Field Evaluation of Lime-Flyash-Soil Compositions for Roads

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A number of field projects have been studied in which lime-flyash-soil compositions have been used in the construction of roads, parking areas, an airfield runway, and an earthwork wall. Performance has been evaluated by physical inspection, by the use of sonic procedures and by testing of undisturbed specimens which have been removed from the base. These results were compared with laboratory studies involving pozzolanic activity tests conducted at elevated temperature and bearing tests made on specimens which were subjected to alternate wetting and drying cycles. The results of the survey have been quite favorable. Except for minor indications of distress on a few of the projects involving unsatisfactory subgrade or drainage conditions, the bases covered with bituminous wearing course are in excellent condition. A recommended laboratory evaluation procedure for the lime-flyash compositions is presented.

● THE investigations described in this paper are continuations of studies described several years ago in reports to the Highway Research Board and elsewhere (1 to 14). Since that time hydrated lime and flyash compositions have been used commercially in numerous applications including roadways, base course and shoulder construction, airport runways, parking lots, drive-in theaters, soil embankments and the like. Most of these field projects have been constructed within the last three years (although a few are older than this), and it is therefore realized that a full evaluation of the compositions cannot yet be made. However, it is felt that sufficient time has elapsed to permit a first evaluation of a representative number of these projects. The records of frequency of frost cycles have indicated that the winter of 1954-55 was particularly severe in the Philadelphia area, and this was felt to be a further justification of making a report of conditions of the jobs at this time.

In addition to making the initial appraisal of the performance of the projects, an effort has been initiated to correlate results in the field with the previous tests that were made in the laboratory. In order to do this a number of undisturbed specimens were removed from the field projects and brought to the laboratory where they were tested for unconfined compressive strength and other properties. The results of the tests on these specimens have uncovered some data which, in general, support the earlier laboratory tests. Furthermore, the findings to date have suggested improved methods of laboratory testing which may afford a realistic basis for evaluation of the anticipated performance of the compositions and assist in making adequate design calculations for applications employing the lime-flyash treatment.

It is clearly evident that the lime-flyash treatment is only indirectly related to other forms of soil treatment, and therefore requires its own testing techniques. It was, of course, natural for the early tests that were reported previously to employ existing test methods such as unconfined compressive strength, wetting and drying and freezing and thawing tests using wire brush techniques, dynamic modulus tests, pulse velocity tests and the like. Some of these precedures (particularly the sonic tests) are still useful in the evaluation of lime-flyash compositions, but, in general, the test methods which are considered to be adequate for projection into field performance are substantially different in character from the procedures used for other forms of soil treatment. These tests are presented in this paper.

THE FIELD SURVEY

Various construction methods are currently being employed in the use of lime and flyash for the treatment of in-place or select materials. The materials include stone screenings, slag, cinders, and soils ranging from the sandy or gravelly forms to the fine grained and plastic variety. All but two of the projects listed in this presentation were constructed by mixed-in-place operations, several types of mixing and compaction equipment being used. The exceptions were constructed with a complete plant mix consisting of dolomitic lime, flyash, and crusher screenings. Figure 1 shows a road base being built with this material. The plant or pre-mix method has a number of advantages which have made this method commercially attractive — advantages such as a reduction in the total construction time and in the amount of road building equipment which is used. A further advantage is the ability of the lime and flyash mixtures to be stockpiled for periods of several weeks before or during construction. Figure 2 is a picture of one of the plants that have been set up to produce these compositions as a plant controlled mix.

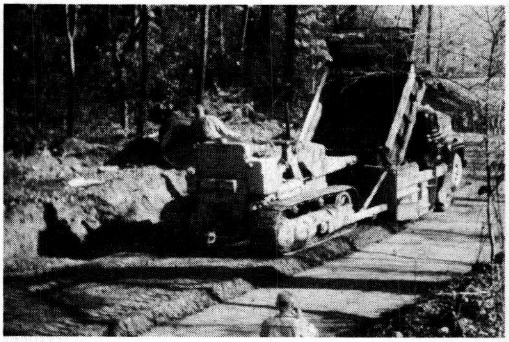

Figure 1. Plant mix lime-flyash-stone screenings being applied with bulk spreader.

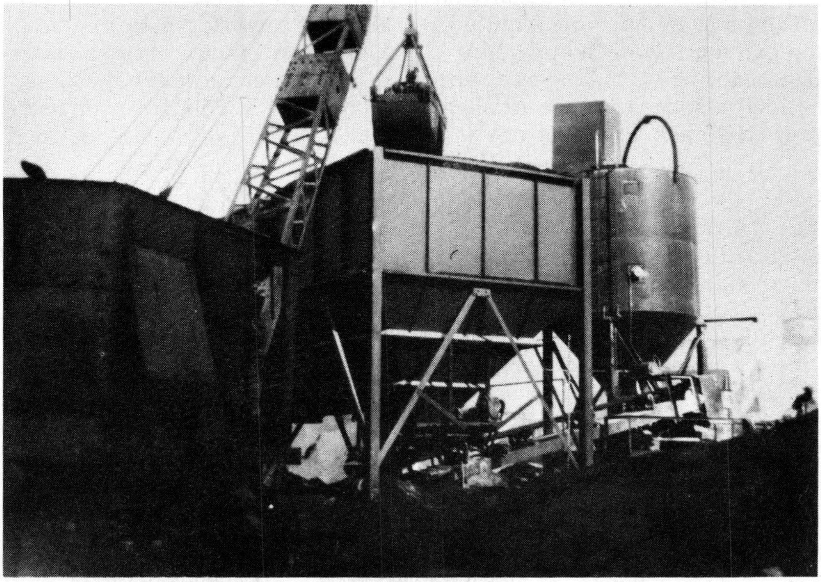

Figure 2. A ready-mix plant of Pozzolan Products Company, Chicago, Illinois which is producing a lime-flyash-slag mixture for general use in road bases and similar construction.

The selection of jobs for inclusion in this report was felt to be representative of the type of construction being considered. It is to be pointed out that many other jobs have been installed using the lime-flyash treatment, but, in order to keep the presentation at reasonable length, these have not been included. In general, the performance of these compositions conforms with those described below.

Since the use of lime and flyash treatment is relatively new, it is natural that the testing procedures and techniques have been undergoing some change. Therefore, the pattern of tests are not always identical for each project. In general, the evaluation has consisted of a periodic inspection of the job, removal of specimens for laboratory study, and, in a few instances, measurements of in-place pulse velocity to evaluate the condition of the base composition at various times. Tables 1 to 5 represent a compilation of pertinent facts which have been determined from the field projects. In addition to the information given in these tables, several special tests were carried out in the field to develop additional information which was felt might be of interest in the evaluation of other projects. These tests were considered of sufficient interest that

Figure 3. Route 422 shoulder - Break up of bituminous wearing course over stone base.

