Structural Properties of Lime-Flyash-Aggregate Compositions

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● LIME-FLYASH-AGGREGATE compositions in highway and airfield base courses and highway shoulders have been in existence for periods up to seven years. Reports have been made previously on the properties, construction, and performance of these compositions. It is the purpose of this paper to present additional information concerning these materials with particular regard to their structural properties or their load transmission characteristics, as measured by triaxial and CBR tests. The paper contains a discussion of the use of the CBR method for designing lime-flyash-aggregate base courses for highways and airfields. A further evaluation of existing installations is presented. Also included is a comparison between lime-flyash-aggregate compositions and lime-soil mixtures.

Previous work (1) has shown that the magnitude of the pressure transmitted through a base course is dependent on the materials used in the base course. Smaller pressures occurred beneath good base and subbase materials than occurred beneath poor materials. It was further illustrated that the relative effectiveness of the materials could be predicted by means of the triaxial test. It is logical to assume that this same qualitative relationship could be determined by other tests such as the CBR and stabilometer. Previous work (2) has also shown that the curing conditions, particularly those involved with wetting and drying, have a substantial effect on the properties of the compositions. Considerations have been given to the use of various methods of measuring the durability of lime-flyash-aggregate mixtures when subjected to freezing and thawing tests at early ages.

A broad analysis of the use of lime-flyash and aggregate mixtures has indicated that in many instances the compositions possess characteristics differing substantially from the products that are formed in typical soil stabilization operations. In order to evaluate the engineering features of lime-flyash and aggregate mixtures, a program has been established which is concerned with both the development of adequate test procedures and the utilization of the data for design purposes. This program includes studies involving the effect of aging of the compositions under various conditions of wetting and drying, high or low humidity, and a study of the resistance of the compositions to freezing and thawing also under varying curing conditions. Furthermore, an effort is being made to evaluate the proportions and properties of the aggregates and aggregate mixtures which are effective in producing compositions of the desired properties.

The work which is presented in this report covers only the initial phase of the investigation and describes tests which have been made on specimens that have been tested at early ages. It includes only the work done with mixtures of lime and lime-flyash with natural soils and does not include data on the modification of the natural aggregate with supplementary aggregate material to improve gradation. A paper will be presented later describing some of these other studies which are currently underway.

The initial laboratory work reported is considered to be useful for establishing the relative effectiveness of base courses of lime-flyash-aggregate compositions over those of natural soil for reducing the amount of pressure transmitted to the subgrade. The data presented give comparative results of triaxial and CBR tests performed on the compositions. It is to be emphasized that the evaluation of the lime-flyash-aggregate base material has been carried out before any pozzolanic reaction had taken place.

TESTING PROCEDURE

Triaxial Test

The triaxial tests were performed on an A-4 silt and on a mixture of lime and flyash with the A-4 soil as an aggregate. The soil is a type found in widespread areas in the Commonwealth of Pennsylvania. It is characterized by its relative fineness (64 percent through the No. 200 sieve, in this case) and its moderate to low plasticity. The composition was a mixture of 90 parts of the A-4 soil, 10 parts of fly ash, and 5 parts of hydrated lime, by weight.

Three series of tests were performed. Each series differs from the others only in the length of time allowed for saturation. The first series of tests was performed after the samples were completely saturated. The time required for 100 percent saturation was rather long (from 5 to 7 days), and the results with these test cylinders indicated that some cementing action had taken place during this period. Since it was desired to evaluate the mixtures before any appreciable pozzolanic reaction had occurred, two other series of tests were then run; one after one day of saturation and one after two days of saturation.

All test cylinders were 1.4 in. in diameter and 2.8 in. high. They were carefully molded at optimum moisture by static compaction in a split mold. The static load was held on each sample until it was felt that a uniform density was obtained. Two different densities were used for the cylinders that were 100 percent saturated. Some of the cylinders were at standard AASHO density and some were at a density determined by a compaction test in which the 10 lb. rammer was substituted for the 5.5 lb. rammer. All the cylinders for the one and two day tests were made using the greater density. The samples were not cured except during the saturation period.

The triaxial tests were run to failure at lateral pressures of 2.5, 5.0, and 7.5 psi. The rate of loading was .015 in. per min.

