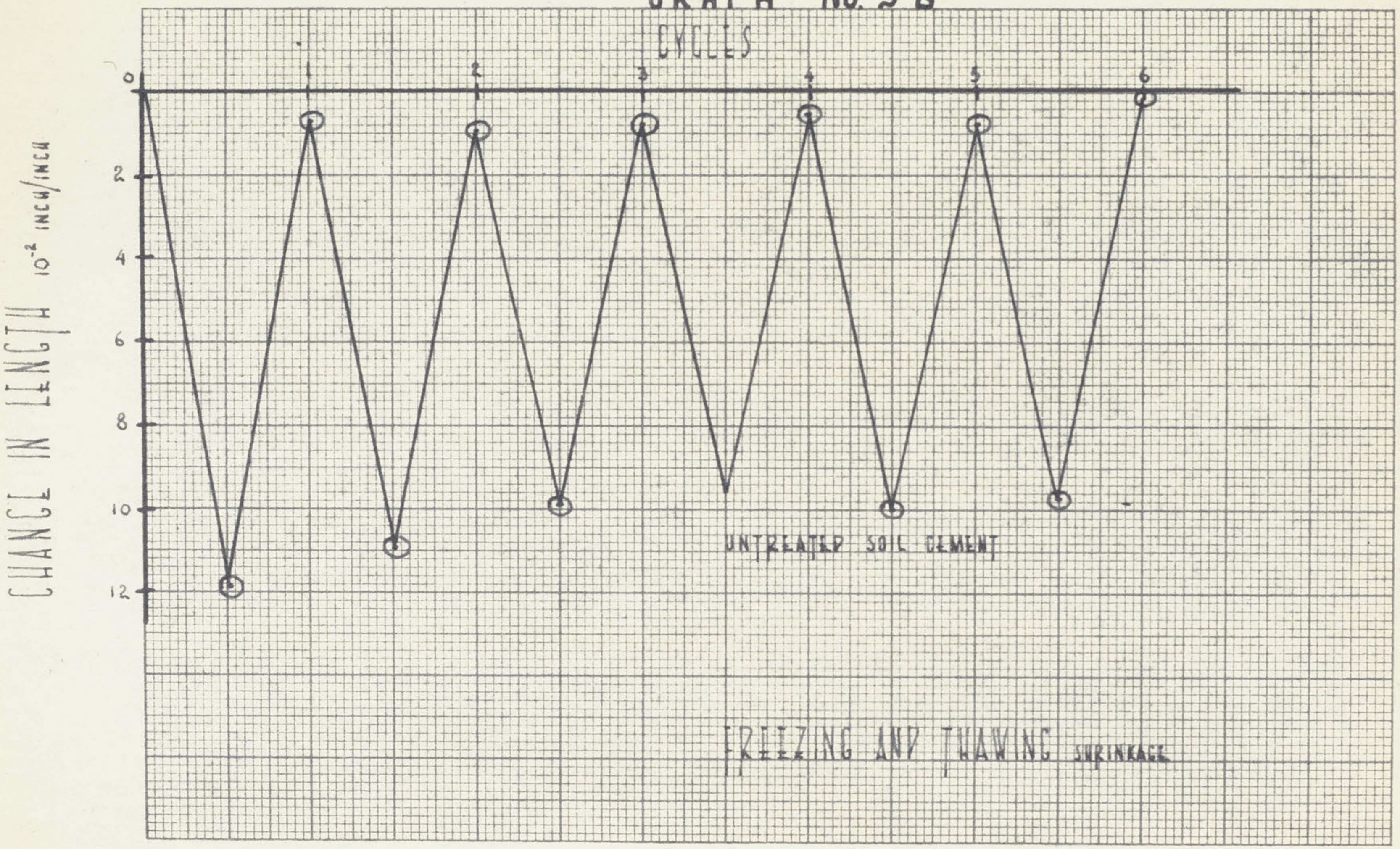


0
1
2
3
4
5
6
7
8
9
10
11
12
CYCLES
-2
-4
-6
-8
-10
-12
-14
-16
-18
PERCENT CHANGE IN LENGTH 10^{-2} INCH./INCH.
SILICONE TREATED LIME CLAY
FAILURE
UNTREATED LIME CLAY
WET AND DRY TEST SHRINKAGE

