DURABILITY TESTS ON LIME-STABILIZED SOILS

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SYNOPSIS

FOR SOME YEARS, studies of soil stabilization have been conducted at Purdue University. Recent investigations have dealt with lime as the stabilizing agent. In the study reported, three soils, a Wisconsin drift soil, an Illinoian drift soil and a river terrace gravel, were tested with additions of 0, 2, 5, and 10 percent lime. After fabrication the specimens were permitted to "cure" in a moist room for periods of 1, 4, 8, 15, and 36 weeks. Companion specimens were made in all cases. At the end of the curing period one of these was broken in unconfined compression to determine the effect of lime upon strength. The other was subjected to freezing and thawing, a 48-hour cycle being employed, until it fell apart or until 12 cycles had elapsed.

In a departure from usual procedures, the specimens which underwent freezing and thawing were tested at the end of each cycle with the soniscope rather than by brushing. This test, a dynamic, nondestructive test, gives results similar to those obtained by the resonant-frequency tests widely used to measure the deterioration of concrete specimens undergoing freezing and thawing. The characteristic measured by the soniscope is the velocity of pulse propagation through the test specimen, which is a measure of rigidity, dynamic modulus of elasticity, etc. Results in these tests were most satisfactory.

Results of this investigation include: (1) two percent lime is insufficient to affect appreciably the performance of the soils tested; (2) five percent lime, or more, significantly increased both strength and durability of these soils; (3) increased length of curing before testing was, in general, beneficial; (4) of the soils tested, the greatest benefits of adding lime were derived by the river terrace gravel and the least by the Wisconsin drift soil; (5) the dynamic test employed seems to be quite adequate as a measure of progressive deterioration and merits further consideration.

● THE PROBLEMS associated with the stabilization of soils have been receiving increased attention for the past several years. Rapidly increasing highway construction costs have accentuated the need for a low-cost farm-to-market road. Primary pavements have suffered because of increased loads and traffic, thus creating a need for experiments in subbase improvement. Under some conditions, stabilized soils appear to be a possible solution to both of these problems.

Various materials have been proposed as stabilizing agents, including lime, cement, and several bituminous materials, as well as a number of chemicals. Most have been used with varying success, the degree of which appears to depend upon such quantities as percentage of admixture, method of construction, exposure, traffic, and a good many others.

Early in 1948 an intensive laboratory project was initiated at Purdue University to investigate the effects of lime upon the physical properties of a wide range of soils sampled throughout the eastern portion of the United States (*2*). The results of this investigation showed that lime changed the plasticity of most of the soils and increased the unconfined compressive strength of the soils tested. At that time it was considered advisable to investigate the durability of lime-soil mixtures.

A series of freezing-and-thawing tests were made on various combinations of lime, bituminous materials, and soil (*8*). These tests indicated that the lime and bituminous materials, when used together, increased the durability of the soil appreciably. Lime-soil mixtures alone, however, appeared to be susceptible to freezing and thawing.

For some years, dissatisfaction has been expressed by some engineers with respect to the methods of testing stabilized soil specimens for durability. Durability has generally been determined by freezing-and-thawing or wetting-and-drying tests in combination with a loss-of-weight test.

Objections to the brushing test often used in conjunction with the loss-of-weight test have centered, primarily, about the large personal element involved, the difficulty in obtaining comparable results when different operators perform the test, and the contention that such a test sets up artificial conditions which are not approximated in field exposures. It is argued that the removal at the end of each cycle, by brushing, of the deteriorated material is unduly severe in that the sound portion of the specimen is always fully exposed to the freezing-and-thawing action. Under field conditions this situation is not likely to occur. If deterioration occurs, the damaged material generally remains in place and may possibly provide some insulation for the remaining sound material. In an effort to overcome these objections, some other method was sought for testing the specimens fabricated for use in this study.

During the past few years numerous advances have been made in the dynamic nondestructive testing of materials. One of the instruments recently developed which shows considerable promise is the soniscope. This instrument, developed and used primarily for testing concrete, measures the velocity with which minute, pulsed vibrations travel through the test specimen. The operation of the device and something of the history of its development has been reported by Leslie and Cheesman (*3*) and Whitehurst (*5*).

Reports have been made on the use of the soniscope for testing concrete structures in Canada (*1*) and in the United States (*6*). It has also been suggested (*4*, *6*) that similar tests might be made on soil specimens, but very few data were available when this study was undertaken to support this contention.

At the time the present study was initiated, a soniscope had just been completed in the laboratories of the Joint Highway Research Project, Purdue University (*7*). It was felt that perhaps this device could be used for determining the relative durability of the lime-soil mixtures. As a matter of fact, several tests on soils had been performed at Purdue to determine the suitability of this method of testing soils and to compare the results of soniscope tests with those of the more conventional brushing test. Results indicated that measured changes in velocity were at least as indicative of changes in the condition of the specimens as was loss in weight due to brushing. Further, the testing did not damage the specimens, and with the exception of those which failed entirely, they could be tested in compression at the end of the weathering cycles. It was agreed that the personal element was reduced to a minimum.

As a result of this pilot study, it was decided that velocity tests would be used to determine relative durability in the current study. The method proved highly satisfactory, and it was found that with a little training laboratory technicians could obtain consistent results. The data developed in the current study were reported to the National Lime Association in May 1951 (*9*).

