Accelerated Curing for Lime-Stabilized Soils

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This paper is concerned with the preliminary steps of a general study the ultimate goal of which is to develop specifications for the required unconfined compressive strength of lime-stabilized base and subbase materials. Specifically it deals with the possibility of establishing a correlation between the strengths of field-cured specimens and those of laboratory-cured specimens that might be used to predict the former from the latter.

Two soils were chosen for study. Harvard mold-size specimens were tested for unconfined compressive strength after being subjected to field curing and to laboratory curings of 120 and 140 F. Evaluation of the data consists of determining the time of accelerated curing required to achieve 45-day field strengths.

The limited data indicate that a strength prediction based on laboratory curing can be made with reasonable accuracy.

●IT OFTEN has been found difficult to obtain suitable base or subbase materials within reasonable hauling distances of construction projects. If the addition of a small percentage of lime can condition the in-place subgrade or bring a nearby borrow material within the limits of specifications, economy will result. In several instances in Virginia, lime stabilization could have been used to bring about such economy. In these instances, although a blanket material was available near the job, no material meeting the specifications could be found. The soils laboratory of the Virginia Council of Highway Investigation and Research has been asked on several occasions to investigate the possibility of stabilizing, with lime, some of the materials found in place or near certain projects.

On the basis of laboratory investigations several experimental projects were constructed but because no method of test or design had been correlated with field performance it was considered necessary that a method of determining the rate of strength gain of materials stabilized in the field be developed. Because no single soil property such as bearing value or strength can be considered as the most essential in highway performance, a practical laboratory test, which can be easily replicated, such as the unconfined compressive strength test, was favored for this study. It was believed that a specification requiring a given unconfined compressive strength of soil-lime mixtures and based on an accelerated curing of the test specimens could be developed (1).

This paper covers the preliminary data obtained during the summer of 1960 in the first step of the general study, the investigation of the possibility of predicting field strengths of lime-stabilized soil specimens on the basis of accelerated laboratory curing. In this paper, only the data obtained on the two soils tested is presented and discussed; no generalizations are made. It is hoped the findings can be generalized in the future, as more types of soil of different origins are studied.

The soils used in the study were taken from experimental lime-stabilization projects previously installed in Virginia (2). This was done in an effort to specify an unconfined compressive strength based on the accelerated laboratory curings and the performance of these soils under traffic.

LIMITATIONS OF THE STUDY

The measurement of the compressive strength of soils under pavements by coring involves such a number of variables that strength determinations obtained in this way are often not comparable to laboratory values. Therefore, no coring will be attempted. The specified value of the unconfined compressive strength would be based on observations of the performance of the previously installed projects and the results of tests on soil samples obtained from these projects.

This study did not consider such variables as movement of moisture or repetition and magnitude of loads but was concerned with the effect of maturity (temperature x time) on gain of strength. Only one percentage of lime, 5 percent by weight of the soil-lime mixture, was selected for the study.

TABLE 1

PHYSICAL PROPERTIES OF SOILS TESTED

Property	Soil A	Soil B
Percent passing No. 4	100	100
Percent passing No. 10	86	99
Percent passing No. 20	68	97
Percent passing No. 40	45	89
Percent passing No. 60	31	76
Percent passing No. 80	28	63
Percent passing No. 100	26	55
Percent passing No. 200	25	39
Percent silt (0.05 - 0.005 mm)	3	29
Percent clay (x 0.005 mm)	21	4
LL	35	40
PI	11	N.P.
Sp Gr	2.70	2.75
Max den. plain soil, pcf (AASHO-T99)	118.3	96.0
Max den. with 5% lime, pcf (AASHO-T99)	117.0	94.8
Opt moist cont plain soil, %	13.0	23.2
Opt moist cont with 5% lime, %	13.4	24.4
HRB classification	A-2-6(0)	A-4(1)

The precision of the equipment used, such as the oven and the scales, is of the same order as that of an average laboratory. The temperatures maintained during laboratory curings were constant within ± 3 F.

PROPERTIES OF THE SOILS TESTED

Two soils were chosen for study. The physical properties of these soils are given in Table 1.

Soil A is a clay gravel, common in the northeastern part of the state. The particular sample tested was taken from a borrow pit in Fairfax County. Previous tests on soil from this pit showed that it reacts very well with lime. When stabilized with lime, it produces fairly high unconfined compressive strengths and a very high CBR value, and resists the freeze-thaw and wet-dry tests satisfactorily (3). Due to the size of the unconfined compression test specimens only the portion passing the No. 4 screen was sampled. However, the pit contains from 30 to 60 percent material retained on the No. 4 screen. It is believed that when stabilized with lime this material could be used as an alternate to the available local crushed aggregate.