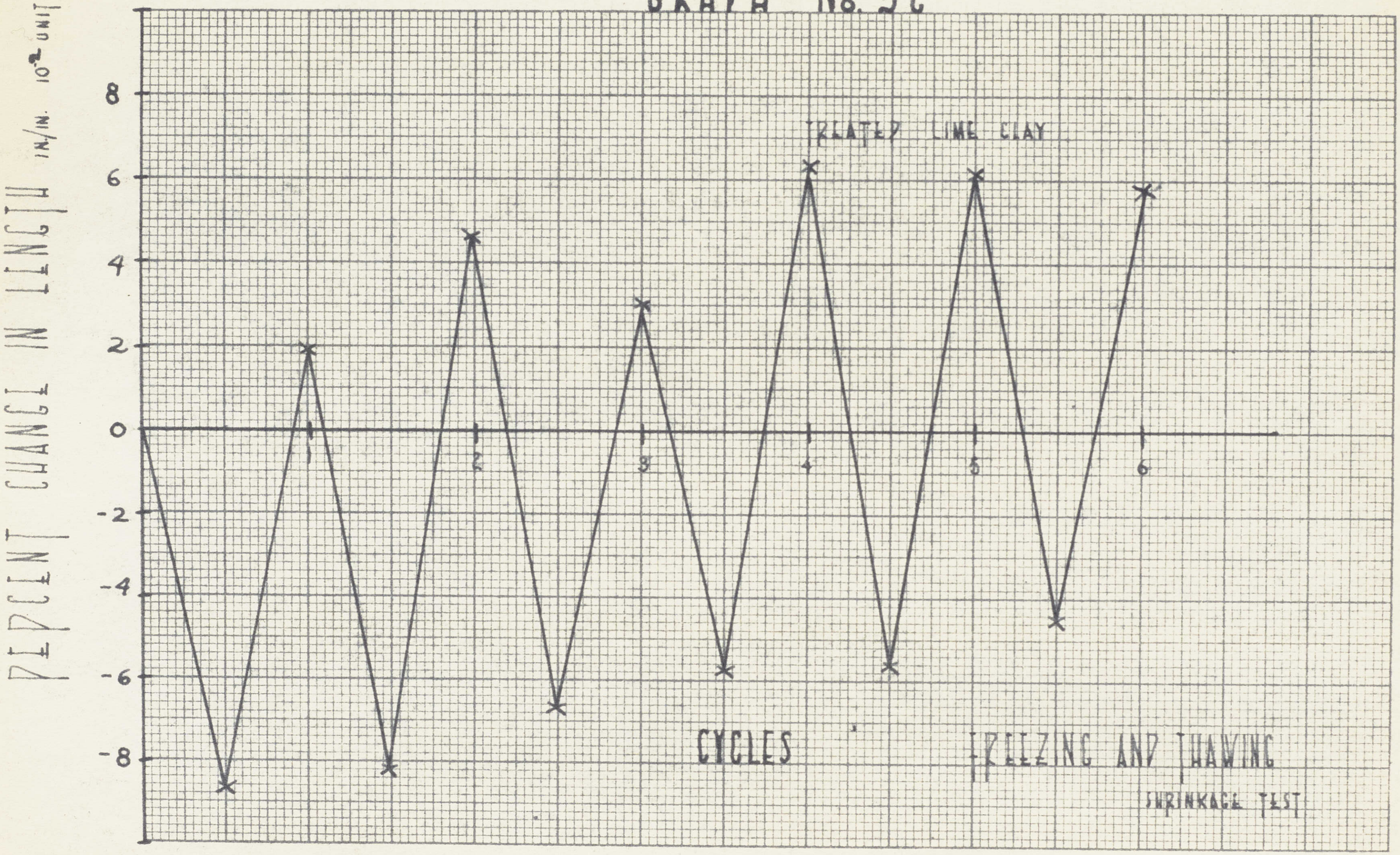
GRAPH No. 3A


CYCLES
0
1
2
3
4
5
6
2
4
6
8
10
TREATED SOIL CEMENT
FREEZING AND THAWING SHRINKAGE
% CHANGE IN LENGTH 10^{-2} INCH/INCH.