TABLE 1

FIELD SURVEY - COMPOSITION CHARACTERISTICS

Sample No.	Job Location	Engr. Class of Subgrade Material (H.R.B.)	Soil used in composition: Textural Classification	P.I.	Liquid Limit	Engr. Class	Composition (% by weight): Soil	Agg.	Fly Ash	Lime
1	Ply. Wht. School, Pa.	A-6	Sandy Loam	13	28	A-6	60	30	10	5
2	7th St., Camden, N.J. (Slag)	A-1-b	Wet bottom boiler slag	-	-	A-1-b	-	75	25	4
3	7th St., Camden, N.J.	A-1-b	Mixture(sand & Cinders)	-	-	A-1-b	90	-	10	5
4	Wings Field, Pa. (Runway)	A-4*	Sandy Loam	10	35	A-5	45	45	10	5
5	Wings Field, Pa. (Parking)	A-4	Sandy Loam	10	25	A-5	60	30	10	5
6	Laurelton Circle, N.J.	A-3	Gravel and Sand	NP	-	A-1-b	90	-	10	5**
7	Phila. Int. Airport	A-1-b	Coarse sand	NP	-	A-1-b	90	-	10	5
8	Jenkintown Sta., Pa.	A-4	Fine sandy loam	9	24	A-4	60	30	10	5
9	Burlington Sta., N.J.	A-1-b	Wet bottom boiler slag	-	-	A-1-b	-	75	25	4
10	Phila. Cricket Club	A-4	Loam	8	32	A-4	45	45	10	6
11	Rt.422, Ply.Mtg., Pa.	A-6	Sand and gravel	13	29	A-1-b	90	-	10	5
12	Mainline Drive-In, Pa.	A-5	Fine sandy loam	7	42	A-5	60	30	10	4.5
13	Laurel By-Pass, Md.	-	Sand and gravel	NP	-	A-1-a	90	-	10	5**
14	Rt. 322 By-Pass, N.J.	-	Wet bottom boiler slag	-	-	A-1-b	-	75	25	3
15	Quarry Rd., Ply.Mtg., Pa.	A-6	Wet bottom boiler slag	-	-	A-1-b	-	75	25	3
16	Barbadoes Sta., Pa.	A-4	Quarry screenings	-	-	A-1-b	-	90	10	3
17	Snowhill, Md.	-	-	-	-	A-2-4	90	-	10	5**

*Lime stabilized soil subbase six inches thick used under base.
**These projects used high calcium hydrated lime; all other jobs used dolomitic hydrated lime.

TABLE 2

FIELD SURVEY - JOB CHARACTERISTICS

Sample No.	Job Location	1 Thickness Base Course (In.)	2 Type and Thickness Wearing Course	3 Drainage Conditions	4 Construction Date	5 Type of Construction	6 Volume of Traffic	7 Traffic Loading
1	Ply.Wht. School, Pa.	5	None	Poor	8/54	Parking area	Low	Light
2	7th St., Camden, N.J.	6	2" Hot mix	Good	7/54	Road Base	4640 Veh/da.	3% Heavy
3	7th St., Camden, N.J.	6	2" Hot mix	Good	7/54	Road Base	4640 Veh/da.	3% Heavy
4	Wings Field, Pa.	6	1" 3 course penetration	Good	8/54	Runway base	Low	5% Heavy
5	Wings Field, Pa.	6	Double application oil & chips	Good	9/54	Parking area	Low	5% Heavy
6	Laurelton Circle, N.J.	6	Double application oil & chips	Good	9/53	Shoulder base	-	-
7	Phila. Int. Airport	6	2" (ID-2) hot mix	Good	10/53	Parking area	High	Light
8	Jenkintown Sta., Pa.	5	2" (HE) cold mix	Good	6/53	Parking area	Low	Light
9	Burlington Sta., N. J.	6	One application oil & slag	Good	11/52	Road Base	Low	50% Heavy
10	Phila. Cricket Club	6	2" (HE) Cold mix	Good	5/54	Road and Parking area	Low	Light
11	Rt.422, Ply.Mtg., Pa.	6	2"(ID-2) Hot mix	Poor	7/54	Shoulder base	7800 Veh/da.	15% Heavy
12	Main Line Drive-In, Pa.	6	One application oil & chips	Poor	7/53	Road base	700 Veh/da.	Light
13	Laurel By-Pass, Md.	6	One application oil and crushed gravel	Good	6/51	Shoulder base	-	-
14	Rt. 322 By-Pass, N.J.	6	2" Cold mix	Poor	10/51	Road base	High	10% Heavy
15	Quarry Rd., Ply.Mtg., Pa.	4.5	None	Poor	5/51	Road base	Low	90% Heavy
16	Barbadoes Sta., Pa.	4	2" (HE) Cold mix	-	-	Parking area	Low	Light
17	Snowhill, Md.	6	-	-	11/54	Road base	-	-

Low - 1000 or less vehicles per day
High - Several thousand or more vehicles per day
Light - Automobile and light truck
Heavy - Heavy trucks

they could be briefly mentioned and are included later in this presentation.

One of the more important projects which was studied was in connection with a shoulder construction on Route 422, a Pennsylvania highway near Norristown. This project was of special interest because it involved a lime-flyash treated shoulder base constructed on one side of the highway at the same time that the shoulder base on the opposite side of the highway was constructed using conventional Pennsylvania Department of Highways practice. This latter shoulder base has served as a reference or control mix and consists of a crushed aggregate Type A stone placed over an overlay of stone screenings, built up in two layers to a depth of eight inches. The limestone screenings were applied as a choke material. Both of these shoulders were constructed under State Highway supervision and used the same material as wearing course (Pa. Highway Department Type ID-2). This project was constructed rather late in the season, too late in fact for the lime and flyash to develop its ultimate pozzolanic "set." After a few months of service the control or stone base shoulder showed signs of developing small hair check cracks. After some six months these cracks had developed to the point where they were readily apparent and had spread over much (approximately one-half) of the total area. In the spring of 1955 the shoulder showed considerable distress to the extent that it began to "pothole" and developed the common type of failure which is very prevalent in many of the secondary roads in the suburban Philadelphia area. The lime-flyash treated shoulder, however, did not show distress. Figures 3 and 4 show the two sides of the road taken at the time the sample of lime-flyash base was removed.

It is felt that this particular project has been of considerable value in establishing

TABLE 3

FIELD SURVEY - JOB APPEARANCE

Sample No.	Job Location	Appearance (At time sample was removed)*
1	Ply. Wht. School, Pa.	Lamination at the surface (1/8 to 1/4 inch deep). No appreciable amount of surface raveling.
2	7th St., Camden, N.J.	No base failures, no raveling or cracking of wearing surface.
3	7th St., Camden, N. J.	No base failures, no raveling or cracking of wearing surface.
4	Wings Field, Pa. (Runway)	No base failures, no raveling or cracking of wearing surface.
5	Wings Field, Pa. (Parking)	Some distortion (approx. 5% of area) of base and wearing surface, caused by frost damage in first 3 months of service. Wearing course showed no failure after initial repair work.
6	Laurelton Circle, N.J.	No base failures, occasional hair cracks in wearing surface.
7	Phila. Int. Airport	No base failures, no raveling or cracking of wearing surface.
8	Jenkintown Sta., Pa.	No base failures, no raveling or cracking of wearing surface.
9	Burlington Sta., Pa.	Several shear cracks in base, some raveling of wearing surface at several locations.
10	Phila. Cricket Club	No base failures, one crack (4 ft. in length) in wearing surface.
11	Rt. 422, Ply. Mtg.,Pa.	No base failures, no raveling or cracking of wearing surface.
12	Mainline Drive-In, Pa.	No base failures, considerable raveling of wearing surface (mostly on curves).
13	Laurel By-Pass, Md.	No base failures, no raveling or cracking of wearing surface.
14	Rt. 322 By-Pass, N.J.	No base failures, no raveling or cracking of wearing surface.
15	Quarry Rd., Ply. Mtg.,Pa.	Some lamination noticed throughout base, probably caused by method of construction.
16	Barbadoes Sta., Pa.	No base failures, no raveling or cracking of wearing surface.
17	Snowhill, Md.	

