LIME–FLY-ASH–SOIL COMPOSITIONS IN HIGHWAYS

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SYNOPSIS

HYDRATED LIME and fly-ash have been found to be quite effective for the stabilization of various types of soil. An extensive study has shown that the improvement is developed in two ways. First, an immediate beneficial change is brought about in the engineering properties of the soil as evidenced by a marked reduction in plasticity index, an improvement in shrinkage and drainage characteristics, etc. Second, due to the cementing effect caused in part by the pozzolanic reaction between the lime and fly-ash, the compositions upon aging develop relatively high compressive strength and good resistance to freezing and thawing and wetting and drying. Optimum proportions for the compositions are indicated by the use of compressive strength tests and by fundamental transverse frequency determinations. An investigation is also being made of a pulse velocity technique for evaluating the durability and field performance of the compositions.

The soils studied thus far were secured principally from New Jersey and Maryland. They were chosen upon the recommendation of members of the highway departments of these states, because they are representative of soil types prevalent in their respective areas.

In addition to the laboratory program, several experimental field projects have been carried out in the above-mentioned states and valuable information has been received concerning the field performance of lime–fly-ash compositions. Results are given of a field project in New Jersey. Specimens taken from this project after one year show that the compressive strength of the lime-fly-ash mixture has reached 2,400 psi. Microphotographs have been made on this material and the formation of a cementitious matrix is clearly in evidence.

● A PREVIOUS PAPER (*1*) has described an investigation of several lime–fly-ash–aggregate compositions which may be used in the construction of the base course of highways. In this paper a continuation and extension of the previous study is presented. The investigation is directed to a study of finely grained soils and several coarsely grained aggregate-type materials. In addition, a field test is described of a lime–fly-ash–boiler-slag mixture used in the base-course construction of a detour road in New Jersey.

It has been found that the effect of the additions of lime and fly-ash to soil is twofold. First, there is a marked change in the engineering properties of the soil immediately after the mixtures are prepared. These changes depend in measure upon the nature of the untreated soil but are generally demonstrated by a drop in plasticity index, improvement in drainage characteristics and a decrease in volumetric shrinkage. The second change that is developed is a relatively slow setting of the mixtures into strong monolithic compositions resembling the type of structure developed when soil is stabilized with portland cement. Somewhat similar improvements have been reported (*2*) where lime is used alone in the stabilization of soil, although in this case the development of high compressive strength has, in general, not been obtained. Many soils are lacking in pozzolanic activity, and therefore the addition of fly-ash, which in itself is strongly pozzolanic, results in a substantial increase in compressive strength, as well as a marked improvement in resistance to freezing and thawing and wetting and drying. It is also evident that the fly-ash mixtures require lower lime contents, decreasing the cost of the final composition.

One purpose of the investigation was to evaluate the durability of the lime–fly-ash compositions. This has been done in the laboratory by means of the conventional wetting-and-drying and freezing-and-thawing tests, together with studies made using fundamental

transverse-frequency determinations and by the use of pulse-group-velocity measurements. Some of the compositions were very striking in that considerable resistance to weathering conditions was indicated, particularly as compared with the untreated soil.

The previous investigation described the use of density criteria for establishing optimum proportions of the ingredients of the mixtures. This method is not applicable to the fine-grained soils since the voids in the soil are considerably smaller than the coarse-grained aggregates, therefore resulting usually in a small drop in the density of the mixture when the lime and fly-ash are added. The most convenient criteria for establishing optimum proportions for the fine-grained soils is the use of compressive strength tests, although the measurements of transverse fundamental frequencies and pulse-group velocities indicate that these may be an equally effective basis for developing this information. The use of the soniscope or similar apparatus for measuring group velocities is felt to be of considerable importance to investigations of this type, since the method may be used both on laboratory and on field specimens without disturbing the material, and thereby a correlation between the two sets of results may be established.

Laboratory test data is also presented for several coarsely grained materials which have been grouped together under the heading of "Soils with Plasticity Index Less than 6.0." Freezing-and-thawing, wetting-and-drying, and compressive-strength tests show good performance for these latter materials.

Standard testing procedures were, in general, used for the tests, although slight modifications had been adopted in a few instances. For example, in the preparation of specimens for durability tests, modified compaction procedure was employed. Also, a slightly elevated temperature was used for curing some of the samples in order that compressive strength measurements could be obtained in 7 as well as in 28 days. The latter was felt to be of value in setting up techniques that could be used to prevent delays in running field projects. Furthermore, the pozzolanic reaction between the lime and fly ash is relatively slow and the use of elevated temperature was considered as a possible means of accelerating the reaction.

TABLE 1
SOIL CLASSIFICATIONS AND PROPERTIES

Code No.	HRB Classification	Location	Liquid Limit	Plasticity Index	Proctor Density	Optimum Moisture
			percent	*percent*	*lb. per cu. ft.*	*percent*
50	A-7	North of Hagerstown, Maryland	75.0	38.8	94.4[a]	23.8[a]
51	A-2-6	Southern Maryland	32.3	11 4	103.5[a]	18.0[a]
103	A-1-b	Hamilton Township, New Jersey	—	NP		
104	A-1-b	Laurelton, New Jersey	22.5	5.1	134.1	7.0
105	A-2-4	Chambers Corners, New Jersey	—	NP	134.0[a]	11.0[a]
120	A-2-4	Between Ringoes and Flemington, N. J.	20.4	NP	139.4	6.7

[a] Standard Proctor values; all others determined using 3 layers, 25 blows per layer of 10-lb. hammer dropped through 18 in.

TABLE 2
PROPERTIES OF HYDRATED LIME AND FLY-ASH

	Hydrated Lime	Fly Ash	
		Sample No. 1	Sample No. 2
Chemical analysis:			
SiO_2	1.0	44.29	38.16
Fe_2O_3	0.4	17.17	29.25
FeO	0.0		
Al_2O_3	0.2	26.97	26.75
CaO	47.8	2.71	6.35
MgO	33.8	0.88	1.36
Loss on ignition	16.3	4.98	8.46
CO_2	0.8		
H_2O	0.5		
Sieve analysis (sieve no.):			
60 (total percent retained)	1.00	2.23	0.84
100 (total percent retained)	2.8	8.33	2.79
200 (total percent retained)	5.6	19.14	10.56
Specific gravity	2.60	2.3	2.43
Dry rodded density—lb. per cu. ft.	45	—	—

MATERIALS

The soils used in the investigation were selected with the coöperation of state highway officials in Maryland and New Jersey. These particular soils were selected because they were representative of soil types which were quite prevalent in their respective areas. The classification and properties of these soils are given in Table 1.

The fly-ash used in the test was selected from sources of supply in the states where the

soil was tested, although the majority of the tests employed sample No. 1. Table 2 gives the chemical and physical analysis of several of these materials.

The hydrated lime was a standard dolomitic hydrated lime, the analysis of which is also given in Table 2.

TEST PROCEDURE

In view of the fact that the soils differed widely in type, the tests employed in the evaluation of the materials were divided into two parts. The first portion of the investigation was directed to those soils with a P. I. greater than 6. For this series all of the test methods given were used with the exception of the tests for wetting and drying. For the second part of the study, which was concerned with soils having a P. I. of less than 6, only those test procedures were used which gave the most significant information. These included tests for unconfined compressive strength and resistance to wetting and drying and freezing and thawing.

In order to gain information over the complete range of samples, the proportions of lime, fly-ash, and soil were varied as shown in Table No. 3.

The following group of test methods were used in the investigation:

Plasticity Index. The compositions were evaluated for liquid limit, plastic limit, and plasticity index in accordance with AASHO Designation T-89–49, T-90–49, and T-91–49.

Optimum Moisture. Standard Proctor procedure for determining of optimum moisture was used on a sufficient number of samples to develop the proper moisture content for proportioning mixtures for use in the performance tests given below. For some materials a greater compactive effort was used to determine optimum moisture. In these instances the Proctor specimens were compacted in three layers with 25 blows per layer of the 10-lb. hammer dropped through 18 in.

Water Retentivity. Each of the test mixtures was prepared by the addition of water to a consistency suitable for use in the standard shrinkage limit determination. A small pat of the material was placed on a standard blotter (such as used in the lime industry for determining water retentivity in lime pastes) and a count was made of the time required for the water to pass through to the opposite side of the blotter. This time is reported as water retentivity.

Volumetric Shrinkage and Shrinkage Limit. A standard shrinkage limit determination was run on the sample prepared for the water retentivity test using AASHO Method T-92–42. Results are reported as shrinkage limit and volumetric shrinkage.