PURPOSE AND SCOPE

The purpose of this study was three-fold: first, to determine the durability characteristics of lime-soil mixtures as affected by such variables as soil texture, soil density, and quantity of lime; second, to determine the effect of moist curing on the unconfined compressive strength and durability of lime-soil mixtures; and third, to explore further the suitability of dynamic testing techniques for evaluating the performance of such mixtures.

Three different soils, listed in Table 1, were used in this investigation. Soil 2849 was a silty clay of Wisconsin glacial age, a calcareous drift soil typical of that overlying a large portion of the central states. Soil 2853 was an Illinoian drift soil. The third soil, 3068, was a pit-run gravel with all material larger than ¼ in. discarded. Since the fine fraction of the gravel is the portion having the greatest effect upon its durability, it is felt that the gravel was not altered appreciably, for purposes of this study, by the sieving process.

The effects of the several variables upon strength were evaluated by unconfined compression tests. Relative durability was determined by freezing-and-thawing and velocity tests. Curing times ranged from 1 to 36 weeks and the quantity of lime from 0 to 10 percent by weight. Some tests were made on specimens of varying density.

PROCEDURES

Processing and Molding—Each soil, upon being brought into the laboratory, was air dried and sieved. All material retained on the No. 4 mesh was discarded. The soil was then thoroughly mixed and, by the process of quartering and by use of the Riffle sampler, split down into approximately 5-lb. samples. It is felt that this procedure made possible the fabrication of uniform specimens throughout the testing program, even though all the specimens from each soil were not made at the same time. Standard classification tests, including the Atterburg limits, mechanical analysis, and Proctor compaction, were made on representative samples of each soil.

Specimens were molded in a split cylinder the size of the standard Proctor cylinder ($\frac{1}{30}$ cu. ft.). They were molded at optimum moisture content as determined by the compaction tests. The quantities of lime used were 2, 5, and 10 percent by dry weight. weighed and measured, tested with the soniscope, and returned to the freezer. Twelve of the above described cycles constituted the durability test for each specimen.

Unconfined Compression Testing—The companion specimens of those subjected to freezing and thawing were tested for unconfined compressive strength at the end of the curing period. Since these specimens were molded in the standard Proctor mold (4 in. in diameter by 4½ in. high) the L/D ratio was very close to one. Only relative strengths were desired, however, and it is felt that the specimens were satisfactory for this purpose.

Specimens were loaded at a rate of 0.05 in. deformation per min. The ultimate compres-

TABLE 1
SOILS TESTED

Soil no	Designation and derivation	Depth represented	L.L.	P.I.	Proctor weight	Grain size			
						#60	#200	0.05 mm	0.005 mm
		in.	*%*	*%*	*lb. per cu. ft.*	*percent finer*			
2849	Crosby—Wisconsin Drift	12–36	36	10	107.0	93	85	77	24
2853	Vigo—Illinoian Drift	24–48	32	14	114.2	78	56	43	17
3068	Warsaw—River Terrace Gravel	36+	—	NP	128.5	15	9	—	—

Whenever practicable the lime and water were mixed into the soil one day prior to compaction to insure even distribution of moisture throughout the sample. Duplicate specimens were made in all cases.

Curing and Freeze-and-Thaw Testing—After compaction each specimen was weighed and placed in a moist room to cure for periods of 1, 4, 8, 15, and 36 weeks. After the prescribed curing period, one of each pair of specimens was weighed, measured, and placed in a freezer for 24 hr. Air temperature in the freezer was maintained at 24 F. This temperature was chosen since soil temperatures in the Midwest seldom go below this level.

Upon the completion of the 24-hr. freezing period, the specimens were removed from the freezer, reweighed, measured for volume change, and permitted to thaw. During the 24-hr. thawing period the specimens rested on porous stone disks with free water available for absorption through the disks. At the end of this period the specimens were again

sive strength, in lb. per sq. in., was taken as the peak breaking load divided by the corrected cross-sectional area.

The majority of the specimens which survived 12 cycles of freezing and thawing were also broken in unconfined compression at the end of the twelfth cycle. A few, those showing unusual durability, were subjected to further freezing and thawing, the total number of cycles varying with the durability of the individual specimens.

Soniscope Testing—The soniscope consists of two piezo-electric transducers, one for transmitting and the other for receiving the test vibrations, and a portable electronic unit which generates the transmitted pulses, amplifies the received signal, and measures the transit time of the vibration in passing between the transducers. If the distance between transducers is measured, the velocity of pulse propagation may be computed. The accuracy of the time measurement is in the order of ±0.5 microsecond.

In testing a specimen, the transmitting transducer is pressed firmly against one end of the specimen and the receiving transducer against the other. The operator then observes the transmitted and received signals on the face of a cathode-ray tube which is part of the soniscope and, by the use of electronic techniques, measures the transit time of the vibrations passing through the specimen. Figure 1 shows the soniscope as used in testing soil specimens.

Soil 2849, the Wisconsin drift soil. Columns 7 and 8 (counting from the left in the tables) show that but for two exceptions (2 percent lime cured 4 weeks and 5 percent lime cured 8 weeks) the lime-soil specimens showed increases in strength as the length of curing was increased from 1 to 36 weeks. After this time, the specimen containing 10 percent lime showed an increase in strength of 183 percent. All of this increase, however, cannot be attributed to the action of the lime alone. Companion specimens containing no lime also showed an increase in strength with curing time amounting to as much as 88 percent after 15 weeks, at which time the increase of the specimen containing 10 percent lime was 172 percent.

