Properties of Lime-Flyash-Soil Compositions Employed in Road Construction

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AN evaluation of field projects in which lime and flyash are used for the stabilization of several types of soil indicates that the resulting compositions are very satisfactory as road bases. The evaluation includes laboratory tests for unconfined compressive strength, wetting and drying, freezing and thawing, and pulse group velocity. The equipment used to measure pulse velocity is described in some detail. The velocity measurements are found to be beneficial in evaluating the strength and durability of the compositions and good correlation is found to exist between the different test series. The construction work utilizes the mixed-in-place method. Several types of surface treatment have been applied to the stabilized bases.

● THE use of lime and flyash for the stabilization of soil and in the preparation of lime-flyash-aggregate mixtures has received considerable attention in recent years (1, 2). In the evaluation of these compositions the earlier work showed that the lime and flyash develop, through pozzolanic action, a cementitious matrix which acts to bond the material together into a coherent mass. For fine-grained and plastic soils the addition of lime and flyash also produces a substantial improvement in the engineering properties of the soil immediately after preparation of the mixtures. The method has given good results with natural soils and with aggregate materials such as crushed stone, boiler slags, and cinders. These compositions are currently being used in road construction with very satisfactory results. A few of these projects are described in this paper.

In order to adequately evaluate the field compositions, a laboratory investigation has been carried out on the same soils which were used in the field projects. As part of this study it has been necessary to give consideration to test methods which are applicable to compositions of this type and which are of use in developing relationships between laboratory tests and field performance. These methods include compressive-strength tests and a study of the effects produced by wetting and drying and by freezing and thawing. Since results obtained from sonic test methods (2, 3) have indicated that measurements of velocity of sound through the composition are of value in considering the durability and other physical characteristics of the test mixtures, this method has been included as an important part of the investigation.

The equipment employed in making group-velocity measurements is somewhat different from that reported by other investigators (3, 4, 5). A detailed description of the apparatus and the electric circuit is therefore included below. The equipment was found to give unusually stable readings with laboratory samples and also worked very well as a portable battery operated unit in the field. Longitudinal wave-front velocities, both compression and traction, have been measured and the results compared to other data such as water content, compressive strength, and durability measurements.

While most of the field projects will require more time before a complete evaluation can be made, sufficient in-

TABLE 1

SOIL CLASSIFICATION

Soil	Soil Designation	SCREEN ANALYSIS Weight Percent Passing Screen 2 in.	1½ in.	1 in.	¾ in.	⅜ in	No. 4	No. 10	No 40	No. 60	No. 200	Liquid Limit	Plasticity Index	Std. Proctor Density lb. per cu. ft.	Std. Proctor Optimum Moisture Percent
N J Turnpike New Brunswick Interchange 9	A-1-b Sandy Gravel	--	--	100	89 7	70.0	66 2	56 4	23.2	13 2	8 2	18.7	NP	133	8 5
N J Turnpike Hightstown Interchange 8	A-1-b Sandy Gravel	--	--	100	95	88	85	75	41	32	14.5	20.0	NP	126	9.0
N J. Turnpike Bordentown Interchange 7	A-1-b Sandy Gravel	--	--	100	93	86	73	56	36	19	11	17.0	3 5	125	10.0
N J Turnpike Burlington Interchange 5	A-1-b Sandy Gravel	--	--	100	96	87	80	66	48	35	17	22	NP	125	9 0
Marlboro By-Pass Marlboro, Md.	A-2-5 Silty Sand	--	--	--	--	--	--	100	99	93	19	28	NP	107	17.0
Navajo St. HiNella, N. J Contains Some Glauconite	A-5 Fine Sand	--	--	--	--	--	100	94	43	26	11	--	NP	124 5	8 0
Crestwood Ave Somerdale, N J Contains Glauconite	A-5 Fine Sand	--	--	--	--	--	100	86	40	26	9.6	--	NP	120 0	9
U S Avenue Lindenwald, N J	A-3 Fine Sand	--	--	--	100	89	86	83	65	52	1	--	NP	125 0	8 5
Mercer Rd. Barrington, N J. No. 1	A-3 Fine Sand	--	--	--	--	100	99	96	82	63	9	--	NP	118	10
Mercer Rd. Barrington, N J No. 2	A-3 Fine Sand	--	--	--	100	99	93	89	69	51	10	--	NP	122	10
A-3 Soils Whaleysville, Md	A-3 Fine Sand	--	--	--	--	--	--	100	79.5	55	2 8	--	NP	127	9
East Atlantic Ave , Oaklyn N J	A-1-a Sandy Gravel	100	92	89	81	72	64	49	27	19	4	--	NP	113 8	11.5
Underwood Hospital Woodbury, N J	A-1-b Sandy Gravel	--	--	100	88	74	66	49	24	18	16	--	NP	111 0	10 5
Laurel By-Pass Laurel, Md.	A-3	100	97	94	92	83	70	45	20	17	7	16 5	NP	124.3	9 5

formation is available to indicate the properties and the early performance of the stabilized compositions.

MATERIALS

The materials used in the investigation were selected from the sites where the field projects were to be carried out. The physical properties of the soils used in the study are given in Table 1. A few of the soils contained appreciable quantities of a bituminous fraction from previous surface treatments of the roads with asphaltic oil or tar and stone chips.

The chemical and physical characteristics of the hydrated lime and flyash used for practically all of the work are given in Table 2. In the field projects the flyash was supplied in moist condition usually containing from 10 to 20 percent water. The hydrated lime was supplied dry in paper bags.

TEST PROCEDURE

The previous papers (1, 2) described the methods employed to develop optimum proportions of lime and flyash for both fine- and coarse-grained materials.

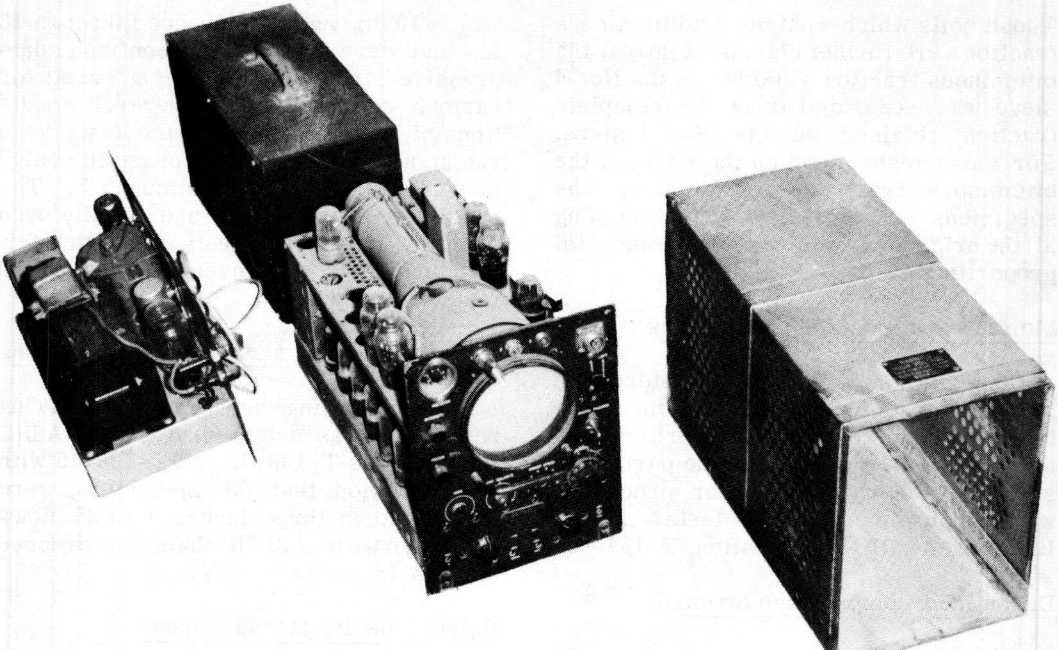


Figure 1. Pulse-velocity equipment with covers removed.

The same procedure was employed in the present investigation. In order to cut down on the amount of work, the durability studies were largely confined to the investigation of these optimum mixtures. The field projects also employed proportions as used in the laboratory tests.

The following procedures were used in the laboratory investigation.

Soil Classification

The soil samples were classified in accordance with standard AASHO methods.

TABLE 2

PROPERTIES OF HYDRATED LIME AND FLYASH

Chemical Analysis	Dolomitic Hydrated Lime	Flyash Philadelphia Area	Flyash Baltimore Area
SiO_2	1.0	35.95	44.17
Fe_2O_3	0.4	22.67	17.28
FeO	0.0	-	-
Al_2O_3	0.2	23.13	28.65
CaO	47.8	7.06	2.79
MgO	33.8	1.01	0.89
Loss on Ignition	16.3	6.15	4.97
CO_2	0.8	-	-
H_2O	0.5	0.28	0.21
Sieve Analysis			
Sieve No.			
60 (Total % Ret.)	1.0	0.75	2.23
100 (Total % Ret.)	2.8	4.60	8.33
200 (Total % Ret.)	5.6	-	-
325 (Total % Ret.)	-	28.58	27.84
Specific Gravity	2.60	2.46	2.31
Dry Rodded Density (lb. per cu. ft.)	45	70	70

Those soils which contained a bituminous fraction were further classified so that the bituminous fraction retained on the No. 4 sieve was separated from the complete fraction retained on the No. 4 sieve. For those tests in which the effect of the bituminous fraction was studied, the specimens were prepared by recombining all the original ingredients in their original proportions.

Moisture-Density Characteristics

The optimum moisture was determined for samples of natural soil and for lime-flyash-soil mixtures of proportions determined to be suitable for the particular soil type. Standard Proctor procedure was employed for these tests, as outlined in AASHO Designation T-134-45.

Unconfined Compressive Strength

Specimens were compacted in the Proctor mold with 25 blows per layer with a 10-lb. hammer dropped through 18 in. and were tested for unconfined compressive strength after being cured for various ages and under several conditions of storage. Most of the tests were run at seven days with storage in sealed jars at 140 F., plus or minus 5 F. The specimens were capped and usually oven dried for most of the tests although a few measurements were made under saturated moisture conditions.

Wetting - Drying and Freezing -Thawing

Wetting-drying and freezing - thawing resistance was established using AASHO Designations T-135-45 and T-136-45 with the exception that the specimens were compacted in three layers with 25 blows per layer with a 10-lb. hammer dropped through 18 in.