California Bearing Ratio

Comparative CBR tests were performed on four different soils; on the lime-flyash-aggregate mixtures using the four soils as aggregates and on lime-soil mixtures. Of the four soils used, two were A-4 and two were A-2-4. In each case, the composition consisted of 90 parts of soil, 10 parts of flyash, and 5 parts of hydrated lime, by weight. Three percent lime, by weight, was added to the soil in the lime-soil mixtures.

The penetration tests were performed on samples that were compacted to 100 percent of CBR density, soaked for four days, and drained for 30 min prior to testing. The loading rate was .05 in. per minute.

The properties of the soils used in both the triaxial and CBR tests are shown in Table 1.

TEST RESULTS

Triaxial Tests

An examination of Figure 1 shows that the vertical pressures at failure after one and two days of saturation, of the lime-flyash-aggregate compositions were of a magnitude greater than those of the raw soil cylinders at the same lateral pressures. The additions of lime and flyash to the A-4 soil changed the shearing properties. Failure of the natural soil was evidenced by a uniform bulging of the cylinders while failure of the compositions was evidenced by a shearing failure along a single plane. The inconsistencies which are apparent in the vertical pressures at failure shown in Figure 1 for varying lateral pressures on supposedly identical test cylinders are believed to be due to the difficulty of reproducing exact moisture conditions short of 100 percent saturation. Regardless of these inconsistencies, the relationship between lime-flyash mixtures and the natural soil cylinders is clearly shown.

Figure 2 shows the stress-strain curves that were derived from triaxial tests performed on 100 percent saturated cylinders. The test cylinders were molded and cured under different conditions and tested at various lateral pressures, as shown in Table

TABLE 1

PROPERTIES OF SOILS USED IN INVESTIGATION

	Triaxial Test	California Bearing Ratio Test			
Soil Number	CT-2	CB-7	CB-8	CB-9	CB-10
Mechanical Analysis Percent Passing:					
3/8 in.	100.0	100.0	100.0	100.0	-
No. 4	99.0	99.5	100.0	98.7	86.3
No. 10	96.8	99.4	100.0	95.4	80.1
No. 20	91.9	97.0	99.5	85.9	67.0
No. 40	86.8	91.0	92.9	75.0	54.5
No. 60	82.3	86.9	76.2	68.7	47.7
No. 140	70.1	78.9	15.7	57.0	33.6
No. 200	63.7	73.6	12.9	51.9	26.8
Liquid Limit	34	-	-	34	28
Plasticity Index	5	NP	NP	8	4
Standard AASHO Density	112.0	104.3	-	-	-
Optimum Moisture	17.8	17.8	-	-	-
CBR Density	-	-	123.2	113.0	132.1
Optimum Moisture	-	-	11.6	16.0	11.0
BPR Classification	A-4	A-4	A-2-4	A-4	A-2-4

TABLE 2

MOLDING AND TESTING CONDITIONS FOR TEST CYLINDERS OF FIGURE 2

Curve Designation	Composition of Cylinder	Density	Curing	Lateral Pressure - psi
A	Natural soil	Standard	None	2.5
D	Natural soil	Modified	None	2.5
E	Natural soil	Modified	None	5.0
F	Natural soil	Modified	None	7.5
U	Lime, flyash, soil	Standard	7 days at elevated temp.	7.5
W	Lime, flyash, soil	Modified	7 days at elevated temp.	5.0
Y	Lime, flyash, soil	Standard	None	5.0
Z	Lime, flyash, soil	Standard	None	7.5

2. An approximate average for the saturation time for the test cylinders was seven days. The curves fall into two distinct groups. The stress-strain curves for the lime-flyash cylinders are grouped along the vertical axis and those for the natural soil cylinders are along the horizontal axis. It is evident that the vertical pressures at failure are far greater for the lime-flyash mixtures than for the natural soil.

California Bearing Ratio Tests

The CBR values obtained using standard test procedures are shown in Figure 3 and 4. Considerable improvement can be noted when additions of lime and flyash or lime only are made to the natural soil. Since these samples remained completely submerged in water from the time they were molded until shortly before the penetration was performed, it is felt that little or no pozzolanic reaction occurred.