Columns 9 and 10 show the increase in strength of the lime-soil specimens over that of companion raw-soil specimens cured for the same length of time. It may be seen that curing affected the specimens containing lime more than those with no lime and that the effect increased as the amount of lime was increased. For example, after curing these specimens for 8 weeks the 2 percent lime specimen was 37 percent stronger, the 5 percent specimen 77 percent stronger, and the 10 percent

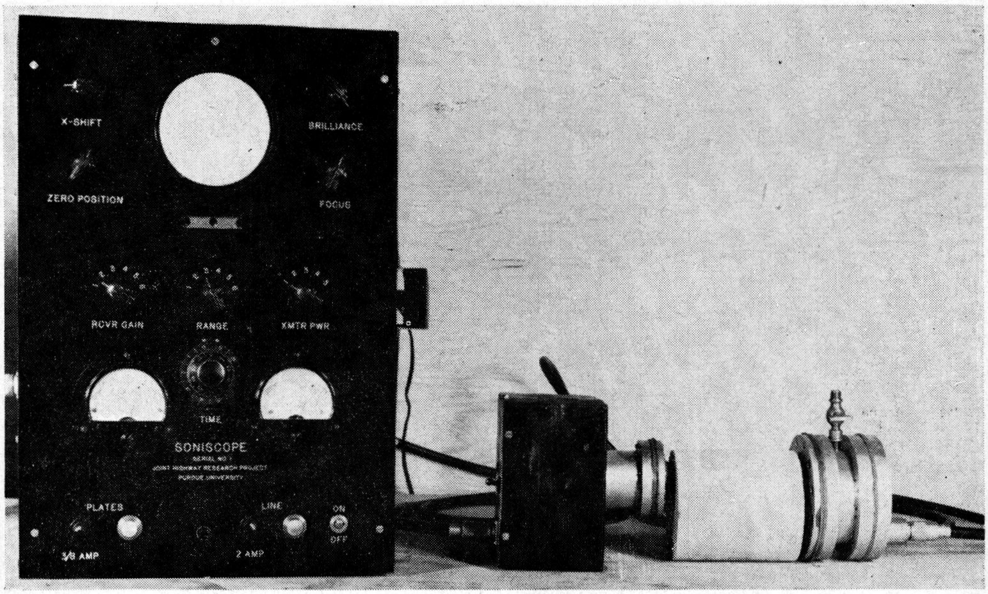

Figure 1. Soniscope testing of lime-soil specimen.

RESULTS

In most cases control specimens containing no lime were prepared, cured, and tested under the same conditions as the lime-soil specimens to facilitate the isolation of the variables of lime content and length of curing.

Unconfined Compression Tests—The results of unconfined compression tests are shown in Tables 2, 3 and 4. It may be noted that the unit weights of the lime-soil mixtures were, for the most part, lower than those of the companion raw-soil specimens. In general, the unit weights decreased as the lime content increased.

Table 2 gives results of tests performed on specimen 250 percent stronger than the raw-soil specimen. After 15 weeks of curing, these values were −11, 141 and 208 percent, respectively. No raw-soil specimens were cured for 36 weeks.

TABLE 2
EFFECT OF CURING TIME ON COMPRESSIVE STRENGTH—WISCONSIN DRIFT SOIL (2849)

Spec. no.	Admixture	Curing time	Density	Moisture @ test	Comp. str.	Strength increase from 1 week[a]		Strength increase over raw soil[b]	
						psi.	%	*psi.*	%
	%	*wks.*	*lb. per cu. ft.*	%	*psi.*				
69	0	1	111.9	15 1	65	—	—	—	—
49	0	4	112.0	14.6	65	0	0	—	—
17	0	8	114.1	17.5	60	−5	−7	—	—
9	0	15	107.0	15.6	102	57	88	—	—
70	2	1	107.8	16.3	81	—	—	16	25
50	2	4	109 5	14.9	78	−3	−4	13	20
18	2	8	111.0	17.4	82	1	1	22	37
10	2	15	109.1	16.2	90	9	12	−12	−11
92	2	36	107.3	21.1	212	131	162	—	—
71	5	1	106.0	15.7	119	—	—	54	83
51	5	4	107.0	13.5	136	17	142	71	110
19	5	8	107.5	17.3	106	−13	−11	46	77
11	5	15	107.5	15.5	247	128	107	145	141
93	5	36	105.2	21.3	299	180	151	—	—
72	10	1	102.2	15.1	116	—	—	51	78
52	10	4	103.0	13.9	138	22	19	73	110
20	10	8	103.5	17.1	210	94	81	150	250
12	10	15	104.6	15.7	316	200	172	213	208
94	10	36	104.5	11.7	328	212	183	—	—

[a] Increase in compressive strength over duplicate specimen with same amount of lime added but cured only one week
[b] Increase in compressive strength over specimen containing no lime and cured same period of time.