Pulse-Velocity Measurements

The equipment used for the measure-

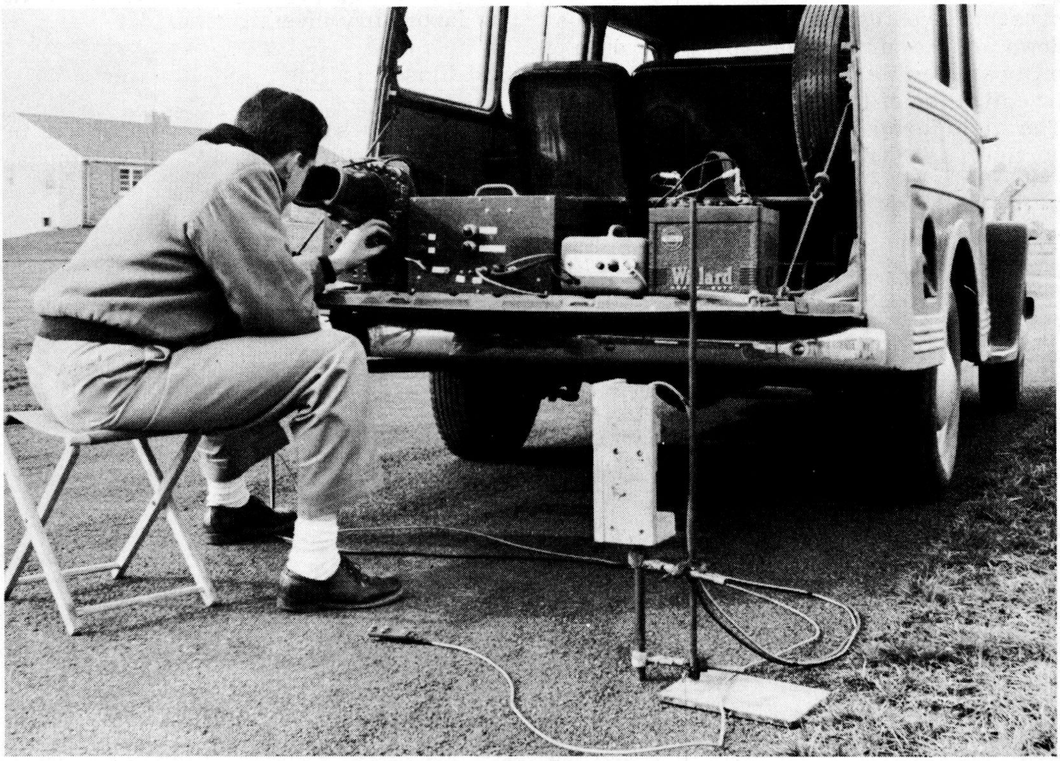


Figure 2. Measuring pulse velocity with portable field unit.

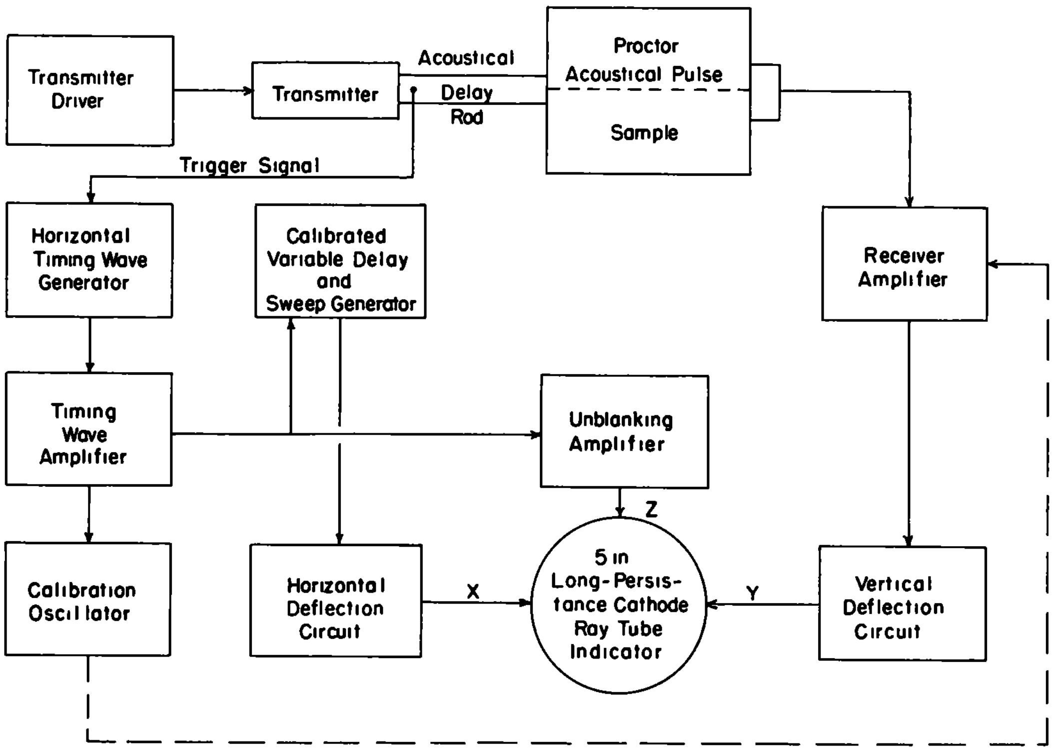


Figure 3. Block diagram for compressive wave-front-velocity measurement of a proctor sample A, transmitter driver, B, transmitter, C, acoustical-delay rod, D, proctor sample, E, receiver, F, receiver amplifier, G, vertical-deflection circuit, H, horizontal timing-wave generator, J, timing-wave amplifier; K, unblanking amplifier, L, calibrated variable-delay and sweep generator; M, horizontal-deflection circuit, and N, calibration oscillator.

ment of pulse group velocity is described in the next section in detail. A number of the laboratory samples prepared for the program were tested with this equipment. Specific efforts were made to obtain measurements for compression wave-front velocity during the wetting and drying, and freezing and thawing tests, and on samples which were tested for unconfined compression. Measurements were also made on specimens with different moisture contents to determine the effect of water on the test results.

In addition to the laboratory tests, velocity measurements were made in the field. Some of the tests were carried out using axial in-line placement of the transmitter, receiver, and sample, which resulted in the use of the compressional wave. In order to do this, sufficiently large depressions were cut in the road to allow placement of the transducers 3 in. below the surface. The transducers were then pressed laterally face to face against a significant length of road base, usually about 20 in. An oiled-clay mixture was placed between the road base and each transducer to assure good transfer of energy. The reading was made of the time required for the impact leaving the transmitter to reach the receiver.

In order to reduce the amount of disturbance to the road resulting from preparation of the base for the longitudinal wave-front tests, traction impact velocities were also measured at several field locations, and have been used in the majority of the recent tests. Traction

TABLE 3

Soil and Sample Designation	Remarks	Composition Soil	FA	Lime	Moisture (dry basis)	Dry Density	Curing Oven	Moist.	Comp Str	Velocity
		parts by weight			%	lb per cu ft.	Days	Months	psi.	ft. per sec
N J Turnpike A-1-b New Brunswick Interchange 9										
Field Sample		90	10	5	10.0	125 0	7	--	583	
" "		90	10	5	10 0	125 0	7	--	535	
" "		90	10	5	10.0	125 0	7	--	694	
" "		90	10	5	10 0	125.0	14	--	1050	
" "		90	10	5	10 5	125 0	7	2/3	704	
" "		90	10	5	11 5	125 0	7	2/3	800	4620
" "		90	10	5	11 5	125 0	7	2/3	810	4670
" "		90	10	5	9 0	125 0	7	2/3	621	3420
" "		90	10	5	12 0	123 0	7	3	920	4145
" "		90	10	5	10.0	126.0	7	3	398[f]	3430[f]
" "		90	10	5	10.0	126 5	7	3	706[f]	4880[f]
" "		90	10	5	11 5	123.5	7	3	850[f]	4170[f]
" "		90	10	5	10.0	126.0	7	2½	865[a]	5100[a]
" "		90	10	5	11 5	124.0	7	2½	780[b]	3050[b]
N J Turnpike A-1-b Hightstown Interchange 8										
Lab Sample	Bituminous	(90	10	5	10 0	125 0	7	--	400	
" "	fraction	(90	10	5	9 0	124.0	7	--	430	
" "	omitted	(90	10	5	9 0	124 0	7	2/3	1191	
" "		(90	10	5	9 0	124.0		3	1225	
" "	Bituminous	(90	10	5	10 0	125 0	7	--	375	
Field Sample	fraction	(90	10	5	9 5	123 5	7	5	871[a]	4330[a]
" "	included	(90	10	5	9 5	123 5	7	5	872[b]	3590[b]
N J Turnpike A-1-b Bordentown Interchange 7										
Lab Sample	Bituminous	(90	10	5	10 0	122 0	5	--	655	
" "	fraction	(90	10	5	10 0	122 0	7	--	750	
Field Sample	omitted	(90	10	5	11.5	123 5	7	--	708	
Lab Sample	Bituminous	(90	10	5	10 0	122.0	5	--	485	
" "	fraction	(90	10	5	10 0	122 0	7	--	735	
Field Sample	included	(90	10	5	10 0	122 0	7	2½	280[a]	2130[a]
N J Turnpike A-1-b Burlington Interchange 5										
Field Sample		90	10	5	9 0	125 0	7	--	375	
" "		90	10	5	7 9	120 2	28	--	960	
" "		90	10	5	7 9	120 2	28	2	732	
Marlboro By-Pass A-2-5 Marlboro, Md.										
Field Sample		90	10	5	9 2	121 0	7	--	467	
" "		90	10	5	9 0	121 0	7	2/3	896	6250
" "		90	10	5	9.0	121 0	7	2/3	912	6650
" "		90	10	5	9 5	121 0	7	2½	910[b]	6170[b]
" "		90	10	5	9 5	121 0	7	2½	1280[a]	6190[a]
HiNella, N J A-5										
Lab Sample		90	10	4	8 0	125 0	5	--	350	
" "		90	10	4	9 0	124.0	5	--	360	
Field Sample		90	10	4	8 0	125 0	7	--	1010	
" "		90	10	4	8 0	125 0	7	2/3	1253	

TABLE 3 (continued)

Soil and Sample Designation	Remarks	Composition: Soil (parts by weight)	FA	Lime	Moisture (dry basis) %	Dry Density lb. per cu ft.	Curing: Oven Days	Moist. Months	Comp. Str. psi	Velocity ft. per sec.
Crestwood Ave										
A-5										
Somerdale, N. J.										
Lab Sample		90	10	4	8 0	124 5	7	--	450	
" "		90	10	6	9 0	120.0	7	--	390	
Field Sample		90	10	3	9 0	130.5	7	2/3	1605	6450
" "		90	10	3	9 0	132 0	7	--	1382	6450
" "		90	10	3	9 0	131 2	7	--	1185	6350
" "		90	10	3	9 0	130.2	7	--	1180	6550
" "		90	10	3	9 0	123 8	7	1 1/2	1660[b]	7010[b]
U S Avenue										
A-3										
Lindenwald, N. J										
Lab Sample		85	15	3	8.0	127 2	2	--	177	
" "		85	15	4	7.8	128.2	2	--	244	
" "		85	15	5	8.0	127.2	2	--	365	
Mercer Ave										
A-3										
Barrington, N J										
Lab Sample No 1		90	10	3	10 0	120 5	4	--	585	
" "		90	10	5	11 7	118.8	4	--	758	
Lab Sample No 2		90	10	3	9 0	117.6	1	--	242	
" "		90	10	5	9 0	117 8	1	--	258	
Field Sample		90	10	4	9.0	127 5	7	--	1345	5720
" "		90	10	4	9.0	128 5	7	--	1365	5790
" "		90	10	4	9.0	128.8	7	--	1680[a]	5410[a]
" "		90	10	4	9.0	128.0	7	--	1325[c]	5840[c]
" "		90	10	4	9 0	128.1	7	--	1610[d]	5320[d]
" "		90	10	4	9 0	128.2	7	--	1790[b]	4620[b]
" "		90	10	4	9 0	128.7	7	2/3	1459[e]	6440[e]
Whaleysville, Md.										
A-3										
Lab Sample		85	15	6 3	6 5	124.1	7	--	1420	8280
" "		80	20	5 3	5 2	124.8	7	--	984	5640
" "		75	25	3 0	5 3	124.8	7	--	1152	5720
E. Atlantic Ave										
A-1-a										
Oaklyn, N. J										
Lab Sample		92.2	7 8	3.0	10 2	117 2	7	--	374	3760
" "		92.2	7 8	3.0	10.2	114.2	7	--	371	3760
" "		90.25	9 75	3 25	9 5	116.0	7	--	383	
" "		90.25	9 75	3 25	9 5	116.0	7	--	328	
Woodbury, N. J.										
A-1-b										
Lab Sample		90	10	4	9.0	121 0	7	--	390	
" "		90	10	4	9 0	121 0	7	--	365	
Field Sample		90	10	4	9 0	121 0	7	--	580	
" "		90	10	4	9 0	121.0	7	--	590	
Laurel By-Pass										
A-2-5										
Laurel, Md.										
Lab Sample		90	10	5	9 0	127.0	7	--	900	
" "		90	10	5	9 0	127.0	7	--	920	

[a]After 12 cycles of wet-dry

[b]After 12 cycles of freeze-thaw

[c]After 12 cycles of wet-dry, tested in saturated state.