Preparation and Curing of Samples for Performance Test. The remaining tests described below were used to evaluate the performance of the compositions. Each mixture was prepared at optimum moisture content into samples of two sizes, one group of which measured 1 by 1 by 4 in. in size and the other measuring 2 by 2 by 2 in. After the samples were molded, they were removed from the molds and placed in a glass container with a tight fitting lid to prevent evaporation of water. The samples in the glass container were then placed in an oven at a temperature of 120 to 140 F. and kept there during the curing period. The age of the specimens varied depending on the requirements of the test method used.

TABLE 3
PROPORTIONS OF MIXTURES

Series No.	Fly-Ash	Lime[a]	
		Soils with PI Greater than 6	Soils with PI Less than 6
	percent	*percent*	*percent*
A(1)	0	0	0
A(2)	0	3	2½
A(3)	0	6	5
A(4)	0	9	7½
B(1)	10	0	0
B(2)	10	3	2½
B(3)	10	6	5
B(4)	10	9	7½
C(1)	20	0	0
C(2)	20	3	2½
C(3)	20	6	5
C(4)	20	9	7½
D(1)	30	not used	0
D(2)	30		2½
D(3)	30		5
D(4)	30		7½

[a] Percentages are by weight using a reference of dry soil plus dry fly-ash. Lime percentages therefore are additive.

Plastometer Penetration. A 2- by 2- by 2-in. cube of each mixture was tested using a Pusey & Jones Plastometer with the kilogram weight removed and using a ¼-in. ball point. The test was run at 24-hr. intervals. The data were plotted in graphical form to determine the effect of curing on resistance to the penetration of the needle.

Sonic Beam Test. One of the 1- by 1- by 4-in. specimens was measured for fundamental transverse-resonant frequency using equipment and techniques as described in the ASTM Sonic Method C215–47–T. Tests were run at 24-hr. intervals on the samples aged under the conditions specified above under preparation and curing of samples. The data were plotted in graphical form to determine the effect of curing on the improvement of the specimen for elasticity measurements.

Unconfined Compressive Strength. The 2- by 2- by 2-in. cubes were tested for compressive strength after being cured for seven days, using the method outlined above under preparation and curing of samples.

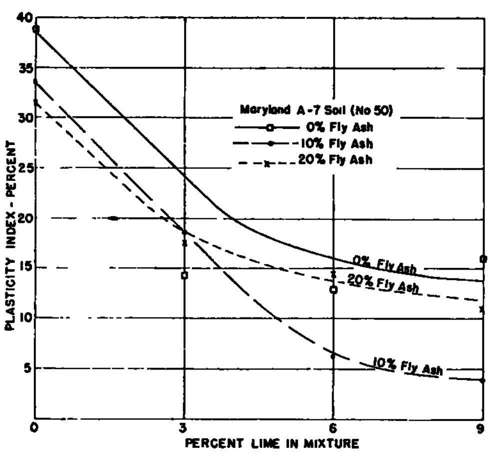

Figure 1. Plasticity index.

Freezing-and-Thawing Tests. Upon completion of the tests outlined above, several of the compositions showing best performance were prepared in the Proctor mold and a freezing-and-thawing test run in accordance with AASHO Designation T-136–45.

Wetting-and-Drying Tests. For those mixtures which were treated for wetting-and-drying resistance, the test was run in accordance with AASHO Designation T-135-45.

Group-Velocity Measurements. Some of the samples prepared in the investigation were measured for group velocity. The equipment and the techniques used are discussed below under the heading on the pulse-group-velocity measurements.

TEST RESULTS

Soils with P.I. Greater Than 6.0

The results of the tests run on the Hagerstown, Maryland, A-7 soil and the southern Maryland A-2(6) soil are as follows:

Plasticity Index. Figures 1 and 2 show the immediate beneficial drop in P.I. brought about in the soils and tested by the addition of varying amounts of lime and fly-ash. The P.I. of the A-7 soil was lowered from 38.8 for the natural soil to 4.2, and that of the A-2(6) from 11.4 to zero.

Water Retentivity. Figures 3 and 4 point out that the ability of the materials to retain

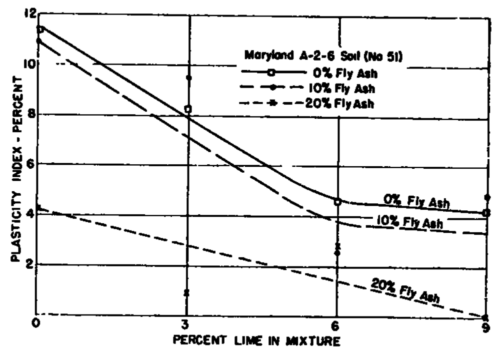

Figure 2. Plasticity index.

water was reduced when lime and fly-ash were added. This effect was particularly marked in the case of the A-7 soil.

Volumetric Shrinkage and Shrinkage Limit. It can be seen that considerable control of the volume change is obtained when additions of lime and fly-ash are made to the A-7 soil. An examination of Figure 5 shows that the volumetric shrinkage was reduced from 82.5 percent to 15 percent on a dry basis. Corresponding to this there was a substantial increase in the shrinkage limit (Fig. 6). The shrinkage properties of the A-2(6) soil were not significant and thus are not reported here.

Plastometer Penetration. Figures 7 and 8 show a hardening effect of the lime and fly-ash in that the penetration of the plastometer needle was decreased considerably.

Sonic Beam Test. Figures 9 and 10 show a definite pattern of results which indicate the improvement of the materials during the curing periods. In both soils there was a tendency

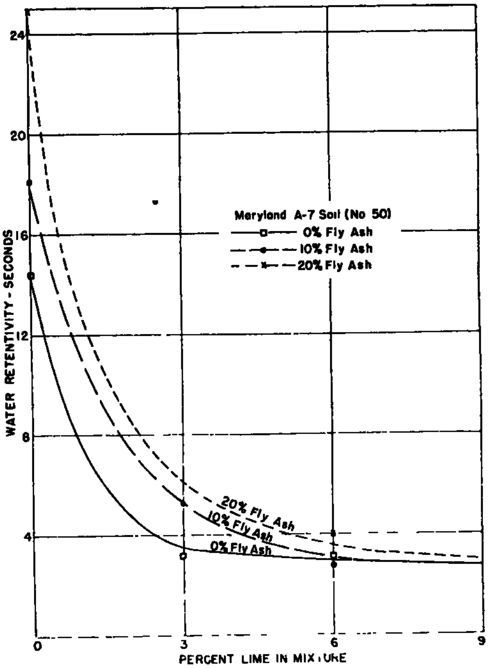

Figure 3. Water retentivity.

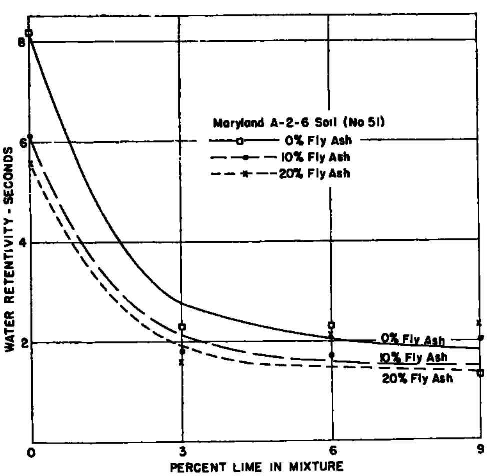

Figure 4. Water retentivity.

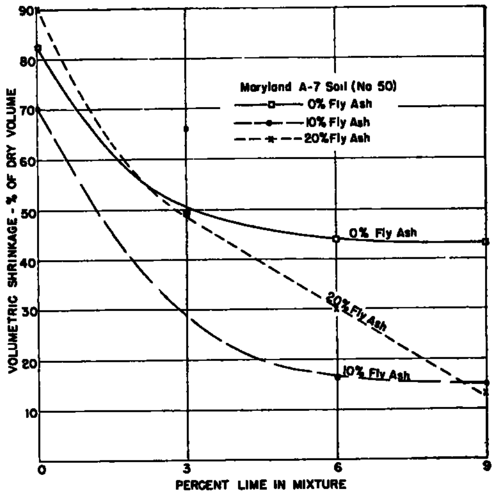

Figure 5. Volumetric shrinkage.

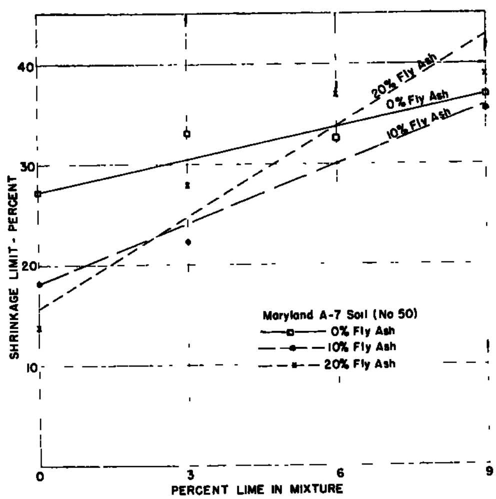

Figure 6. Shrinkage limit.

for the curves to level off as the curing was continued. The values which are shown as ordinates in these curves are the quantities (frequency)^2 times weight and are proportional to the dynamic moduli of the specimens. Only the data secured from the better mixes have been shown in these figures.