TABLE 3
EFFECT OF CURING TIME ON COMPRESSIVE STRENGTH—ILLINOIAN DRIFT SOIL (2853)

Spec no.	Admixture	Curing time	Density	Moisture @ test	Comp. str.	Strength increases from 1 week[a]		Strength increase over raw soil[b]	
						psi.	%	*psi.*	%
	%	*wks.*	*lb per cu. ft.*	%	*psi.*				
57	0	1	123 0	13.5	49	—	—	—	—
63	0	4	113 0	—	49	0	0	—	—
31	0	8	122 0	13 3	51	2	4	—	—
25	0	15	117.7	11.1	No Test	—	—	—	—
58	5	1	115.6	14.5	116	—	—	67	138
64	5	4	111 2	15.6	179	63	57	130	278
32	5	8	116 8	13.0	120	4	3	69	136
26	5	15	112.6	11 0	245	129	111	—	—
97	5	36	115.0	18.4	417	301	259	—	—
59	10	1	113.5	15.1	130	—	—	81	165
65	10	4	107.0	14.8	190	60	46	141	310
33	10	8	114.0	14.3	219	89	68	168	340
27	10	15	108.5	10.6	284	154	118	—	—
98	10	36	110.7	19.9	415	285	219	—	—

[a] Increase in compressive strength over duplicate specimen with same amount of lime added but cured only one week.
[b] Increase in compressive strength over specimen containing no lime and cured same period of time.

These data show that curing the lime-soil for a period of 36 weeks increased its strength as much as 180 percent over the strength at 1 week, and that even though appreciable increase in strength resulted from curing the raw-soil, the specimens containing 5 or 10 percent lime were 100 to 200 percent stronger than the raw-soil specimens when cured for 15 weeks compared to 25 to 80 percent after curing only 1 week. These data bring out the desirability of constructing lime-stabilized bases early in the spring, so that additional strength may be realized from the "setting up" properties of the lime before freezing-and-thawing damage occurs.

It is also indicated that stabilization of soil with lime in amounts less than 5 percent is not feasible. This confirms the results of previous studies.

cent for the gravel. The effect of curing is clearly shown in Column 10 of Table 4. After 15 weeks the river terrace gravel specimen containing 10 percent lime was 640 percent stronger than the companion specimen containing no lime.

TABLE 4
EFFECT OF CURING TIME ON COMPRESSIVE STRENGTH—RIVER TERRACE GRAVEL (3068)

Spec. no	Admixture	Curing time	Density	Moisture @ test	Comp. str.	Strength increase from 1 week[a]		Strength increase over raw soil[b]	
						psi.	%	psi.	%
	%	wks	lb. per cu. ft	%	psi.				
83	0	1	134.5	8.0	9	—	—	—	—
77	0	4	129.2	7.5	14	5	50	—	—
43	0	8	134.3	6.3	19	10	110	—	—
37	0	15	128 2	6 6	25	16	176	—	—
84	5	1	131.0	5.0	45	—	—	36	398
78	5	4	124.9	8.0	64	19	42	50	346
44	5	8	130.5	7.4	119	74	164	100	530
38	5	15	128.5	7.2	175	130	290	150	570
101	5	36	130.5	4 8	282	237	526	—	—
85	10	1	124.1	5.7	58	—	—	49	540
79	10	4	119.4	7.8	91	33	57	77	530
45	10	8	130.8	9.3	120	62	107	101	535
39	10	15	124.0	9.2	184	169	290	159	640
102	10		125.0	4.8	306	248	428	—	—

[a] Increase in compressive strength over duplicate specimens with same amount of lime added, but cured only one week.
[b] Increase in compressive strength over specimen containing no lime and cured same period of time.

TABLE 5
EFFECT OF COMPACTIVE EFFORT ON COMPRESSIVE STRENGTH—ILLINOIAN DRIFT (2853)

Admixture	Compaction blows	Density	Moisture @ test	Unconfined compression	Increase strength from 15 blows[a]		Increase strength over raw soil[b]	
					psi.	%	psi.	%
%	no.	lb. per cu. ft.	%	psi.				
0	15	114.7	12.0	54	—	—	—	—
0	45	119.9	10.6	86	32	59	—	—
0	90	121.1	11.5	102	48	89	—	—
5	15	107.7	11.9	65	—	—	9	16
5	45	113.9	11.4	142	77	118	56	65
5	90	118.6	11.5	284	119	183	182	178

[a] Increase in compressive strength over duplicate specimen with same amount of lime but compacted with only 15 blows of the hammer.
[b] Increase in compressive strength over specimen containing no lime and compacted with same compactive effort.

Tables 3 and 4 show similar data for Soil 2853, Illinoian drift, and Soil 3068, river terrace gravel, respectively. The same trend is indicated; in order to realize the benefit of the added lime, the mixture should be cured much in the same manner as other cementing materials. For these soils, however, the greatest increase in strength percentage-wise, over the 1-week strength occurred when 5 percent lime was used. After 36 weeks, these increases were 259 percent for the Illinoian drift and 526 per-

Table 5 shows the results of tests made on specimens compacted to different densities. Only one soil, the Illinoian drift soil was tested. It may be observed that increasing the compactive effort from 15 to 90 blows resulted in increased strength for both the raw soil and that containing 5 percent lime, but that percentage - wise the lime specimens showed greater increases than the raw-soil. It is of interest to note that the specimen with 5 percent lime compacted by 45 blows was stronger than the raw-soil specimen compacted by 90 blows, or at twice the compactive effort.