[d]After 12 cycles of freeze-thaw, tested in saturated state

[e]Tested in the saturated state

[f]Tested in the 100 percent relative humidity state

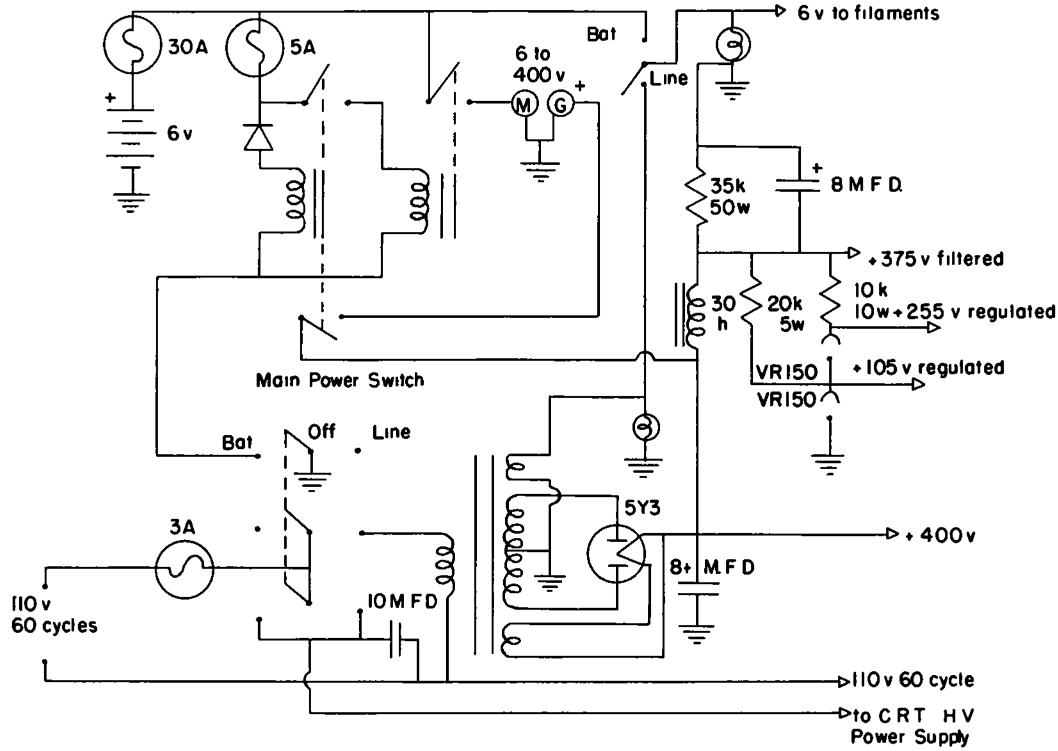


Figure 4. Battery-line-regulated power supply.

impacts were generated by inserting the transmitter delay rod vertically into a 1-in.-diameter hole cored two thirds of the way into the road base. For this type of measurement the pick-up was placed at a number of points on a 3-in. circle around the transmitter and was applied face down to the surface of the road. Another procedure which is currently being investigated involves the measurement obtained by placing both the transmitter and receiver vertically downward upon the surface of this base material. In some cases cuts were made in the material between the transmitter and receiver to determine the

TABLE 4

Typical Example of Five Soils Measured for Compression Wave-front Velocity in the Saturated and Dried States of Wetting-Drying Cycle Tests on Cured, Optimum Range, Lime-Flyash-Stabilized Soil Compositions

Woodbury, New Jersey

Cycle	Moisture Content Saturated %	Moisture Content Dried %	Velocity Saturated ft. per sec	Velocity Dried ft. per sec
0	15 2	9 0[a]	4,180	4,590[a]
1	14 6	1 5	4,190	4,200
2	14 1	0 9	4,010	4,280
3	14 2	0 7	3,780	3,770
4	14 6	0 6	4,120	3,870
5	13 8	0 5	3,990	3,910
6	13 8	0 4	4,220	4,030
7	14 0	0 8	4,260	4,260
8	13 7	0 8	3,950	3,710
9	13 5	1 1	4,040	4,460
10	13 4	0 9	3,830	4,310

[a]Sample as cured at 100 percent relative humidity

depth to which some of the waves penetrated. In making the measurements on the road base, the condition of the base was carefully noted, particularly with respect to moisture content. In general, the tests were run at times when the road base was either quite dry or in a wet state rather than at times when the material was in a partially dried out condition.

SONIC TEST EQUIPMENT

Leslie and Cheesman have found the velocity of sound as measured by the soniscope (4) to be a useful method for investigating the characteristics of concrete. The soniscope has been used by Whitehurst in the evaluation of concrete (5) and also by Whitehurst and Yoder in the study of lime-soil stabilization (3). The authors wish to express appreciation to the above mentioned investigators for their very helpful assistance and advice during the construction of the instrument used in the previous study (2) and as modified for the present investigation. This apparatus represents a consider-

TABLE 5

Field inspection data from three lime-flyash-stabilized soil shoulder installations in the New Jersey Turnpike
Composition, parts by weight. Lime, 5, flyash, 10, soil 90

Item No	Curing-Days Field	Type of Wavefront Measured	Details Concerning Velocity Determination	Velocity Determination Ft. per Sec
Location	New Brunswick Interchange No. 9 Ramp to south on Route S28 Station 0 + 20 situated under an overpass Material at this location was generally wet, cool, and subject to little traffic			
1	0	Direct Compression	Received signal weak and wavefront degenerated	1,710
2	0	" "	" " " " " "	2,050
3	0	Traction	Dial readings 253, 266, 295, and 300	1,260
4	87	"	" " 140, 141, 137, and 144	3,100
	Drilling was fairly difficult, material compact, frequent visible particles of lime one-quarter inch and smaller evident from test hole corings.			
5	87	Traction	Dial readings 143, 135, 141, and 131	3,200
6	"	"	" " 141, 140, 153, and 140	3,000
7	88	Compression	On sample removed from road	4,030
8	"	"	" " " " "	4,180
Location	New Brunswick Interchange No. 9 Ramp to south on Turnpike Station 2 + 80. Material at this location bearing steady traffic and the majority of heavy trucks rising and accelerating.			
9	87	Traction	Dial readings 106, 110, 107, 103	4,500
	Drilling was extremely difficult using star drill and hand sledge Some visible particles of lime one-quarter inch and smaller were evident from test hole corings The appearance of the shoulders was excellent and no distinction between shoulders and the pavement was evident from performance under traffic			
Location.	Hightstown Interchange No 8 Northbound Exit Ramp, right-hand shoulder Station 12 + 15. The traffic load observed was heavy.			
10	9	Direct Compression	Signal path, 3 12 ft.	3,520
11	"	" "	" " 1.33 ft.	3,550
12	"	Traction	Dial Readings 175, 183, 174, 202	2,135
	These readings were taken at the center of the shoulder			
13	95	Traction	Dial Readings 132, 140, 142	3,300
	These readings were taken one foot from the outer edge of the pavement.			
14	95	Traction	Dial Readings· 195, 160, 152	2,400
	These readings were taken one foot from the outer edge of the shoulder			
15	95	Traction	Dial Readings. 151, 150, 155	2,800
Location.	Bordentown Interchange No 5 Ramp "B" Station 333 + 00 This location is on a "J" Loop before the southbound acceleration lane Traffic was light, but generally rode on the shoulder No visible distinction between pavement and shoulder was evident from appearance			
16	180	Traction	Horizontal distance between transducers, 1½ in.	3,870
17	"	"	" " " " 3 in.	4,250
18	"	"	" " " " 4 in.	4,060
19	"	"	" " " " 5 in.	3,960
	The initial wave front intensity decreased steadily as the distance between transducers was increased. The received signal showed a second wavefront of lower velocity increasing with receiver distance			