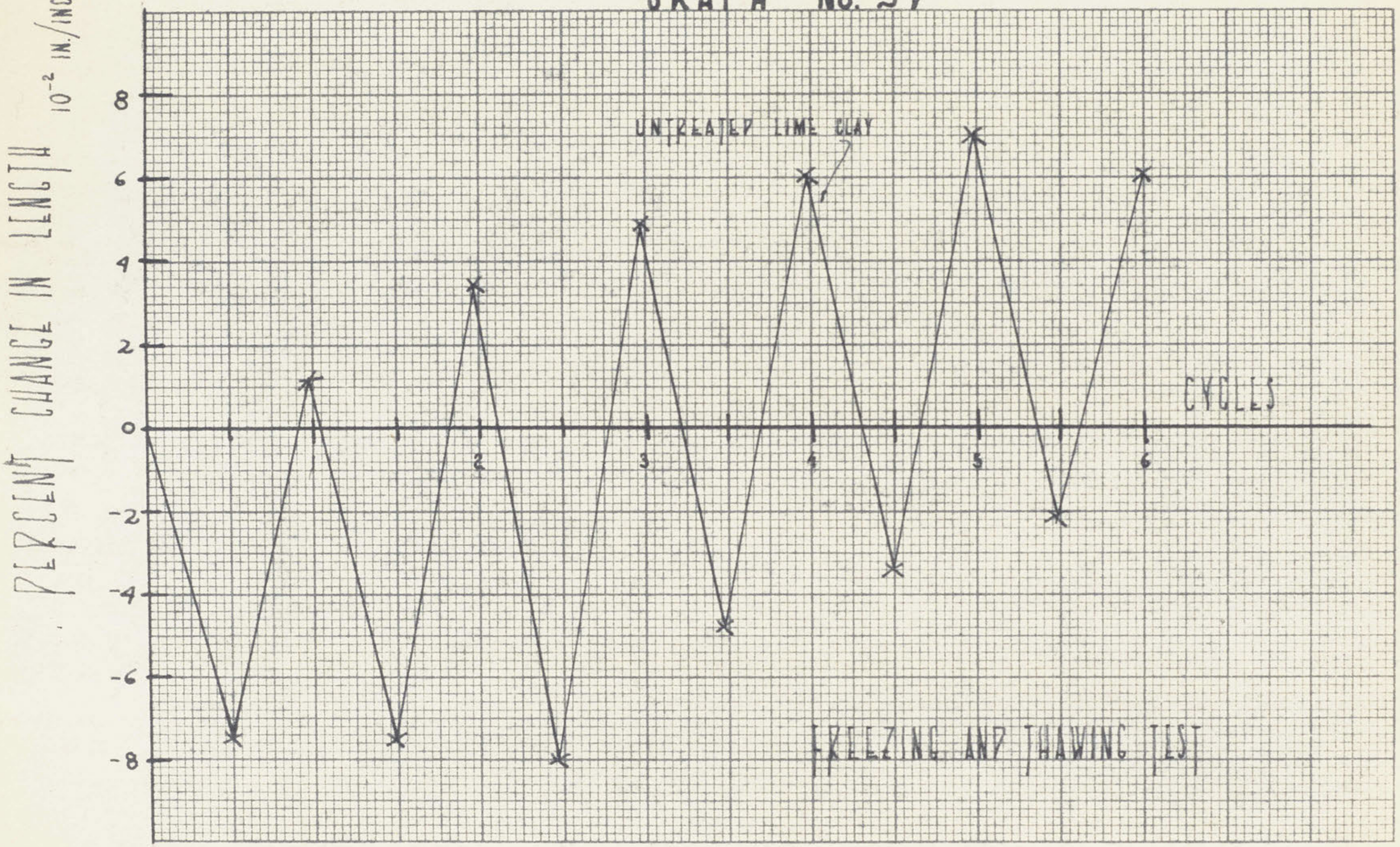
GRAPH No. 3B


CYCLES
0
1
2
3
4
5
6
2
4
6
8
10
12
CHANGE IN LENGTH 10^{-2} INCH/INCH
UNTREATED SOIL CEMENT
FREEZING AND THAWING SHRINKAGE

GRAPH No. 3C

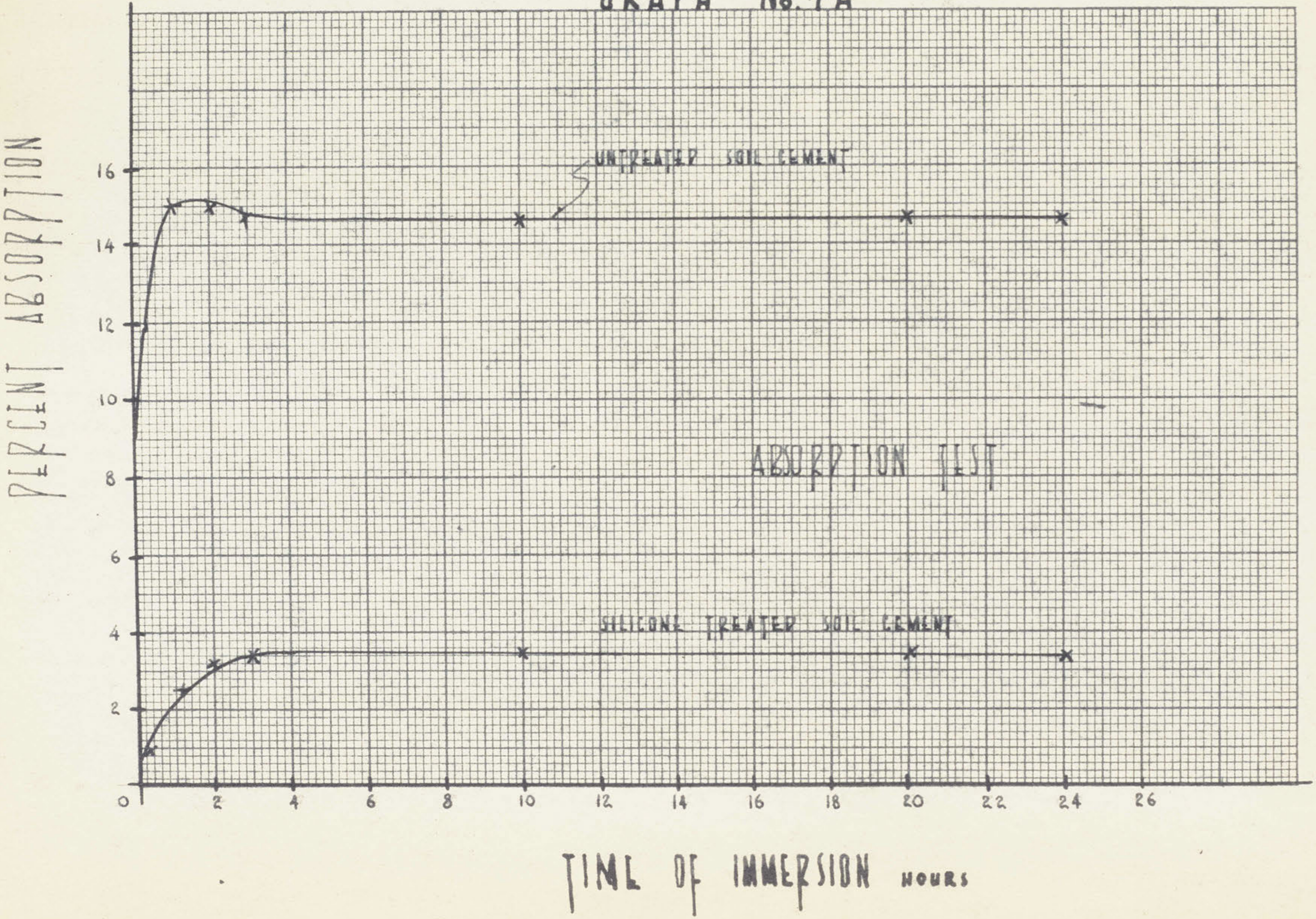

PERCENT CHANGE IN LENGTH IN/IN. 10^{2} UNITS.
8
6
4
2
0
-2
-4
-6
-8
1
2
3
4
5
6
TREATED LIME CLAY
CYCLES
FREEZING AND THAWING
SHRINKAGE TEST