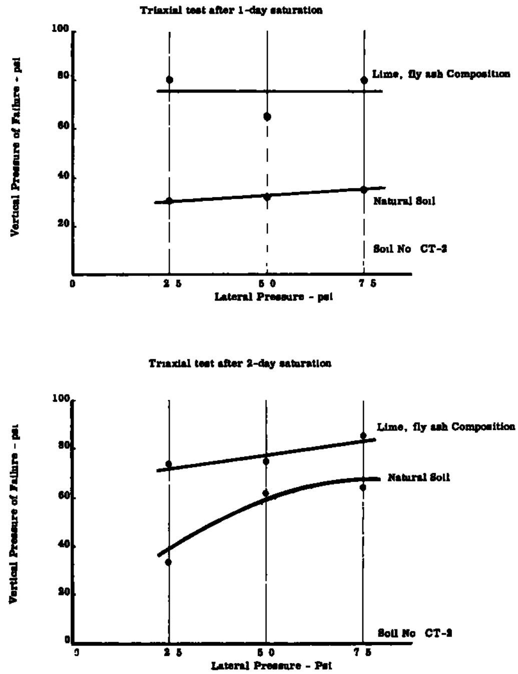


Figure 1. Relationship between vertical and lateral pressure.

Discussion of Test Results

The results obtained in this investigation again indicate the immediate improvement in soil properties brought about by additions of hydrated lime and flyash. The comparative triaxial tests show that the compositions of lime-flyash if used as a base course would be more effective than the natural soil in distributing the load over the subgrade. This superiority shows up as soon as one day after molding. The effectiveness of the composition increases with time even though adverse moisture conditions are encountered. The vertical pressures at failure of the 100 percent saturated cylinders, which were tested approximately seven days after molding, ranged from two to four times as much as the vertical pressures for one and two day cylinders. Some difficulty was encountered in reproducing accurately the results in the triaxial test. It is felt that, unless further investigation should produce a technique for improving the reproduceability of results, the triaxial method may not be as suitable for base course design for lime-flyash compositions as in the CBR method.

In three of the four cases tested in the CBR investigation the values of 168, 190, and 151 show that the compositions would be suitable for use in a road base immediately below the wearing course. The CBR tests on the compositions were found to be reproducible and easily performed. Figure 5 shows a typical stress-strain curve for one of the A-4 soils used in the investigation together with the curves for the lime-flyash and the lime-soil mixture.

DESIGN METHOD FOR LIME-FLYASH-AGGREGATE COMPOSITIONS

It is proposed that the CBR design method for flexible pavements be used to determine the thickness of the lime-flyash-aggregate base required under given conditions of traffic volume, load, and subgrade conditions. In designing a flexible pavement, it is usually desired to evaluate the components of the cross-section under the most adverse conditions that occur in the actual road. With lime-flyash this would involve subjecting the material to saturating conditions immediately after it has been placed in the road. At the end of four days of soaking, with no initial curing, it is felt that the lime-flyash-aggregate mixture would be in the most critical physical state that it would encounter during its life in the pavement. A design thickness based on its prop-

TABLE 3

DESCRIPTION OF FIVE MAJOR LIME, FLY ASH, AGGREGATE INSTALLATIONS

LOCATION	TYPE OF CONSTR.	DATE CONSTR.	TRAFFIC			WEARING SURFACE		BASE			SUBBASE			SUB-GRADE
			Type Vehicle	Weight Vehicle	Density	Type	Thickness	Composition	Aggregate	Thickness	Composition	Aggregate	Thickness	
Camden N.J.	City Street	July 1954	97% Passenger 3% heavy truck	--- 22000# Single axle	ADT 5000 (1954)	Bit. Conc.	2"	Lime, Fly Ash, Aggregate	A-1-b	6"	---	---	---	A-1-b
Wings Field, Pa.	Runway Taxiway Parking area	Aug. 1954	Aircraft	12000# Single wheel load	52000 movements per year	Asphalt and stone chips	---	Lime, Fly Ash, Aggregate	A-5 + coarse agg.	6"	Lime Stabilized	A-5	6"	A-5
New Castle, Del.	Auto Parking area	Aug. 1956	Passenger cars	---	---	Bit. Conc.	2"	Lime, Fly Ash, Aggregate	A-4 + coarse agg.	6"	Lime Stabilized	A-4	3" to 4"	A-4
International Airport Phila., Pa.	Auto Parking Area	Oct. 1953	Passenger cars		1500 cars daily	Bit. Conc.	2"	Lime, Fly Ash, Aggregate	A-1-b	6"	Compacted Gravel			A-1-b
Salem, N.J.	County Road	Sept. 1956	Passenger and Trucks	22,000# Single axle	ADT 1650 (1957)	Bit. Conc.	1-5/8"	Lime, Fly Ash, Aggregate	A-1-b	6"	---	---	---	A-1-b