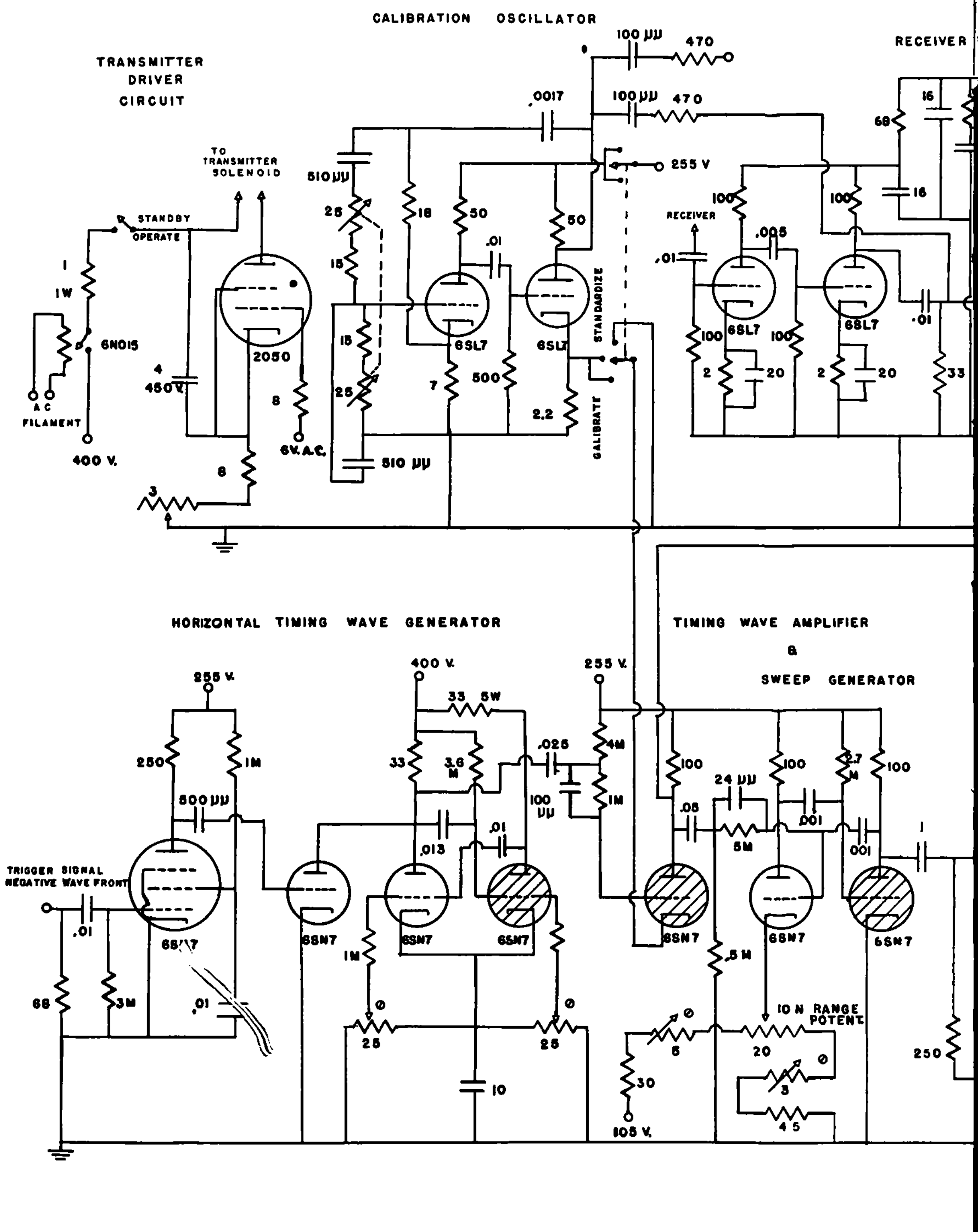
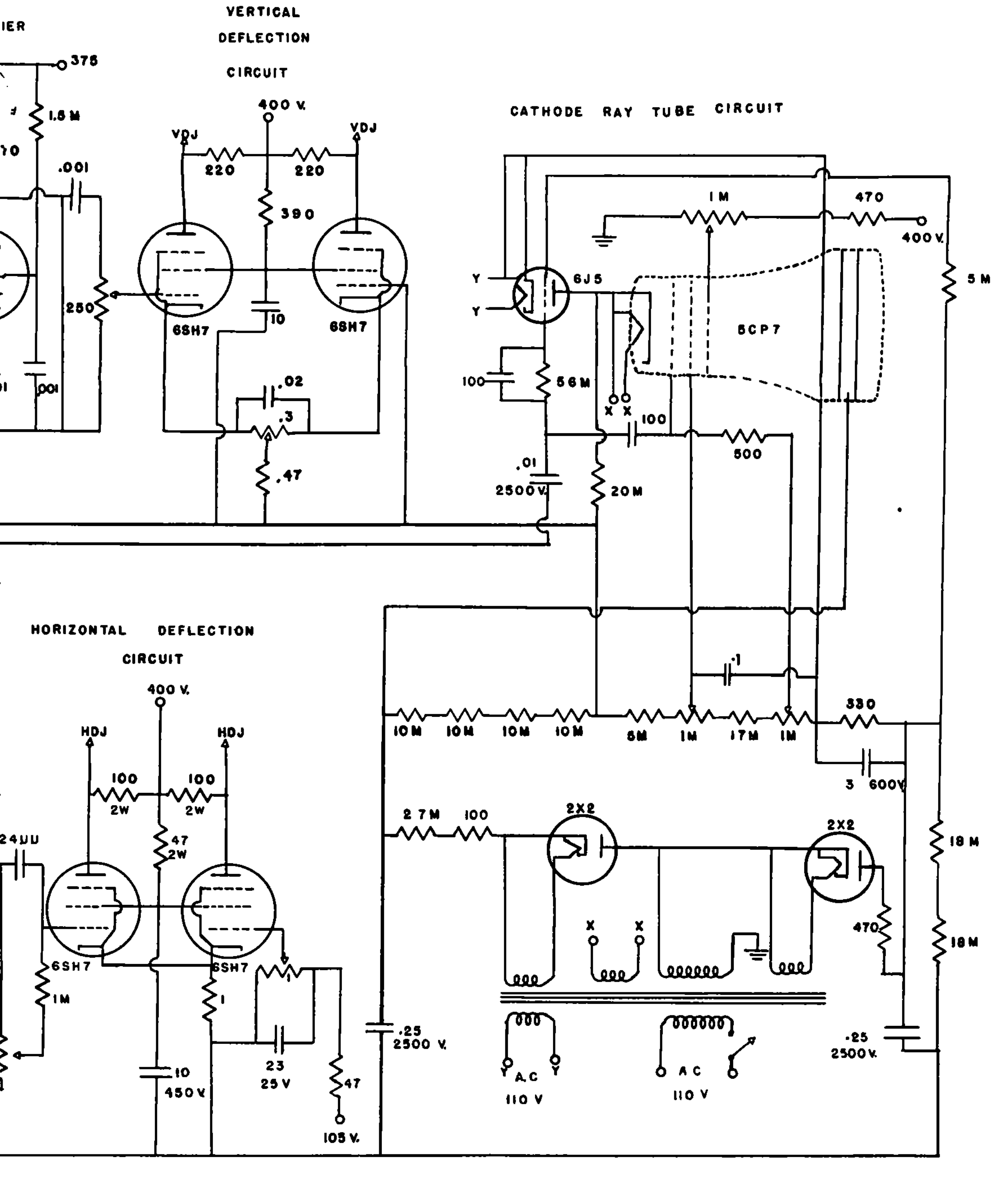


Figure 5. General schematic: Resistance in kilohms



acitance in microfarads unless otherwise stated.

Figure 6. New Jersey Turnpike project: Condition of shoulder prior to treatment.

Figure 7. Preparation of shoulder for treatment. Blade is removing loose bituminous material. This operation is followed by scarifying to desired depth with the motor grader, N. J. Turnpike project.

Figure 8. Bulk flyash being spread by motor grader, N. J. Turnpike project.

able departure in design from that described by the above investigators, although measurements made on both type instruments give substantially identical results on the same laboratory specimens. Recently Meyer (6) has described a modified form of soniscope which also employs a different transmitter system to that described in the early investigations.

Calibration has been carried out by the use of standard frequencies and by measurements of materials for which the velocity values are available in the literature. It is felt that the instrument described in this paper not only measures pulse velocity but is adaptable to other quantitative measurements of particular use in soil stabilization work. This instrument has given stable readings upon numerous materials in the field and laboratory. The unit may be operated from 100- to 130-volt, 60-cycle, A. C. lines or by a conventional 6-volt lead-acid storage battery. A 120-amp.-hr. battery provides 4 hr. of continuous service from a full charge. The instrument was built up from both new and surplus components, and the cost of all parts (some of which are not now in use) was approximately $500. There has been practically no maintenance required on the equipment, even though it has been subjected to rather rough usage on numerous field trips.

Views of this instrument are shown in Figures 1 and 2. The unit is divided into two-handle-equipped major units of approximately equal weight for convenience in transportation between the laboratory and field locations. Storage batteries are maintained as separate units as well as a 65-watt inverter which it is planned to eliminate by circuit revision.

The internal operation of the apparatus is outlined by Figure 3, a block diagram. An acoustical pulse is generated by a thyratron-driven electric hammer which strikes a target at a rate of approximately three times a second. The leading edge of this impact triggers the horizontal and unblanking systems for a long-persistence-screen cathode-ray

Figure 9. Mix-in-place Pulvimixer incorporates the lime and flyash into the existing shoulder. Lime was supplied in 50-lb. sacks and dropped on shoulder as shown, N. J. Turnpike project.

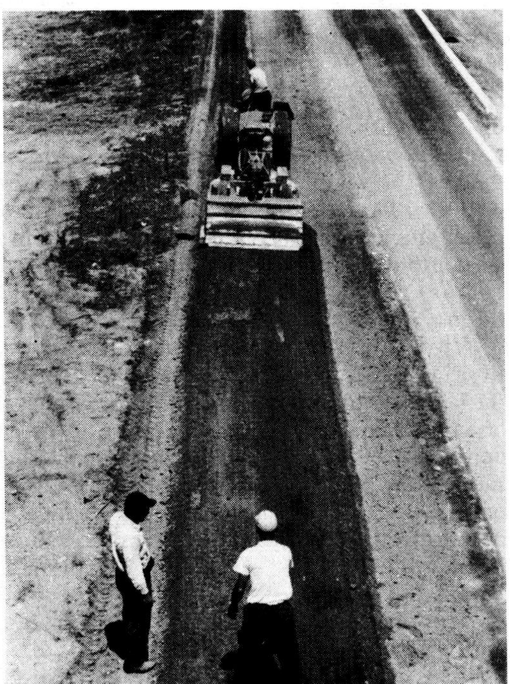


Figure 10. After several passes with Pulvimixer a homogeneous composition results which is ready for moisture check and rolling with rubber-tired and flat-wheeled rollers, N. J. Turnpike project.

tube. The pulse is conducted through a steel delay rod 1 ft. long at the end of the transmitter to the sample where transfer is effected through an oil clay mixture. The impact passing through a sample path of known length is registered by the receiver pickup. The polarity (compression or traction) and modulation of the wave front as well as the transit time required in the sample are indicated by vertical displacement of the trace. Measurement of the transit time is effected by the introduction of an equivalent calibrated

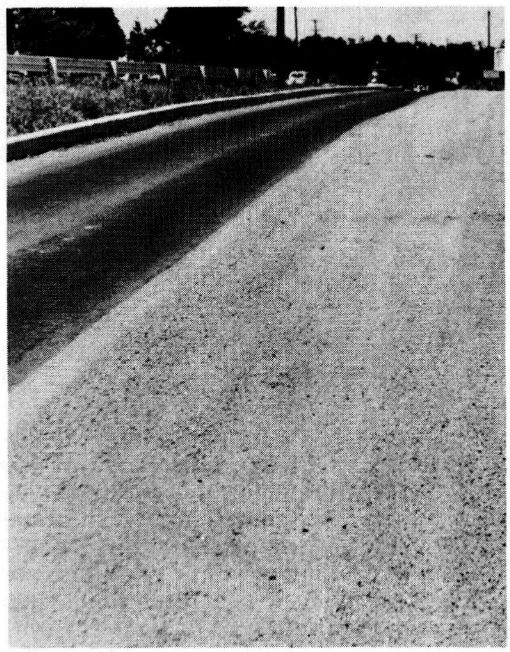


Figure 11. Completed shoulder after application of oil and stone chips to stabilized base, N. J. Turnpike project.

delay in the horizontal sweep; this results in the leading edge of the wave-front trace being translated to zero. The first portion of the sweep is rapid which permits easy measurement. In addition, the latter portion of the sweep may be varied by the horizontal gain control to provide for convenient interpretation.