GRAPH No. 3D

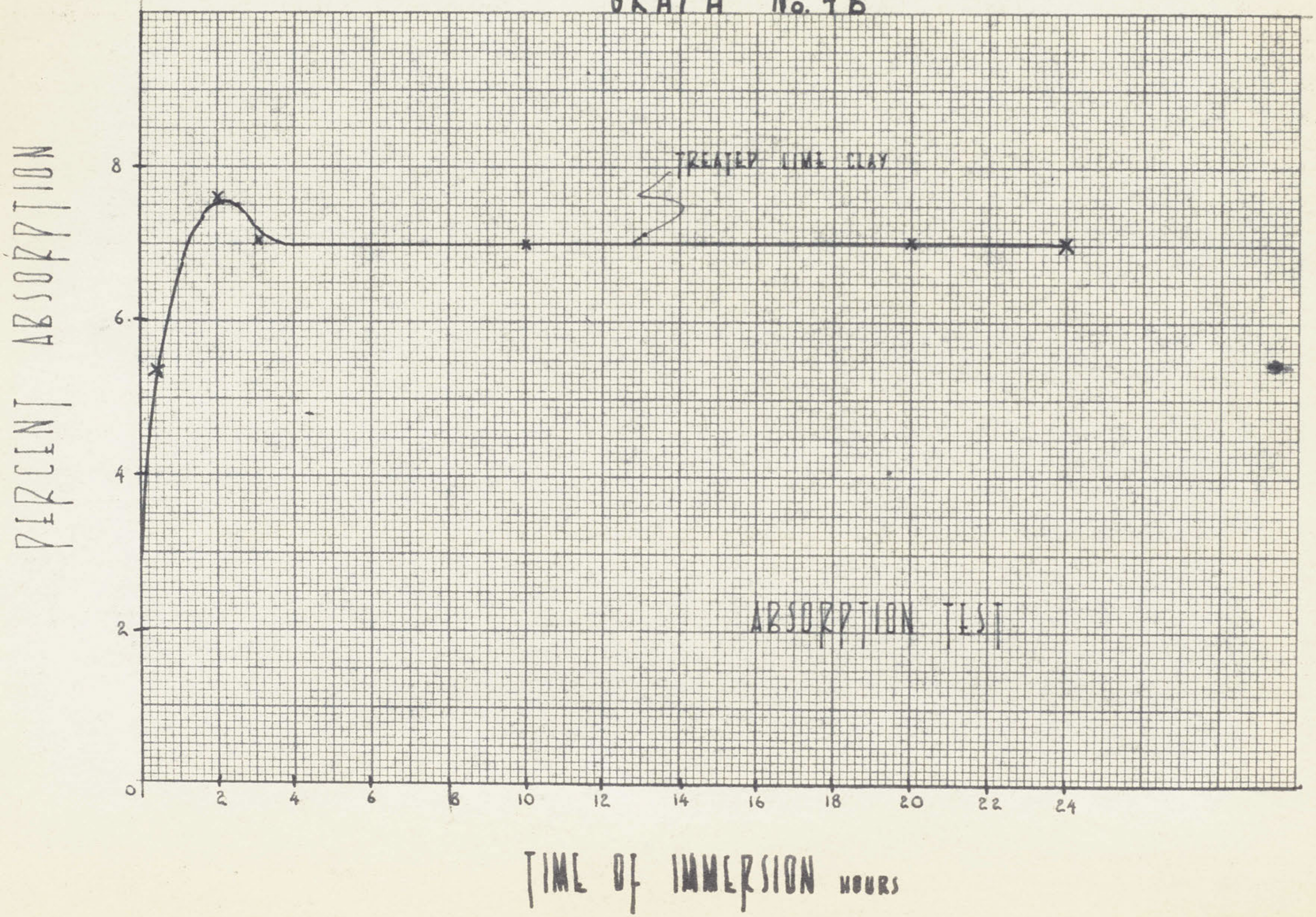


PERCENT CHANGE IN LENGTH 10⁻² IN./INCH.
8
6
4
2
0
-2
-4
-6
-8
UNTREATED LIME CLAY
CYCLES
1
2
3
4
5
6
FREEZING AND THAWING TEST