Soil B is a micaceous silty soil of fairly common occurrence in Virginia and is usually regarded as being a "troublesome soil". A similar soil was stabilized with various percentages of lime, cement, and lime-fly ash and used as a subbase on an experimental section of project 1770-03, US 58, Patrick County. The project was built in 1956 and since then valuable data have been obtained on the performance of this soil (2).

About 600 lb of each soil were air dried, sieved through the No. 4 screen, and stored in closed containers. The moisture content of the soil in the containers was determined prior to each molding or testing.

TEST PROCEDURE

In this study the unconfined compressive strengths of field-cured specimens were compared to those of specimens cured at 140 and 120 F in the laboratory when both were stabilized with 5 percent lime. However, because the Virginia Department of Highways uses the CBR method of design for flexible pavements, it was thought appropriate to include some CBR specimens in the field curing. The values obtained from the field-cured CBR's were compared to the values obtained from specimens cured in the moist room.

Size and Number of Specimens

Statistical calculations made in pilot studies indicated that for the unconfined compression test at least 8 specimens for each period of oven curing and at least 11 specimens for each period of field curing had to be used to obtain satisfactory precision at the 95 percent confidence level. For this reason the Harvard miniature mold size (1.34-in. diameter and 2.8-in. height) was chosen as the size of the unconfined compression test specimens to keep the amount of soil needed to a minimum and to obtain a homogeneous mixture. However, due to the large size of the CBR specimens, only two were used for each period of field and moist-room curings.

Molding

The maximum density and the optimum moisture content of each soil, with and without lime, were determined in accordance with AASHO T99-57 Method A.

The Harvard miniature mold was used for the compression specimens; however, the spring hammer furnished by the manufacturer was replaced with a homemade drop hammer. The drop hammer was constructed to have a 1-lb weight falling 10 in. The diameter of the hammer head was one-half that of the mold. Using the Harvard miniature mold and this hammer, it was observed that at optimum moisture content five layers and 15 blows per layer would produce a density very close to the maximum density obtained by AASHO T99-57 Method A. The Virginia standard procedure was used to mold the CBR specimens (4).

All specimens were molded close to their optimum moisture contents, wrapped with aluminum foil, and coated with a special wax to preserve the molding moisture content during the curing period. The CBR specimens were wrapped in their molds.

Field Curing

Forty-five days of field curing was assumed to be a reasonable period, because it was believed that this would be the maximum time allowed for lime to react before the roads were opened to traffic. However, to obtain a better estimate of what happens when a soil is cured under simulated field conditions, both the CBR and the unconfined compression test specimens were cured for 30, 45 and 60 days.

Field Curing Schedule.—The study was started in May 1960. At that time 33 unconfined compression test specimens and 6 CBR specimens were molded and subjected to field curing. At 30, 45 and 60 days, respectively, 11 of the compression specimens and two of the CBR specimens were tested. These 39 specimens are referred to in this paper as Series I.

In July 1960 another set of 33 unconfined compression test specimens and 6 CBR specimens were molded, subjected to field curing, and then tested. These specimens are referred to as Series II.

Specimens for Series III were molded and subjected to field curing in September

1960. However, because tests on these specimens were not completed at the time of this writing, this paper is concerned with only Series I and Series II. The outline of the field-curing schedule and the accumulated maturities at each date of testing are shown in the Appendix (Table 3).

Figure 1 shows the depths at which the test specimens were located in the simulated road. These dimensions are typical flexible pavement design coverages for bases and subbases used in Virginia. For this reason in some instances reference will be made to soils A and B as base and subbase soils, respectively.

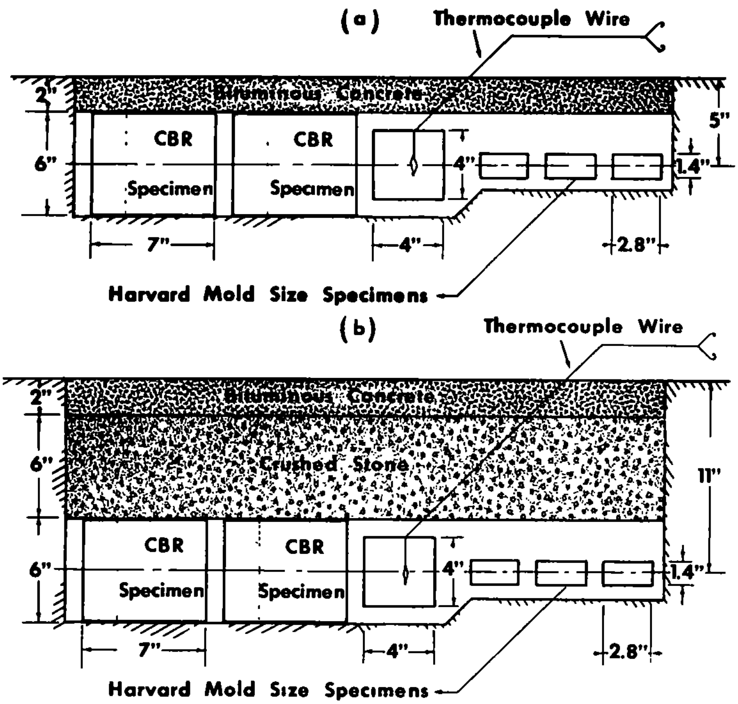

Figure 1. Sketch illustrating the depth of field-cured specimens: (a) base soil specimens, and (b) subbase soil specimens.

