Research Report
KTC-89-56

PRELIMINARY ENGINEERING, MONITORING OF CONSTRUCTION, AND INITIAL PERFORMANCE EVALUATION: USE OF PONDED FLY ASH IN HIGHWAY ROAD BASE

by

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16. Abstract
This report summarizes findings of laboratory and field trial evaluations of ponded fly ash used as a component in a stabilized aggregate base course. Ponded fly ash is the fine portion of pond ash which is a by-product of a coal burning process and is disposed by sluicing to a disposal pond.

Three stabilized aggregate base mixtures containing various proportions of dense graded aggregate, ponded fly ash, and hydrated lime were evaluated in the laboratory relative to maximum dry density, optimum moisture content, and unconfined compressive strength. The mixture that was selected for field trial evaluation had the highest unconfined compressive strength and consisted of 85% dense graded aggregate, 11% ponded fly ash, and 5% hydrated lime.

A 750-foot section of a 22-foot wide roadway was constructed in May 1988. Approximately 80 tons of ponded fly ash were utilized in constructing the experimental base. Prior to construction, in-place California Bearing Ratio tests, moisture content determinations and Road Rater deflection tests were performed on the prepared subgrade. The stabilized aggregate base was placed in one 8-inch lift. During construction, relative compaction and moisture content of the base material were monitored by nuclear devices. Post construction evaluations included Road Rater deflections tests and coring to obtain samples for laboratory evaluation.

To date, the section containing the stabilized aggregate base is performing very well in comparison to the conventionally paved section.

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EXECUTIVE SUMMARY

This report summarizes findings of laboratory and field trial evaluations of ponded fly ash used as a component in a stabilized aggregate base course. Three stabilized aggregate base mixtures containing various proportions of dense graded aggregate, ponded fly ash, and hydrated lime were evaluated in the laboratory relative to maximum dry density, optimum moisture content, and unconfined compressive strength. The mixture that was selected for field trial evaluation had the highest unconfined compressive strength and consisted of 84% dense graded aggregate, 11% ponded fly ash, and 5% hydrated lime.

A 750-foot section of a 22-foot wide roadway was constructed in May 1988. Approximately 88 tons of ponded fly ash were utilized in constructing the experimental base. Prior to construction, in-place California Bearing Ratio tests, moisture content determinations and Road Rater deflection tests were performed on the prepared subgrade. The stabilized aggregate base was placed in one 8-inch lift. During construction, relative compaction and moisture content of the base material were monitored by nuclear devices. Post construction evaluations included Road Rater deflection tests and coring to obtain samples for laboratory evaluation.

Design and construction procedures for the use of a ponded fly ash-hydrated lime-limestone aggregate base have been demonstrated. Problems encountered during construction included consistency and moisture content of the pozzolanic mixture and production of the material at the concrete batch plant.

Observed performance of the pozzolanic base relative to the conventional dense graded aggregate base has been favorable. Compressive strength evaluations indicate low initial strengths but exceptional long-term strength gain. Deflection measurements indicate a significant increase in the overall stiffness of the structure with time. Rutting of the asphaltic concrete layers above the pozzolanic base has been minimal.

Based upon short-term observations, the ponded fly ash-hydrated lime-limestone aggregate base has apparently enhanced overall pavement performance and continued use of these materials should be evaluated as long-term performance data (structural stability and durability, freeze/thaw resistance, etc.,) become available. It is quite probable that pavement life may be extended at reduced costs by using coal by-product waste materials such as ponded fly ash in constructing roadway bases.

INTRODUCTION AND BACKGROUND

Kentucky has traditionally been among the leading producers of coal. Coal fields of eastern Kentucky produce low-sulfur, bituminous coals while western Kentucky coal fields produce a high-sulfur variety of bituminous coal. Coal-fired electric generating facilities are abundant in Kentucky and as a result, by-products in the form of fly ash, flue gas desulfurization sludge, boiler slag, and bottom ash are generated in large quantities. Approximately three million tons of fly ash are produced annually from Kentucky power plants.

Ashes from coal-fired plants consist of fly ash and bottom ash. Fly ash, used in this study, and bottom ash are codisposed of by sluicing to a disposal pond. These ponds require significant amounts of land area and when they become full, either the ash must be removed or new ponds must be constructed, either of which costs considerable amounts of money.

With the escalating costs of materials and construction for highways and streets, many agencies charged with the responsibility of designing and constructing highways are utilizing by-product stabilized (pozzolanic) materials. Low-strength (pozzolanic) materials have been used fairly extensively in some areas of the United States as well as abroad. In general, pozzolanic materials have been used to stabilize an aggregate base or subbase by addition of fly ash and lime to produce a cementitious reaction.

Until recently, the use of stabilized materials in highway and street construction in Kentucky was not often considered as being economically competitive with abundant supplies of high-quality aggregates. However, as costs of production and processing aggregate materials have increased, so has the feasibility of stabilized bases, and particularly by-product stabilized base materials.

In January of 1987, representatives of the Kentucky Transportation Center (KTC) and the Tennessee Valley Authority (TVA) met with representatives of the Kentucky Transportation Cabinet (KyTC) to discuss the possibility of an experimental project using various waste materials from TVA's Shawnee Power Plant, near Paducah, Kentucky, as base and subbase course material. The Kentucky Transportation Cabinet, Department of Highways, had an upcoming project locally and agreed to the experimental use of TVA's by-product materials. TVA officials agreed to provide the by-product materials at no cost to the Department. By-product materials to be provided by TVA's Shawnee Power Plant were pond ash (bottom ash and fly ash) and residue from an Atmospheric Fluidized Bed Combustion (AFBC) process. The AFBC residue is a by-product from a pilot plant using new clean-coal technology to lessen the amount of sulfur dioxide emissions produced by coal-fired electric generating plants. The pond ash is a by-product from the more conventional coal-fired electric generating plants.