Figure 4 shows the 110-v. -A. C. -to-6-v. -D. C. -power-supply schematic drawing not including the inverter which at present provides low-wattage 110 volts of A. C. on battery operation for the cathode-ray-tube power supply. Figure

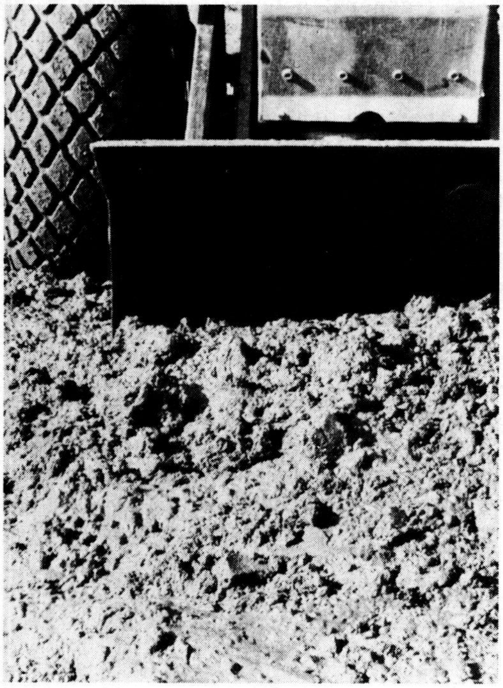


Figure 12. Soil at HiNella, N. J.: Project contained appreciable quantities of green sand marl.

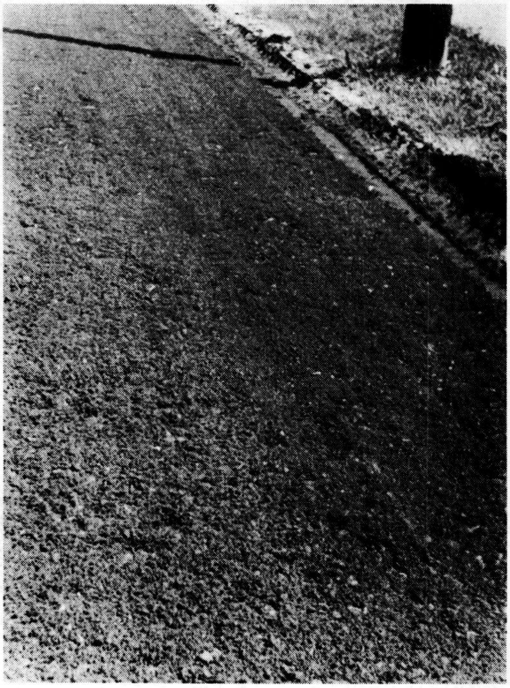


Figure 13. Condition of road base prior to compaction and after mixing lime and flyash into the soil, HiNella, N. J.

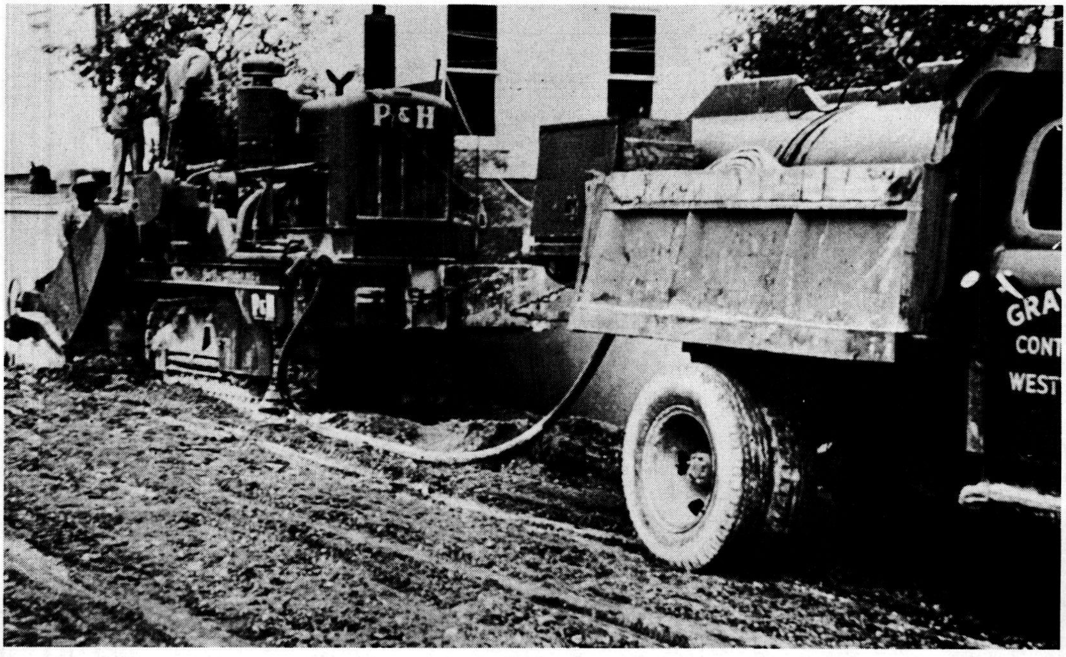


Figure 14. Stabilization project at Woodbury, N. J.,using P&H single pass unit for incorporating lime and flyash into the soil.

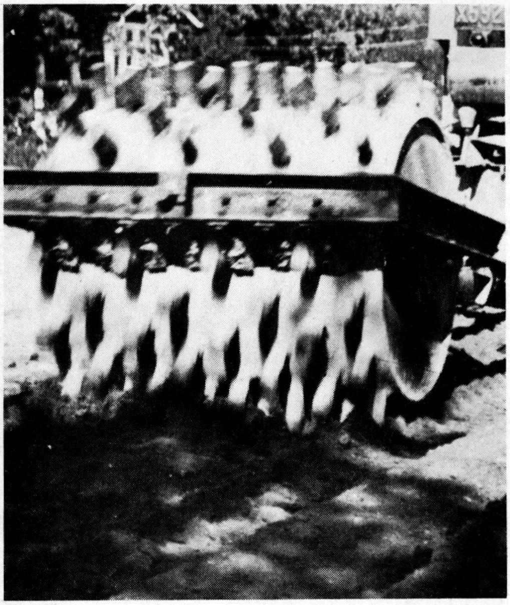


Figure 15. Compaction of stabilized shoulder using sheepsfoot roller, followed by rubber tire and flat steel rollers. Taken on shoulder at Somerdale N. J.

5 is a general schematic diagram of the instrument.

The signal generated contains an initial high-energy wave front which passes from the steel rod to the sample with a satisfactory acoustical impedance ratio for the materials giving good high-frequency transfer. Fast initial rise provided in the wave front by the high-frequency component results in sharp resolution in small samples. In addition, the attenuation effect of the samples as related to the wave form is felt to be useful in the further evaluation of the compositions. The peak force of the impact may be set to allow relatively low receiver-amplifier gain despite passage of the signal through such field specimens of high attenuation as stabilized soil. Good orientation of the transducers is also beneficial in such applications.

FIELD PROJECTS

The field projects reported in this paper represent mixed-in-place opera-

TABLE 6

Field inspection data from the lime-flyash-stabilized soil project at Woodbury, N. J.
Composition, parts by weight: Lime, 4; flyash, 10; soil, 90.

Item No.	Curing-Days Field	Type of Wavefront Measured	Station No.	Details Concerning Velocity Determination	Velocity Determination Ft. per Sec.
1	55	Traction	U-1	Dial readings: 114, 118, 120, and 113	5,420
	This material showed good mixing, compaction, and was difficult to drill. This station was observed to bear maximum traffic and to be exposed to weathering.				
2	55	Traction	U-2	Dial readings: 170, 185, 168, 162	2,450
	Test hole drilling was very easy and the corings indicated a variable composition. The job history showed that the machine mixer could not operate in this station. See item No. 7 below.				
3	55	Traction	U-3	Dial readings: 137, 142, 150, 148	3,130
	The location and properties of station U-3 were intermediate to U-1 and U-2.				
4	55	Traction	U-4	Dial readings: 130, 125, 126, 142	5,070
	This area was exposed to weathering. Test hole corings show particles of lime one-quarter inch and smaller.				
5	55	Traction	U-5	Dial readings: 117, 124, 142, 138	3,750
	This area is shaded by a large tree. Particles of lime one-quarter inch and smaller were present.				
6	55	Traction	U-6	Dial readings: 141, 151, 132, 141	3,140
	This station similar to U-5 though traffic load was greater.				
7	133	Traction	U-2	Dial readings: 102, 122, 149, 122	4,260
	Drilling was rather difficult. Compare with item No. 2 above.				
8	133	Traction	U-3	Dial readings: 147, --, 125, 147	3,080

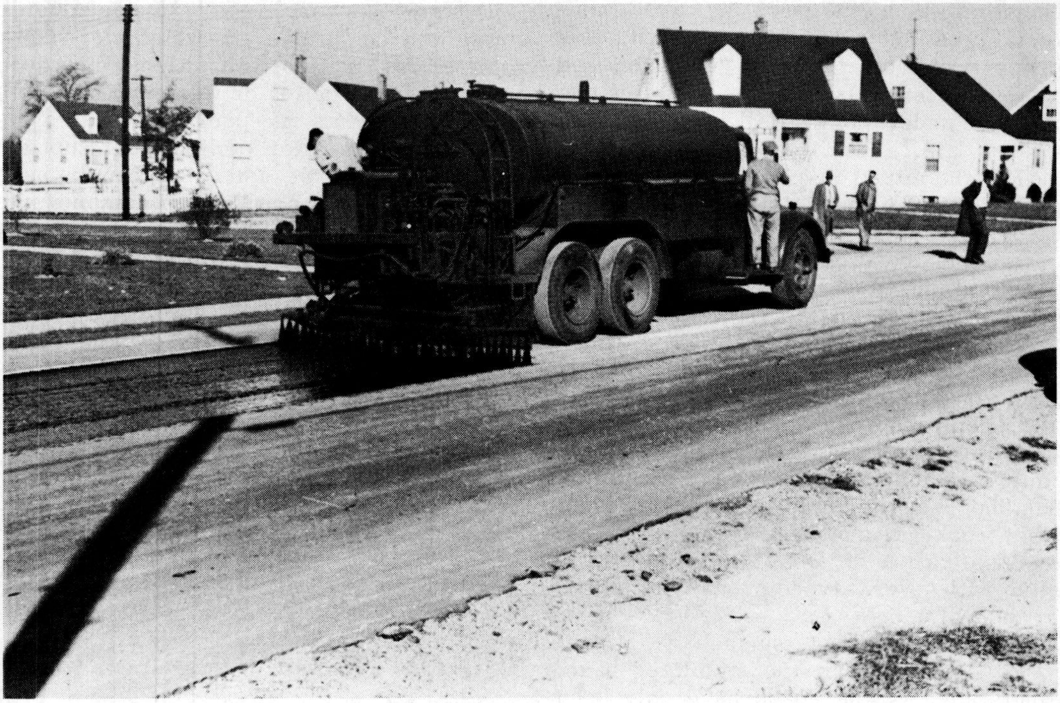


Figure 16. Application of MC-3 oil on stabilized base at project in Lindenwold, N. J.

Figure 17. Application of stone chips over shoulder project at US 301, Marlboro, Md.

tions in which the existing road material was subjected to the stabilization process. Projects using manufactured material imported to the job sites are likewise under way but will be reported at a later date.

For the mixed-in-place operation, the procedure in general followed that illustrated in Figures 6 to 11. The chief concern during construction was to establish good mixing and proper compaction. Constant check of moisture and density was carried out during the operation. Figures 12 to 19 show scenes taken from field projects constructed with the materials referred to in this paper.

A few tests were run using hydrated lime supplied in bulk form. While this has not been employed in the present field work, it has been established that the application of bulk lime is quite feasible with several types of sand spreaders in general use.