Laboratory Curing

On the basis of previous experience with accelerated curing, 0.5, 1, 3 and 5 days of oven curing were employed, both at 120 and 140 F for the unconfined compressive strength correlation. CBR specimens were cured for 3, 7, 14 and 21 days in the moist room at 70 F.

Testing

Unconfined compression test specimens were tested at a rate of strain of about 0.12 percent per second. The Virginia standard procedure was used for testing the CBR specimens. Moisture contents of the test specimens were determined after testing to indicate the loss of moisture during each curing period.

Maturity

It is known that time and temperature have important effects on the reaction and hardening of cemented mixtures. Experiments with concrete indicate that, other variables being constant, the strength of concrete is a function of its maturity (reckoned in temperature-time) at any curing temperature (5, 6).

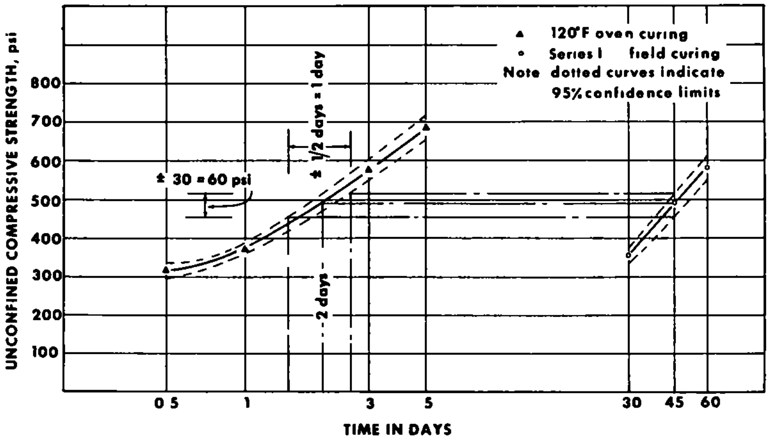

Figure 2. Comparison of Series I field curing and 120 F oven curing for Soil A.

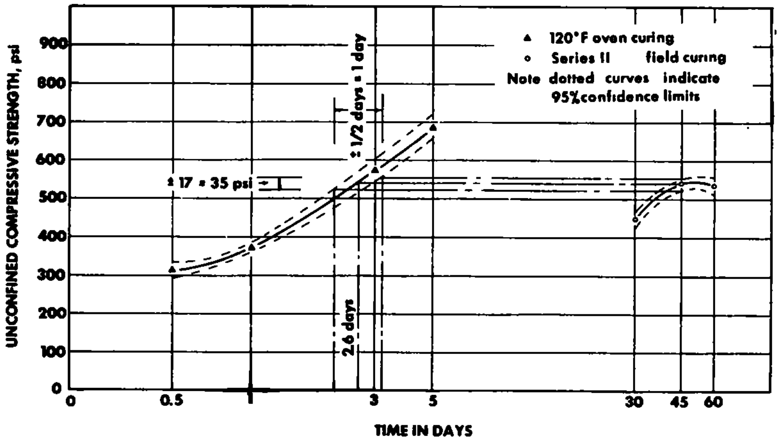

Figure 3. Comparison of Series II field curing and 120 F oven curing for Soil A.

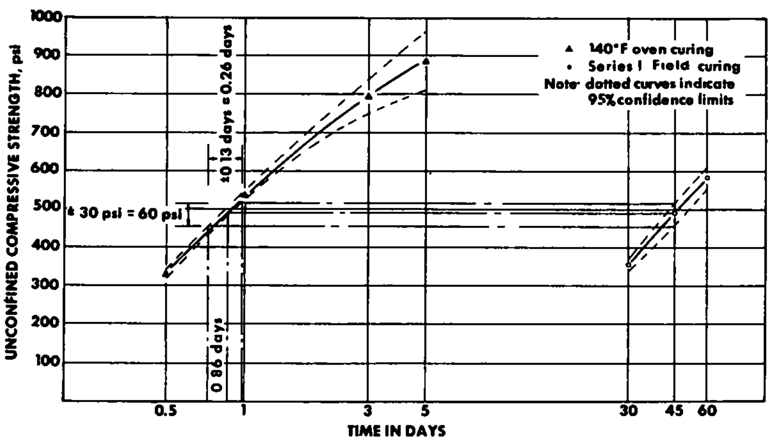

Figure 4. Comparison of Series I field curing and 140 F oven curing for Soil A.