This report describes the preliminary engineering, construction activities, and initial performance evaluations of using ponded fly ash as a component of a stabilized aggregate base course.

HIGHWAY DESIGN SPECIFICS

The experimental project is a 750-foot section contained within the 1.5-mile reconstruction of KY 3074, Bleich Road, in central McCracken County (see Figure 1). McCracken County is located in the far western part of Kentucky and borders the Ohio River. Climate in the area is generally mild with average summer temperatures of 78°F and average winter temperatures of 40°F. Typical yearly rainfall in the region is 50 inches and yearly snowfall is typically about 14 inches.

KY 3074 is a collector road extending from US 45 to KY 994. The design average daily traffic is 8,800 vehicles per day with approximately five percent trucks. The highway consists of two 11-foot lanes located in flat to slightly rolling terrain. The highway is crowned with turf shoulders. The design speed is 40 mph. Pavement thickness designs were determined on the basis of 410,000 Equivalent Single Axleloads and a subgrade material having an estimated California Bearing Ratio of 5%. The conventional pavement design for KY 3074 called for 8.0 inches compacted asphaltic concrete above 4.0 inches crushed stone base placed on a properly compacted subgrade.

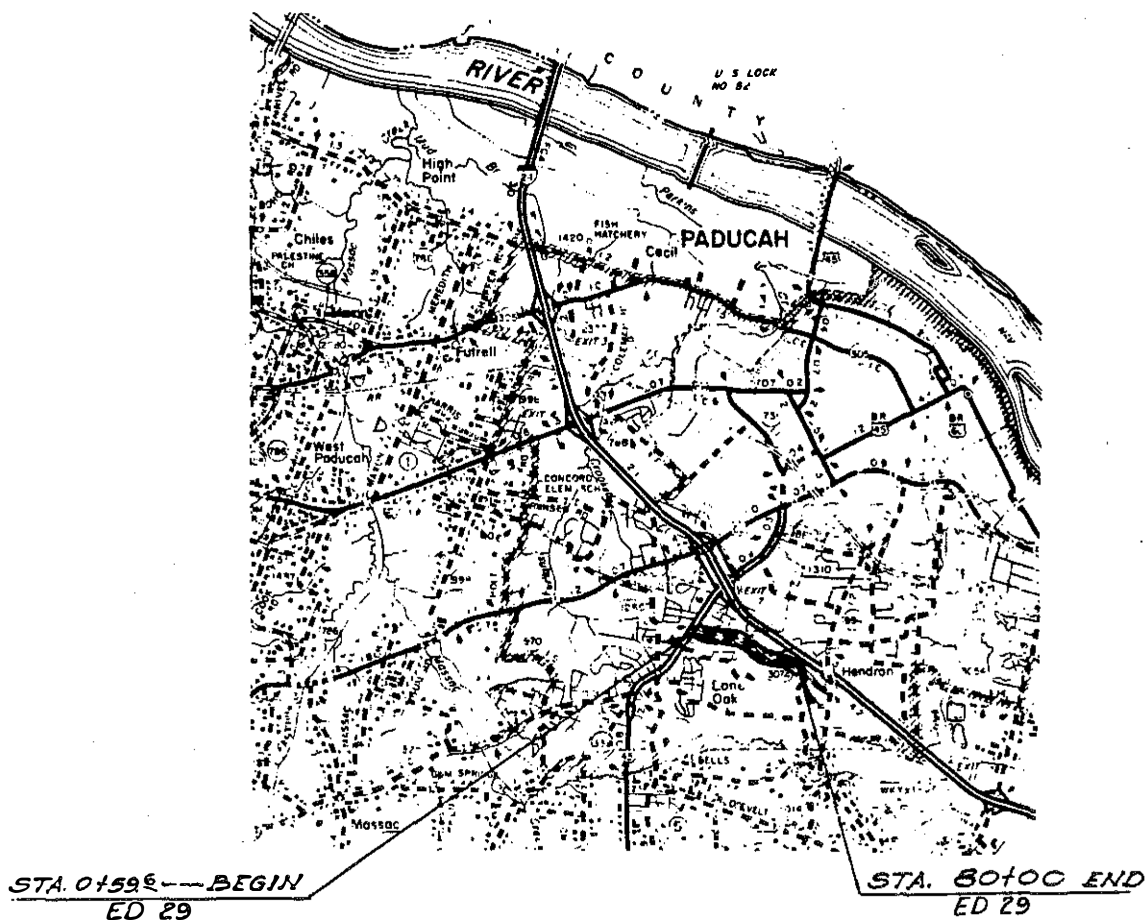

Figure 1. Location of Project.

Materials Information

Ponded fly ash was supplied by TVA and was obtained from TVA's Shawnee ~~Power Plant located in McCracken County. The Shawnee Power plant is located~~ within 15 miles of the project site. Typically, the loss on ignition of the ponded fly ash ranges from 1.9 to 8.0 percent. The fineness by the 325 sieve is generally within the range of 20 to 30 percent with specific gravity ranging between 2.2 and 2.4. Chemical composition of the ponded fly ash is presented in Table 1. Sieve analyses of the ponded fly ash were performed in accordance with ASTM C 136, "Sieve Analysis of Fine and Coarse Aggregates". A composite sieve analysis is presented in Figure 2.