*See Table 5.

TABLE 4

FIELD SURVEY - TEST RESULTS

		1	2	3	4	5
		Dry Density*		Percentage of Lab. Density Obtained In field	Moisture Content in saturated state	
Sample No.	Job Location	Lbs/cu.ft. Lab. Sample	Lbs/cu.ft. Field Sample		Lab.Sample %	Field Sample %
1	Ply.Wht. School, Pa.	121.4	115.3	95.1	8.4	11.6
2	7th St.,Camden, N.J.(slag)	135.0	145.6	107.8	7.5	7.2
3	7th St., Camden, N.J.	110.2	120.8	109.5	11.1	9.5
4	Wings Field, Pa. (runway)	128.0	120.4	94.0	10.5	15.0
5	Wings Field,Pa.(parking)	124.0	103.7	83.5	10.5	19.9
6	Laurelton Circle, N.J.	127.3	134.1	105.8	7.5	6.8
7	Phila. Int. Airport	128.0	122.4	95.7	8.8	8.1
8	Jenkintown Sta., Pa.	120.0	99.5	82.6	9.5	21.6
9	Burlington Sta., N.J.	139.5	140.6	100.8	7.5	7.1
10	Phila. Cricket Club	125.0	122.8	98.0	9.5	7.2
11	Rt. 422, Ply. Mtg., Pa.	121.2	112.0	92.4	6.8	8.4
12	Main Line Drive-In, Pa.	126.0	105.5	83.7	10.0	16.1
13	Laurel By-Pass, Md.	120.0	105.4	88.0	9.0	-
14	Rt. 322, By-Pass, N.J.	140.0	132.5	94.7	8.0	8.8
15	Quarry Rd., Ply.Mtg., Pa.	139.5	133.0	95.4	8.0	-
16	Barbadoes Sta., Pa.	136.2	131.6	96.5	6.5	8.3
17	Snowhill, Md.	124.0	-	-	-	-

*Modified Proctor - 3 Layers.

TABLE 5

FIELD SURVEY - TEST RESULTS (Continued)

Sample No.	Job Location	1 Compressive Strength (psi) Lab 140 F, 7 da. Dry	2 Saturated	3 Field Dry	4 Field Saturated	5 Pulse Velocity Ft./Sec. Field Dry	6 Saturated	7 Age of Field Sample
1	Ply. Wht. School, Pa.	1270 ± 80	-	1770 ± 20	1240*	5300	4920	1 Year
2	7th St., Camden, N.J.	1870 ± 120	-	2000 ± 320	1845 ± 170	4200	3840	1 Year
3	7th St., Camden, N.J.	1770*	1335 ± 40	1690 ± 15	1340 ± 70	5130	4980	1 Year
4	Wings Field, Pa. (Runway)	1360 ± 90	-	1545 ± 25	1315 ± 45	4920	3870	1 Year
5	Wings Field, Pa. (Parking)	1120 ± 110	-	270 ± 20	100 ± 25	2770	2080	1 Year
6	Laurelton Circle, N.J.	870 ± 40	785 ± 30	1055*	605*	6100	4850	2 Years
7	Phila. Int. Airport	745 ± 5	-	1935 ± 50	1015 ± 100	4950	4630	2 Years
8	Jenkintown Sta., Pa.	900 ± 30	-	680 ± 5	370 ± 10	2720	2410	2 Years
9	Burlington Sta., N.J.	1870 ± 115	-	2080 ± 45	1640 ± 20	5380	4950	3 Years
10	Phila. Cricket Club	-	-	1420 ± 15	550 ± 25	4170	3480	15 Months
11	Rt. 422, Ply. Mtg. Pa.	800 ± 40	-	2680 ± 100	1910 ± 130	5360	4050	1 Year
12	Main Line Drive-In., Pa.	620 ± 15	-	750 ± 20	290 ± 40	2445	1940	2 Years
13	Laurel By-Pass, Md.	900*	-	2090*	-	6310	-	18 Months
14	Rt. 322, By-Pass, N. J.	1850 ± 60	-	3350 ± 500	2900*	6585	5840	11 Months
15	Quarry Rd., Ply. Mtg., Pa.	450 ± 55**	-	4315 ± 100	-	-	-	4 Years
16	Barbadoes Sta., Pa.	1700 ± 80	-	740 ± 40	500*	3470	3420	4-1/2 Years
17	Snowhill, Md.	1520 ± 10	-	1750*	-	-	-	6 Months

*Based on Single Value.
** Cured at 70 F for 90 days.

the merit of the lime-flyash composition. Obviously this composition produced a base of adequate design for the heavy wheel loading and high traffic volume and for the climatic and subgrade conditions prevailing at this site. On the other hand, the stone base, while thicker, was inadequate for this service. This is an indication that the type of base employed may significantly affect the overall design thickness of a pavement.

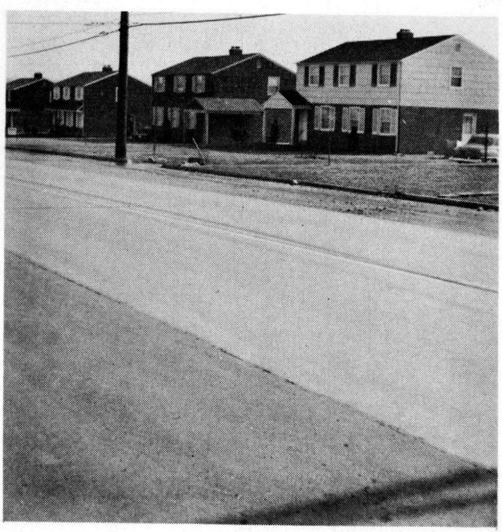

Figure 4. Route 422 shoulder - Lime-flyash-soil construction on shoulder opposite that given in Figure 3.

EVALUATION TESTS

Unconfined Compressive Strength of Field Specimens

The tests included in Columns 3, 4, 5 and 6 of Table 5 were obtained from "undisturbed" samples removed from the field. Figures 5 and 6 show the method of taking the samples. The size of the specimens which were cut out of the pavement were from 18 inches to 24 inches square. These were taken back to the laboratory where they were further cut by Clipper saw into smaller sizes so that they could be tested for unconfined compressive strength. The samples were stored outdoors for several weeks prior to final cutting and testing. Figure 7 shows a few of these samples as prepared in the laboratory. For the unconfined compressive strength test the procedure adopted was to cut out specimens of cubes which were then broken both in dry condition and in

Figure 5. Sample removal with Clipper saw.

saturated wet condition. The method of drying was to place the specimens in a large laboratory oven at 140 F until they reached constant weight. The saturated samples were immersed in water and kept there a minimum of one week. Discussion of the results of these tests is included below in the section on accelerated test methods.