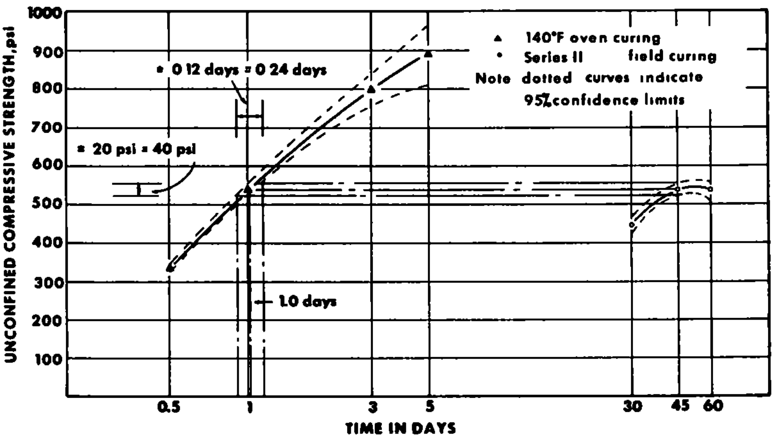

Figure 5. Comparison of Series II field curing and 140 F oven curing for Soil A.

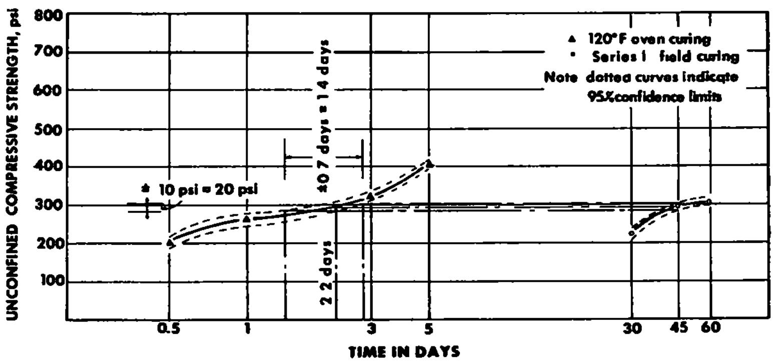

Figure 6. Comparison of Series I field curing and 120 F oven curing for Soil B.

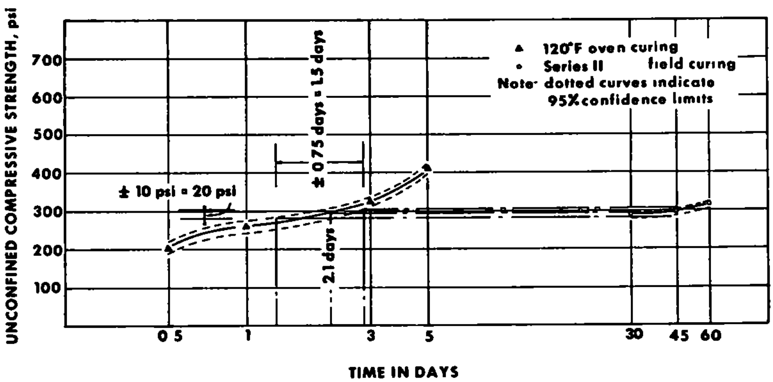

Figure 7. Comparison of Series II field curing and 120 F oven curing for Soil B.

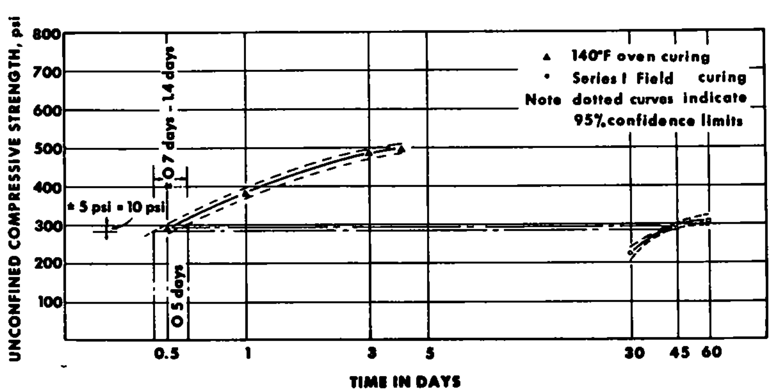

Figure 8. Comparison of Series I field curing and 140 F oven curing for Soil B.

To determine the feasibility of this approach for soil-lime mixtures it was decided to investigate the maturity of field-cured specimens. Because no temperature recorder was available at the time, a thermocouple was installed for each soil at its average depth (Fig. 1). It was hoped that the temperatures of the subbase and base specimens could be predicted by conducting 36-hr soil temperature surveys and correlating these surveys to the air temperature data available at the Council.