Hydrated lime was supplied by the Mississippi Lime Company, Ste. Genevieve, Missouri, through the Federal Materials Corporation, Paducah, Kentucky. Specifics describing the characteristics of the hydrated lime are listed in Table 2.

Limestone aggregate materials were supplied by Reed Crushed Stone Company, Gilbertsville, Kentucky. The limestone aggregate source is located within 25 miles of the project site. Aggregate properties are summarized in Table 3.

TABLE 1. CHEMICAL ANALYSIS OF PONDED FLY ASH

Element/Parameter		Typical Range of Concentration
Moisture Content		Less than 1%
Loss on Ignition		1.9 - 8.0%
Fineness		20 - 30%
Specific Gravity		2.2 - 2.4
Silicon Dioxide	SiO_2	41 - 58%
Aluminum Oxide	Al_2O_3	18.1 - 28.6%
Iron Oxide	Fe_2O_3	3.9 - 26%
Calcium Oxide	CaO	0.8 - 4.5%
Magnesium Oxide	MgO	0.7 - 1.4%
Sodium Oxide	Na_2O	0.2 - 0.6%
Potassium Oxide	K_2O	1.5 - 3.3%
Titanium Dioxide	TiO_2	1.0 - 1.9%
Sulfur Trioxide	SO_3	0.1 - 2.2%
Phosphorus Pentoxide	P_2O_5	nil - 1.5%
pH		4.1 - 9.5%

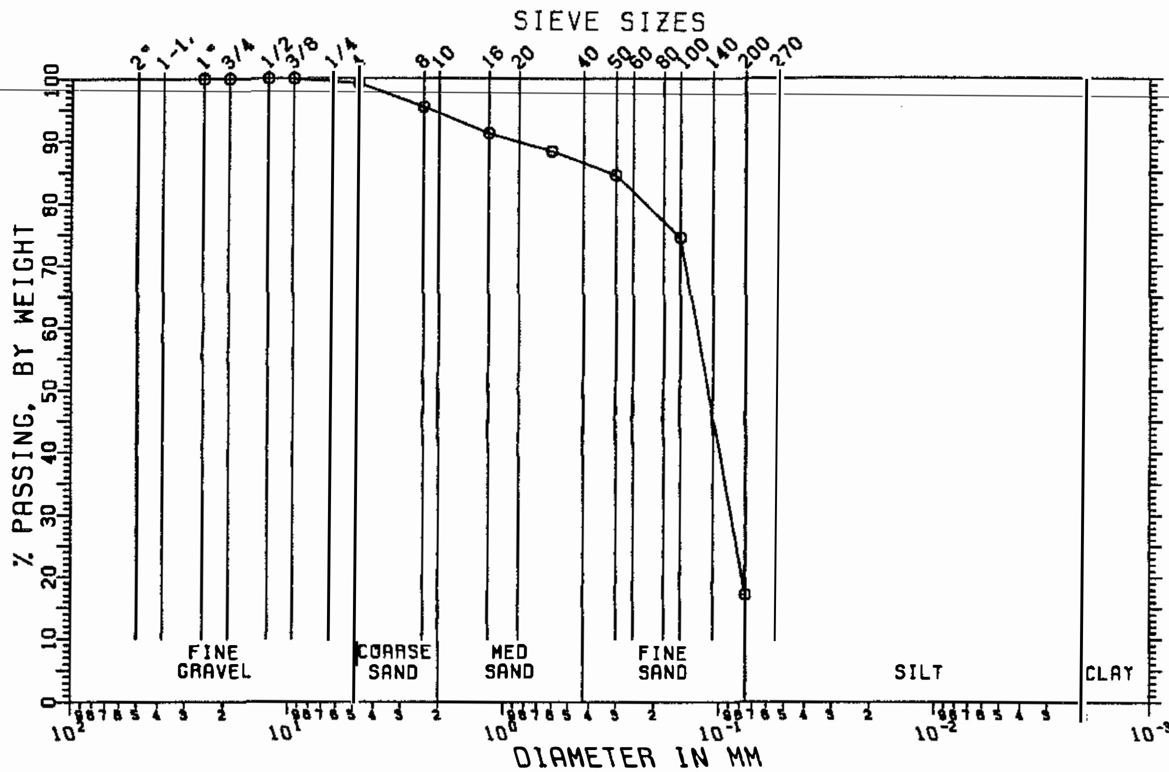

Figure 2. Average Gradation of the Ponded Fly Ash.

TABLE 2. CHEMICAL ANALYSIS OF HYDRATED LIME

Element/Parameter		Typical Range of Concentration
Moisture Content		0.3 - 0.95%
Loss on Ignition		N/A
Fineness (325 Sieve)		92.0%
Specific Gravity		2.2
Calcium Carbonate	$CaCO_3$	0.65 - 1.75%
Calcium Hydroxide	$Ca(OH)_2$	96 - 97.2%
Magnesium Oxide	MgO	0.38 - 0.55%
Calcium Sulfate	$CaSO_4$	0.15 - 1.0%
Silicon Dioxide	SiO_2	0.38 - 0.65%
Iron Oxide	Fe_2O_3	0.07 - 0.10%
Aluminum Oxide	Al_2O_3	0.20 - 0.30%