Several types of surface treatment have been placed on the stabilized base. Since most of the roads have only been constructed recently, it is too early to determine the relative merits of the various methods employed. The oldest application has been through three winters and is holding up quite well, showing no sign of deterioration. The use of both asphaltic oil and tar with applications of stone chips has been tried. In addition, the use of bituminous concrete in thickness of 1 to 2 in. has been employed and this treatment also appears to be performing satisfactorily.

There have been frequent inspection trips made to the field projects and a definite program of checking has been set up. Of particular interest are those points which were prepared under adverse weather conditions or which were subjected to unusual conditions of traffic during construction or were involved with such problems as poor drainage conditions, high water tables, poor subbase material, etc. Occasional specimens have been removed for unconfined compressive strength. The use of the portable equipment for making pulse-velocity measurements in the field has been in operation for about 6 mo. These measurements were usually made during the early stages on those roads recently constructed. Since this is the age period where considerable increase in strength is developed, the

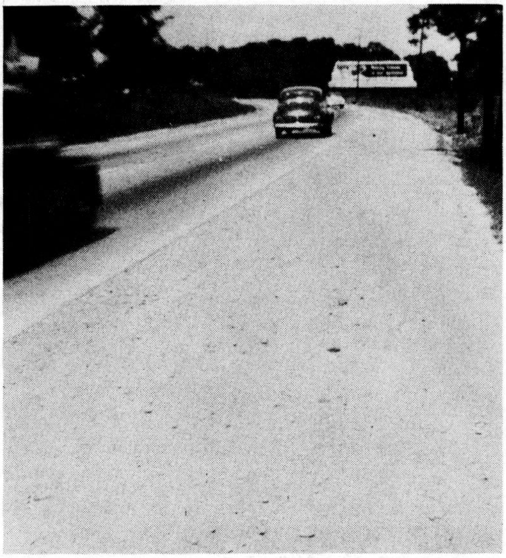


Figure 18. Condition of stabilized shoulder after one winter of service, no wearing course applied, US 1 Bypass, Laurel, Md.

TABLE 7

Field inspection data from the lime-flyash-stabilized shoulders of Navajo Road, Camden County, New Jersey. Composition, parts by weight: Lime, 4; flyash 10; soil, 90.

Item No.	Curing-Days Field	Type of Wavefront Measured	Station No.	Details Concerning Velocity Determination	Velocity Determination Ft. per Sec.
1	68	Traction	1	Dial readings: 116, 112, 123, 133	3,930
The native soil underlying this road and that used in the road, contained considerable glauconite.					
2	68	Surface Compression	4	Distance between transducer center axes, 3 in.	4,170
3	"	"	"	Distance, 6 in.	3,850
4	"	"	"	Distance, 9 in.	3,710

Figure 19. Condition of shoulder adjacent to stabilized section. US 1 Bypass, Laurel, Md.

results of these measurements are considered to be quite pertinent. Some of the observations made of the field tests are included in Tables 5, 6, and 7.

TEST RESULTS

The results of tests on optimum density-moisture requirements are included in Tables 1 and 3. In general, it has been noted that there is a slight drop in density with the lime-flyash mixtures as compared with those of the straight soil. Also there is a small change in the water requirement for the optimum compositions.

Unconfined Compressive Strength

Table 3 includes results for compressive strength tests for various soils. Most of these results are based on oven curing for 7 days, although it may be noted that the soil designated Mercer Avenue, A-3, was tested at 1 and 4 days, and the soils designated New Brunswick, New Jersey A-1-b and Marlboro, Maryland, A-2-5 were tested after additional 21 days curing at room temperature in a moist curing room. Also the soil designated Hightstown, New Jersey A-1-b was tested after aging three months by curing under moist conditions at room temperature. The soils marked HiNella, A-5 and Somerdale, A-5 both contained appreciable quantities of glauconite.

A number of compressive-strength values are given for specimens which were first subjected to freezing-and-thawing and wetting-and-drying tests. The strengths of these specimens were observed to be quite good.

It will be noted that the test results are included with the Bordentown, New Jersey, Soil A-1-b for those specimens which contained a bituminous fraction. Tests at both 5 and 7 days are presented. It is evident that the sample containing the bituminous fraction shows a significantly lower compressive strength value in 5 days, although the 7-day results are more nearly in agreement with the sample free of bituminous material.

Two of the soils, Mercer Avenue A-3 and New Brunswick A-1-b, were tested for compressive strength both in wet and in dry condition. From the results of the latter tests as well as other data available but not reported here, it is indicated that the samples which are in wet condition at the time they are tested give slightly lower compressive-strength values than

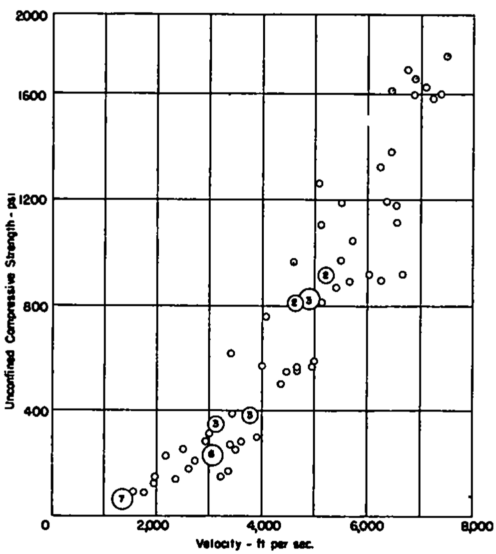


Figure 20. Unconfined compressive strength and velocity data for cured lime-flyash-stabilized soil samples in the oven dry state. These values represent both Proctor and 2-in. cubes of various soil classifications and curing conditions. The compositions include optimum and non-optimum proportions. Clusters of points are represented as circled numerals indicating the quantity of data contained in the area.

samples which have first been dried to constant weight. This would appear to conform to the results obtained from velocity tests described below.

All of those values which represent optimum proportions of lime and flyash are quite good, although it has been found that the laboratory results are usually somewhat lower than the results obtained on samples which were made from material mixed at the job site, prepared in the field, and then brought back to the laboratory. For example, in the soil designated Somerdale, New Jersey, A-5, the results from the field specimens were approximately 1,200 psi. as compared with the laboratory specimens which were 400 psi. The lime content in this field test was lower than that used in the laboratory mix. Similarly, the tests taken at HiNella showed nearly three times the strength in the field specimens. In addition to the above, samples removed from the road after being in service for periods of 6 mo. or longer usually averaged better than 2,000 psi. in unconfined-compression tests.

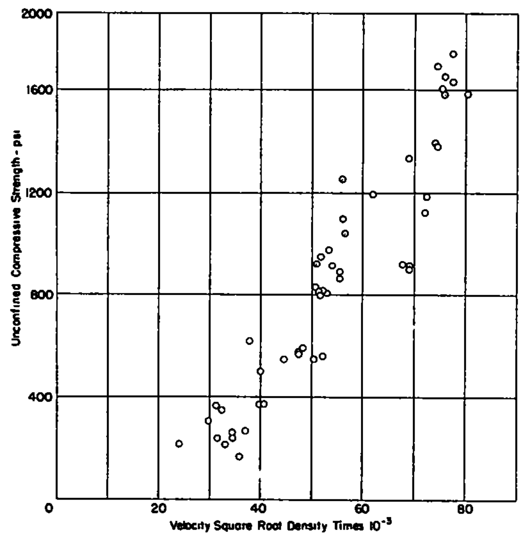


Figure 21. Unconfined compressive strength versus velocity-square-root density for optimum range lime-flyash-stabilized soil compositions. Proctor samples in the oven dry state.

Wetting and Drying

Wetting-and-drying specimens gave the same type results described in the previous papers (1, 2). The results of the wetting-and-drying tests are shown in Figures 23 to 27, and as will be noted, the specimens show good resistance to this treatment. In addition, the results are compared with the pulse-velocity tests. This is discussed more fully below.

Freezing and Thawing

Results of the standard test on the Proctor specimens showed that the materials with lime and flyash developed excellent resistance to freezing and thawing. The results of the test are given in Figures 23 to 27 inclusive. This method of determining freezing-and-thawing resistance is also compared with the pulse-velocity method as discussed in the next section.

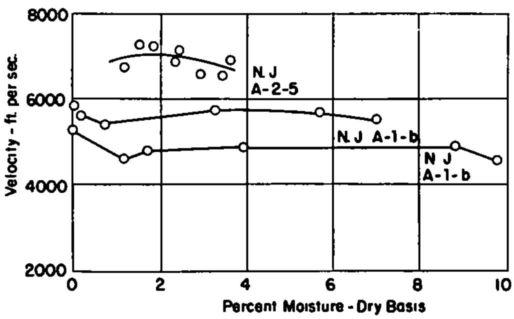


Figure 22. Moisture-velocity curves for cured lime-flyash-stabilized soil samples.

Pulse-Velocity Tests

Results of the pulse-velocity measurements are contained in Tables 4 to 7 and Figures 20 to 27 inclusive. A preliminary correlation between unconfined compressive strength and pulse velocity for cured lime-flyash-stabilized soil samples was reported in a previous paper (2) and included both optimum and nonoptimum compositions for an A-2-5 and an A-7 soil. Figure 20 gives an overall plot of unconfined compressive strength against pulse velocity measured on oven-dry samples prepared in the present investigation and also includes the data previously reported. Fourteen soils are represented including the following designations: A-1-a, A-1-b, A-2-5, A-3, and A-5. Also included are four points representing values for a lime-fly-ash-stabilized cinder mix which was available for use in this study. Those points which indicate a drift to the left at low values of compressive strength in Figure 20 represent the previous data on compositions made up with nonoptimum proportions while the companion compositions using optimum proportions fall into the general pattern.

Figure 21 is a plot of velocity compensated for the effect of density against unconfined compressive strength for optimum compositions measured in the oven dry state. The variation introduced by nonoptimum compositions is eliminated from this chart but very little change in overall correlation is indicated between the various soils by this operation.

The effect of the presence of water with several nonoptimum range compositions of A-7 soil was also previously studied and significant variations were reported. Figure 22 shows the effect of moisture content upon the pulse velocity of several optimum-range lime-flyash-stabilized soils from saturation to oven dryness. Table 4 shows group velocity data typical of five different stabilized soils from saturation to low moisture contents during wetting and drying cycles. This data indicates that velocity is not greatly affected by moisture in the case of optimum range compositions for the soils so far tested. Several sets of data taken during wetting-drying and freezing-thawing cycles showed that velocity is not greatly affected by temperature variations above 40 F. for cured optimum range lime-flyash-stabilized soil compositions. Mechanical stress, however, has been observed to decrease transit time by as much as 25 percent and the major portion of the data given in Figures 20 and 21 is known to have been affected by considerable variation in axial loading from transducer contact pressure.