Freezing and Thawing Studies

Laboratory Tests. Figures 8 and 9 show the laboratory set-up used for making freezing and thawing studies on the lime-flyash-soil compositions. In making these

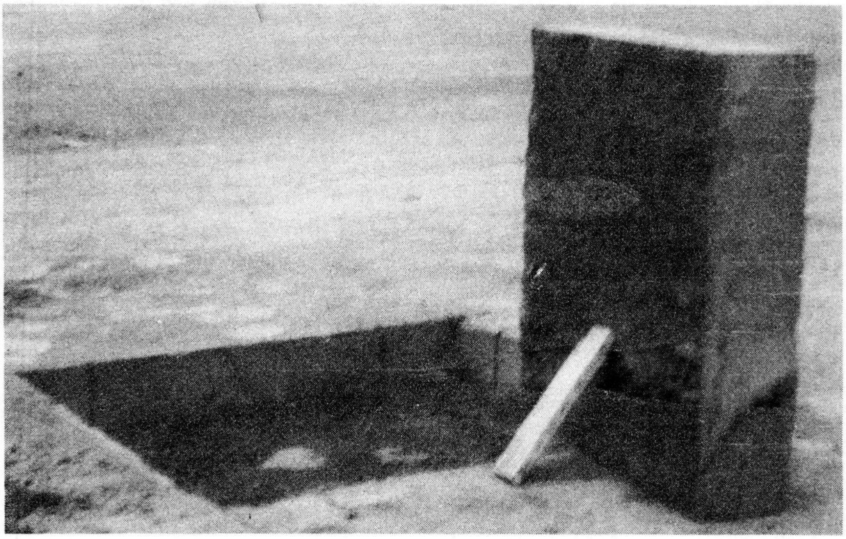

Figure 6. Typical undisturbed base specimen.

tests several variations have been used, such as changes in the size of the specimens and in the method of curing the specimens. The cubes were prepared as 6-inch or 12-inch cubes and were molded by compacting the material in 1½ to 1¾ inch layers (compacted depth) with a 10 pound square shaped tamper using 50 blows per layer. This resulted in a dry density equivalent to that developed in the other laboratory tests. The specimens were set into larger sized wooden boxes which contained the subbase material. The specimen rested upon several inches of the subbase material, and in some instances was completely imbedded in it. In other cases the material surrounding the specimen was selected either from the job area or was a select material of specific drainage characteristics. In a number of instances a bituminous wearing course was applied to the top surface simulating conditions used in the field. In order to record the temperature several thermistors were permanently imbedded in the specimens and these were connected with indicating meters enabling the testing engineer to observe the temperature drop. After preparation, the complete assemblage was submerged in water for 24 hours after which it was placed on a laboratory bench and a block of dry ice was set on

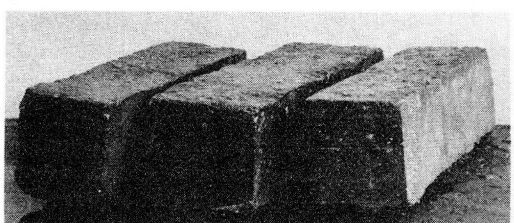

Figure 7. Lime-flyash-soil specimen.

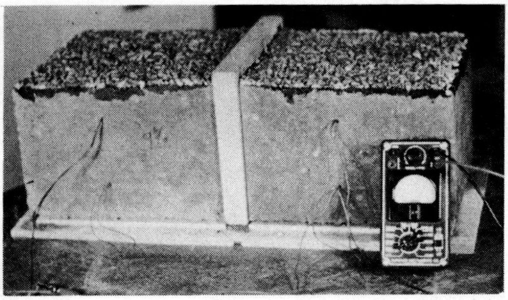

Figure 8. Freezing and thawing set-up.

Figure 9. Typical specimen used in freezing and thawing test.

the upper surface of the specimen. A record was kept of the temperature change and when the temperature of the lower thermistor reached a sufficiently low value to indicate that the specimen and underlying material had frozen, the dry ice was removed and the assemblage was allowed to thaw out either under laboratory conditions or by the use of infrared lamps directed to the top surface. The freezing and thawing procedure was repeated for 10 cycles, the assemblage being resaturated after each thaw period.

Table 6 and Figure 10 give typical results of these tests. Several observations can be made from these data, namely that the method shows changes in internal structure as indicated by changes in the rate of freezing. Secondly, the heave of the specimens was found in some instances to be significant giving an indication of what could be expected under field conditions with a similar combination of base and subbase materials.

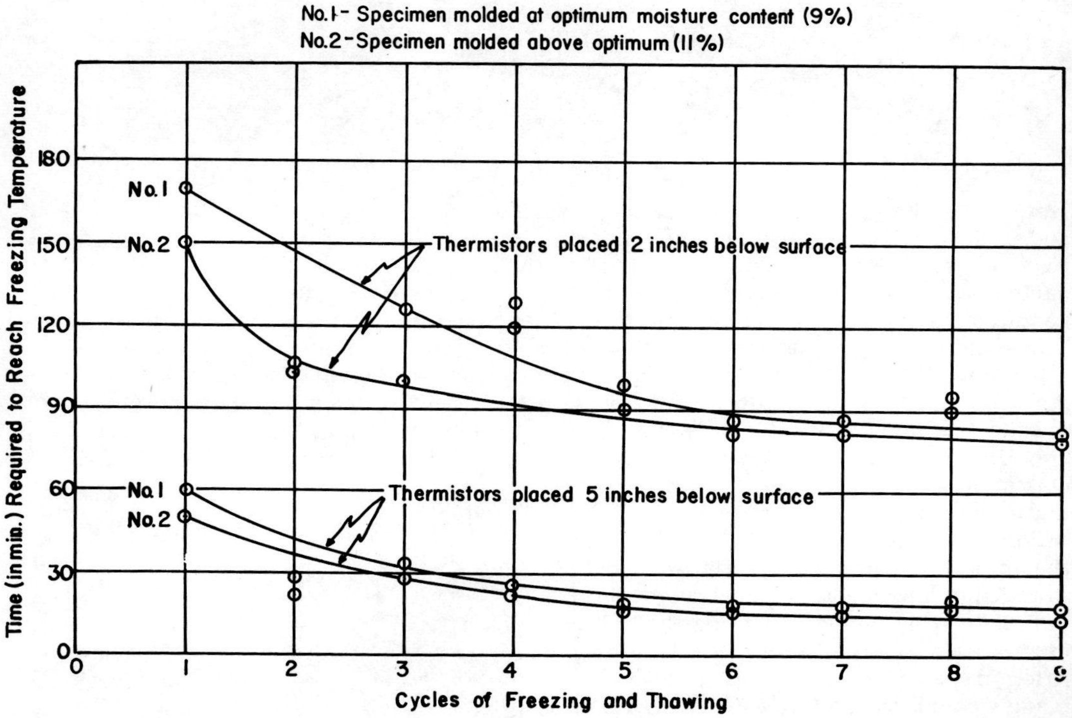

Figure 10. Change in rate of freezing of lime-flyash-soil specimens during successive cycles of freezing and thawing.