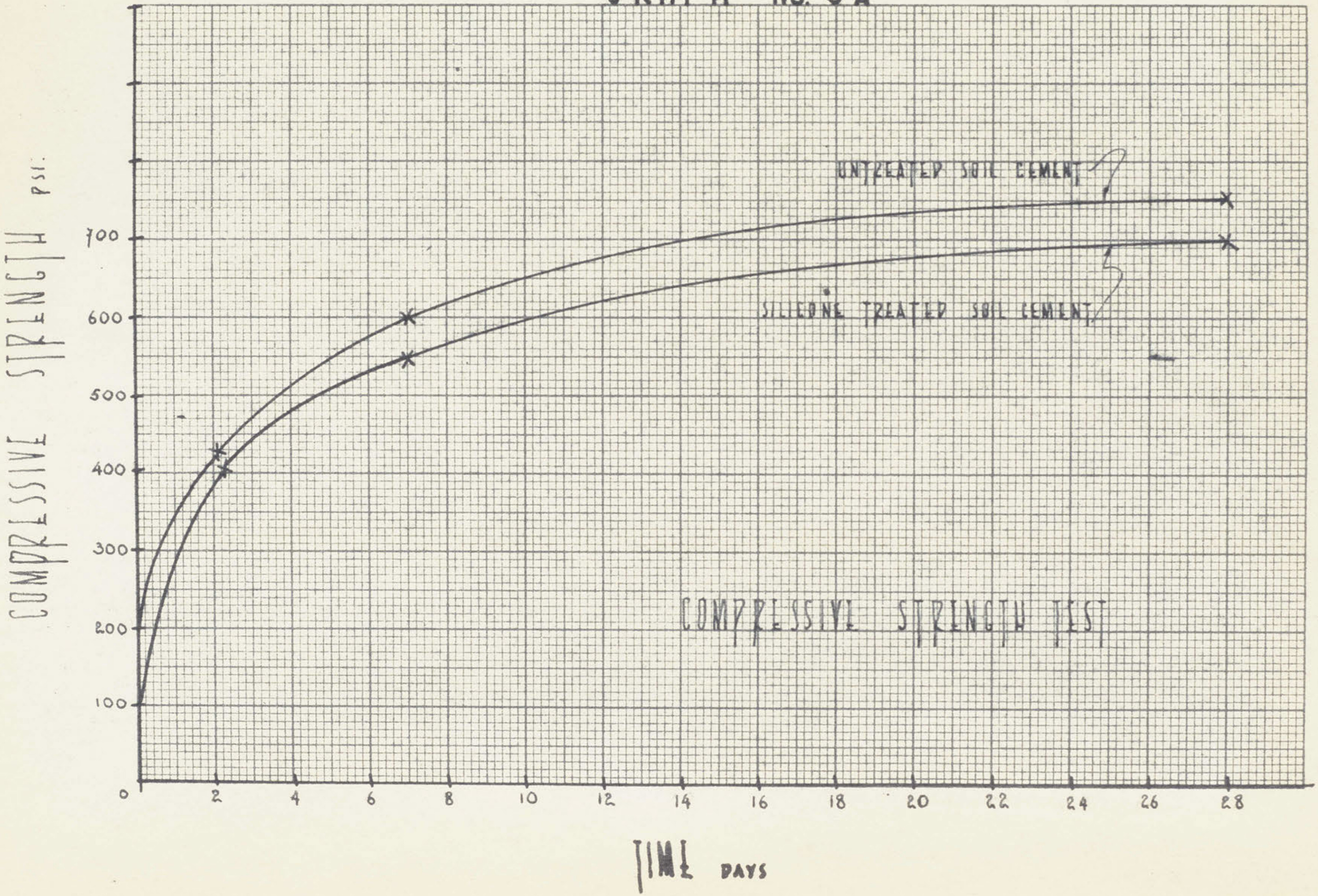
GRAPH No. 4A


UNTREATED SOIL CEMENT
SILICONE TREATED SOIL CEMENT
ABSORPTION TEST
PERCENT ABSORPTION
TIME OF IMMERSION HOURS
0
2
4
6
8
10
12
14
16
18
20
22
24
26