In Figures 23 to 27 the cumulative weight loss, moisture content, and pulse velocity for a number of compositions during wetting-and-drying and freezing-and-thawing cycles is presented. For the materials tested the velocity values at the termination of the durability cycles showed a gradual decrease during the course of the test. Circled points at the end of the velocity curves of Figure 27 indicates that measurements taken on the core of the sample after the outside had been carefully removed are essentially equal to the measurements made on the complete sample. Several points which fall above the general pattern indicated in Figure 20 were obtained from unconfined compressive-strength tests made on samples which had been subjected to wetting-and-drying and freezing-and-thawing tests. It is indicated from these

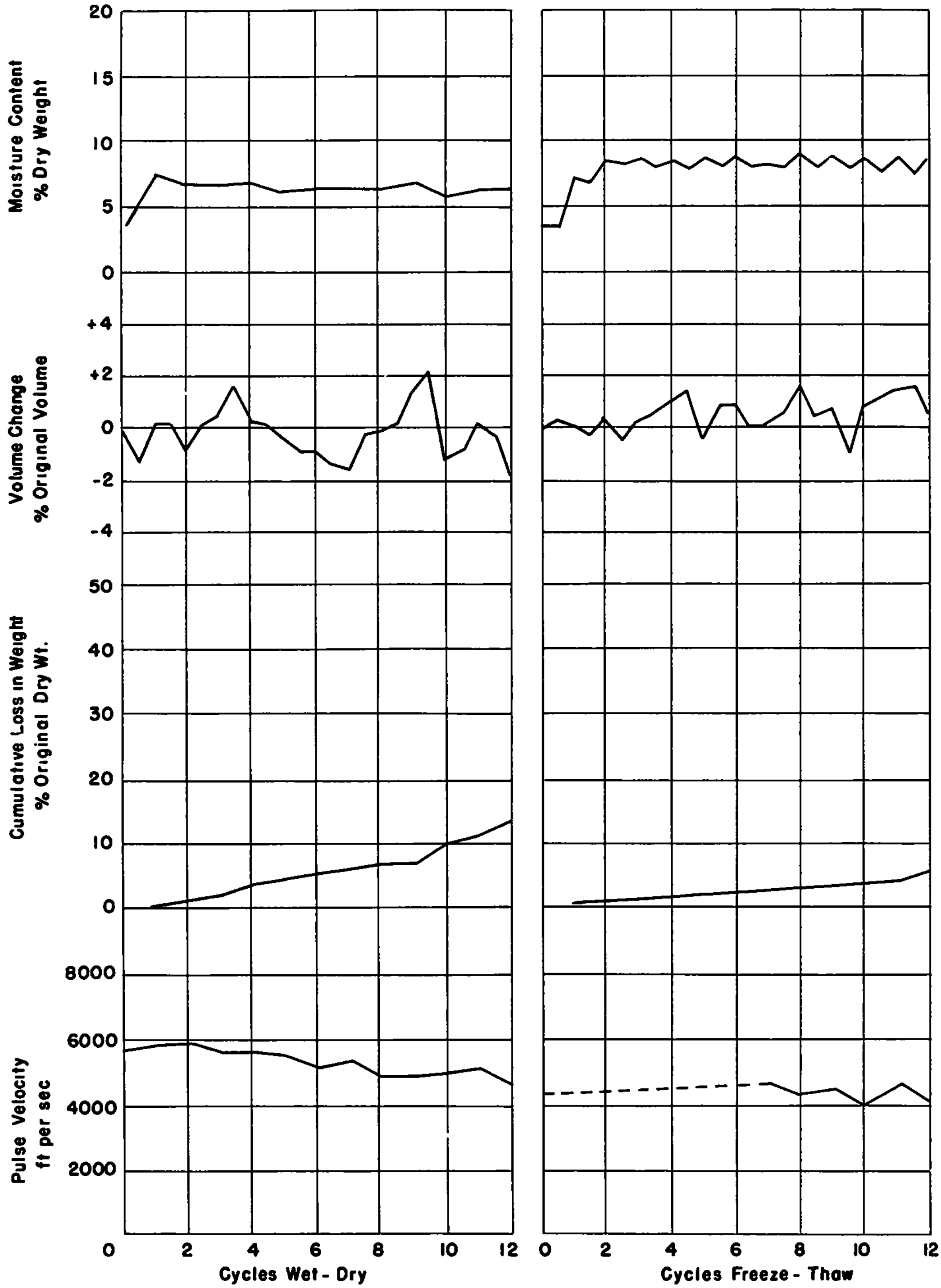


Figure 23. New Jersey Turnpike, New Brunswick Interchange.

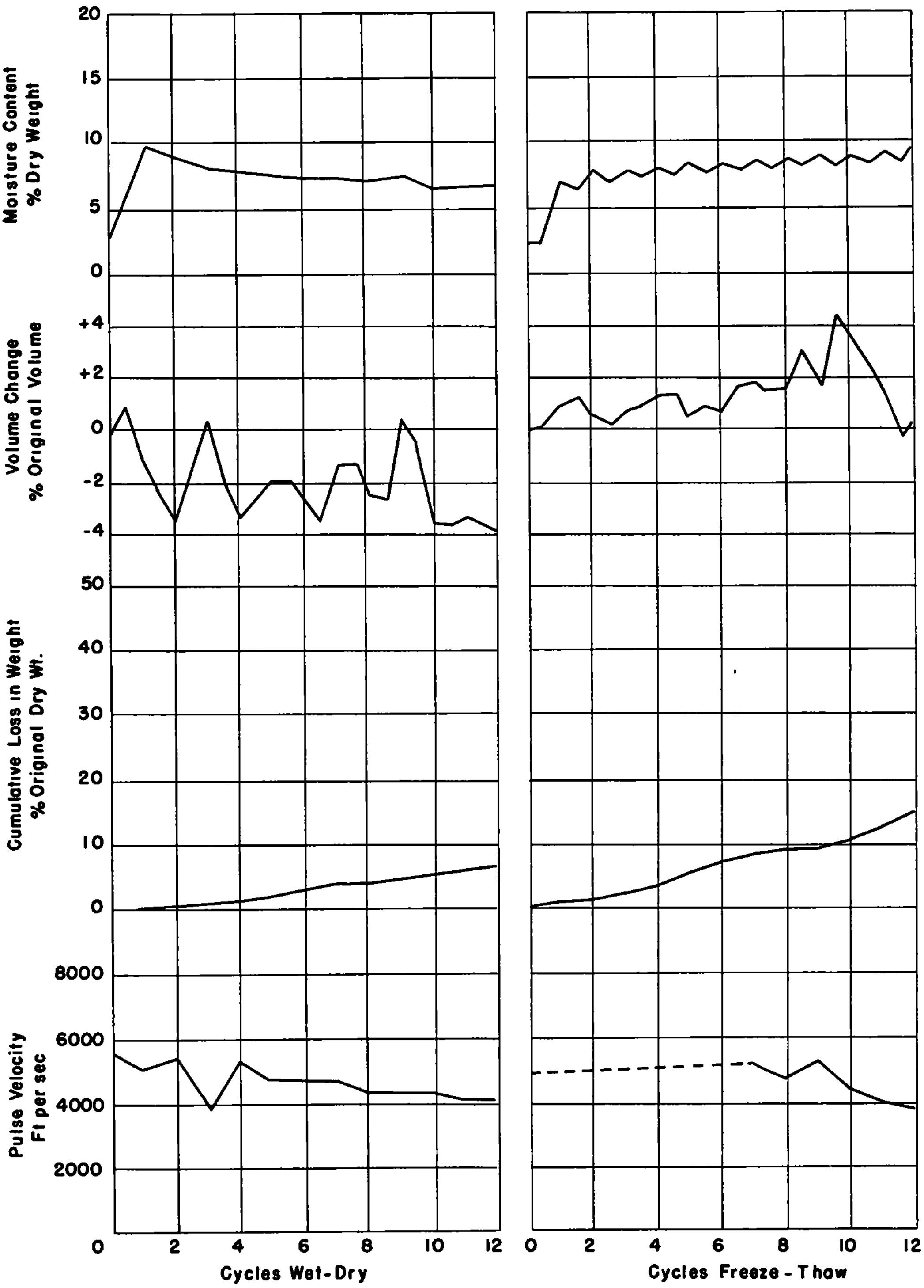


Figure 24. New Jersey Turnpike, Hightstown Interchange.

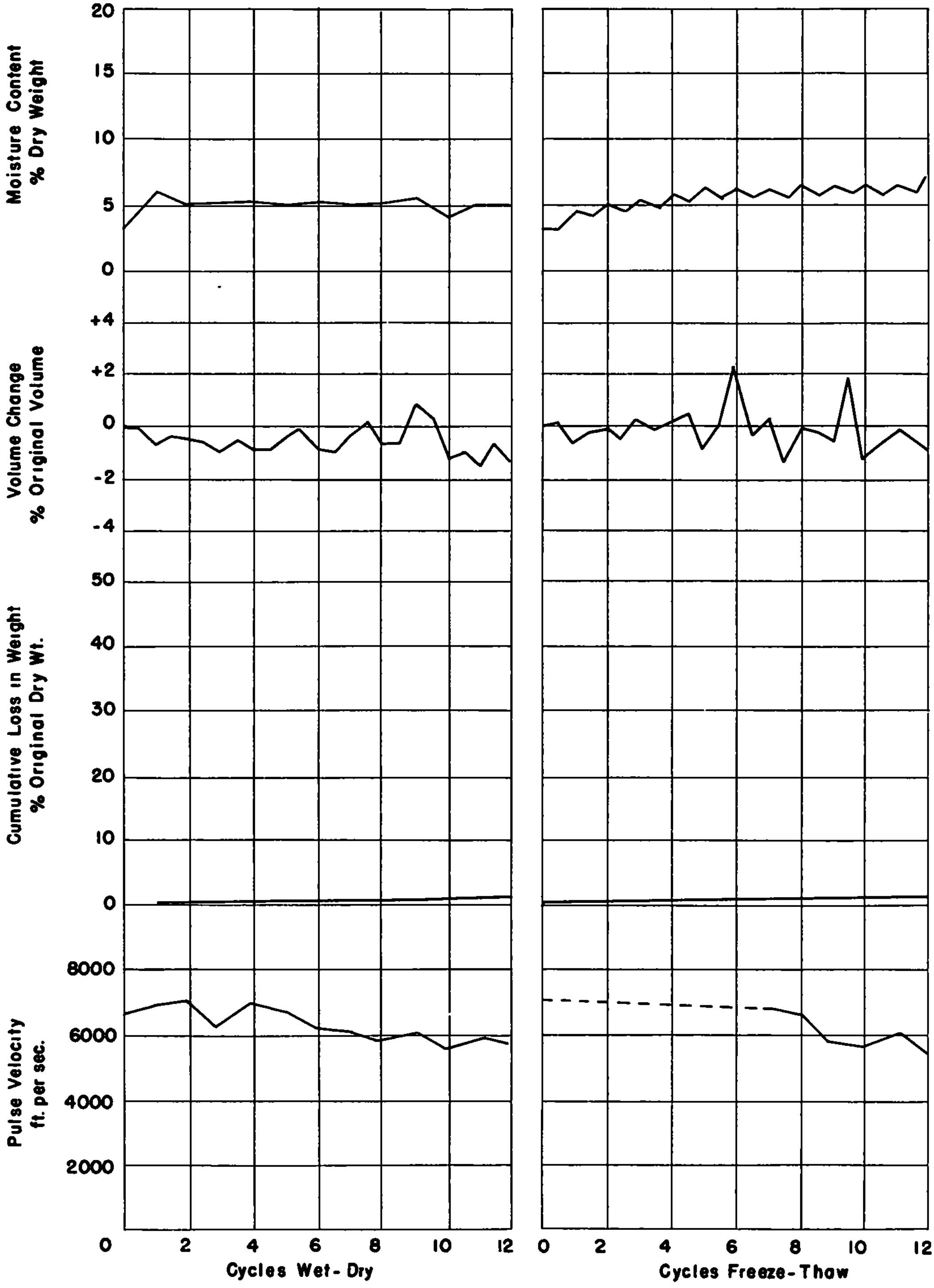


Figure 25. Marlboro, Md.