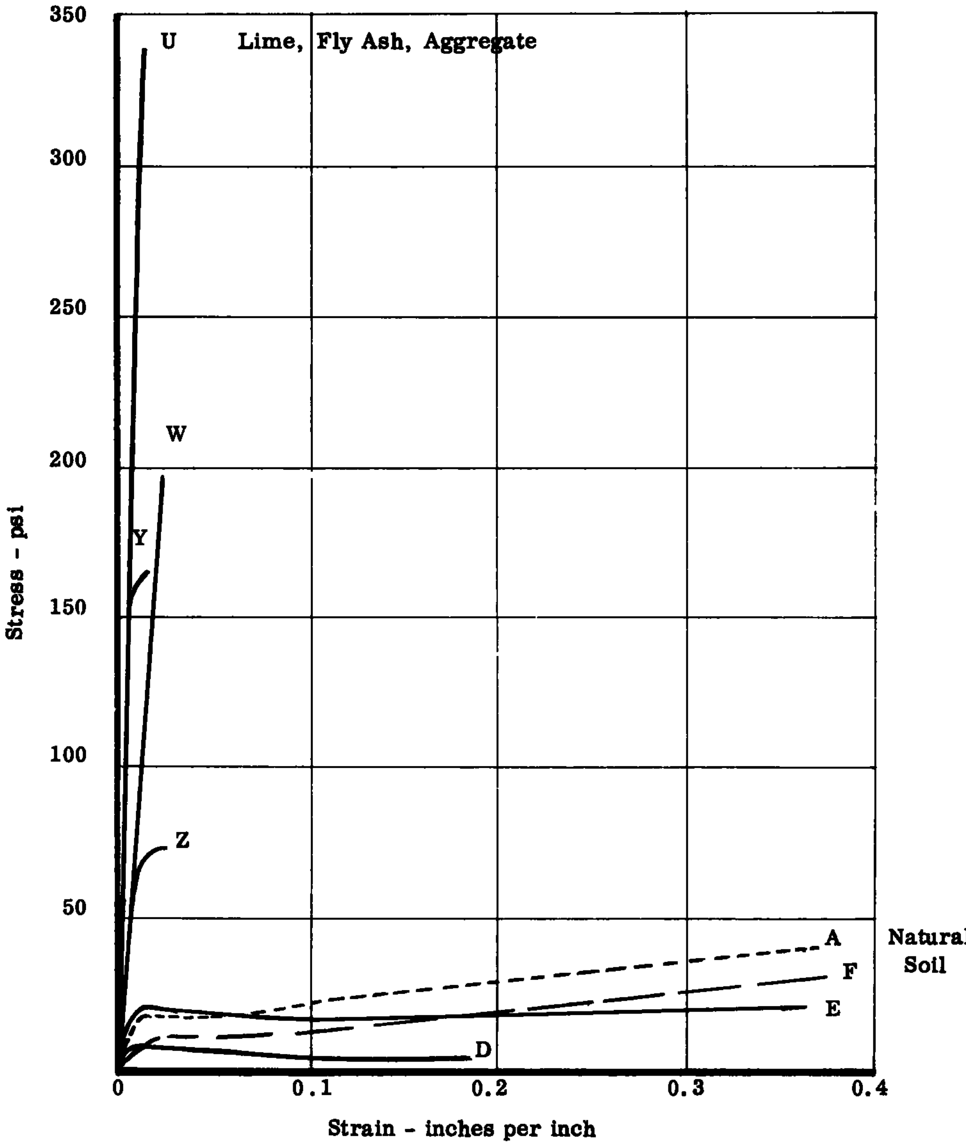


Figure 2. Stress-strain curves for triaxial test, samples 100 percent saturated, Soil No. CT-2.

erties at this critical time should be amply safe. The question now arises as to how the cementing action, which occurs in the mixture affects its performance in a road designed as a flexible pavement.