TABLE 6

LABORATORY FREEZING AND THAWING TEST

SOIL TYPE: A-5
SUBBASE TYPE: A-5

Cycle No.	Temp. when reading °F	Heave of specimen as determined by cathetometer reading in cm for 6" depth: First Sample Optimum moisture	Second Sample Excess moisture	Remarks: First Sample	Second Sample
0	65	-	-	-	-
1	60	0.00	0.01	No distress evident	No distress evident
2	65	0.01	0.03	No distress evident	No distress evident
3	59	0.00	0.02	Horizontal crack near one corner	Several horizontal cracks 2 sides near surface
4	54	0.03	0.04	Crack progressing along side near top	Crack progressing on other sides
5	56	0.02	0.04	No change	Cracks slightly larger
6	60	0.04	0.06	Cracks slightly larger	No further change
7	57	0.05	0.07	No change	No change
8	60	0.04	0.06	No change	No change
9	58	0.05	0.08	No change	No change

In addition, the formation of laminated rupture planes in the uncured material in a few cases was helpful especially in indicating the type of distress that could be expected should the composition be used over poor subgrade soils and when placed too late in the season to permit adequate pozzolanic set.

On the basis of these preliminary studies a more extensive series of laboratory tests are being developed, and it is hoped that information on this will be available in a subsequent paper. It is indicated that this method should be a valuable means of determining the resistance to freezing of the lime-flyash treated base in contact with its subbase or subgrade materials.

Field Freezing Test. The procedure described above for making freezing and thawing tests on lime-flyash-soil mixtures in the laboratory proved to be sufficiently informative that an effort was made to run several field tests of a similar nature. These were run on the airfield runway listed in Table 1. The procedure consisted of cutting away a small area in the bituminous surface course measuring 12-inch by 12-inch. This section was then completely saturated with water applied over a period of several hours by intermittent soaking. At this point a block of dry ice was placed over the lime-flyash base composition and the material was allowed to freeze while in saturated condition from the top downward. The time required to bring the temperature down to 0 F degrees was measured, and at this point the dry ice was removed and the base was permitted to thaw under natural ambient conditions. Temperature was measured by the use of an imbedded thermistor as described above under the laboratory tests. The ambient temperature did not exceed about 60 F during the tests. The freezing and thawing cycles were repeated for 10 cycles, each time a record being taken of the time required to freeze the material.

In the particular tests described there was no noticeable effect on the base material. It was concluded that the condition of the base was satisfactory from a point of view of being capable of resisting an early frost. Since this particular project was constructed fairly late in the season, it was realized that very little pozzolanic set could be expected until the following spring. It was therefore indicated that for the particular design involved (lime-flyash base; lime stabilized subbase) that adequate frost resistance could be expected in the partially set composition. It is to be pointed out, that as a result of low densities in one area in this project, some surface failure was observed. This is indicated in Table 1 as the parking area. Unfortunately this low density area (Table 4) was not tested with the freezing and thawing procedure described above. The areas which were tested were on the main runway where the compaction was adequate and where to date there has been no indication of base failure.

Pulse Group Velocity Tests

Pulse group velocity measurements were made following the procedures outlined in a previous paper (3). Longitudinal readings were taken on the laboratory specimens that were cut out of the field samples. Field evaluation has also been continued and is reported for one of the projects in Table 7. Figure 11 compares the pulse velocity values with pozzolanic strength. This figure also includes a curve which is taken from the previous laboratory investigation (3). It is evident that the relationship between velocity and pozzolanic strength is somewhat different in the field series to the previous laboratory series, although, in general, a fair correlation exists between the velocity value and pozzolanic strength. It is interesting to note that the present curve is in agreement with the previous series in one other respect; namely, that the relationship is substantially independent of the moisture content of the specimens.

Pulse attenuation data was also observed for the field samples by noting the receiver gain setting required to obtain a vertical signal of a given height. While results of these tests are not included in this paper, it may be noted that the attenuation appeared to be a fairly sensitive factor and decreased with moisture content particularly in samples showing some degree of laminar separation parallel to the bedding plane.

TABLE 7

PULSE VELOCITY TESTS DETERMINED IN PLACE. POZZOLANIC STRENGTH DETERMINED AS UNCONFINED COMPRESSIVE STRENGTH ON SPECIMENS REMOVED FROM FIELD.

		Pulse Velocity (ft./sec.)		Pozzolanic Strength psi	
Location	Age	Dry	Wet	Dry	Wet
Laurelton Circle, N. J.	2 Days	2200	-	-	-
	5 Days	3010	-	-	-
	3 Weeks	3210	-	448	-
	1 Year	6650	-	-	-
	2 Years	6100	4850	1050	605

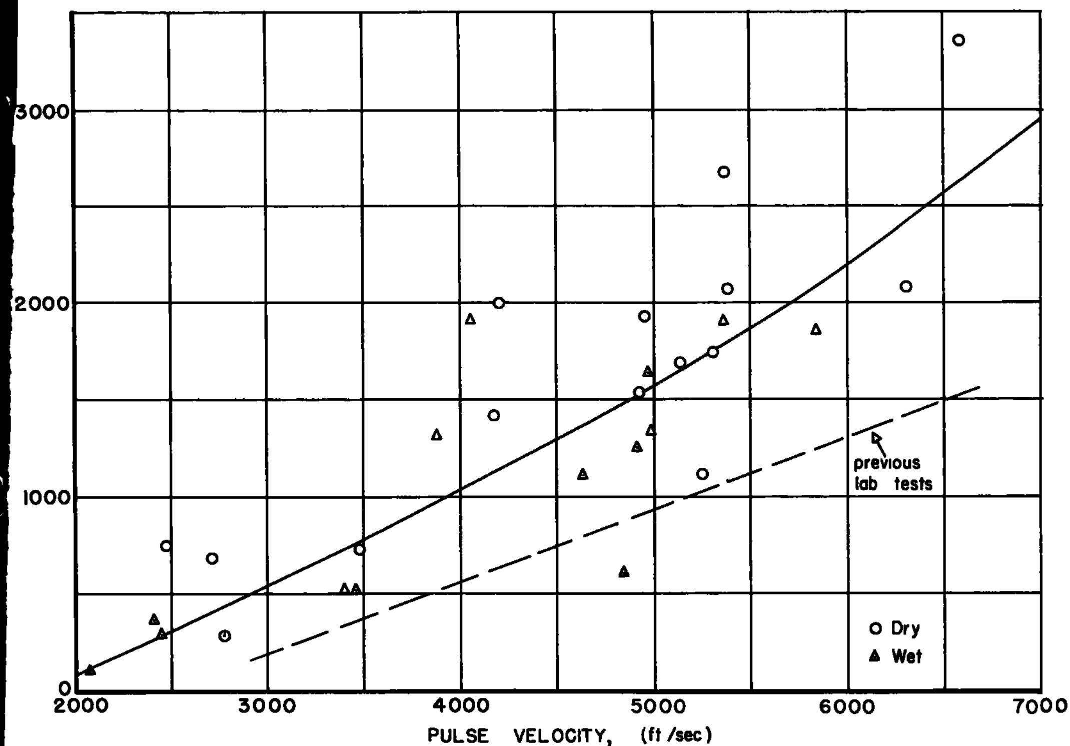

Figure 11. Comparison of pozzolanic strength of field and laboratory specimens to pulse velocity.