Unconfined Compressive Strength. The results of this test made on 2-in cubes are shown in Figures 11 and 12. The maximum compressive strength attained by the specimens in seven days was 2,000 psi. for the A-7 and 300 psi. for the A-2(6).

Freezing and Thawing. Remarkable improvement can be seen in Figure 13 in the durability of the A-7 soil when subjected to alternate cycles of freezing and thawing. While the

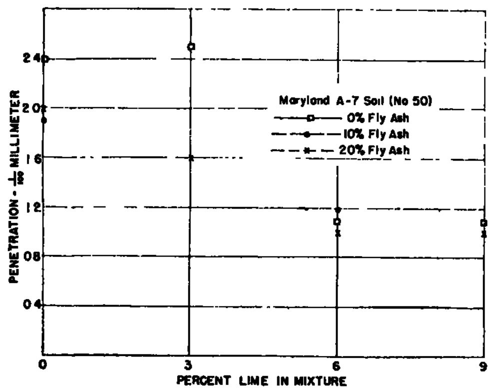

Figure 7. Penetration test.

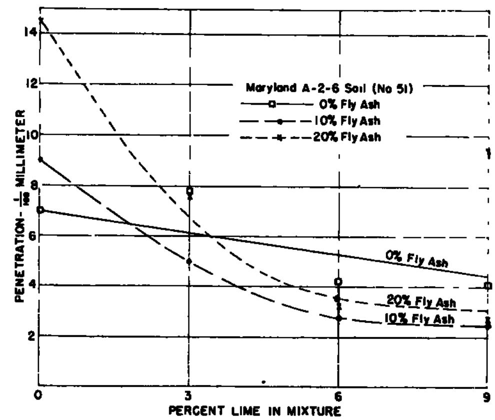

Figure 8. Penetration test.

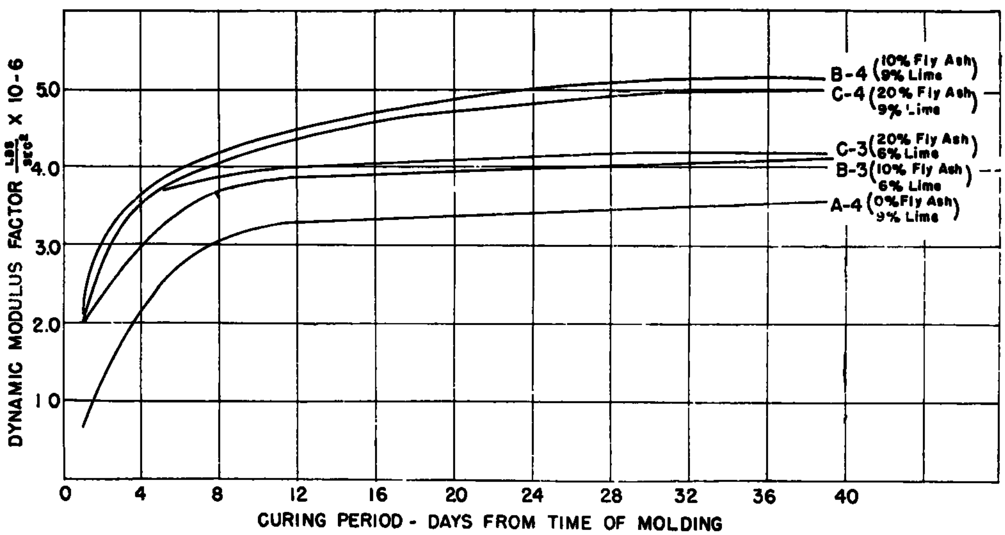

Figure 9. Sonic beam tests on Maryland A-7 soil (No. 50). Fundamental transverse resonant frequency of 1- by 1- by 4-in. beams. Size, shape, and Goen's correction factors not applied.

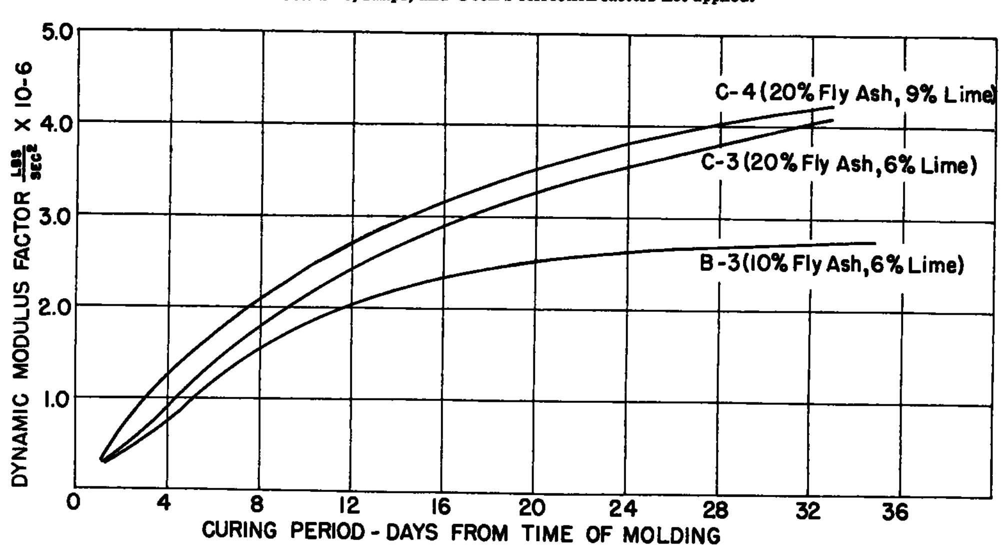

Figure 10. Sonic beam tests on Maryland A-2-6 soil (No. 51). Fundamental transverse resonant frequency of 1- by 1- by 4-in. beams. Size, shape, and Goen's correction factors not applied.

natural soil failed during the first cycle, three of the four mixes tested with additions of lime and fly-ash completed the 12 cycles.

Group-Velocity Measurements. The results of the tests using the pulse-group-velocity method are given in Table 5. A discussion of this data is included in a separate section presented below.

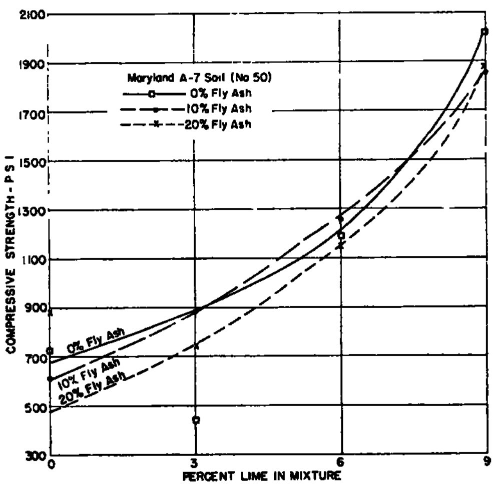

Figure 11. Compressive strength.

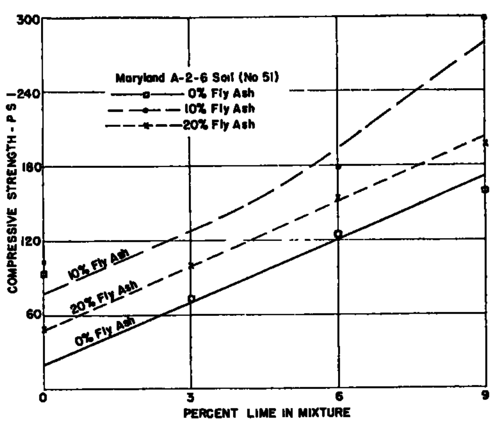

Figure 12. Compressive strength.

Soils with P.I. Less Than 6.0

The investigation of the soils of this group, which are shown in Table 1 under code numbers 103, 104, 105, and 120, consisted mainly of durability tests on the lime–fly-ash–soil mixtures.

Unconfined Compressive Strength. A wide range of compressive strengths was found for the various proportions of lime, fly-ash, and soil, as is shown in Table 4. Values as high as 2,200 psi. were reached. In general, maximum values were reached for mixtures containing 5 percent lime and 10 percent fly-ash.

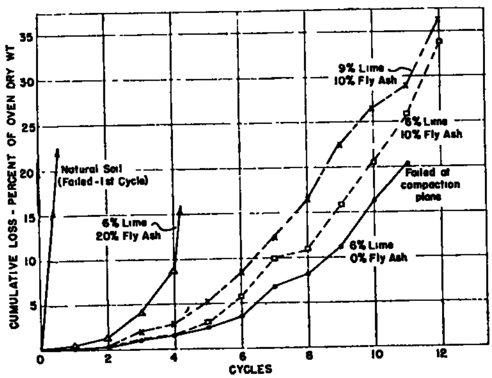

Figure 13. Weight loss during freezing-thawing test. Maryland A-7 soil (No. 50).