Durability Tests—Pulse velocities were measured through all specimens at the end of the curing period and after each cycle of thawing. Each specimen was tested until it failed or until 12 cycles of freezing and thawing were completed. The only exception occurred when the soniscope was overhauled for four days. During this period some specimens underwent two cycles of freezing and thawing without being tested. This is indicated on the attached data curves by dashed lines. These curves have been selected to show the influence of certain variables upon the durability of lime-soil specimens as evidenced by changes in velocity.

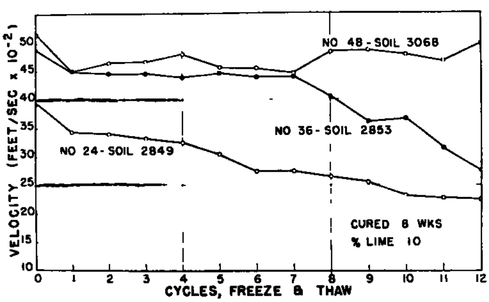

Figure 2. Influence of soil type on durability.

Figure 2 shows the influence of soil type upon durability. Each of the specimens shown contained 10 percent lime and was cured for 8 weeks. A marked difference in performance may be noted. The specimen made from Soil 2849, the Wisconsin drift soil, shows continuous progressive distress, the velocity at the end of 12 cycles being only about 56 percent of the original velocity. The specimen made from Soil 2853, Illinoian drift, showed little distress until after seven cycles were completed. Deterioration then progressed until after 12 cycles, the velocity being only about 58 percent of its value after curing. The specimen made from Soil 3068, river terrace gravel, showed no significant loss in velocity after 12 cycles of freezing and thawing. This specimen was actually put through 30 cycles without suffering severe distress.

Figure 3 shows the influence upon durability of the percentage of lime mixed with the soil. Specimen 34, containing no lime, failed while being handled at the end of two cycles of freezing and thawing after having lost approximately 36 percent of its original velocity. Specimen 35, made with 5 percent lime, showed a more or less gradual loss in velocity throughout the 12 cycles, its final velocity approximating 54 percent of the original value. The specimen with 10 percent lime, No. 36, showed

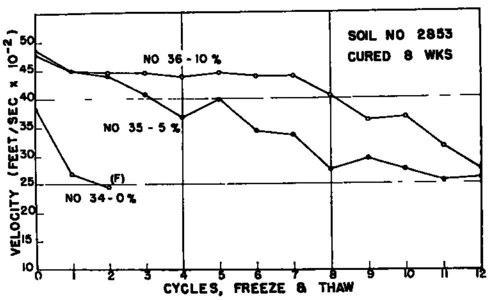

Figure 3. Influence of percent admixture on durability.

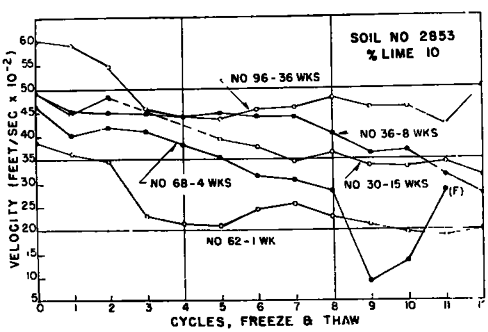

Figure 4. Influence of curing time on durability.

no appreciable loss in velocity until after seven cycles. From this time on, the velocity fell steadily to a value at the end of 12 cycles equal to 58 percent of the original velocity. It may be observed that Specimens 35 and 36 had essentially the same velocity at the end of the curing period and at the end of 12 cycles of freezing and thawing. It may be important, however, that the time at which the loss in velocity begins to occur was considerably delayed by increasing the lime content of the specimen.

Figure 4 shows the effect of length of curing upon durability. Specimens 62, 68, 30, 36, and 96 were cured 1, 4, 8, 15 and 36 weeks, respectively. After 12 cycles of freezing and thawing their respective losses in velocity, based upon their velocities at the end of the curing periods, were 48, 39 (after 11 cycles), 37, 44, and 27 percent. In addition to the comparative loss in velocity during freezing and thawing, attention is called to the actual values of the measured velocities. The specimens cured for 4, 8, and 15 weeks showed a very similar percentage decrease. Generally speaking, however, at the end of any given cycle the specimens all three soils. It may be observed that when the curing period is short, 1 to 8 weeks, there is little difference between the behavior of specimens containing 5 and 10 percent lime. In some cases, the specimen with 5 percent lime shows the better performance. After the longer curing periods, however, the specimens with 10 percent lime are consistently more resistant to freezing and thawing than those with 5 percent lime.