First, let us briefly review the strength characteristics of lime-flyash-aggregate compositions as they are known at this time. Ordinary compression tests on cubes and Proctor size cylinders prepared in the laboratory have shown compressive strengths ranging between 200 and 1,900 psi. Samples removed from a highway shoulder this past summer, three years after construction of the shoulder, gave compressive strengths as high as 3,360 psi. when broken in an oven dry condition. Within the past two years, flexural tests have been performed on lime-flyash aggregate beams (3). The aggregate used in the beam was an A-2-4 silty sand. Tests with this particular aggregate have indicated a relatively low strength in flexure. The estimated tensile strength at

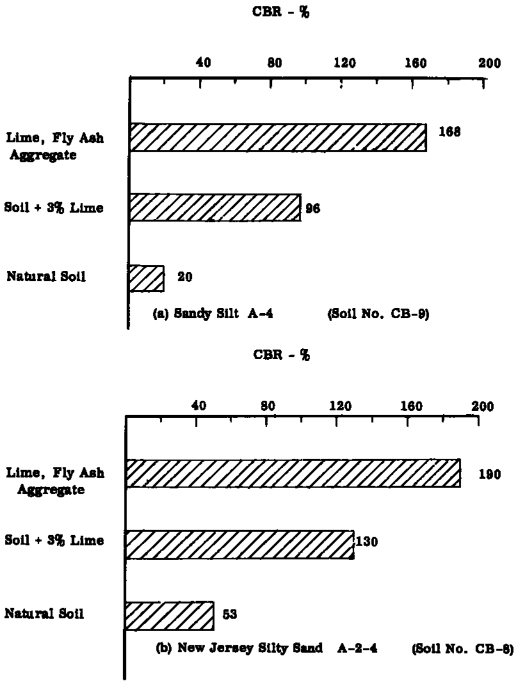


Figure 3. Comparative results of CBR tests. All samples were soaked for four days before testing.

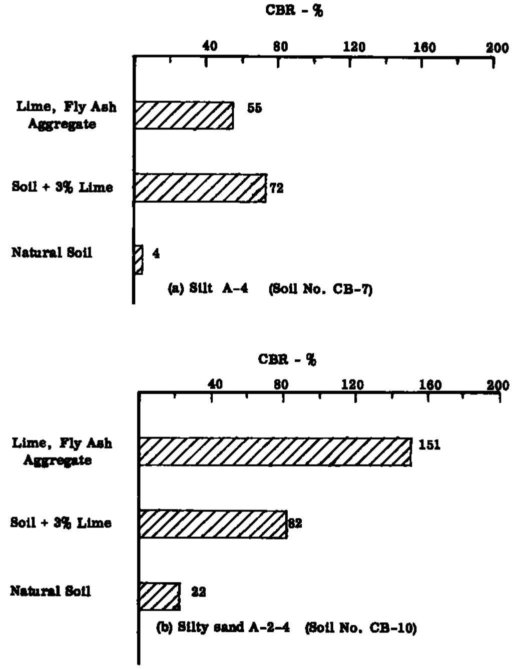


Figure 4. Comparative results of CBR tests. All samples were soaked for four days before testing.

failure was found to be 15 to 20 psi. The compressive strength of these mixtures was approximately 500 psi. Additional testing of the flexural strength of lime-flyash-aggregate compositions, to clearly define this property, is warranted.

The significance of a compressive strength value in connection with a road base material is questionable. An increase in compressive strength in any given material does, however, indicate an increase in cohesion. Strength in compression is also an indication that the individual particles which make up the composition are cemented togather. The permanence of this bonding is dependent upon the leaching effects caused by weathering forces such as ground water, freezing, etc. The ability of a material to resist shearing stresses is increased by increased cohesion and increased bonding of its particles. It would seem, therefore, that its ability to distribute a load over a considerable area would also be improved. Compressive strength is then, at least, a qualitative index of the load transmission characteristics of a base material.

In lime-flyash-aggregate compositions the individual particles are more or less cemented together, but the compositions at early ages apparently possesses low strength in flexure. The lack of any significant strength in bending would insure action as a flexible base rather than a rigid one.

The concept of designing a structure using a material which will be many times stronger as its age increases is a rare and in many ways comforting situation. The uncertainties involved in the structural design of a highway are well known. One of the least predictable factors is the amount, type, and weight of traffic that a road will be required to carry during its lifetime. The ability of lime-flyash-aggregate compositions to become stronger over a long period of time tends to compensate for the possibility of the road having to carry more severe loads then those for which it was designed.