TABLE 4

COMPRESSIVE STRENGTHS FOR LIME-FLY-ASH-SOIL COMPOSITIONS (SOILS WITH P.I. LESS THAN 6)

Age of Specimens, 7 Days

Serial No.	Code No.			
	103	104	105	120
	psi.	*psi.*	*psi.*	*psi.*
A-1	20	330	175	690
A-2		290		
A-3		630	275	
A-4		980		
B-1	55	490	250	315
B-2	1,060	380	245	1,200
B-3	2,000	2,220	770	1,700
B-4	2,200	2,810	140	1,950
C-1	70	230	80	285
C-2	1,600	375		1,200
C-3	1,880	3,015	410	1,600
C-4	1,815	3,065		1,400
D-1				
D-2		255		
D-3		450	172	
D-4		700		

Wetting-Drying. Specimens subjected to this test showed a very slight deterioration in the beginning, but further cycles actually seemed to improve the composition. A few specimens were broken in compression at the end of the test and showed extremely high compressive strengths. Test results are shown in Figures 14 to 18, inclusive.

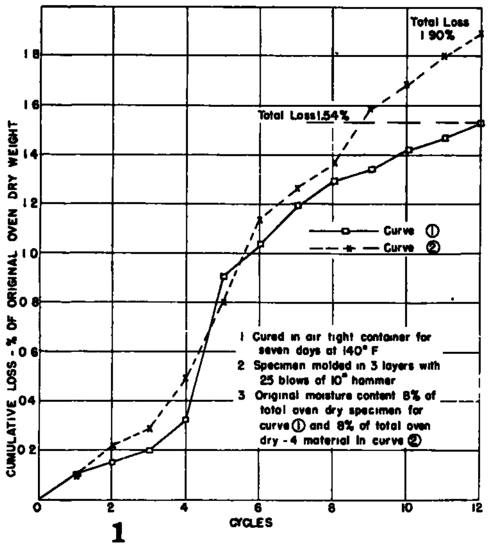

Figure 14. Weight loss during wet-dry test. Laurelton circle gravel (with 5 percent lime, 10 percent fly-ash) AASHO T135-45. Soil No. 104.

could be obtained with road-construction equipment. Test results are shown in Figures 19 to 23 inclusive.

DETERMINATION OF OPTIMUM PROPORTIONS OF OF LIME, FLY-ASH, AND SOIL

Soils with P.I. Greater Than 6.0

In connection with the specific lime requirement for the A-7 and A-2(6) soils, the results show that within the range of percentages of lime employed in the tests that the increase in compressive strength is proportional to the lime content. For both the A-7 and A-2(6) soils a minimum lime requirement of 6 percent is indicated for obtaining the higher values of compressive strength and sonic beam test values, as well as for obtaining the desirable reduction in plasticity and improvement in the other physical properties studied. The measurements made with the group-velocity method on the A-2(6) soil also agree with this finding. Additional tests for

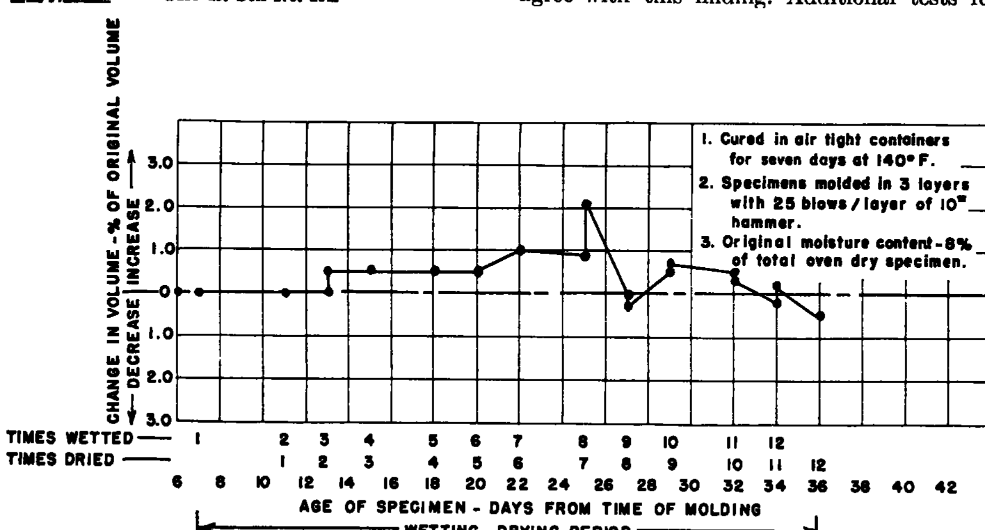

Figure 15. Volume change during wet-dry test. Laurel ton circle gravel (with 5 percent lime, 10 percent fly-ash) AASHO T135-45. Soil No. 104.

Freezing-Thawing. This test proved to be the most severe of the durability tests but the stabilized coarse-grained soils tested showed excellent results. The degree of compaction proved to affect the results of this test. The one difficulty which developed was the separation of the specimen at the compaction planes early in the test. The 10-lb. Proctor hammer was therefore used in the preparation of samples. Densities obtained by this means were felt to be comparable with those which

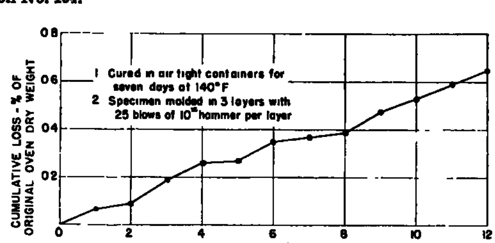

Figure 16. Weight loss during wet-dry test. Ringoes shale (with 5 percent lime, 10 percent fly-ash) AASHO T135-45. Soil No. 120.

higher lime content would be expected to show lower test values. However, this information would not be significant from a practical point of view, since it is obviously desirable to use the smallest lime addition that is feasible to assure minimum cost.

fly-ash range is not indicated as being optimum. It is believed that the fly-ash range might be more definitely established for this soil if higher percentages (higher than 20 percent of fly-ash) are investigated.

The results for the A-2(6) soil of the un-

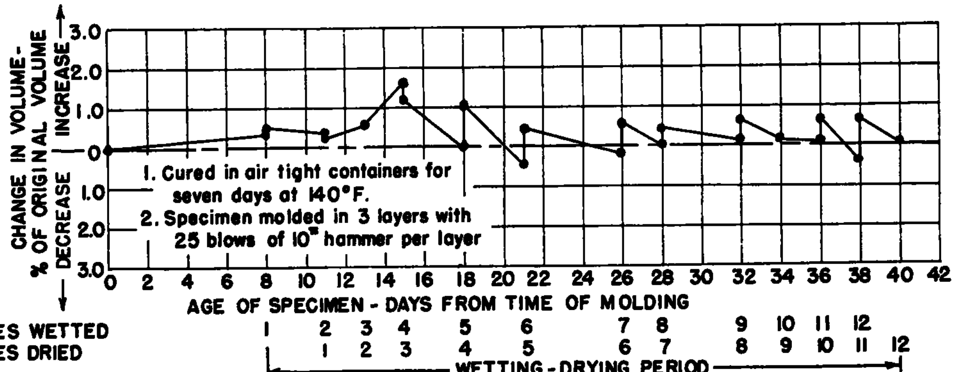

Figure 17. Volume change during wet-dry test. Ringoes shale (with 5 percent lime, 10 percent fly-ash) AASHO T135-45 Soil No. 120.

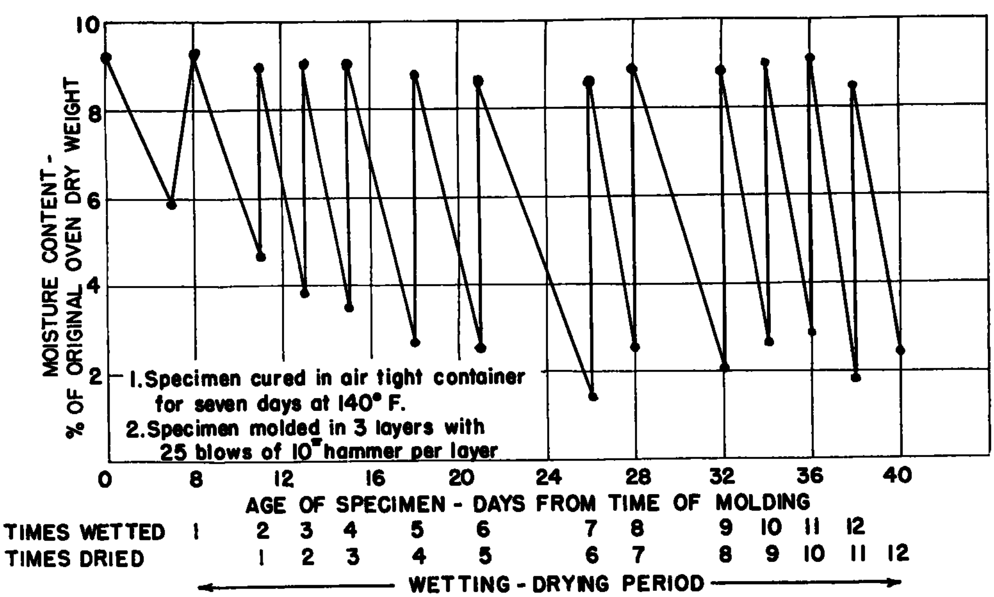

Figure 18. Moisture change during wet-dry test. Ringoes shale (with 5 percent lime, 10 percent fly-ash) AASHO T135-45 Soil No. 120.