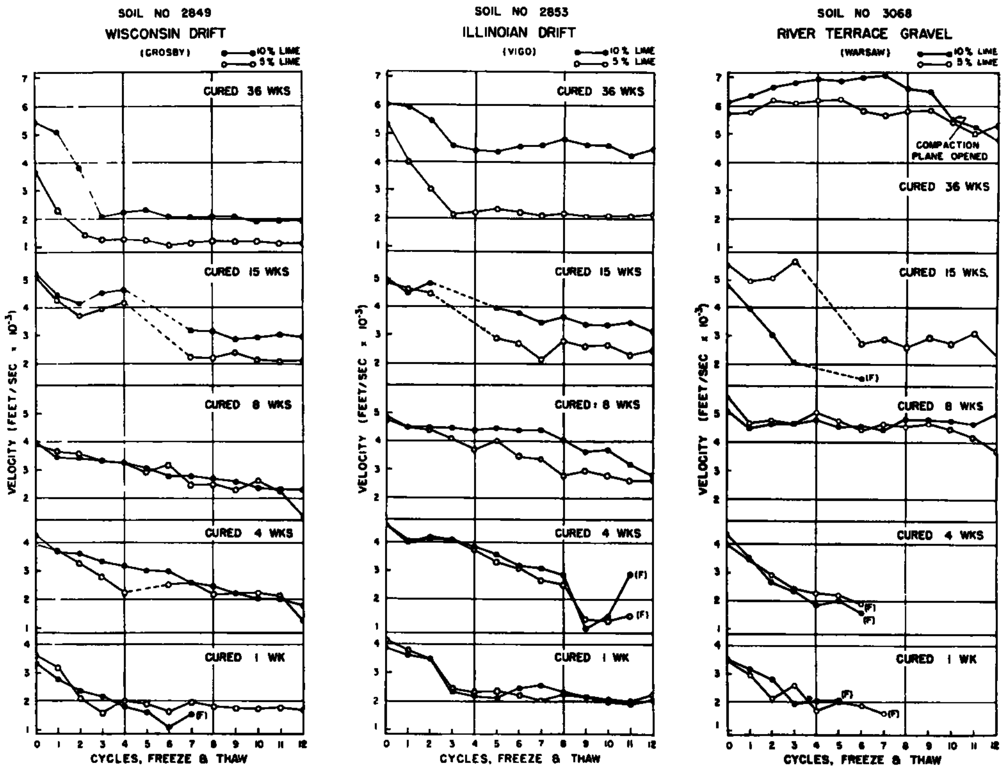

Figure 5. Influence of curing time and percent admixture on durability.

with the longer curing periods had the higher velocities. This indicates, in the light of past experiences in testing other materials, that the physical properties of these specimens (modulus of elasticity, strength, etc.) were higher than those of the specimens cured for the lesser time.

In trying to analyze the relative durabilities of these specimens, it is difficult to completely isolate any one variable. Figure 5 shows the combined effects of length of curing and percent admixture upon specimens made from

Another interesting comparison which can be made on Figure 5 is that of the relative performance of the three soils. It may be seen that with few exceptions the Illinoian drift soil performed in a manner superior to the Wisconsin drift soil. The river terrace gravel shows at once the best and the least consistent performance. The specimens cured for 1, 4, and 15 weeks showed poor durability. Those cured for 8 and 36 weeks showed high resistance to freezing and thawing, some surviving as many as 40 cycles. The specimens which failed generally parted at one of the compaction planes, indicating that less uniform specimens were made from this material than from the two drift soils.

freezing and thawing. It may be observed that although additional curing almost invariably increases the original velocities, the final velocities are rather similar for any soil until

TABLE 6
SUMMARY OF DURABILITY TESTS
SOIL NO. 2849

Admixture	Curing time	Density before F.T.	Moisture before F.T.	Moisture after 12 cycles F.T.	Pulse velocity before F.T.	Pulse velocity after 12 cycles F.T.
%	*wks.*	*lb. per cu. ft.*	%	%	*ft. per sec.* × *10*⁻²	*ft. per sec.* × *10*⁻²
0	1	112.5	16.5	—	29.3	(1)[a]
0	4	111.3	15.2	—	26.8	(2)
0	8	112.2	16.3	—	31.5	(3)
0	15	107.3	18.6	—	36.2	(2)
2	1	109.0	15.9	—	29.8	(8)
2	4	109.0	14.4	—	30 2	(4)
2	8	109.9	15.5	—	29.3	(10)
2	15	104.3	18.0	—	33.5	(7)
2	36	107.3	21.1		17 6	(2)
5	1	106.0	15.5	23.5	36.1	16.4
5	4	106.2	15.9	25.2	39.5	17.4
5	8	106.5	16.5	24.3	39.0	13.1
5	15	102.0	19.0	26.0	51.4	21.3
5	36	105.2	21.3	—	36.6	11.5
10	1	103.6	13.2	—	33.5	(7)
10	4	103.2	15.9	27 6	42.6	12.0
10	8	103.7	15.9	25.3	39.4	22.5
10	15	100 5	18.0	24.0	52.8	18.2
10	36	104.5	(20.0)	29.0	54.7	19.6

[a] Parentheses indicate failure cycle if specimen did not complete 12 cycles.

TABLE 7
SUMMARY OF DURABILITY TESTS
SOIL NO. 2853

Admixture	Curing time	Density before F.T.	Moisture before F.T.	Moisture after 12 cycles F.T.	Pulse velocity before F.T.	Pulse velocity after 12 cycles F.T.
%	*wks.*	*lb. per cu. ft.*	%	%	*ft. per sec.* × *10*⁻²	*ft. per sec.* × *10*⁻²
0	1	120.0	14.6	—	21.2	(2)[a]
0	4	112.8	15.6	—	33.8	(3)
0	8	122.0	13.5	—	38.3	(3)
0	15	117.5	12.3	—	44.6	(4)
5	1	116.2	14.3	15.8	41.2	21.8
5	4	110.8	13.0	13.6	46.3	13.6
5	8	117.0	13.9	12.7	48.1	10.8
5	15	112.5	11.7	19.2	48.7	18.2
5	36	115.0	18.4	23.8	53.6	21.3
10	1	112.2	15.9	16.9	38.7	20.1
10	4	106.4	14.8	23.3	46.3	28.2
10	8	114.4	14.0	19.0	48.7	27.5
10	15	107.8	12.9	19.3	49.4	31.2
10	36	110.7	19.9	(28.5)	60.5	44.3

[a] Parentheses indicate failure cycle if specimen did not complete 12 cycles.