GRAPH No. 4B

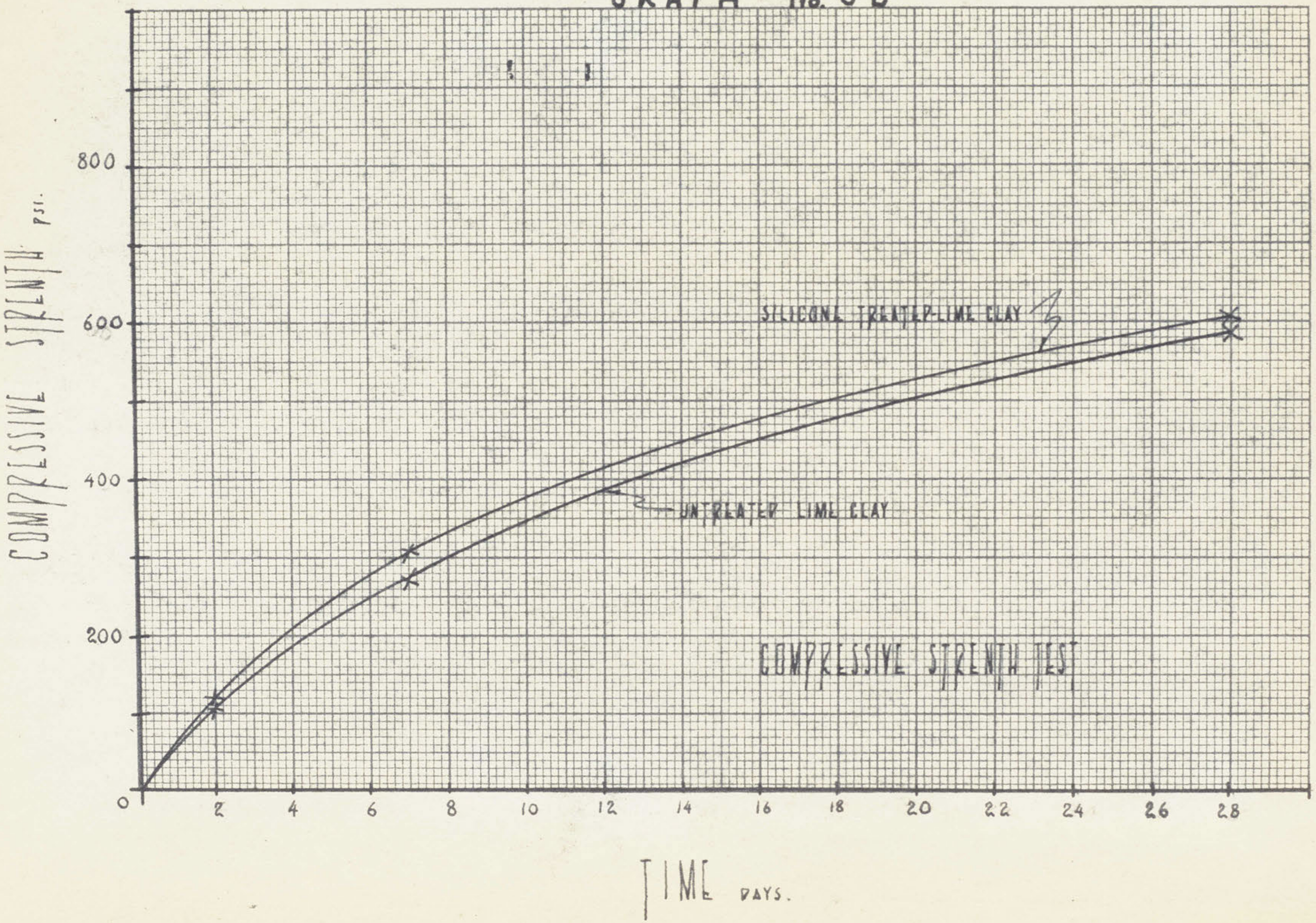

TREATED LIME CLAY
ABSORPTION TEST
PERCENT ABSORPTION
TIME OF IMMERSION HOURS
0
2
4
6
8
10
12
14
16
18
20
22
24

GRAPH No. 5A



UNTREATED SOIL CEMENT
SILICONE TREATED SOIL CEMENT
COMPRESSIVE STRENGTH TEST
COMPRESSIVE STRENGTH PSI.
TIME DAYS
0
100
200
300
400
500
600
700
2
4
6
8
10
12
14
16
18
20
22
24
26
28

GRAPH No. 5B



COMPRESSIVE STRENTH PSI.
800
600
400
200
0
SILICONE TREATED-LIME CLAY
UNTREATED LIME CLAY
COMPRESSIVE STRENTH TEST
2
4
6
8
10
12
14
16
18
20
22
24
26
28
TIME DAYS.

Probable sources of error

The shrinkage tests performed were the most difficult; care had to be taken in placing the sample perfectly vertical. The changes in length were so small that it was very easy to make a mistake by tilting the cylinder very slightly.

This was by far the greatest possible source of error, and may be attributed to the two factors; the impossibility of always having the cylinder vertical and the relatively small changes in length.

Except for the shrinkage test the precision of measurements is accurate to indicate the behavior of the stabilized cylinders and their behavior under the different tests.

Results of Tests

Results and computations of the tests performed are shown in the data sheets and in the graphs.

In order to make more clear these graphs and to provide a clear picture of the test results, the following information and explanations will serve as a supplement of the tests.

Wetting and Drying Tests

The graphs for the percent loss in weight are self explanatory. Figure 10 shows four cylinders after 12 cycles of wetting and drying tests; the two cylinders to the left are of soil cement. One is silicone treated and the other not. The cylinders to the right are made from clay and lime, the one to the far right is untreated, and the one to the near right is silicone treated.