TABLE 3. PROPERTIES OF LIMESTONE AGGREGATE

Gradation		Physical Characteristics	
Sieve	Percent Passing		
2"	---	Specific Gravity (SSD)	2.66
1-1/2"	---	Absorption	1.0%
1"	100	L. A. Wear (500)	19%
3/4"	92	Sand Equivalent Value	83%
1/2"	---	Minus 200 Wash	7.3%
3/8"	59		
No. 4	37		
No. 8	---		
No. 10	21		
No. 16	---		
No. 30	---		
No. 40	13		
No. 50	---		
No. 100	---		
No. 200	8		

Mixture Design

Three stabilized aggregate base mixtures containing various proportions of ponded fly ash, hydrated lime, and dense graded aggregate were evaluated. Initial evaluations of the stabilized aggregate mixtures consisted of determining moisture-density relationships and ultimate compressive strengths of samples. Mixture compositions are summarized in Kentucky Department of Highways' Special Note for Experimental Use of Waste Materials in Highway Construction (see Appendix A). Moisture-density relations were determined in general accordance with ASTM D 1557, Method C, (1). Deviations from that method involved the use of a 5.5-lb rammer having a 12-inch free fall and 5 lifts were replaced with 3 lifts. Maximum dry density and optimum moisture content were determined using a polynomial curve fitting procedure. A smoothing technique was used to eliminate localized changes in concavity. Appendix B contains results of moisture-density relationships for the three mixtures evaluated.

Specimens for evaluation of compressive strength were prepared in general accordance with ASTM C 593 (2), in 4-in. by 4.6-in. molds. Specimens were compacted at the optimum moisture content, as determined previously. The specimens were cured in general accordance with ASTM C 593. Specimens were placed in sealed paint cans and cured in a 100^{0} F oven for four, seven, 14, and 28 days. ASTM C 593 requires submerging samples for four hours prior to compressive strength testing; however, the pozzolanic specimens began to slake within a short time after submergence. The occurrence of slaking was more pronounced for the specimens cured the shortest period of time. The specimens were tested for compressive strength development in accordance with ASTM C 39 (3) after removal from the soaking tank. Appendix B contains results of unconfined compressive strength determinations for each mixture.

The three stabilized aggregate base mixtures contained various proportions of ponded fly ash, hydrated lime, and dense graded aggregate. Trial mixture designs are summarized in Table 4. The amount of ponded fly ash, in the three mixes evaluated, varied from six to 11%. The amount of hydrated lime in the mixes varied from three to five percent. Dense graded aggregate varied from 84 to 91% of the total mixture. Average results of moisture-density and unconfined compressive strength determinations for the three mixtures are listed in Table 4. Because of the ultimately higher compressive strength development, mix number two was chosen for the optimum mixture design. The optimum moisture and maximum dry density of the optimum mix was 9.6% and 130.6 pcf, respectively. These values represent the mean of at least two series of tests performed to determine the optimum moisture and maximum dry density relationships. Figure 3 illustrates a typical determination of the optimum moisture content and maximum dry density for the mixture containing 84% dense graded aggregate, (DGA), 11% ponded fly ash, and 5% hydrated lime.

TABLE 4. SUMMARY OF MOISTURE-DENSITY RELATIONSHIPS AND COMPRESSIVE STRENGTH DEVELOPMENT

Mix No.	Mixture Component	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Age At Break (days)	Average Compressive Strength (psi)
1	Fly Ash: 9%	9.2	133.6	7	305
	Lime: 4%			14	595
	DGA: 87%			28	695
2	Fly Ash: 11%	9.6	130.6	7	260
	Lime: 5%			14	535
	DGA: 84%			28	780
3	Fly Ash: 6%	8.4	135.2	7	220
	Lime: 3%			14	445
	DGA: 91%			28	650