Two simple examples will show clearly the proposed application of the CBR method to the design of a flexible pavement with a lime-flyash-aggregate base and/or subbase.

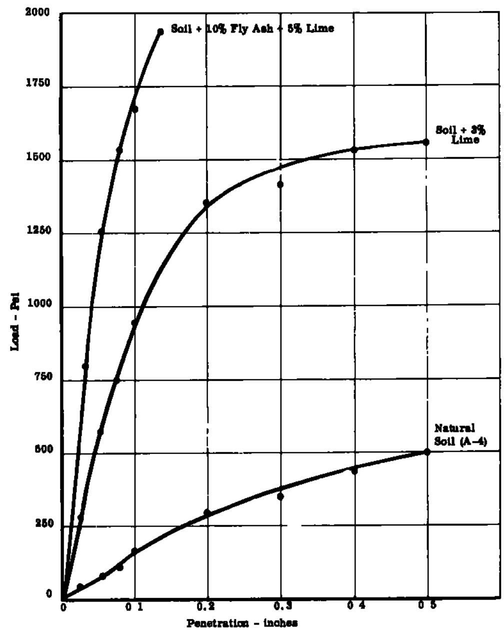


Figure 5. Stress strain curves, CBR test, Soil No. CB-9.

Example 1. CBR of subgrade = 4 percent; maximum single-axle load = 22,000 lb; traffic—heavy.

Using design curves of the Asphalt Institute ("Thickness Design, Flexible Pavements for Streets and Highways," The Asphalt Institute, Fig. 2, pp. 14 and 15) the total thickness of flexible pavement would be 15 in. A lime-flyash-aggregate composition of the subgrade soil with 10 percent flyash and 5 percent lime would furnish a CBR value of 55 percent. This would be suitable for a subbase. A 7-in. layer of this material would leave 8 in. for base and wearing course. A small percentage of screenings or coarse aggregate added to the lime-flyash-aggregate of the subbase would produce a mixture acceptable for the base (CBR 80 percent or better). A 5½-in. lime-flyash-aggregate base and 2½-in. course of asphaltic concrete would complete the cross-section as shown in Figure 6.

Example 2. CBR of subgrade = 3 percent; maximum single-axle load = 8,000 lb; traffic—light.

The design curves show a thickness of 6 in. of flexible pavement is needed. A 4-in. layer of a lime-flyash-aggregate composition with a CBR of 80 percent or better and a 2-in. layer of asphaltic concrete will provide this thickness. For the subgrade material in this example a suitable composition might consist of 60 percent of the subgrade soil, 30 percent gravel or sand, and 10 percent flyash with a 5 percent lime additive. The cross-section is shown in Figure 6.

Evaluation of Existing Installations

Data are given in Table 3 on five major lime-flyash-aggregate installations. These jobs were constructed between 1953 and 1956. The types of installations represented here are varied. Two are automobile parking areas, one an urban street, one a rural road, and one a runway, taxiway, and parking aprons at a commercial airport for light planes.

One of the more interesting projects has been the runway and taxiway at Wings Field, Pa. The runway was constructed in August 1954. The subgrade soil is an A-5. A 6-in. base was constructed on top of a 3 to 4 in. subbase of lime stabilized soil. A 1-in. asphalt wearing surface was provided. Thus, the total thickness of flexible base that was provided was between 10 and 11 in.