The results for the A-7 soil of unconfined-compression tests indicate that the specimens containing 10 percent fly-ash are consistently higher than those containing 0 and 20 percent fly-ash. The sonic beam and group velocity results for the same soil show that the 9-percent-lime, 10-percent-ash mix is the optimum. For the 6 percent-lime mix, the 10 percent-

confined-compression tests, in general, conform to the optimum proportions of fly-ash given for the A-7 soil. The compressive strength for those mixes with 10 percent fly-ash are higher than those with 0 and 20 percent fly-ash for all percentages of lime tested. The sonic-beam and group-velocity test results indicate that the optimum fly-ash content is closer to 20

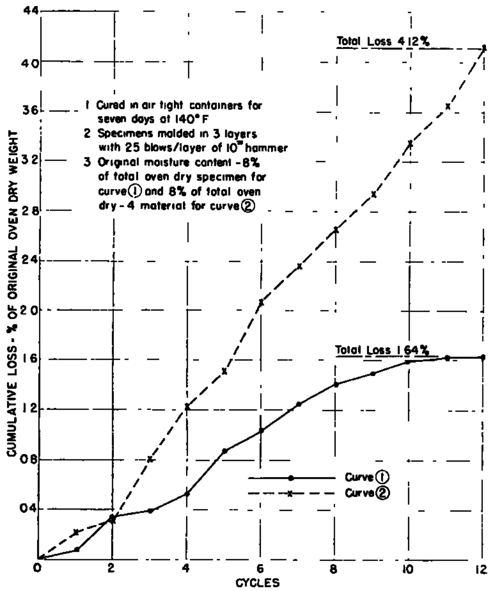

Figure 19. Weight loss during freeze-thaw test. Laurelton circle gravel (with 5 percent lime, 10 percent fly-ash) AASHO T136-45. Soil No. 104.

Soils with P.I. less than 6.0

It is believed that the amount of lime and fly-ash needed to satisfactorily stabilize any given soil in this category can be determined from the results of unconfined-compression tests run on 2-in cubes. These cubes should be molded from mixtures of soil with varying amounts of lime and fly-ash so that a rather wide range of compositions can be tested. The investigation has shown that the optimum amount of fly-ash ranges between 10 and 20 percent and the optimum lime content between 2 and 7 percent, using the unconfined-compressive strengths as a criterion. The wetting-drying and freezing-thawing tests, which were performed on those mixtures which gave the highest or close to the highest values in compression, showed very satisfactory results for the lime–fly-ash–soil compositions.

The use of sonic-beam tests and group-velocity measurements were not employed with these soils. Evidence is available, however, which indicates that a good correlation exists between compressive-strength test and sonic methods (see Table 6).

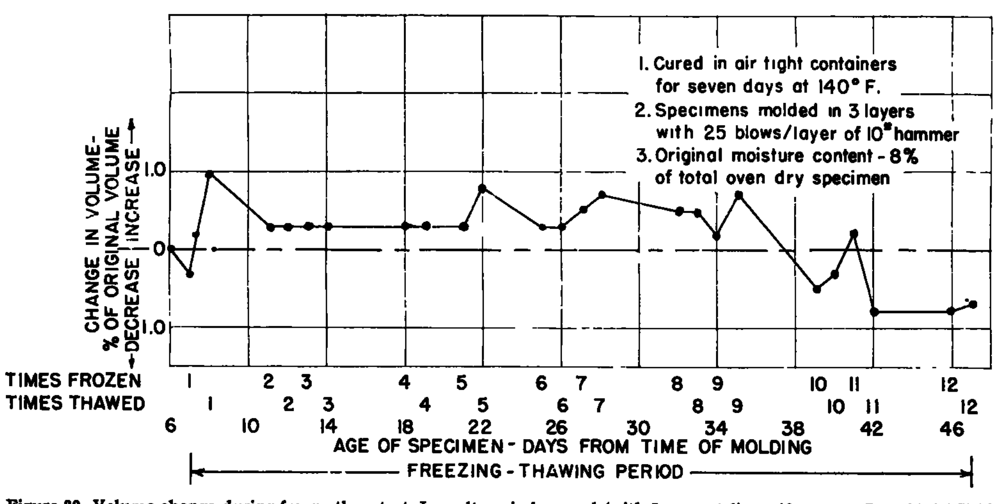

Figure 20. Volume change during freeze-thaw test. Laurelton circle gravel (with 5 percent lime, 10 percent fly-ash) AASHO T136-45. Soil No. 104.

than 10 percent. Since this would establish the optimum range on the basis of both compressive-strength results and sonic tests to be somewhere between 10 and 20 percent fly-ash, it is evident that additional tests could be run at intermediate percentages to determine if an optimum fly-ash content exists common to both tests.

PULSE-GROUP-VELOCITY INVESTIGATION

Measurements of pulse-group-velocity have been found to be useful for investigating the characteristics of concrete (*3*). A soniscope has also been used by other investigators (*4*)

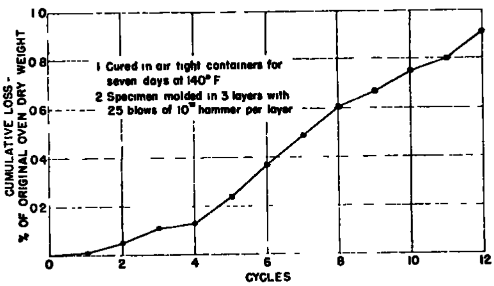

Figure 21. Weight loss during freeze-thaw test. Ringoe shale (with 5 percent lime, 10 percent fly-ash) AASHO T136-45. Soil No. 120.

in studying the durability of lime-soil mixtures, and the results obtained using this equipment appeared to be of considerable interest in investigations of this nature. Therefore, a similar instrument was constructed for use in the present investigation. Figure 24 is a photograph of the apparatus. Unfortunately, the instrument was not completed in time to be of use with all of the compositions reported in this paper. Preliminary information is available however, from the results obtained with a few soil samples.

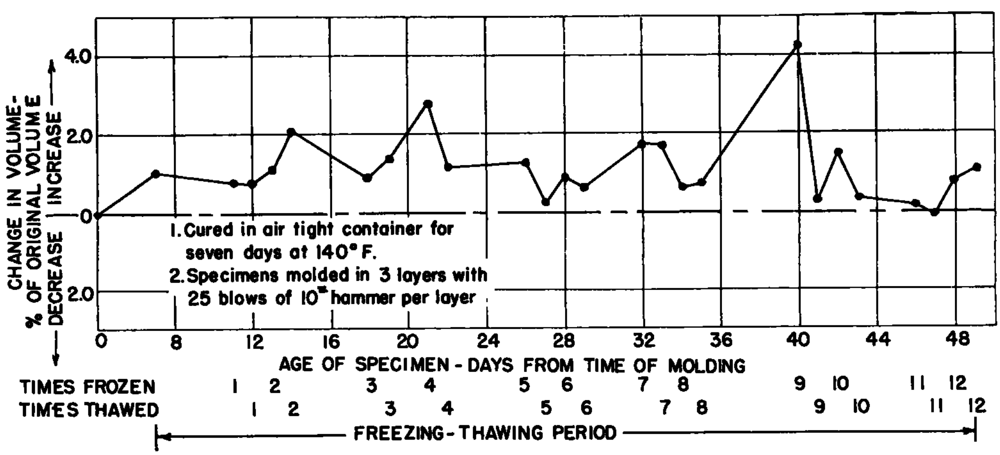

Figure 22. Volume change during freeze-thaw test. Ringoes shale (with 5 percent lime, 10 percent fly-ash) AASHO T136-45. Soil No. 120.