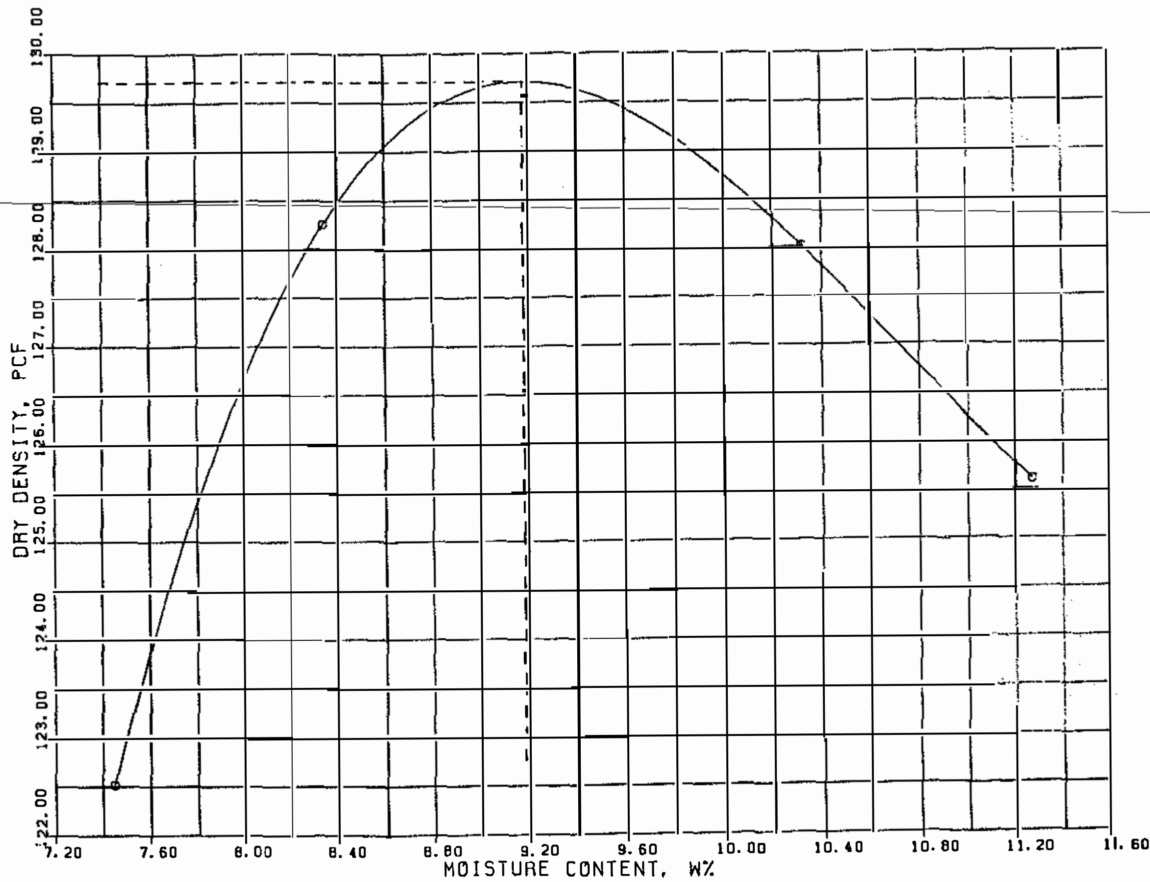

Figure 3. A Moisture-Density Determination for Mix No. 2.

Pavement Thickness Design Procedures

Thickness design procedures for flexible pavements in Kentucky have been developed on the basis of a limiting strain-repetitions criterion (4). The flexible pavement criterion limits the vertical compressive strain at the top of the subgrade and the tensile strain at the bottom of the asphaltic concrete. Preliminary analyses indicated elastic layer concepts may also be applied for thickness design of pozzolanic bases (5). Thickness design requirements for the pozzolanic base alternate were determined by using the Kentucky flexible pavement design procedure to determine thickness requirements using conventional materials (asphaltic concrete and crushed limestone). American Association of State Highway and Transportation Officials' (AASHTO) structural coefficients $a_1 = 0.44$ for the asphaltic concrete and $a_2 = 0.14$ for crushed stone were used to determine the structural number for the conventional design determined from the Kentucky procedure (6). The structural number (SN) was then used in combination with the AASHTO design equation;

$$SN = [a_1 \times d_1] + [a_2 \times d_2] \qquad [1]$$

and structural coefficients for asphaltic concrete a_1 = 0.44 and a_2 = 0.28 for the pozzolanic base material to determine the thickness requirement for the pozzolanic base material. The thickness design requirements based on these analyses indicated a pozzolanic base thickness of 8.0 inches.

The pavement design of the experimental pozzolanic section also specified a stress relief layer, to minimize the occurrence of reflective cracking, 2.0 inches of compacted bituminous concrete base, 1.5-inches compacted bituminous binder, and 1.0-inch compacted bituminous concrete surface. A bituminous tack coat was specified between bituminous concrete layers. A typical section for the experimental section is shown in Figure 4. The control section was conventionally designed and constructed and consisted of 4.0 inches of crushed aggregate base, 5.5-inches compacted bituminous concrete base, 1.5-inches compacted bituminous concrete binder and 1.0-inch compacted bituminous concrete surface. A bituminous tack coat was specified between bituminous concrete layers. A typical section for the experimental section is shown in Figure 5. A schematical diagram detailing locations of the experimental and control sections is shown in Figure 6.

CONSTRUCTION PROCEDURES

The project, McCracken County SSP 073 3074 000-002, is a combined grade, drain, and surfacing project. The contract was awarded to Jim Smith Contracting Company, Inc., and Subsidiaries, of Grand Rivers, Kentucky on June 30, 1987. Grading and drainage work were initiated during August, 1987.

Preparation of the soil subgrade was completed in May 1988. Measurement of in-situ subgrade strength, by KTC personnel, was in general accordance with ASTM D 1883 (7), except that the tests were performed on the soil in its actual in-situ condition. Measurement of subgrade strength was also by the Clegg Impact Test using the Clegg Impact Soil Tester (8). Moisture content of the soil for these tests was determined in accordance with ASTM D 2216 (9). Values of California Bearing Ratio (CBR) for each method of determination and subgrade moisture content are contained in Table 5. The in-situ bearing strength and moisture content of the subgrade materials were not that uniform or consistent. The subgrade of the pozzolanic section had an average in-situ CBR of 43% and moisture content averaged 6.9%. The subgrade of the control section averaged 33% and 14.6% for the in-situ CBR and moisture content, respectively.