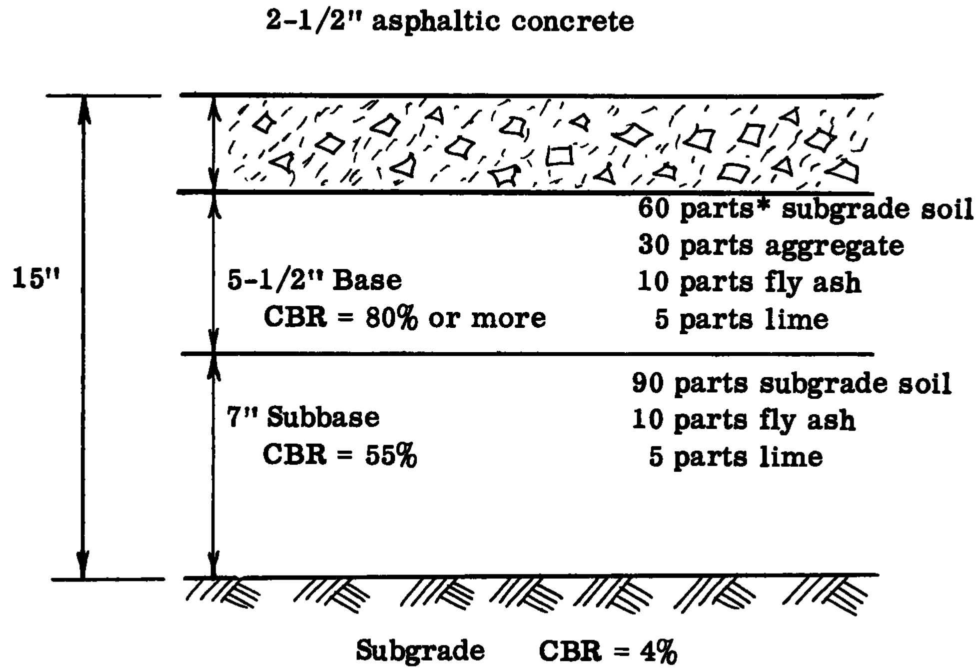
The traffic at Wings Field consists primarily of light and medium planes with maximum single-wheel load of 12,000 lb (Fig. 7). An estimated total at 52,000 plane movements are made per year. A takeoff or landing constitutes one plane movement.

An estimated value of the CBR for the A-5 subgrade soil is 7 percent. Using this value and the CBR design charts developed by the U.S. Corps of Engineers for taxiways and runways, the thickness of flexible pavement required would be approximately 13 in. for a taxiway and 12 in. for a runway.

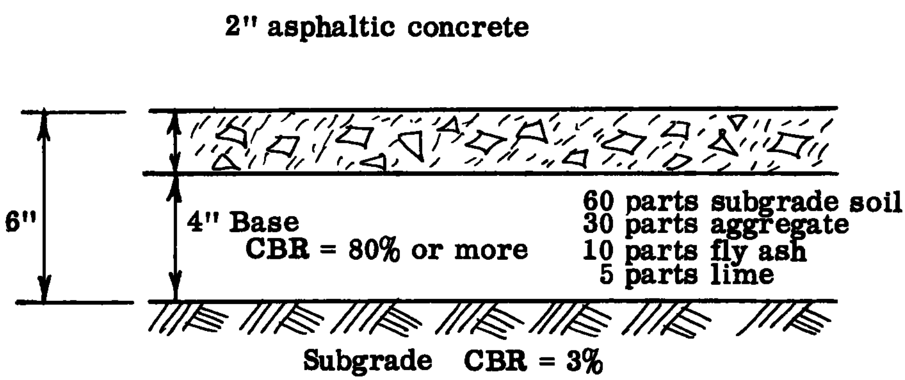
The existing thickness of 10 to 11 in. has been in use for more than three years and continues to perform satisfactorily. A recent visual inspection of the site showed the runway to be in excellent condition (Fig. 7).

Another lime-flyash aggregate base was constructed in the summer of 1956. This was the base for a 3½-mi section of two lane county road in Salem Co., New Jersey. The average traffic volume for this highway in 1957 was 1,650 vehicles per day. The

Example (1). Heavy Traffic, 22,000 lb. axle load



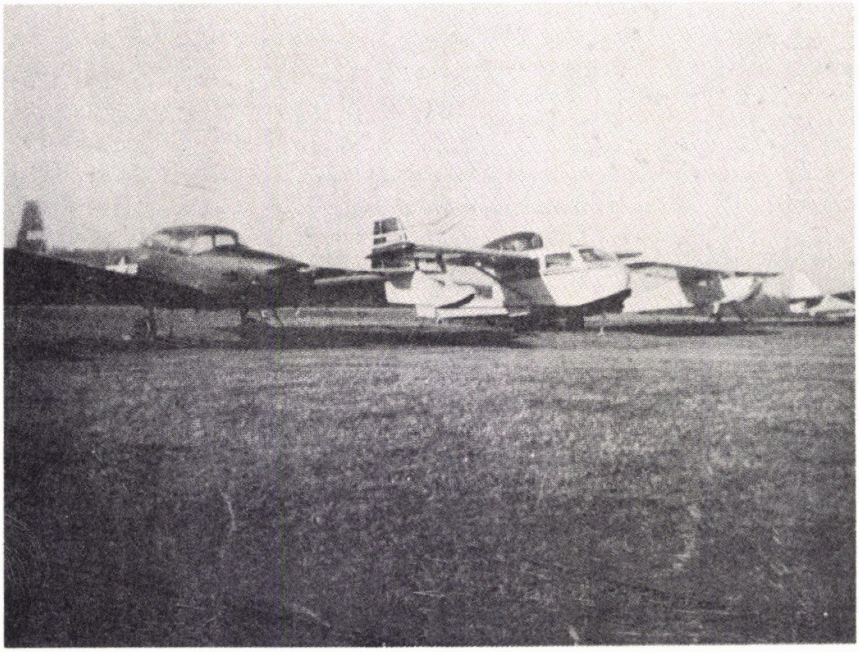
Example (2). Light Traffic, 8,000 lb. axle load