LIME-FLYASH-SOIL POZZOLANIC PROPERTIES

Material Characteristics. The chemistry of lime-flyash-soil reactions is quite complex. Any study involving pozzolanic reactions requires careful consideration of the properties of the individual ingredients as well as of the final composition which is made from them. With respect to the hydrated lime, much is already known since it is actually one of the oldest of all engineering materials. It has been used for many centuries as a component of mortar for masonry purposes, and its record of accomplishment in this field is second to no other construction material. The desirable properties obtained from lime include excellent bond, high extensibility, viscous traction, autogenous sealing or healing of ruptured joints or shrinkage cracks and the gradual hardening effect which results from the reaction of the hydrated lime with the carbon dioxide in the air. It is essential to note that the natural process which stimulates the desirable curing or aging of lime compositions is that of wetting and drying and cyclic changes in humidity. It is the change in moisture content which results in the transfer of calcium and magnesium ions to the critical areas in the composition where the cementitious and plugging effects are required. The lime further reacts with the plastic soils in a rather striking manner and immediately after mixing converts the soils to a more acceptable form of engineering material of low plasticity and liquid limit.

In the presence of flyash, a material that has unique properties in itself among which is its strong pozzolanic characteristic, the lime reaction is further enhanced by the formation of a cementitious matrix comprising reaction products of both the calcium and magnesium ions with the aluminum, silicon, and iron constituents of the flyash. Although it is convenient to consider these reactions from the standpoint of pozzolanic strength, it is to be remembered that additional characteristics are developed in lime-flyash-soil compositions and these should be considered in an overall evaluation of the material.

The remarkable effects discovered by Havelin and Kahn (5, 6) in connection with compositions of lime, flyash and soil serve to describe the results that are produced when these materials are combined and used in the construction of road compositions.

Accelerated Test Methods. Pozzolanic reactions occur very slowly and, in fact, require many months or years to develop their ultimate strength. Engineers working in the field of concrete have learned that when pozzolanic admixtures are used it becomes desirable to devise laboratory test procedures which measure the contribution to strength made by the pozzolan on an accelerated basis. Studies made by the Bureau of Reclamation, for example, have shown that the use of elevated temperature cure of mortar specimens produce, in a reasonable period of time (i. e. 28 days), results which may be correlated to room temperature or ambient cure for a period of six months or a year. ASTM uses accelerated procedures in connection with the determination of pozzolanic strength (16, 17). One of these methods, developed by R. E. Davis, employs lime, pozzolan and sand, cured under moist conditions for 24 hours at room temperature, and an additional six days at 130 F.

Any laboratory test which is devised to evaluate the pozzolanic strength of lime-flyash-soil mixtures should likewise be based on an accelerated procedure if reasonable times are to be considered in the test procedure. Columns 1 and 2 of Table 5 give the results of laboratory tests which were made on specimens that were subjected to moist curing conditions at 140 F (2, 3, 9). A comparison of the unconfined compressive strength values with those obtained in the field survey and which are shown in Columns 3 and 4 show that the accelerated laboratory test values give results that in general fall within the range of results obtained in the field. While it is realized that such factors as age of specimen and density may influence the results to a degree, it is felt that the correlation is good and that the use of the accelerated or high temperature cure as a measure of pozzolanic strength is justifiable.

One point of interest that is illustrated by the data is that pozzolanic strength values vary over a considerable range, specifically from a low value of 100 psi. (saturated) for sample No. 5 to 4315 psi. (dry) for sample No. 15. These values depend upon the particular materials involved and also upon the degree of compaction or density of the mix; for example, the low value of sample No. 5 is directly traceable to the low density of this particular area. Unquestionably this was a major factor in connection with the distress noted. Also it is clear from sample No. 8 that a value of 370 psi. (saturated) is adequate for conditions of service as experienced in the Philadelphia climate. Examination of the data suggests that a minimum requirement for pozzolanic strength value should be set in the neighborhood of 300 psi. (saturated) and 500 psi. (dry). Lower values than this would, in general, indicate that the composition would be unacceptable for adequate resistance to the action of excessive water or frost.

Figures 12 and 13 show in graphical form a comparison of pozzolanic strength as determined in the field samples with the moisture and density of the specimens. In each case the data are plotted in terms of the ratio of the field value to the previously determined laboratory value. The apparent lack of correlation does not eliminate the density and moisture content as factors in appraising the strength of the compositions since previous work (8, 3) has clearly shown on laboratory samples that a correlation can be established. The present studies reflect the influence of other factors, presumably brought about through wetting and drying cycles which, for compositions containing lime, can be expected to develop autogenous plugging or cementitious effects which would be related to and affected by drainage or other moisture conditions.

Figure 14 shows how various samples respond to elevated temperature cure as related to age of treatment. From these graphs it is seen that a curing period of between 7 and 28 days should be adequate to give an indication of the order of magnitude of the ultimate lime-flyash-soil pozzolanic strength values.

It is also felt that it would be reasonable to run the tests at somewhat higher temperatures than those reported; for example, 160 F since this temperature is still within the range which should not develop unexpected side reactions that may affect the compositions. At this higher temperature the pozzolanic strength may be developed at a somewhat earlier time. Laboratory studies are currently underway to investigate this aspect of the problem.