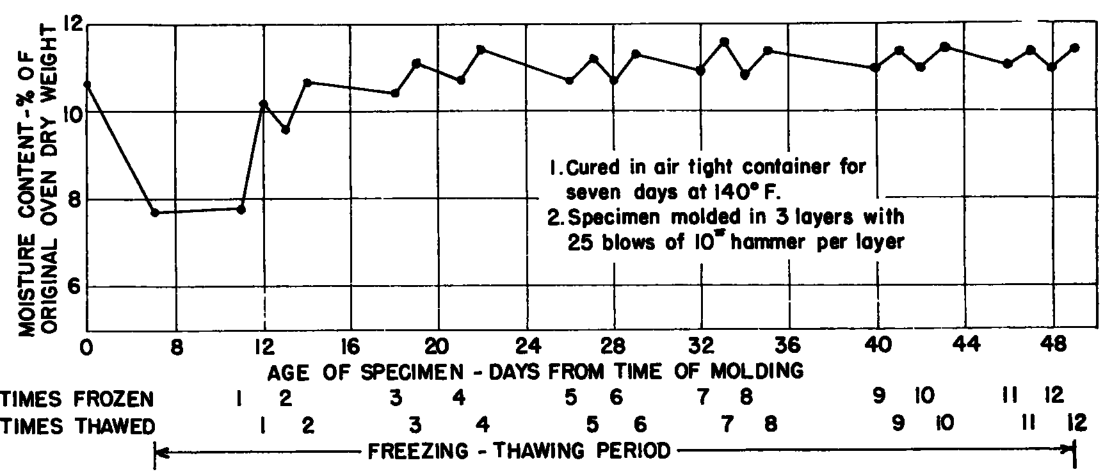

Figure 23. Moisture change during freeze-thaw test. Ringoes shale (with 5 per cent lime, 10 percent fly-ash) AASHO T136-45. Soil No. 120.

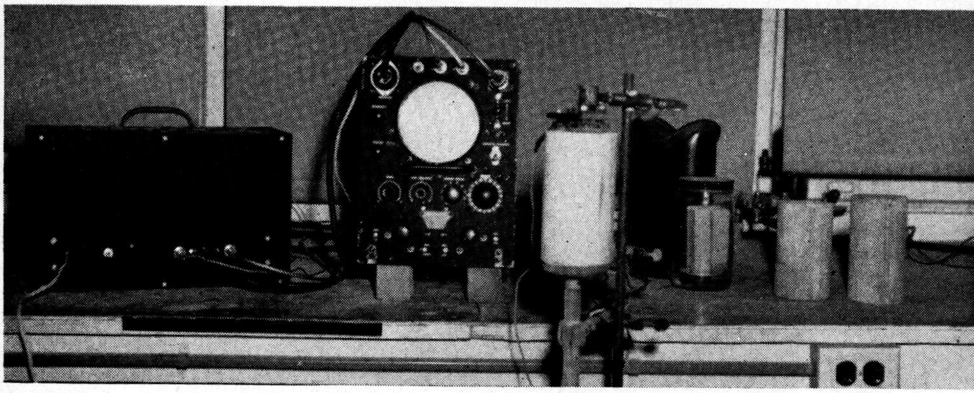

Figure 24. Apparatus used for pulse-velocity test.

TABLE 5
PULSE GROUP VELOCITY MEASUREMENTS ON STABILIZED MARYLAND A-2(6) SOIL

Sample No.	Fly-Ash[a] Content	Hydrated[a] Lime Content	Moisture[b] Content	Group Velocity
	percent	*percent*	*percent*	*ft. per sec.*
A-4	0	9	21.6	2,150
			4.5	2,620
			0	2,920
B-3	10	6	20.0	2,830
			4.5	3,210
			0	4,010
C-2	20	3	21.8	1,830
			4.1	2,315
			0	3,110
C-3	20	6	19.7	3,580
			5.7	3,790
			0	4,170
C-4	20	9	24.2	4,060
			6.2	4,160

[a] See Table 3.
[b] Based on weight of dry sample.

Table 5 gives the data obtained on samples of A-2(6) soil. The specimens are the same samples used for the sonic-beam tests presented above but which were stored in dry laboratory air for an additional eight months. Included in this table are values obtained on the samples when saturated with water, partially dried in the laboratory air, and finally, when dried in an oven to constant weight at 150F. It is evident from these data that the presence of moisture results in a reduction in the group velocity and that additions of fly ash and lime cause a substantial increase in velocity value. It is also evident by comparing this data with that presented in Figure 10 that the highest velocity is obtained with those specimens which gave the highest fundamental transverse frequency.

TABLE 6
RANK ORDER CORRELATION OF UNCONFINED COMPRESSION TESTS AND PULSE GROUP VELOCITY MEASUREMENTS

Unconfined Compressive strength	Group Velocity	Psi.	Rank
psi.	*ft. per sec.*		*ft. per sec.*
756	4060	1	1
384	3410	2	6
373	3780	3	3
347	3030	4	9
294	3920	5	2
282	3620	6	4
278	2900	7	10
254	2500	8	13
247	3470	9	5
245	3200	10	7
211	2670	11	11
177	2600	12	12
150	3180	13	8
148	1970	14	15
142	2370	15	14
101	1420	16	18
100	1570	17	17
88	1760	18	16
86	1350	19	21
85	1420	20	18
74	1310	21	23
70	1320	22	22
60	1420	23	18
58	1270	24	24

Rank Difference Coefficient $\rho = +0.92$

Where $\rho = \frac{6 \Sigma D^2}{N(N-1)}$

and ρ = Rank difference coefficient
N = Number of samples
D = Rank difference between compressive strength and pulse group velocity measurement
Σ = Summation symbol

Table 6 lists a group of data assembled for statistical purposes to compare the correlation between psi. values of 2-in. cubes and the group velocities in these specimens. The majority of these measurements were made on specimens prepared with some soils other than

those included in this paper, although the specimens have all been stabilized with lime and fly-ash. It is to be noted that these data are lined up in rank as determined by compressive-strength values. The column headed "feet per second" gives the corresponding rank as determined by group velocity. The rank order difference correlation factor has been calculated for this set of data and the coefficient turns out to be 0.92. A perfect correlation would be 1.00. The method, therefore, would seem to be effective in developing optimum proportions for the compositions of maximum compressive strength, although other factors, such as the nature of the soil, moisture content, and degree of compaction, must be considered in making an evaluation of this type.

Tests have been run for the purpose of determining the relationships which exist between the weight loss of the standard freezing-thawing and wetting-drying tests and the group velocity measurements. Sufficient trend is established to indicate that the group-velocity values should serve as a suitable basis for following the course of the freezing-and-thawing and wetting-and-drying tests. It is believed that the pulse-group-velocity technique should be superior to the wire-brushing technique for measuring the soundness of the lime–fly-ash–soil mixtures. This applies particularly to those specimens which show marked loss in weight during the brushing procedure. In the latter case the failure may be due to a surface scaling and does not necessarily indicate a change in the internal structure of the composition.

A sample removed from the test road described below under "Field Investigation" has been subjected to freezing-and-thawing cycles and the results of the measurements obtained using the wire-brush technique as well as the group-velocity method are shown in Table 7. A comparison is also shown in Table 7 of compressive-strength and group-velocity values for a number of samples removed from the test road at the same time. It is interesting to note that a substantial difference exists between the tests made on specimens parallel to the plane of compaction and those perpendicular to it.

TABLE 7

COMPRESSIVE STRENGTH, GROUP-VELOCITY MEASUREMENT AND CUMULATIVE WEIGHT LOSS ON TEST-ROAD BASE MATERIAL AND ON SPECIMENS SUBJECTED TO ADDITIONAL FREEZING-AND-THAWING CYCLES

State of Sample at time of Measurement	Orientation of Measurement	Compressive Strength	Group Velocity	Cumulative Weight Loss
		psi.	ft. per sec.	percent
As removed from the road after 1 year of service	Perpendicular to the plane of compaction	2,680	3,400	—
		2,440	4,400	
		——	3,075	
		2,560 Av.	4,350	
			4,350	
			5,760	
			——	
			4,223 Av.	
	Parallel to the plane of compaction	4,000	5,710	
		2,940	7,160	
		3,110	7,640	
		——	7,410	
		3,350 Av.	5,000	
			——	
			6,585 Av.	
After 12 additional cycles of freezing-thawing	Parallel to the plane of compaction	2,700	6,600	0.64

The relative values of velocities (or of moduli of elasticity as calculated from the group velocities) appear to be quite useful for evaluating the degree of compaction and relative durability, as well as establishing suitable means for the determination of optimum proportions for the mixtures.

A separate paper is being prepared which will describe the apparatus used in these studies in considerable detail. In this paper it is expected that much additional data will be included of laboratory tests and field measurements.