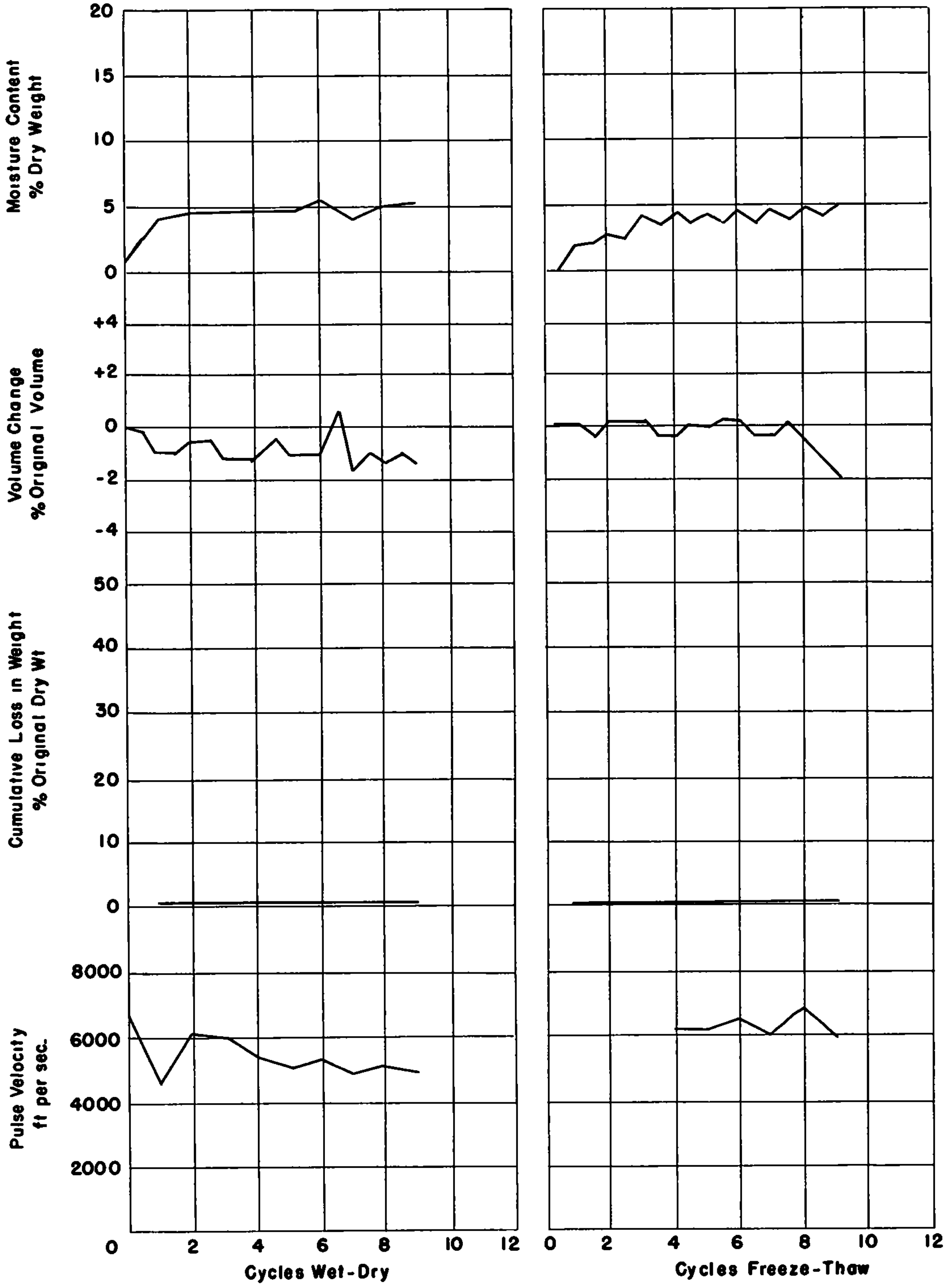


Figure 26. Mercer Avenue, Barrington, N. J.

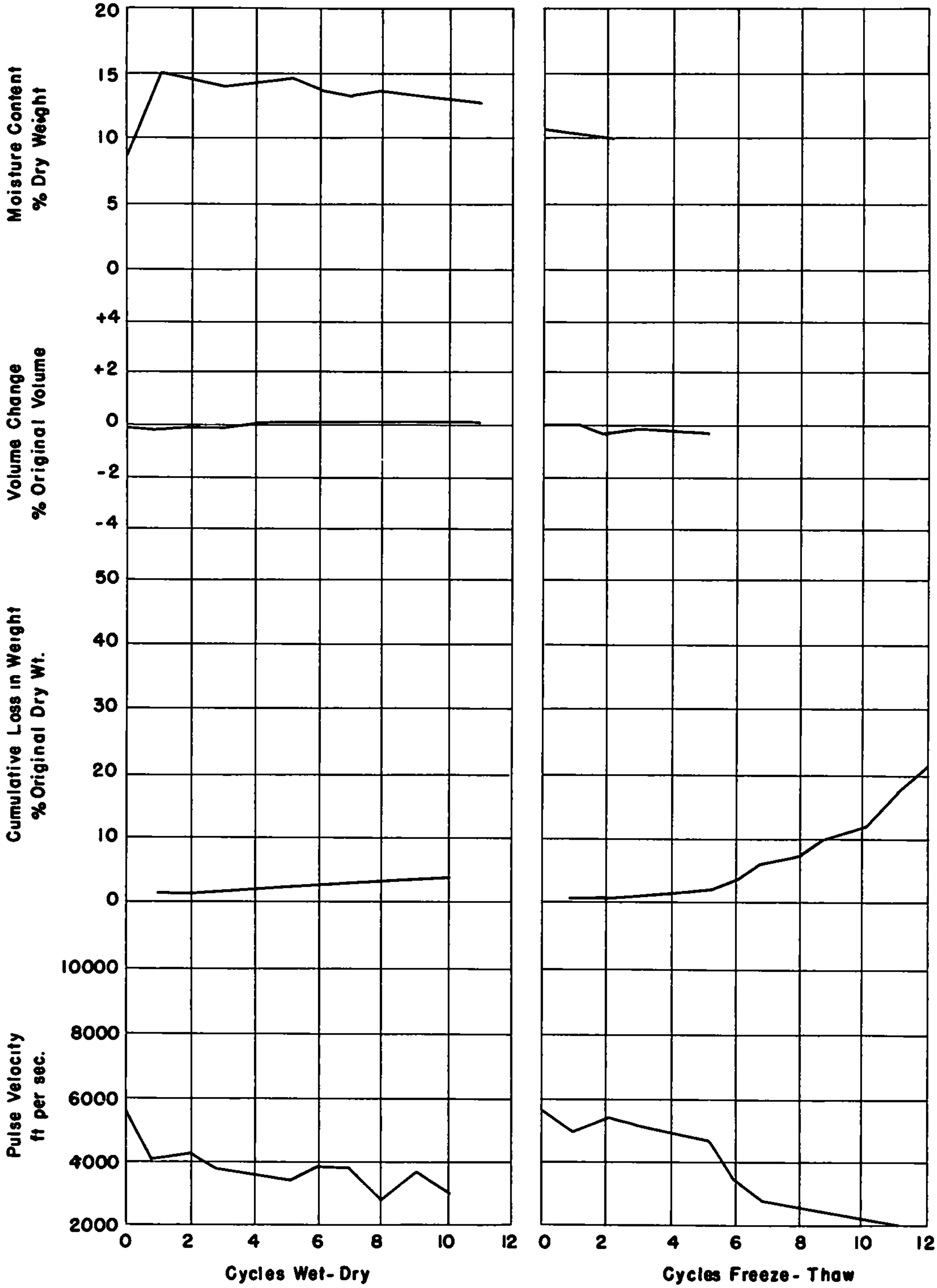


Figure 27. Woodbury, N. J.

values that the velocity measurements may be more effective in evaluation of the durability tests than unconfined compressive strength. Results of pulse-group-velocity measurements taken in the field are given in Tables 5, 6, and 7. It will be noted that initial compression-wave-front-velocity measurements taken with the transmitter and receiver vertically down upon the base material surface gave lower values than direct readings taken with axial in-line transducer orientation[1] under which conditions axial loading of the material is involved as in the case of the measurement of laboratory specimens.

Station numbers were determined to within 10 ft. Where traction readings were taken around a test hole, the instrument dial readings are given to indicate the velocity variation and the average used to calculate velocity from a calibration curve and the signal-path length.

CONCLUSIONS

While the study of lime-flyash-soil treatment has not extended to a point where full information is available, it is possible to draw several tentative conclusions which are indicated by the investigation up to the present time:

1. For the soils studied it is evident that the additions of small amounts of hydrated lime and flyash develop concrete-like compositions of high strength at relatively early ages. When compacted with optimum moisture, unconfined compressive strengths are developed of the order of 1,000 psi. in 28 days (ambient temperature condition). When cured at elevated temperature (140 F.) which accelerates the pozzolanic reaction of the lime and flyash, the compressive strengths obtained in 7 days are of the order of 350 to 1,400 psi. depending upon the soil type used.

2. The weathering resistance of the compositions appears to be exceptionally good since tests for wetting and drying and freezing and thawing show excellent resistance to deterioration after 12 cycles of treatment.

3. The use of pulse-velocity measurements indicates that this method is useful in evaluating the strength and weathering resistance of the compositions both in the laboratory and in the field. A relationship exists between unconfined-compressive-strength and pulse-group-velocity measurements. The presence of moisture in the specimens made with optimum proportions of lime and flyash is found to have little effect on the velocity readings. For nonoptimum mixtures the moisture content has been observed to effect the velocity reading.

It is indicated that the use of pulse-velocity methods are better suited to measuring durability of the compositions than are the standard wetting-and-drying and freezing-and-thawing tests. The laboratory tests are convenient to carry out and the field investigation is markedly simplified, since the measurements may be made on the same section of road at periodic intervals. It is felt that the use of fundamental transverse - resonant-frequency measurements can also serve to give adequate indications of performance of laboratory samples (2, 3). However, this method is involved with shape considerations and is, of course, not readily adaptable to use in the field.

4. The newly developed equipment for measuring pulse velocity is rugged, stable, and inexpensive to build. A portable unit has been produced which is well suited for use in the evaluation of stabilized road bases.

5. Field tests up to the present time show in all cases good performance for the compositions that have been prepared by the mixed-in-place operation. Several procedures are being tested to evaluate surface coverings for the stabilized base and these will be reported at a future date.

ACKNOWLEDGEMENT

The authors wish to express their appreciation of the interest that Havelin and Kahn have taken in this work. These gentlemen are responsible for the original discovery -- the benefit of adding a small amount of lime and flyash to aggregate materials. Also, the authors wish to express their appreciation to the Philadelphia Electric Company for its support of this work.

[1]By comparison to traction wavefront velocity measurements, Table 7, Item No 1 - 4

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