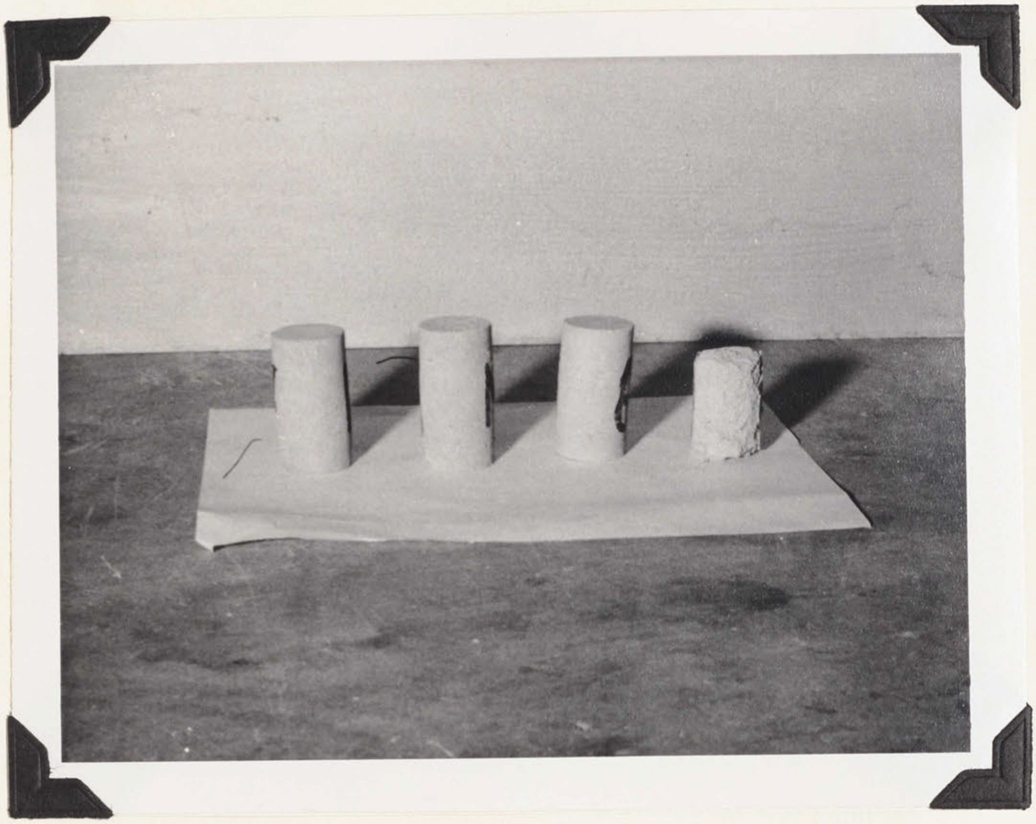


Figure 10
Cylinders after Wetting and Drying Cycles

The graphs for the changes in length are also self explanatory, except for graph 2C; here are plotted two types of cylinders, untreated lime clays, that become soft and failed after 2 cycles and silicone treated clay lime cylinders that resisted the entire 12 cycles.

Freezing and thawing

The graphs provide all information regarding the freezing and thawing tests. The percent loss in weight is not plotted because it was found that it oscillated always between zero and a very small number.

Figure No. 11 shows the four types of cylinders; the untreated cylinders developed a little honeycomb and small cracks on their faces; no damage was apparent on the silicone treated cylinders.

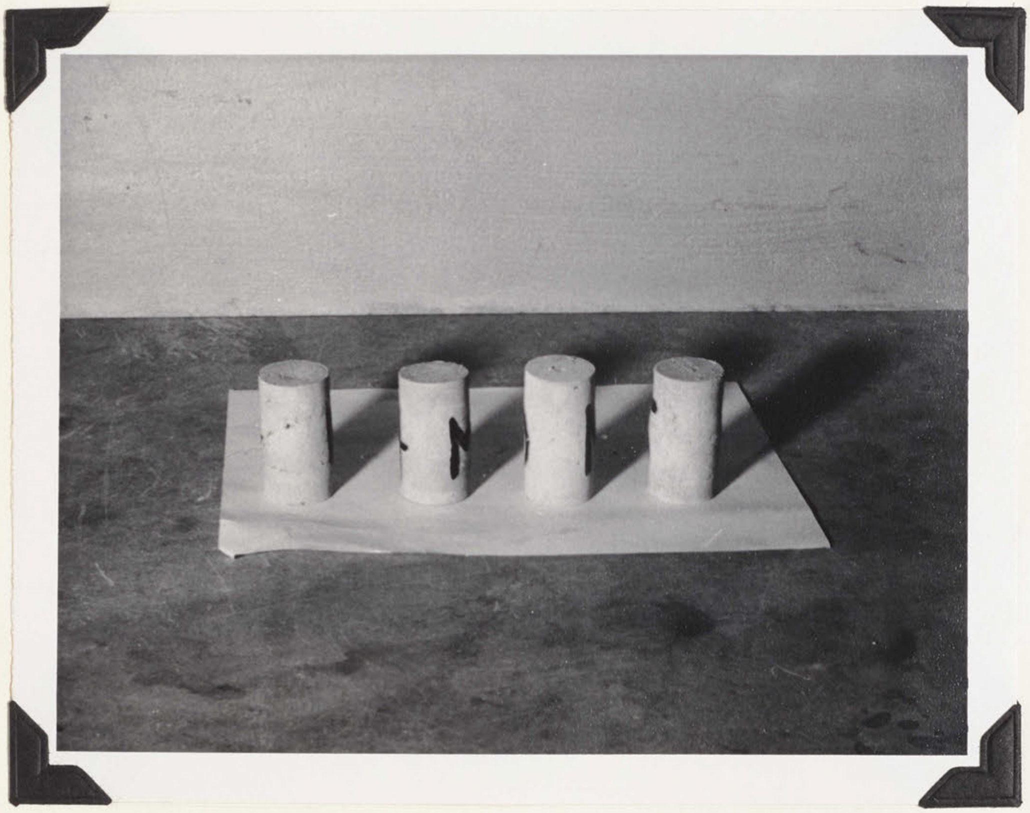


Figure 11

Cylinders after freezing and thawing tests

Compressive Strength

The plots for the compressive strength show how the cylinder resistance against failure increases as the age increases. The cylinders failed with the characteristic 45° angle as shown in figure No. 12. Silicone treatments had very little effect in the compressive strength of the samples.