FIELD INVESTIGATION

Since the laboratory tests indicated that favorable performance of the lime-and-fly-ash

compositions could be expected, several test roads have been constructed to evaluate the compositions in the field. One of these roads was constructed in November, 1950, near Swedesboro, New Jersey, at the intersection of Route 322 and the New Jersey Turnpike. The experimental section was a detour road 2,400 ft. long and 20 ft. wide. This project utilized a lime-fly-ash-boiler-slag mixture which had been tested previously in the laboratory (*1*). Considerable information has been obtained from this project, and some of the observations and data are presented below. Results obtained in the other field tests in which lime and fly-ash were added to soil will be presented in a future paper.

The fly-ash and boiler slag used in the test on Route 322 were obtained from a huge stockpile located at the Public Service Electric & Gas Company's plant at Burlington, New Jersey. A survey of this stockpile showed that fly-ash and slag were mixed in the proportion of approximately 25 percent fly-ash and 75 percent slag, by weight.

The construction was a mixed-in-place operation. The fly-ash-and-boiler-slag mixture was deposited on the subgrade by dump trucks after which the lime bags were placed in rows and then broken open by hand. The mixing in place was done by a Seaman pulvi-mixer and the resulting composition was shaped by a motor-patrol grader and then compacted with a smooth three-wheel roller to a depth of 6 in., and an average dry density of 135 lb. cu. ft. Three percent lime by weight was used in the mixture.

Before final compaction of the road had been secured, it was subjected to a heavy rain for two days. Poor drainage of the road site did not permit final rolling of the base until a week after it had been laid down. Despite this, only a very small amount of refinishing of the surface was necessary before rolling could be continued. This fact indicates that one avantage of lime-and-fly-ash compositions is that the construction can be interrupted for extended periods of time without harm to the composition. After 14 days a 1-in.-bituminous wearing surface was applied and the project was completed.

Test Results for Experimental Road

Fourteen days after the road was built, and at the time the wearing course was being applied, a portion of the base was removed and sawed by means of a clipper saw into specimens suitable for compressive-strength tests. One of the samples was removed from a portion of the base which had remained comparatively soft, due to very poor drainage conditions, and the other was taken from a more representative location. Specimens from the soft spot had an average compressive strength of 500 psi., while those from the other location had a strength of 815 psi. Several more specimens were kept in a moist closet for two weeks and then tested after a total time of 28 days had elapsed. The results averaged 712 psi. for the soft spot and 1,200 psi. for the other. An additional portion of the sample was placed under water and showed no deterioration at the end of a six-month period.

Frequent inspection trips were made to determine the condition of the road during the winter and spring seasons. Test specimens were taken on several occasions. It was evident that the condition of the road was quite satisfactory and that the strength of the composition had continued to increase to a substantial degree. In July 1951 the results of compressive strength determinations on samples removed from the base were as follows:

tested dry	2,400 psi.
tested wet	1,900 psi.

These specimens were sawed with a clipper saw to a dimension of 4 by 4 by 6 in. They were tested in accordance with the procedure employed for concrete cylinders using the usual capping operation. Figure 25 shows the specimens used for the compressive-strength test.

In October 1951 a portion of the road was removed to permit construction of the New Jersey Turnpike. At this time the strength of the base was equal to 2,500-lb. concrete and considerable difficulty was experienced in breaking it up. Figure 26 shows the condition of the road after one year of service. Standard AASHO wetting-and-drying and freezing-and-thawing tests have been run on samples of the road also removed in July 1951, and the results of these tests are shown in Figure 27. From this data it is clear that the composition possesses excellent durability.

A microscopic examination was made of the road base. Figures 28 and 29 show a thin section under normal illumination, and be-

tween crossed nicols. It is evident that considerable birefringent material is present and as may be noted in the photomicrographs this material is highly dispersed throughout the matrix. The matrix resembles the gellike structure found in compositions obtained from other cementing materials such as portland cement, calcium aluminate cements, and the like. The photomicrographs also show a concentration of the birefringent material on the surface of the slag grains. While the exact composition of the birefringent material has not as yet been determined, it is evident that a definite chemical reaction has taken place between the lime and fly-ash which presumably corresponds to the "pozzolanic activity" of these materials.

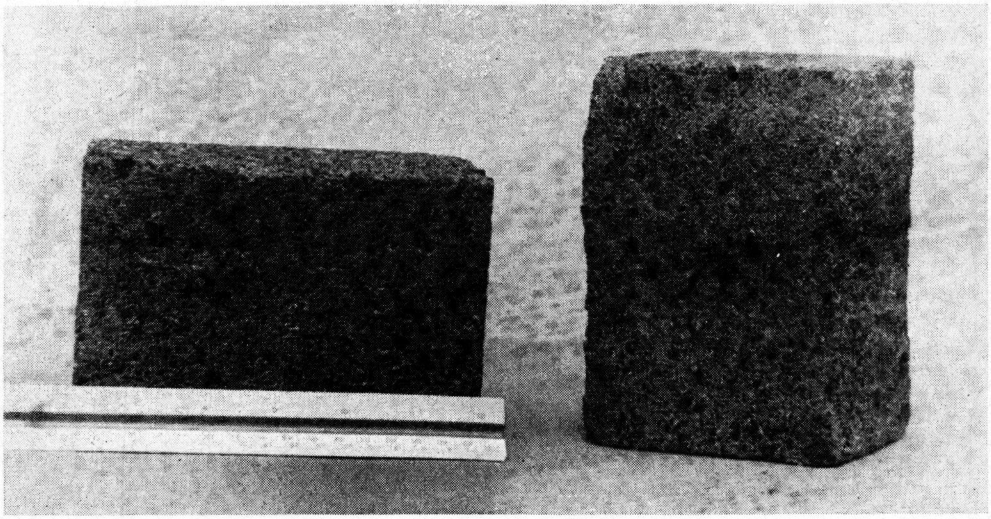

Figure 25. Specimens cut from lime-fly-ash-slag road base.

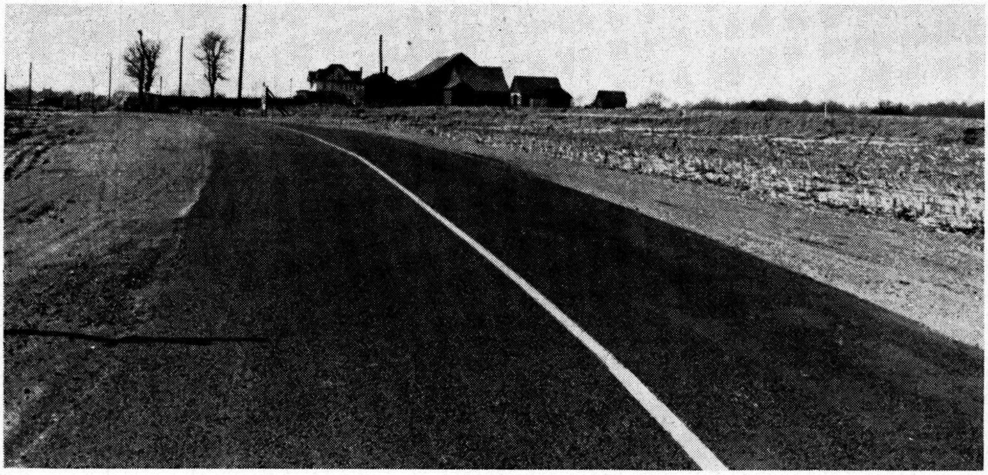

Figure 26. Test road after one year.

Tests with the group-velocity method (presented above) also showed that the composition possessed a high resistance to freezing and

thawing and wetting and drying. In this connection it should be mentioned that several measurements were also made using pulse-velocity techniques in the field. The apparatus was taken to the project and measurements were made through distances up to 10 ft. The results were quite favorable but in view of the fact that the work with group-velocity measurements has only been under way for a short time, this information will be presented at a later date after a better understanding is available to assist in correlating the field measurements with those obtained in the laboratory.

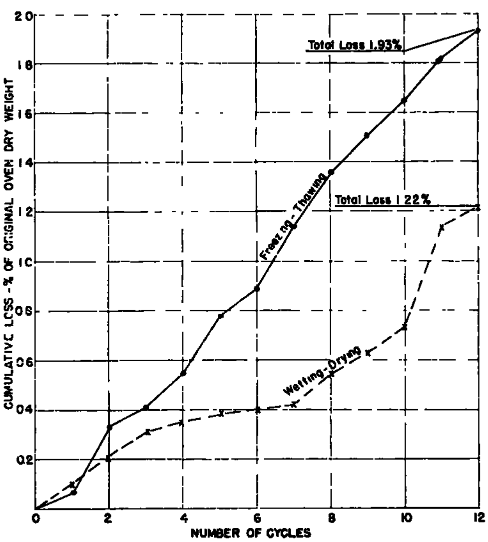

Figure 27. Weight loss during durability tests. Standard AASHO cycles of freezing-thawing and wetting-drying were used on specimens removed from road on June 25, 1951 approximately eight months after construction. (US 322). Total loss 1.93 percent.