Tables 6, 7, and 8 give a summary of the durability tests. The effect of lime is at once apparent in that all specimens containing no lime failed very early in freezing and thawing. Further, Table 6 shows that 2 percent lime is insufficient to improve the soil appreciably, none of the specimens surviving 12 cycles of

the longer curing times are reached. It may also be noted from Table 6 that the specimen with 5 percent lime cured for 36 weeks appeared to be inferior to the similar specimen cured for only 15 weeks. This phenomenon was observed primarily with Soil 2849. These particular tests were repeated with similar results. It was also observed with the 5 percent lime specimen with Soil 2853. This difference in durability is also shown on Figure 5.

This apparent decrease in durability of the fine-grained materials with long moist curing may be explained by the changes in moisture content during the curing period. This is shown in Column 4 of Tables 6, 7, and 8. It may be seen that with Soil 2849, the moisture was increased. By contrast, the moisture content of both the 5- and 10-percent-lime specimens made from Soil 3068 remained essentially constant or decreased as the curing period lengthened. It is believed that this rather large increase in moisture content of the specimens made from fine-grained soils after 36 weeks curing accounts for their reduced durability.

TABLE 8
SUMMARY OF DURABILITY TESTS
SOIL NO. 3068

Admixture	Curing time	Density before F.T.	Moisture before F.T.	Moisture after 12 cycles F.T.	Pulse velocity before F.T.	Pulse velocity after 12 Cycles F.T.
%	wks.	lb. per cu. ft.	%	%	ft. per sec. × 10^{-2}	ft. per sec. × 10^{-2}
0	1	134.3	8.8	—	23.0	(1)[a]
0	4	129.4	—	—	19.7	(2)
0	8	133.5	6.2	—	31.9	(2)
0	15	129.0	7.0	—	29.3	(3)
5	1	131.0	8.3	—	34.1	(7)
5	4	126.3	8.5	—	39.7	(7)
5	8	130.2	7.2	11.1	56.0	36.9
5	15	125.2	7.3	10.9	55.3	23.1
5	36	130.5	4.8	(8.2)	57.3	53.6
10	1	124.1	9.3	—	34.4	(5)
10	4	119.9	9.2	—	43.1	(7)
10	8	127.0	8.3	(10.0)	51.4	48.8
10	15	125.5	10.1	—	48.1	(7)
10	36	110.7	(10.0)	12.9	61.5	48.2

[a] Parentheses indicate failure cycle if specimen did not complete 12 cycles.

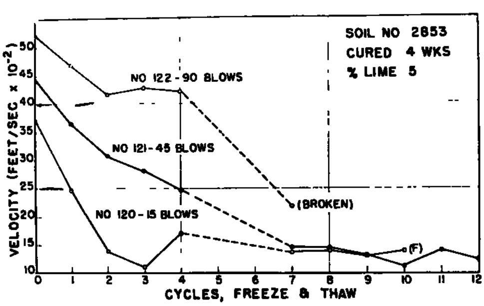

Figure 6. Influence of compactive effort on durability.

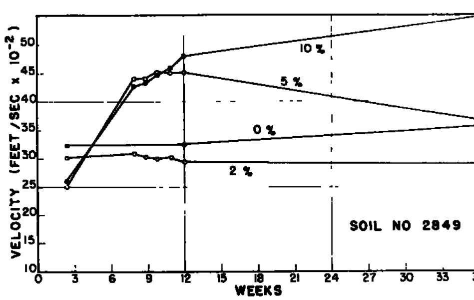

Figure 7. Variations in velocity during curing period.

content of the cured 5-percent-lime specimen increased from 15.5 percent after 1 week curing to 21.3 percent after 36 weeks. The moisture content of the 10-percent-lime specimen increased from 13.2 percent after 1 week to approximately 20 percent at 36 weeks. Similarly, it may be observed that with Soil 2853 the moisture content of the 5-percent-lime specimen increased from 14.3 to 18.4 percent and that of the 10-percent specimen from 15.9 to 19.9 percent as the curing period

To study the effect of density upon durability, specimens were made using three different compactive efforts—15, 45, and 90 blows per layer. Figure 6 shows the results of tests on a group of these specimens. Unfortunately, Specimen 22, 90 blows per layer, was broken at the end of seven cycles. Nonetheless, the improvement in durability which may be attributed to increased density is obvious. As in the case of varying lime content (Figure 3) it seems probable that if freezing and thawing were continued the velocities of all specimens would approach a common, rather low value. As in the case of increasing lime content, however, increased compaction tends to delay the rate of this decrease in velocity.

specimen is driven from the bottom and vibrates longitudinally. The vibration is picked-up at the top. The specimens used for these investigations have a poor L/D for such tests, but the method seems rather promising.