Construction of the experimental base began June 1, 1988. Construction requirements are summarized in Kentucky Department of Highways' Special Note for Experimental Use of Waste Materials in Highway Construction (see Appendix A). The ponded fly ash and lime stabilized base materials were blended at the Federal Materials Corporation's concrete batching plant located on the I-24 Business Loop in Paducah. The plant was a separate weigh-batch increment type

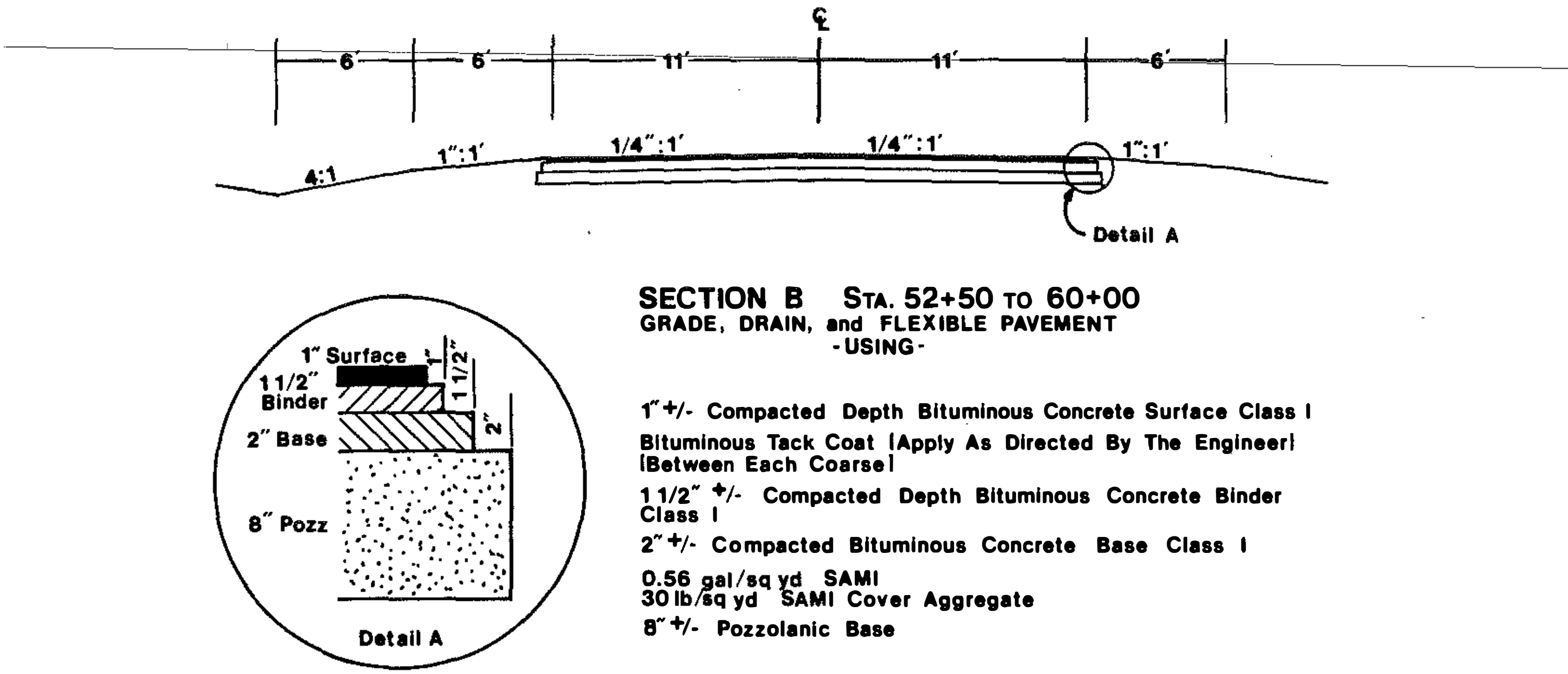

Figure 4. Typical Section and Detail for the Pozzolanic Section.

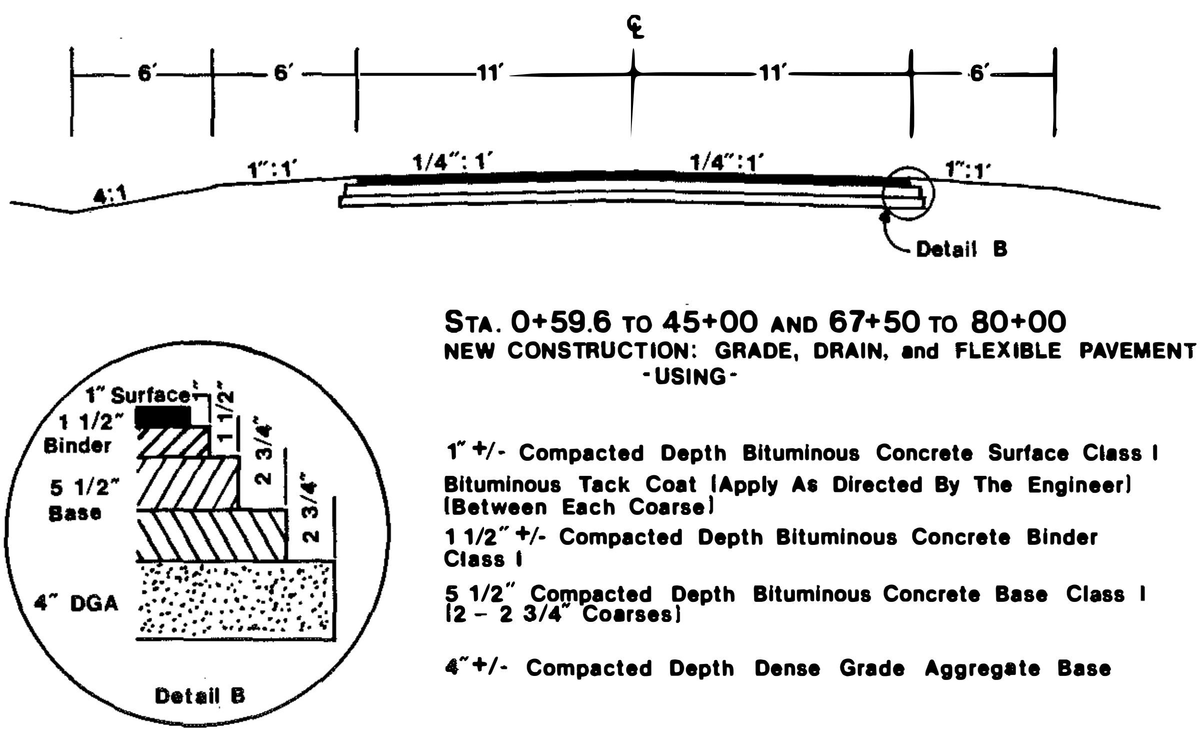

Figure 5. Typical Section and Detail for the Control Section.