The curves given in Figure 14 include wet as well as dry laboratory specimens

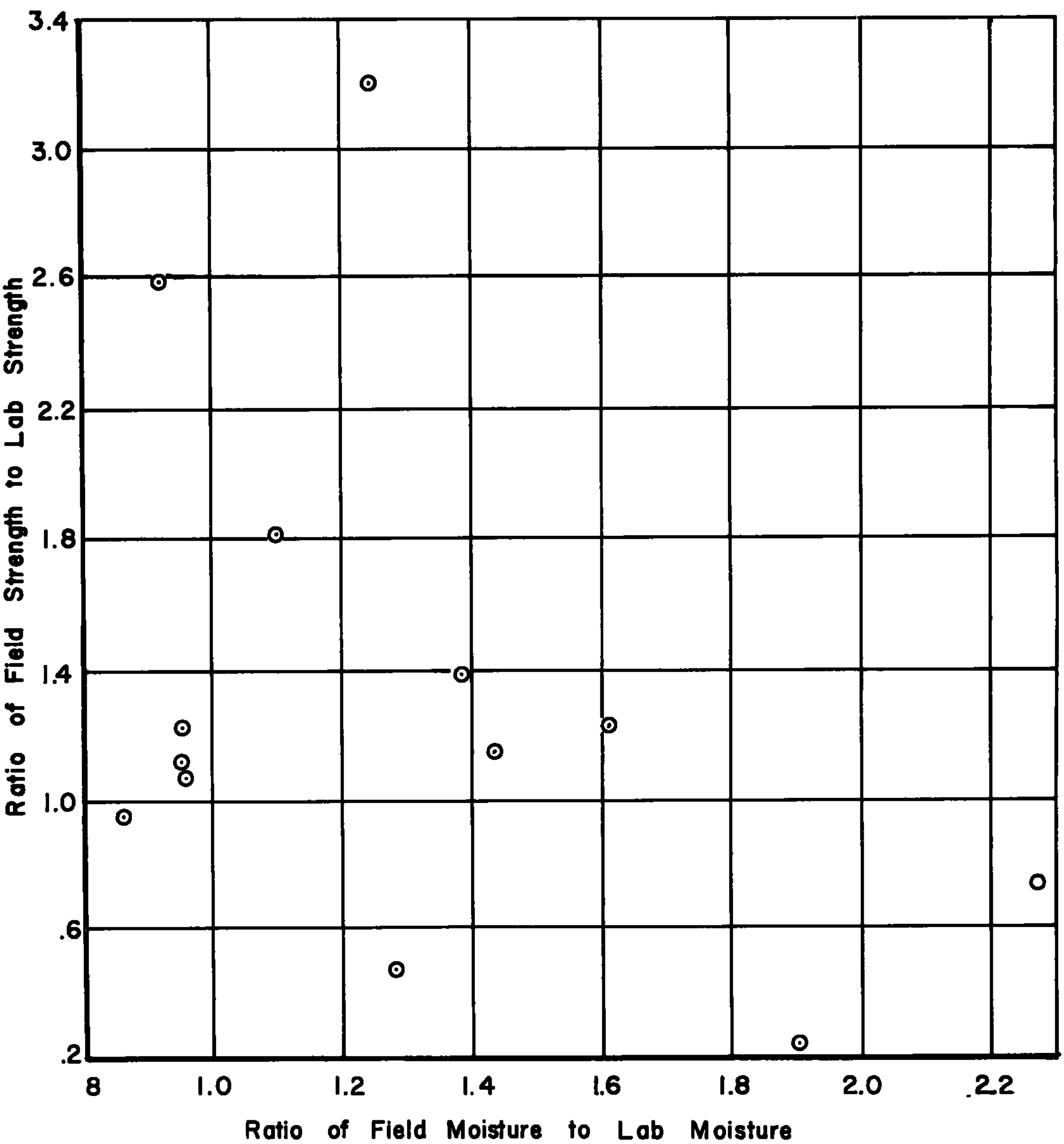

Figure 12. Comparison of the ratio of field moisture to optimum moisture as determined in the laboratory and the ratio of unconfined strength in the field to strength of laboratory specimens.

measured by accelerated test procedure, and it is evident that the wet specimens give values which are somewhat lower than those which would be indicative of anticipated field results. In the recommendations given below the dry procedure has been suggested. The authors recognize that this selection is arbitrary but feel that on the basis of the data it is justified and furthermore feel that it lends itself to a more convenient laboratory technique which makes it possible to avoid the problem of control of moisture content in the test specimens.

LIME-FLYASH-SOIL BEARING CHARACTERISTICS

From the discussion in the preceding section, the question arises as to which of the characteristics of the lime-flyash-soil compositions are responsible for the results in field performance such as have been reported. For example, in the test on Route 422 very little pozzolanic set was realized before frost action was experienced on this material, yet it sustained the action of a very severe winter more satisfactorily than the stone base. Both of these shoulder materials were noticed to develop some heave during this particular winter season, but, for a not too well understood reason, the thinner base of the lime-flyash treated soil resisted the effect of traffic and frost action whereas the other material did not. Recently, Herner (15) has reported on the different performance value of base materials and their effect on the thickness of pavement required to produce equivalent pavement sections. Possibly the pavement reported in this paper in which lime-flyash material shows superiority to the stone base may be a further illustration of the condition suggested by Herner.

In view of the foregoing, the further question may be raised regarding the property of the lime-flyash composition that should be measured to properly evaluate it for de-

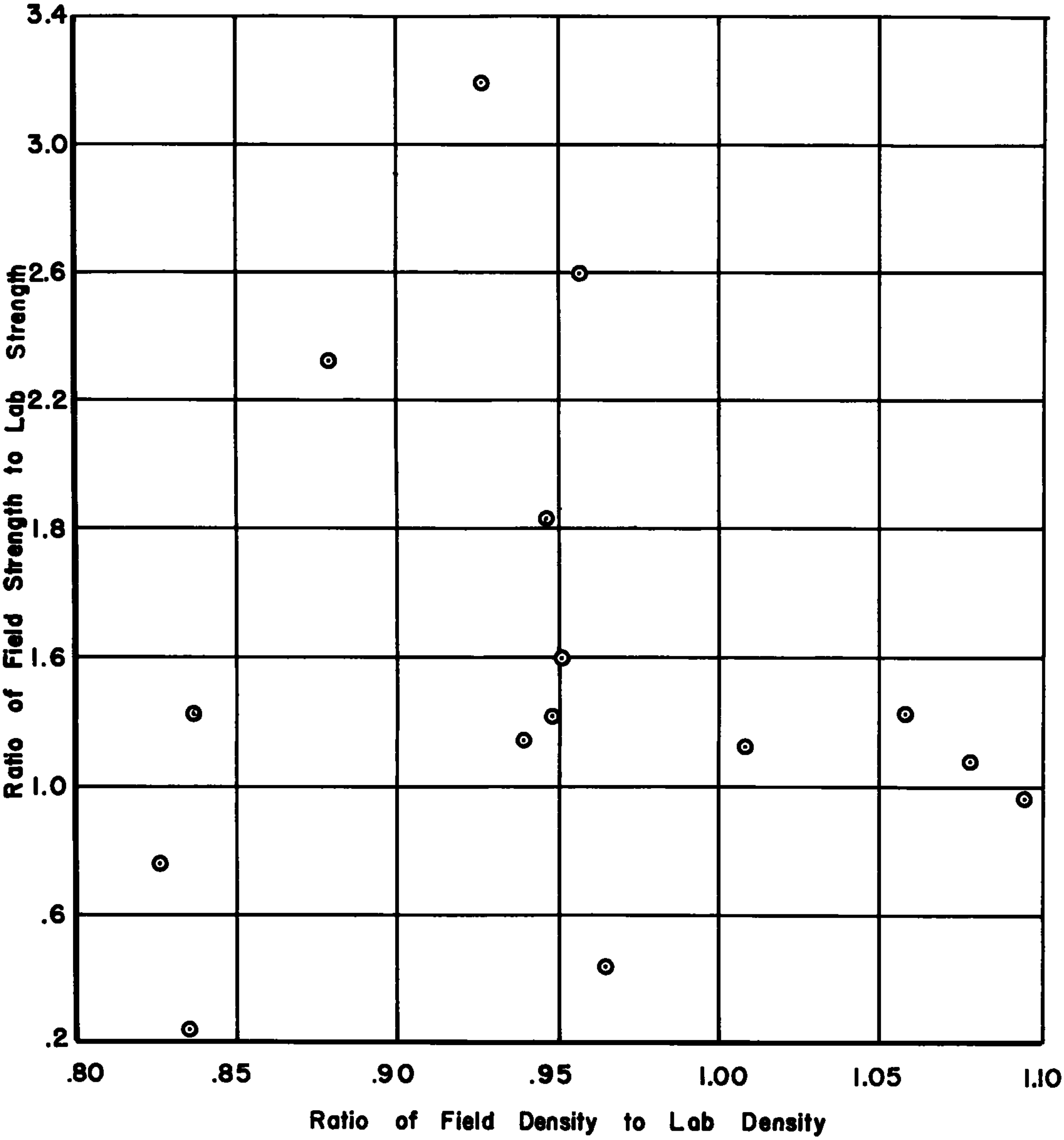

Figure 13. Comparison of the ratio of field density to optimum density as determined in the laboratory and the ratio of unconfined strength in the field to strength of laboratory specimens.

sign purposes. It has been observed that these roads perform satisfactorily immediately after their construction or, to put it another way, weeks or months before pozzolanic set occurs. It has occurred to these authors that perhaps the proper testing technique should involve a bearing test on specimens which are prepared under conditions simulating road mixing and compaction and which are subjected to several cycles of wetting and drying to simulate climatic conditions normally experienced in the field. With this