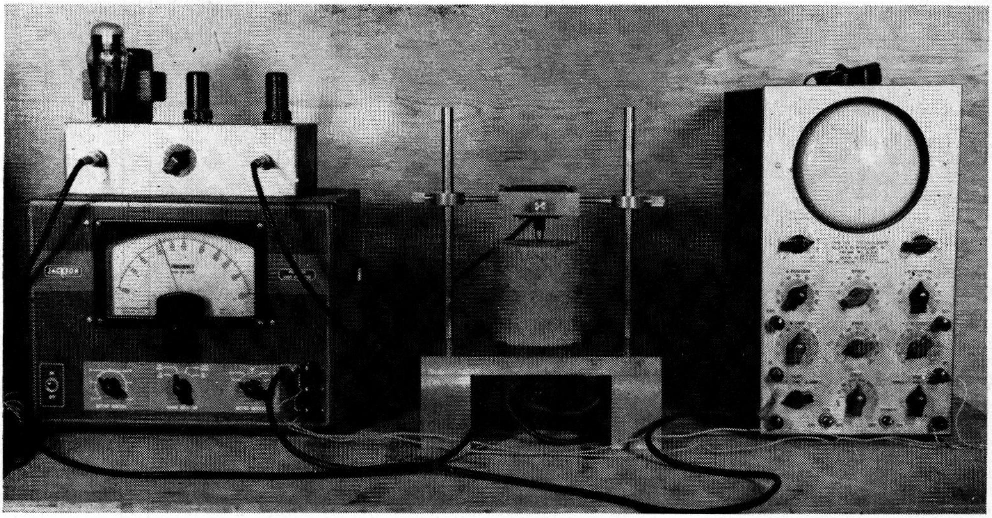

Figure 8. Resonant-frequency testing of lime-soil specimen.

Some of the specimens which were cured for 36 weeks were tested with the soniscope several times during this period. Figure 7 shows the results of these tests on specimens made from Soil 2849. Specimens with 0 and 2 percent lime remained essentially constant, the lower velocity of the lime specimen being attributed to its lower density. The velocities of the 5- and 10-percent-lime specimens rose rapidly for 8 weeks. The 10 percent specimen continued to rise throughout the 36-week period at a slower rate. The 5 percent specimen, however, rose very slowly until 12 weeks had elapsed, after which the velocity decreased. This appears to verify the durability tests on this soil and may indicate that there is some optimum curing time after which the stabilized soil should be put into use.

In addition to the velocity tests used throughout this study, some effort has been directed toward developing techniques for measuring the resonant frequencies of these specimens. If such techniques can be perfected the apparatus involved will be more readily available and less costly than the soniscope. Figure 8 shows the present apparatus. The

CONCLUSIONS

The data developed in this investigation, and notes regarding the testing techniques, have been analyzed in the light of the stated purpose of the study. The following conclusions seem warranted:

1. The texture of the soil has an appreciable effect upon the resistance of the lime-soil mixture to freezing and thawing. The soil-aggregate mixtures appear to have considerable promise. It is indicated, however, that greater care must be exercised in achieving thorough distribution of lime and moisture and proper compaction with these materials than with the fine-grained soils.

For a given lime content, increased compaction, or greater density, results in increased resistance to freezing and thawing.

Lime in quantities of 5 percent, or more, by weight, greatly increased the durability of the lime-soil mixtures, the greater the lime content the greater the durability; 2 percent lime did not appreciably alter the durability characteristics of the soil.

2. In general, moist curing proved very beneficial to the lime-soil mixtures. There is

evidence, however, that when the fine-grained soil mixtures were exposed to 100 percent humidity for lengthy periods, they tended to take up moisture in detrimental quantities.

3. The dynamic test employed in this study, the measurement of pulse velocities through the test specimens, was quite satisfactory. Results were reproducible and there appeared to be little operator error. It is believed that changes in velocity are highly indicative of changes in the quality of the specimens tested and that the method merits further consideration.

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CURING OF SOIL-CEMENT BASES

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SYNOPSIS

This paper describes field experiments conducted on a secondary road in Appomattox County, Virginia, to study the effect of various methods of curing soil-cement bases. The project extended over two general areas, the soils of which are derived from a granite gneiss (Appling soil) and from Wissahickon schist (Cecil soil). Experimental sections were placed in each of these general soil areas—two groups of six panels in each soil area.

The purpose of the project was to: (1) determine the effect of preparing surfaces for receiving curing materials both with and without a prior application of water; (2) determine the effect of different soils on moisture retention in soil-cement mixes; (3) determine the efficiency of bituminous and other materials for retaining moisture in a soil-cement base during the curing period; and (4) revise the specification to be used for moisture-retention material, if the results of the investigation so indicated.

Types of curing materials studied included moist earth, waterproof paper, calcium chloride, RC-2 asphalt, RTCB-6 tar, and AE-2 asphalt emulsion. One panel, used as a control panel, was left open with no cover. Moisture samples were obtained the day the panels were covered and each day thereafter for seven days. Six samples were taken in each panel, three from 0 to $\frac{3}{4}$ in. and three from $\frac{3}{4}$ to $1\frac{1}{2}$ in. Weather conditions during both construction and subsequent curing were observed and recorded.