KY 3074 -- BLEICH ROAD

AFBC CONCRETE BASE SECTION	POZZOLANIC BASE SECTION	STABILIZED BOTTOM ASH SUBBASE SECTION	CONVENTIONAL (CONTROL) SECTION

STA 45+00 ¦---------------¦ STA 52+50 ¦---------------¦ STA 60+00 ¦---------------¦ STA 67+50 ¦---------------¦ STA 75+00

Figure 6. Schematic Detailing Location of Experimental and Control Sections.

TABLE 5. SUMMARY OF SUBGRADE CONSTRUCTION INFORMATION

Station Number	Moisture Content (%)	In-situ California Bearing Ratio ASTM D 1883 (%)	In-situ California Bearing Ratio Clegg Hammer (%)
Pozzolanic Section			
53+50 Rt	6.1	49	48.1
55+00 Lt	4.6	47	43.1
56+50 Rt	7.5	39	43.1
58+00 Lt	11.4	13	12.9
59+50 Rt	5.0	65	59.7
Control Section			
68+50 Rt	15.5	7	7.6
70+00 Lt	11.6	77	33.3
71+50 Rt	11.1	46	32.1
73+00 Lt	16.6	19	10.1
74+50 Rt	18.0	16	5.2

plant. Plant equipment included all components and accessories for stabilization-type mixing plants deemed necessary for proper performance. The ponded fly ash and dense graded aggregate were stockpiled without protection and the hydrated lime was pumped from a pneumatic truck to a storage silo. The ponded fly ash and dense graded aggregate were loaded onto an aggregate conveyor belt at prevailing moisture contents and transported to the mixer. The hydrated lime was dry fed from the silo onto an aggregate belt and carried to the mixer. The amount of mixing water required for optimum conditions was generally estimated and the proper amount of water required for blending was arrived at accordingly. Appendix C contains information relative to production times and material quantities used. The blended base material was transported approximately 15 miles to the paving site in dump trucks.

The base materials were end dumped into and spread by a conventional aggregate spreader box pushed by a small bulldozer (see Figure 7). The 8.0 inches of base material was placed in one lift and compacted using a steel-wheeled vibratory roller having a minimum weight of 10 tons (see Figure 8). A motor grader was used to trim the material to proper grade. Because of scheduling difficulties at the concrete batch plant, three days were required to complete placement of the base material. Summaries of calculated material quantities for production of the ponded fly ash-hydrated lime-limestone aggregate road base are listed in Table 6.

During construction, placement and compaction operations proceeded smoothly when material was available. Placement of the pozzolanic base material was hindered by a lack of production at the concrete batch plant. The base material was placed on Wednesday, Friday and Saturday, June 1, 3, and 4, 1988, respectively. The number of truck loads delivered to the jobsite on Wednesday was only 15, or about 215 tons of material. After delivery of the first load Wednesday morning, problems at the concrete batch plant caused a 244 minute interval between the first batch and second batch. Because of these delays, Thursday's production was canceled and Friday's production was delayed until after noon. Twenty-two truck loads, or about 320 tons of material, were

Figure 7. Placing the Experimental Base Material.

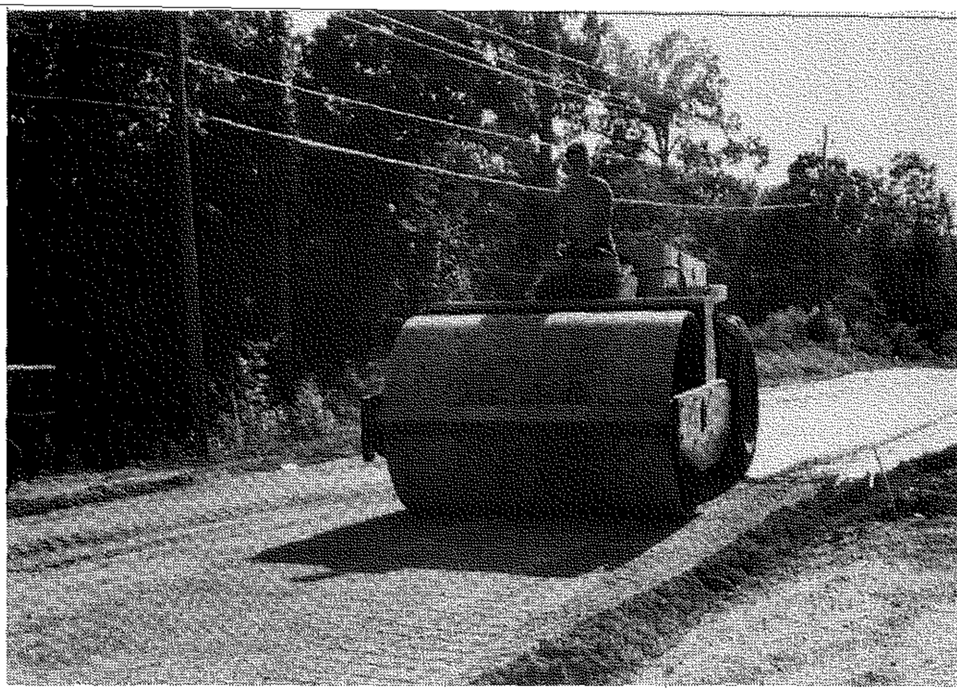

Figure 8. Compacting the Experimental Base Material.