TEMPERATURE STUDIES

Three temperature correlation studies were conducted, two in the middle of the summer and one late in the summer. During these studies the air, base, and subbase temperatures were recorded hourly for about 30-36 hr by the use of the thermocouple. The results of these studies are shown in the Appendix (Fig. 12 and Table 4). The purpose of these studies was to investigate the possibility of using the available data on air temperatures, with a correction factor, to predict the temperatures prevailing at the base and subbase levels.

RESULTS

The unconfined compressive strengths of the field-cured and laboratory-cured specimens vs their ages at the time of test are shown in Figures 2 through 9.

In these figures the average unconfined compressive strength and the 95 percent confidence limits are plotted against curing period. (For actual values see the Appendix (Tables 5 and 6)).

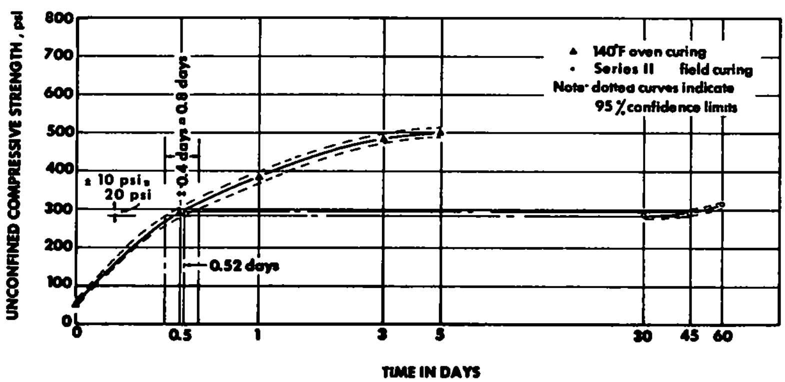

Figure 9. Comparison of Series II field curing and 140 F oven curing for Soil B.

TABLE 2

TIME OF ACCELERATED CURING REQUIRED TO ACHIEVE 45-DAY FIELD STRENGTH

Soil	Oven Curing Temp and Series	Accelerated Curing Days				Strength, psi			
		Min	Max	Avg	Range	Min	Max	Avg	Range
A	120-I	1.5	2.5	2.0	1.0	455	515	490	60
	120-II	2.1	3.2	2.6	1.1	520	555	540	35
	140-I	0.72	0.98	0.86	0.26	455	515	490	60
	140-II	0.92	1.15	1.00	0.24	520	555	540	35
B	120-I	1.4	2.8	2.2	1.4	290	305	295	15
	120-II	1.3	2.8	2.1	1.5	280	300	290	20
	140-I	0.44	0.60	0.50	0.16	290	305	295	15
	140-II	0.44	0.59	0.52	0.15	280	300	290	20

From these curves the time required for laboratory-cured specimens to reach a strength equivalent to that of a field-cured specimen cured 45 days can be determined. These determinations are summarized in Table 2.

From Table 2 it is interesting to note that the average laboratory-curing periods, corresponding to 45 days of field curing, are 2.0 to 2.6 days at 120 F and 0.5 to 1.0 days at 140 F (Col. 5), and that the range of strength values does not exceed 60 psi (Col. 10). Because the temperatures and their durations, namely the maturities of Series I and Series II, were different but close to each other (Appendix, Table 4), this amount of variation in values was not unexpected.

Figure 10 shows the effect of maturity on the unconfined compressive strength of both soils. In this figure the strength values obtained from Series I and II are plotted against the maturity of the specimens at the time of test. It should be pointed out that the maturities plotted are those of the air and not of the subbase or base. However, as can be seen from the Appendix, the average values of air, base and subbase temperatures obtained during the first two temperature correlation studies in the middle of the summer are very close.

Figure 10 indicates that although the strength values of the two soils did not follow the same pattern as would be the case with concrete, each gained strength in relation to its maturity.

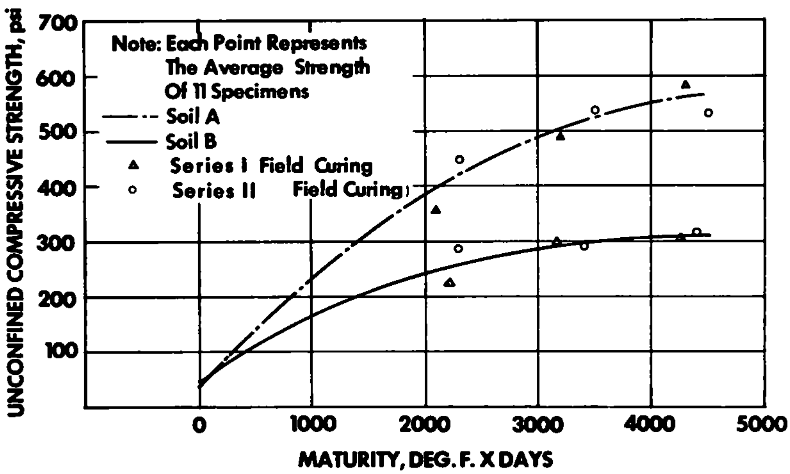

Figure 10. Effect of maturity on unconfined compressive strength.