*Proportions of compositions are by weight.

Figure 6. Typical cross-sections using lime-flyash-aggregate.

(A)



(B)

Figure 7. (A) Runway at Wings Field, Pa.; (B) Typical aircraft using runway at Wings Field, Pa.

traffic is mixed passenger cars, light trucks, and heavy trucks and would be classified as "heavy". The recommended minimum thickness of flexible base and wearing course is 8 in. for this case according to the criteria of The Asphalt Institute. The actual thickness used was between 7½ and 8 in. and consisted of 6 in. of lime flyash and 1½ to 2-in. of asphaltic concrete. The subgrade soil is an A-1-b. After more than one year of service, this highway is in excellent condition with no evidence of deterioration.

The other three projects are also subjected to heavy traffic volumes. A comparison of the pavement thicknesses actually being used with that required by a CBR design would show that the actual would be slightly less than the required. They continue to give satisfactory service after three and four years.

COMPARISON OF LIME-FLYASH-AGGREGATE COMPOSITIONS WITH LIME-SOIL MIXTURES

The fundamental difference between the product of lime soil stabilization and lime-flyash-aggregate compositions is in the cementing action or pozzolanic activity. It is well known that straight lime additives to many soils will enhance their properties which are of importance as far as their suitability as construction material. The action of the lime on the soil is virtually immediate although some cementing effects can be developed later as a result of recrystallization and carbonation of the hydrated lime. It is doubtful that any significant pozzolanic reaction occurs between lime and natural soils. The pozzolans which are produced in nature are usually of volcanic origin although methods have been evolved to process certain select soils, such as shale, by calcination and thereby impart pozzolanic properties to the soil. It has been reported that additions of lime to clay soils have reduced high plastic indexes to a more reasonable value. The supporting power of the soils, as measured by CBR test, has been effectively increased. Numerous field installations, which have been in existence for many years, have performed in a more satisfactory manner than their natural soil counterparts. In essence the addition of lime to fine-grained soils, particularly clay, has transformed the properties to those more nearly of a coarse-grained material. In so doing many separate benefits are realized. The effect of additions of lime is a nearly complete reaction almost immediately except in those soils which contain additions of pozzolanic materials. In those cases there is substantial evidence of a continued cementing process which occurs over a long period of time. The dependence of this long range benefit on the presence of pozzolanic materials with the lime is one of the basic reasons for adding flyash. The addition of flyash insures the presence of a pozzolan in the mixture and thus insures that the mixture will increase in strength over a long period of time. Compressive strengths of samples removed from various installations show increases in strength over periods as long as three years. In two of the three cases analyzed the strength of the compositions has increased.

The comparative CBR tests performed during this investigation show a higher ratio for the lime-flyash mixtures than the lime-soil mixtures in two cases and just the reverse for one other case. It is to be pointed out that the CBR values of the mixtures may be considerably improved after an extended period of aging under wetting and drying conditions. However, the results are significant in that they indicate the abilities of the mixtures to develop considerably improved bearing characteristics over that of natural soil. The composition in which A-4 silt is used requires addition of supplementary aggregate materials to develop optimum bearing power. Experience has shown that where this is done, particularly with lime and flyash, formulations are possible in which heavy proportions of silt may be used in the final compositions.

The results of this study confirm the theory that lime, flyash, aggregate compositions are superior base materials even before any pozzolanic set has occurred. It is felt that pavement designs using lime-flyash aggregate can be made with confidence by the CBR method. Existing installations continue to perform satisfactorily and indications are that they are still gaining strength as predicted.

ACKNOWLEDGMENT

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