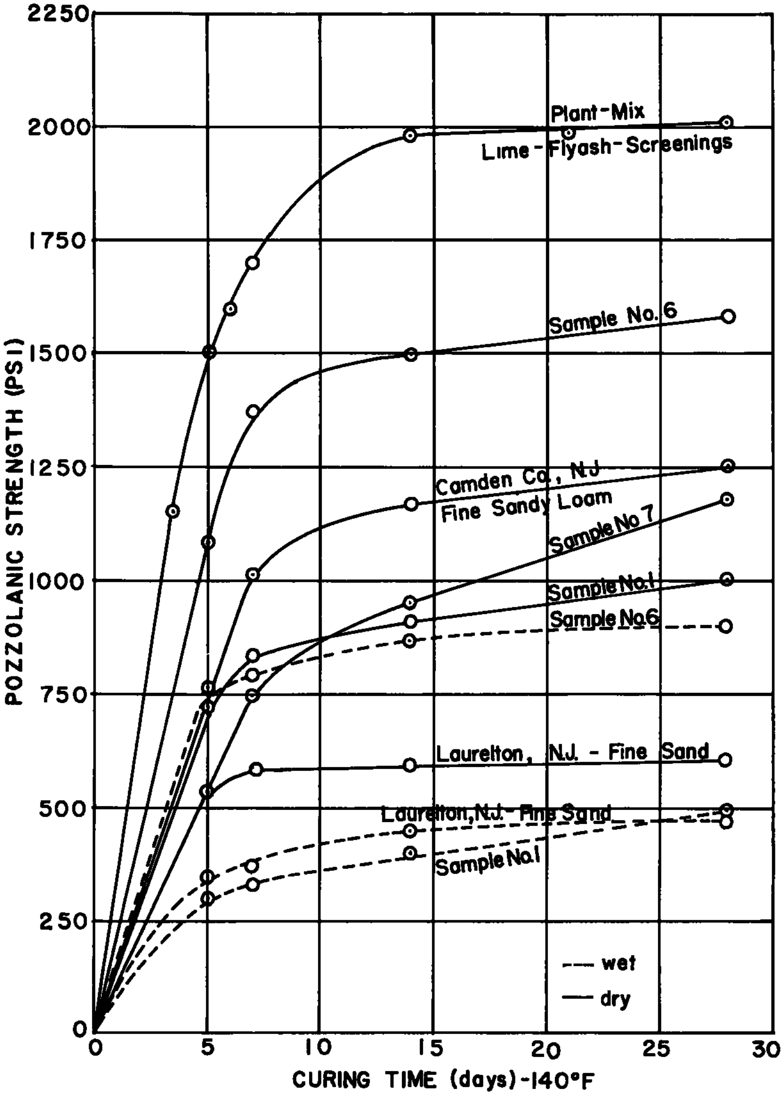

Figure 14. The development of pozzolanic strength lime-flyash-soil compositions at 140 F cured under moist conditions for various ages.

in mind, tests have been initiated involving bearing penetration tests such as used in the California bearing tests as well as triaxial compression tests. Table 8 gives results of a few of these tests.[1] From the very substantial increase in bearing value which the lime and flyash materials develop, it becomes apparent why these compositions show the performance that they do in the early periods. In contrast to this the tests show that alternate wetting and drying has very little effect on the untreated soils.

[1]These tests were made by Professor Richard H. Miller, Civil Engineering Department, Villanova University.

TABLE 8

BEARING RATIOS OF LIME-FLY ASH-SOIL MIXTURES

	Sample No.6 Laurelton, N. J.		Laurelton, N. J.		Sample No. 1 Plymouth-Whitemarsh, Pa. High School	
	Gravel		Sand			
Curing Conditions (a)	Natural Soil (A-1-b)	Lime-Fly ash-Soil Mixture	Natural Soil (A-3)	Lime-Fly ash-Soil Mixture	Natural Soil (A-6)	Lime-Fly ash-Soil Mixture
Air dried - 2 to 4 hrs. Room temperature	77	103	26	49	-	-
Soaked - 45 Min. Drained - 15 Min.	37	69	20	16	-	-
Soaked in water - 22 hrs.					13(55) 11(25) 5(10) (b)	148(55) 64(25) 30(10) (b)
Cyclic Wetting and Drying to constant weight at room temp. and approx. 50% rel. humidity	33(c)	180(c)	21(d)	138(d)	7(d)	Above 200(d)

(a) Samples prepared as CBR specimens and cured as stated.
(b) Numbers in parentheses are number of blows per layer.
(c) Three cycles, 5 days, tested in wet condition.
(d) Four cycles, 7 days, tested in wet condition.

RECOMMENDED LABORATORY EVALUATION

It is recognized that in studying a complex subject of this type that progress is made slowly. Methods of test constantly change as construction procedures improve. In view of the results that have been obtained to date in the field, it is felt that adequate evaluation tests which would indicate the acceptability of the performance of the final composition and which would assist in developing satisfactory design criteria should involve at least the following parameters:

1. Lime-flyash-soil pozzolanic strength test. This test is primarily of use in evaluating the performance of the composition on a long time basis. To a large degree it is an indication of durability to wetting and drying and freezing and thawing action. A minimum requirement of about 500 psi. (unconfined compressive strength) is tentatively suggested using a 7 day moist cure at 140 F and testing in oven dry state. Compositions developing substantially less than 500 psi. should be considered unsatisfactory for use as a base course in those areas of the country where the jobs are subjected to appreciable frost attack.

The pozzolanic strength test may also serve to establish an optimum mix by varying the proportions of lime and flyash in a run-down or test series. Details for running the tests are indicated above and in previous papers (2, 3, 9).

2. Lime-flyash-soil bearing test. This test is primarily of use in determining the thickness of base which is required for the traffic service to which it is subjected. The conventional bearing or triaxial test may be run with the lime-flyash-soil compositions but should be carried out with specimens that have been prepared at optimum moisture, maximum density and cured under conditions of wetting and drying at room temperature for a minimum of three cycles. The age of the test specimen shall be of the order of 7 days (28 days maximum) in order to avoid possible influence of appreciable pozzolanic reaction from the lime and flyash.

3. Freezing and thawing test. This is a supplementary test which should be run where frost is an anticipated problem (particularly under poor drainage conditions). The freezing and thawing test should be conducted involving procedures similar to that outlined in the laboratory procedure given above in which the lime-flyash-soil composition is tested when in contact with the subgrade material corresponding to that existing at the job site. Freezing and thawing should take place from the upper surface downward. A minimum of five cycles is considered to be necessary. Acceptable performance is indicated when no apparent decrepitation of the sample is noted. The change in rate of

ezing shall also be gradual, and based on the limited data available at this time shall increase during the five cycles by more than a factor of two.

4. Supplementary sonic evaluation. Where equipment is available, it is felt that the of sonic tests are helpful to measure characteristics of and changes in the composins, particularly where subsequent field follow-up checks are contemplated.

The above recommendations should give the engineer confidence in the acceptability the composition for any project that he is appraising. It can give him basic informan which he can directly utilize in his design equations and will also give him a meas- of the durability of the material with respect to anticipated wetting and drying and ezing and thawing conditions. From the performance of the numerous jobs which are existance today, it is felt that these recommendations afford a convenient and practical ocedure for evaluating the lime-flyash compositions for commercial use.

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