CONCLUSIONS

As a consequence of the foregoing investigations, certain general characteristics of lime-fly-ash-soil compositions are apparent.

Very marked changes are immediately obtained in the engineering properties of the soils. The plasticity is reduced from values which are quite high to values which are low and desirable for practical use. The shrinkage characteristics are markedly improved and the materials are changed to dimensionally stable free-draining compositions well suited to base-course and shoulder construction.

In addition to the immediate improvement in the engineering properties of the soil, the lime-ash compositions are considerably improved upon aging in the presence of moisture, due to the cementing effect caused, in part, by the pozzolanic reaction between the hydrated lime and fly-ash. This cementing action results in compositions giving high strength when measured in unconfined compression. The specimens containing lime and fly-ash also showed high resistance to successive cycles of freezing and thawing and wetting and drying when compared to the natural soil. It is also evident that the use of the lime-ash-soil mixtures are superior to straight lime-soil mixtures, especially in compressive strength and in durability of the cured material.

The determination of the optimum quantity of lime and fly-ash with fine-grained soils cannot be made by using a maximum-density criterion but may be obtained from an examination of the results of the unconfined-compression tests, sonic-beam tests, and group-velocity measurements, or all of these tests taken together. Both the hydrated lime and fly-ash require specific concentration ranges for the best results as related to strength and durability. In general the finer-grained soils require higher lime and lower fly-ash content than is the case where coarser-grained soils are employed.

Field tests which are being run with compositions studied in the laboratory program are performing quite well up to the present time. The lime-fly-ash-slag mixture used on the detour road on US 322 in New Jersey set up to a remarkably strong, durable base which has performed well under heavy-traffic conditions.

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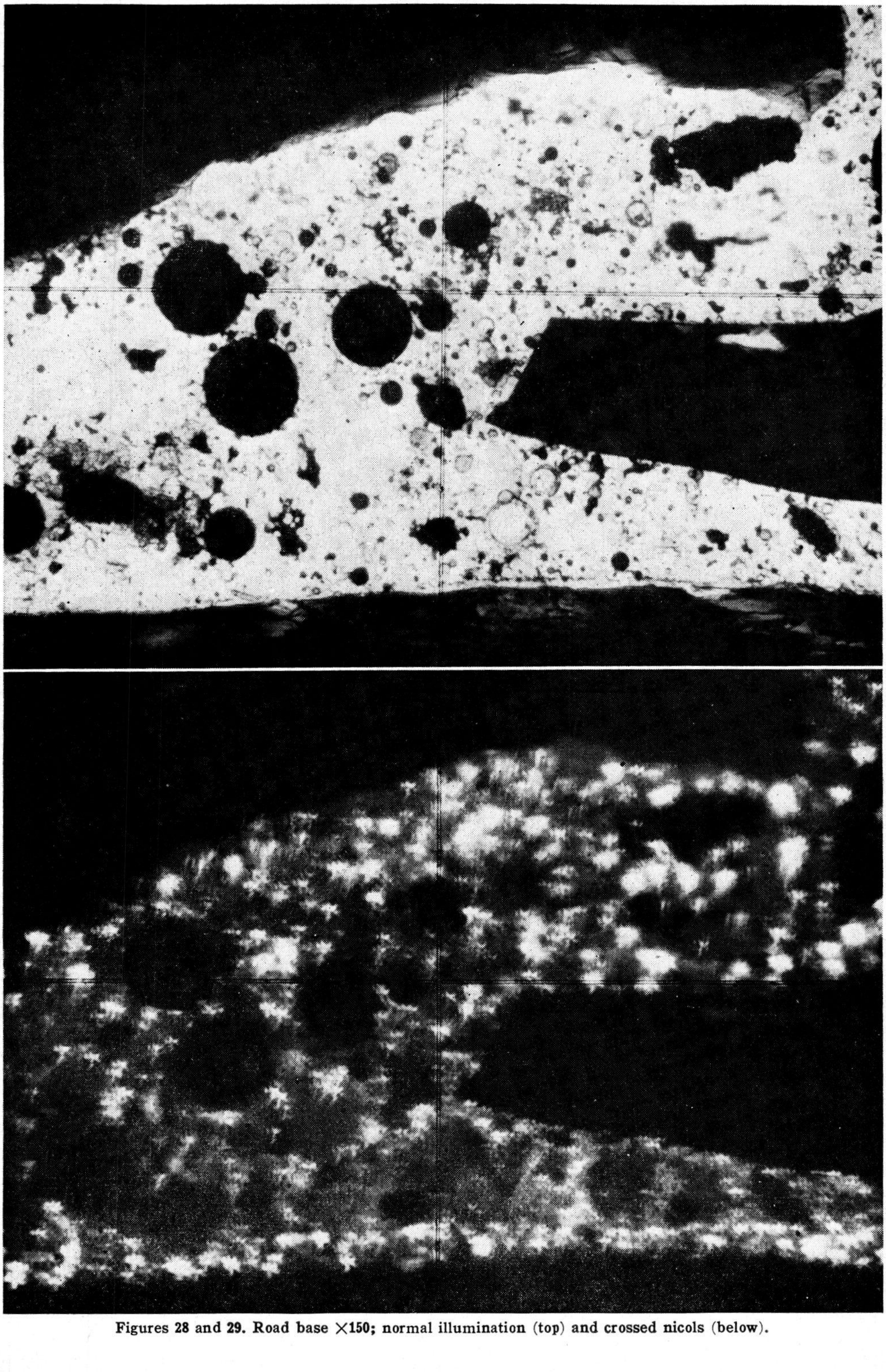

Figures 28 and 29. Road base ×150; normal illumination (top) and crossed nicols (below).

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E. A. Whitehurst, Soniscope Tests, Concrete Structures. Journal American Concrete Inst., February, 1951.
4. E. J. Yoder and E. A. Whitehurst, Durability Tests on Lime Stabilized Soil. Unpublished Report, National Lime Association, May, 1951.

DISCUSSION

Dale T. Harroun, University of Pennsylvania—This writer wishes to use this opportunity to present the results of his test program on lime and fly-ash mixtures at the University of Pennsylvania Soil Mechanics Laboratory.

Results are given for conventional compression tests made on cylindrical specimens with a height equal to twice the diameter and which were cured in a moist closet at room temperature.

This test program covered a period of one year.

Specimens for the first group of tests had the same composition as the Swedesboro test road on the New Jersey Turnpike which was reported in the subject paper, specifically, 74 percent slag, 23 percent fly-ash and 3 percent lime by weight (see Curve A).

Attention is called to the second group of tests to which 1 percent by weight of a hardening agent, calcium chloride, was added to the original mixture. The beneficial effect of high early strength and greatly increased final strength is noted (see Curve B of the figure).

The writer also wishes to comment briefly on the proposed use of the soniscope as a substitute for conventional test methods.

Since the soniscope measures the velocity of sound through the test specimen, its results are a function of the dynamic modulus of elasticity. From this the familiar modulus of elasticity of tension and compression, or Young's modulus, can be derived mathematically.

Thus the method should serve as a measure of the overall soundness of the material tested and should lead to an emperical relation between soniscope results and compressive strength. This was the basis of the original development of the test. See Reference 2, subject paper.

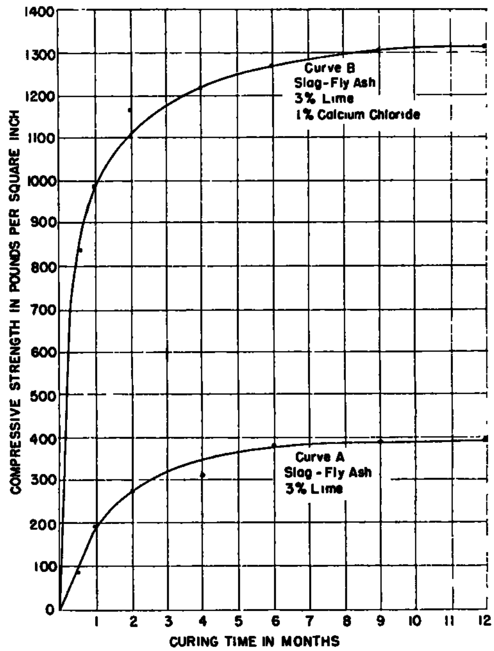

Figure A.

In the case of the conventional freeze-thaw-wire-brushing tests the action of surface layer disintegration is studied primarily. The removal of the protecting debris from the preceding cycle is an important requirement. It is hard to visualize how a method which is fundamentally a function of the soundness of the specimen's core can be used as a measure of an exfoliation phenomenon.

The writer agrees that a substitute for the tedious and time consuming freeze-thaw tests is desirable and trusts that one will eventually be found and proven on the basis of extensive laboratory investigation.