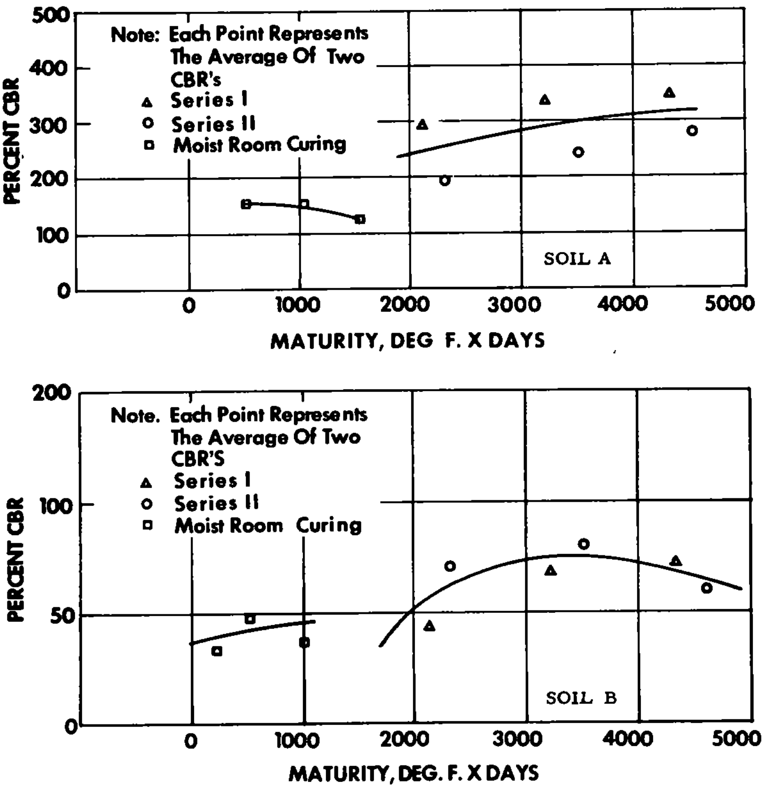

Figure 11. Effect of maturity on the CBR value.

The attempt to establish a field-moist-room curing correlation for the CBR specimens proved to be an unrealistic approach. However to arrive at a significant conclusion testing was continued through Series II. Figure 11 summarizes the results of tests on both soils. The actual strength values of the CBR specimens are given in the Appendix (Table 7).

CONCLUSIONS

The following conclusions derived from this research are restricted to the two soils studied and the use of 5 percent lime as the stabilizing additive.

1. The unconfined compressive strength of specimens field cured for approximately 45 days at summer temperatures could be predicted by an accelerated laboratory curing of either 18 hr at 140 F or two days at 120 F. However, 120 F curing is preferred for the following reasons: (a) less condensation between the specimen and the protective coating during curing; (b) a lower, therefore, a more realistic temperature; (c) convenience of curing time; and (d) increased accuracy obtained with small slopes of the strength-time curves.
2. The strengths of these stabilized soils will be a function of their maturities, when subjected to field curing.
3. The soils' CBR values will increase manyfold. However, these values are sometimes so high as to be unrealistic. Also, due to the size of the specimens and the amount of soil involved, not enough CBR test specimens can be made for statistical evaluations. Therefore the attempted field-moist-room curing correlation for the CBR specimens proved unsuccessful.

FURTHER WORK PLANNED

It is planned to continue the study during the summer of 1961 to generalize the findings reported here. More soils from lime stabilization projects previously installed in Virginia will be used.

Once an accelerated curing period is established, specifications for testing lime-stabilized soils based on strength data obtained from the soils studied will be devised.

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude to Mr. B.B. Chamblin, Jr. for his constructive criticism and continuous help, and to Messrs. G.A. Gatlin and L.R. Staunton for performing the necessary testings and operations for the study.

Special thanks go to Mr. T.E. Shelburne, Director of Research, for his guidance and supervision.

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5. Bergstrom, S.G., "Curing Temperature, Age and Strength of Concrete." Magazine of Concrete Research (Dec. 1953).
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Appendix

TABLE 3

FIELD CURING SCHEDULE

		Series I		Series II	
Soil	Age of Field Curing	Date 1960	Maturity[a] (deg Fx days)	Date 1960	Maturity[a] (deg Fx days)
A	Molding	May 17	0	July 18	0
	30 days	June 16	2,103	Aug 17	2,298
	45 days	July 1	3,194	Sept 2	3,510
	60 days	July 16	4,301	Sept 16	4,502
B	Molding	May 25	0	July 25	0
	30 days	June 25	2,192	Aug 24	2,278
	45 days	July 8	3,142	Sept 8	3,412
	60 days	July 23	4,267	Sept 23	4,430

[a]Maturity = Air temp (in deg F) x days.