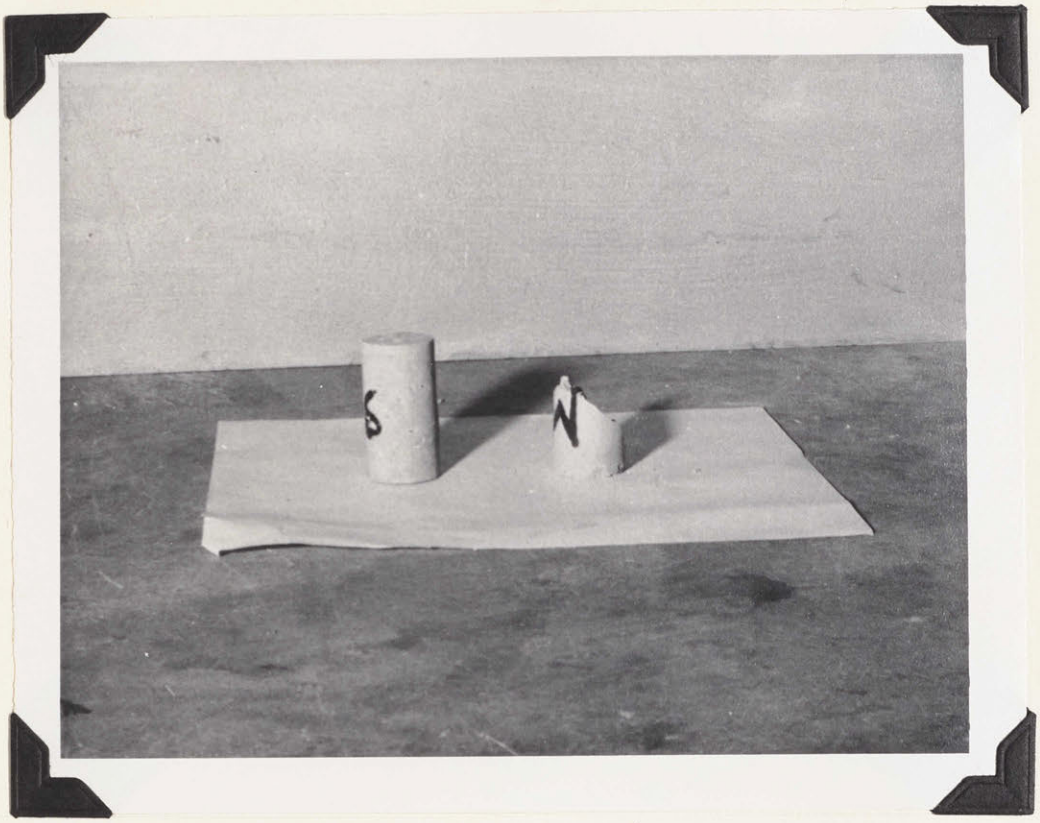


Figure 12

Cylinder before and after compressive strength test

Three samples of each type of cylinder were tested and the average value was taken to determine the compressive strength.

Discussion of Results

General. The results obtained in the previous section show the behavior of a compacted sandy material stabilized with cement; and the behavior of clay stabilized with lime.

The most important aspect from a practical point of view in the construction of low cost houses using stabilized soils, is durability. Therefore, the discussion of the tests will be based mainly on durability.

Untreated clay stabilized with lime show very low durability for wet and dry conditions. They are as strong as the treated cylinders and as durable under dry conditions but with the introduction of water they disintegrate. Graph 1B shows that disintegration occurred at the third cycle. Silicone painted clay lime cylinders stood perfectly the accelerated tests; some samples failed at the corners, and some developed cracks, but in general they stood the tests very well.

Untreated soil cement stood the tests perfectly; there was no apparent failure in the cylinder. The percentage loss in weight was very small as shown in graph 1A. Silicone treated soil cement also stood the wet and dry tests, the percentage loss in weight was very small, and no apparent failure occurred in the cylinders.

The absorption test showed the effect of silicone in treated and untreated cylinders. Graph 4 A shows that untreated soil cement had a maximum absorption of approximately

15.2 percent; while silicone treated soil cement samples had a maximum absorption of 3.4 percent, this maximum was obtained at the third hour of immersion after which the absorption remained constant.

Silicone painted lime clay cylinders had a maximum absorption at the second hour of immersion. Unpainted lime clay cylinders offered a problem since disintegration started to occur when the cylinders were immersed in water. That is why we did not record the corresponding values.

The compressive strength obtained was also good and there is very little effect with the treated and untreated cylinders.

The maximum compressive strength obtained for treated and untreated lime clay cylinders was approximately 600 psi. For untreated and treated soil cement it was around 700 or 750 psi; these results are excellent since for this and higher values Plummer has established that the compressive strength of a wall depends much more on the strength of the mortar than the strength of the blocks. Another thing that must be mentioned is that high compressive strength is not essential since the main use will be in one story dwellings.

Dimensional changes may also have a great effect on durability of stabilized soil constructions. For this reason the length change per unit length were recorded for these cylinders and for various instances. We plotted changes in length for freezing and thawing tests, and for wet and dry tests. Maximum changes that occurred were around .65 percent the cost of application will be around five cents per square foot. This means that the cost of a wall 20' long by 8' high will be increased by $8. This type of protection will be cheaper than stuccoing the walls.

CONCLUSIONS

A) These experiments show that soil cement can be used in the construction of small dwellings. Silicone treated soil cement has almost no difference with the untreated one, absorption is lowered with the daracone coatings, but in general, the behavior of the untreated soil cement is very good.

B) Clay stabilized with lime has good durability under extreme dry weather, but some protection is necessary if this type of stabilization is to be used in highly humid atmosphere or in places where rain is fairly abundant throughout the year.

C) Silicone coatings provide a good protection for clay lime stabilization, the samples behaved very well under the accelerated tests, and the increase in cost was not excessive. A daracone coating appears to be suitable as a silicone treatment for it provides a protective as well as a water resistant shell on the soil. It can be easily sprayed.

More research is needed in this field to develop a cheaper material for protection purposes. Parafin wax dissolved in kerosene might provide a good and cheap protecting agent in lime stabilization.

D) Because of the type of machines used for the fabrication of blocks, and considering that they are hand operated, and they used materials available in situ, this type of construction is more suitable where hand labor is cheap as in undeveloped countries.

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