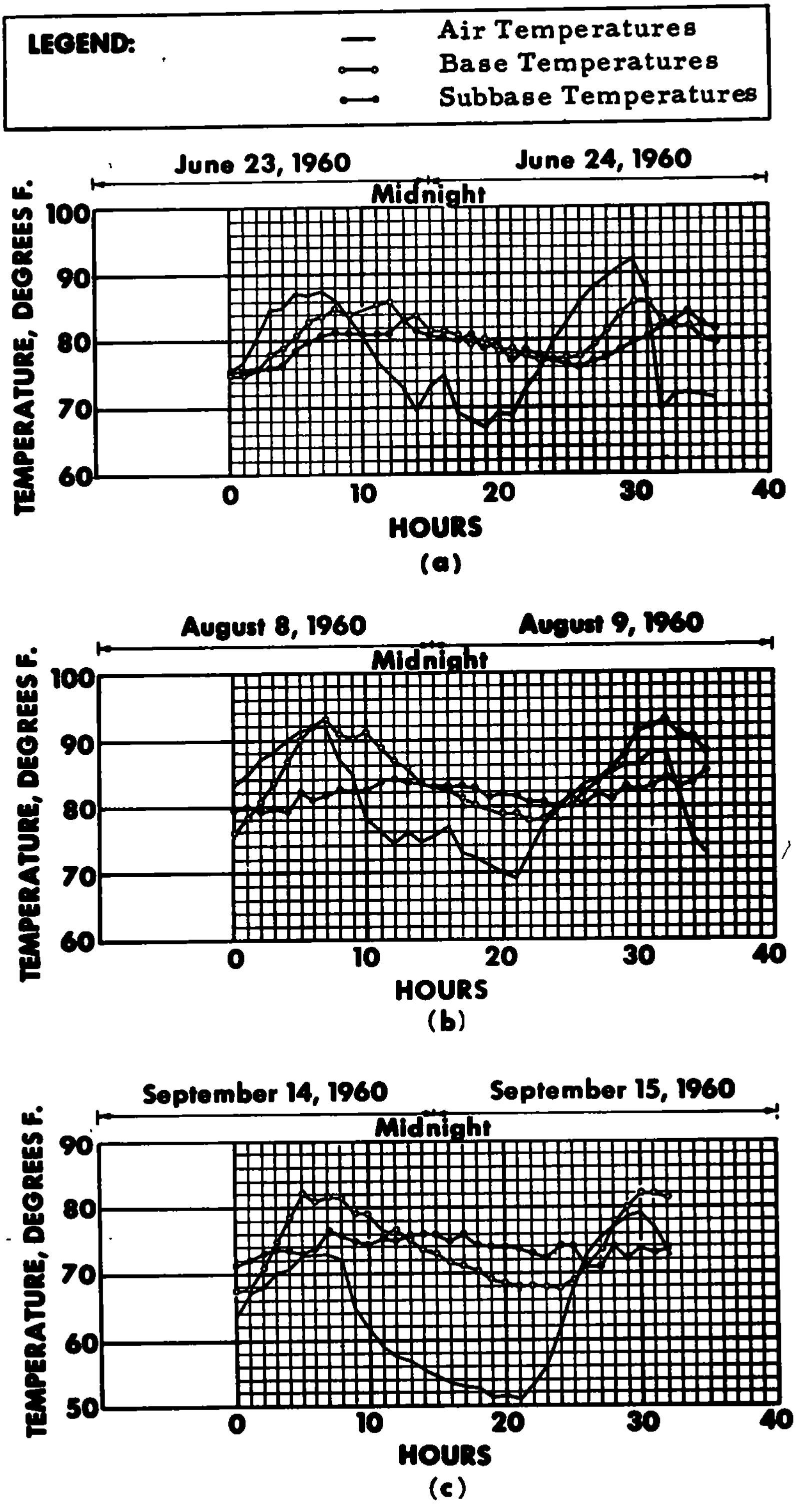

Figure 12. Charts from temperature correlation.

TABLE 4

SUMMARY OF SUBBASE, BASE AND AIR-TEMPERATURE CORRELATIONS

Trial No.	1			2			3		
Date	June 23, 1960			August 8, 1960			Sept 14, 1960		
Depth of Thermocouple, in.	11	5	Air	11	5	Air	11	5	Air
Min daily temp, deg F	76.0	77.0	67.5	80.0	78.0	69.3	71.0	67.8	51
Max daily temp, deg F	83.0	86.0	87.5	84.0	92.8	92.6	76.5	82.0	73
Mean temp, deg F[a]	79.5	81.5	77.5	82.0	85.4	81.0	73.8	74.9	62
Dev from mean air temp, deg F	+2.0	+4.0	-	+1.0	+4.4	-	+11.8	+12.9	-
Avg temp, deg F[b]	79.4	80.9	78.4	82.0	85.1	80.9	73.9	74.4	64.3
Dev from avg air temp, deg F	+1.0	+2.5	-	+1.1	+4.3	-	+9.6	10.1	-

[a]Mean temperature = average of maximum and minimum temperatures.
[b]Average temperature = average of hourly temperatures.

TABLE 5

EFFECT OF AGE AND TYPE OF CURING ON STRENGTH OF SOIL A

Age in Days	Type of Curing	Moisture Cont at Test, %	Unconfined Compressive Strength, psi		
			Mean	95% Confidence Limits, ±	V[a]
0	Field, Ser I	12.6	39	-	-
	Field, Ser II	12.6	39	-	-
30	Field, Ser I	12.9	354	16	6.1
	Field, Ser II	12.5	445	22	7.3
45	Field, Ser I	12.3	487	31	9.3
	Field, Ser II	12.9	538	15	4.2
60	Field, Ser I	12.1	580	27	6.9
	Field, Ser II	12.7	532	23	6.5
0.5	-	12.1	309	10	4.0
1	120 F	12.2	371	8	2.5
3	Oven	12.3	574	27	5.6
5	-	12.3	681	27	4.7
0.5	-	12.7	331	8	3.0
1	140 F	12.5	535	14	3.1
3	Oven	12.9	794	45	6.8
5	-	12.8	887	80	8.6

[a]V = coefficient of variation.

TABLE 6

EFFECT OF AGE AND TYPE OF CURING ON STRENGTH OF SOIL B

Age in Days	Type of Curing	Moisture Cont at Test, %	Unconfined Compressive Strength, psi: Mean	95% Confidence Limits, ±	V[a]
0	Field, Ser I	23.9	48	3	-
	Field, Ser II	23.9	48	3	-
30	Field, Ser I	26.4	222	17	9.8
	Field, Ser II	23.7	286	7	3.6
45	Field, Ser I	23.2	295	6	3.0
	Field, Ser II	22.9	289	8	4.0
60	Field, Ser I	23.2	307	12	5.8
	Field, Ser II	23.4	314	7	3.1
0.5	-	23.5	201	14	7.6
1	120 F	23.4	262	16	8.1
3	Oven	23.4	321	10	3.8
5	-	23.3	407	11	3.2
0.5	-	23.1	291	12	4.8
1	140 F	23.1	383	15	5.1
3	Oven	23.2	483	12	3.0
5	-	23.2	498	12	3.0

[a]V = coefficient of variation.

TABLE 7

RESULTS OF CBR TESTS

	Soil A with 5% Lime					Soil B with 5% Lime				
Type of Curing	Days Curing	Density at Molding (%)	Moisture (%) At Molding	Moisture (%) At Test	CBR (%)	Days Curing	Density at Molding (%)	Moisture (%) At Molding	Moisture (%) At Test	CBR (%)
Moist		-	-	-	-		98.7	24.3	27.0	34
room	3	-	-	-	-	3	98.5	24.5	29.0	34
		101.5	13.1	13.5	152		98.5	22.8	25.1	51
	7	101.0	13.2	14.3	150	7	99.4	22.7	27.1	45
		102.8	13.0	13.4	148		98.1	24.9	26.1	36
	14	97.6	12.9	13.7	146	14	98.2	24.7	23.7	38
		100.8	13.3	14.0	111		-	-	-	-
	21	101.1	13.3	13.5	120		-	-	-	-
Series I	30	100.6	12.8	13.5	300	30	95.2	28.1	26.9	29
		102.1	12.6	12.4	287		98.6	22.9	26.2	56
		100.2	12.9	13.1	347		99.9	23.4	26.3	68
	45	100.2	13.0	13.4	320	45	99.2	22.6	27.0	68
		99.8	13.0	12.8	410		99.5	22.8	26.7	68
	60	101.3	13.3	12.1	292	60	99.1	23.4	25.9	75
Series II		100.9	13.2	13.0	203		98.6	23.1	25.9	72
	30	101.0	13.5	13.1	193	30	100.0	23.3	25.7	70
		100.0	13.6	14.3	220		-	-	27.6	76
	45	100.6	13.4	13.6	265	45	-	-	24.7	83
		100.9	13.2	12.9	328		-	-	22.7	61
	60	101.1	12.8	13.8	238	60	-	-	25.3	56
No curing Plain soil	0	102.0	12.3	12.9	28	0	100.0	23.0	26.6	8