TABLE 6. BASE MATERIAL QUANTITIES

Material	Quantity (Tons)	Percent of Total (%)
DGA	666.82	84.0
Ponded Fly Ash	88.10	11.1
Hydrated Lime	38.87	4.9
Totals	793.79	100.0

delivered to the jobsite on Friday afternoon. The 750-foot experimental section was completed Saturday morning, June 4, 1988. Twenty truck loads, or about 292 tons of material, were placed on the final day. Overall, the consistency of the mix appeared to be fairly good. There were, however, some material segregation and excess moisture observed in some of the loads. The initial loads often contained excess moisture, later loads were sometimes not mixed very thoroughly. The additional moisture in the initial loads often delayed compaction. Material segregation may promote softening of the compacted pozzolanic base in the future.

A compaction requirement of no less than 100% of laboratory dry density was specified for the pozzolanic base construction. In-place densities of the compacted pozzolanic base material were determined by nuclear gages using applicable Kentucky Department of Highways' Test Methods (KM 64-512) (10). A total of ten measurements were made for density and moisture content. A summary of construction density measurements is presented in Table 7. As illustrated in Table 7, eight of ten measurements met or exceeded the specified 100% of maximum dry density. A 5-hour time limit between mixing and completion of compaction was specified. It also was intended that all trimming and fine grading be accomplished during the 5-hour period.

A bituminous curing seal was placed over the compacted base to prevent excess evaporation of moisture from the pozzolanic material. The application rate of the bituminous curing seal was estimated to be 1.2 pounds per square yard per inch of depth. The required curing seal was to be placed as soon as possible, but no later than 24 hours after completion of finishing operations. Although a 5-hour time limit between mixing and completion of compaction was specified, where loads contained excess moisture, the experimental pozzolanic base remained somewhat plastic for several hours. This resulted in difficulties in placing the curing membrane within the specified 24-hour period since the asphalt distributor would often rut the plastic base.

To prevent the occurrence of reflective cracking in the asphalt layers, known to be associated with pozzolanic bases, (11), a polymerized emulsion was

TABLE 7. SUMMARY OF DENSITIES FOR POZZOLANIC BASE CONSTRUCTION

Station Number	Offset	Moisture Content (%)	Field Density (% of optimum)
53+05	Rt	10.1	100.8
53+80	Lt	10.3	100.0
55+76	Rt	8.8	94.6
55+54	Rt	9.1	102.5
56+00	Lt	10.0	99.0
56+00	Lt	10.2	100.0
57+25	Rt	7.9	100.0
57+25	Rt	7.7	101.4
53+90	Lt	7.6	101.0
53+50	Rt	8.4	100.9

used with 9M limestone chips (3/8-inch maximum) to construct a stress relief layer approximately 1/2 inch thick. Application rates of the polymerized emulsion and limestone chips were estimated to be 0.56 gallon per square yard and 30 pounds per square yard, respectively.

Asphalt pavement construction was begun approximately 10 weeks after placement of the pozzolanic base material. Asphaltic concrete was placed and compacted in three lifts: base, binder, and surface. Placement of asphaltic concrete layers was delayed due to observations being made on two additional experimental sections wherein residue from an AFBC process was utilized in constructing base and subbase pavement layers. These experimental sections were constructed contiguous to the experimental ponded fly ash-hydrated lime-dense graded aggregate base. Evaluations relative to the use of AFBC residue in base and subbase pavement layers will be detailed in a separate report.

EVALUATIONS

During and after construction, investigations relative to the engineering properties of the pozzolanic base mixture continued. During construction, specimens were compacted at the jobsite for verification of densities. Moisture content samples also were obtained. Field compacted specimens were taken to the laboratory, cured under ambient conditions in sealed plastic sample bags, and subjected to destructive testing. Additionally, cores of the pozzolanic base were obtained at various times and tested for compressive strength and static chord elastic modulus. Road Rater deflection surveys were performed on compacted subgrade, cured base material, and asphaltic concrete layers. However, for this report, the focus of Road Rater analyses will be limited to the subgrade and pozzolanic base only. Visual distress and rutting surveys were performed to assess the condition of the pavement.

Density, Moisture, Compressive Strength and Modulus of Elasticity of the Pozzolanic Mixture

Specimens were compacted at the jobsite for evaluations relative to density and moisture. Specimens for density determinations were prepared in general accordance with ASTM C 593 in 4-in. by 4.6-in. molds. Deviations from that method involved the use of a 5.5-lb. hammer and a 12-in. free fall instead of the specified 10-lb. hammer and 18-in. drop. Samples were weighed in the field and wet densities were calculated. The 4-in. by 4.6-in. samples were to have been cured in sealed paint cans under various conditions and used for compressive strength and elastic modulus determinations. However, while transporting the specimens to the laboratory, the specimens slumped and these tests were not attempted. Instead, 6-in. by 12-in. plastic cylinder molds were utilized in making samples for compressive strength and elastic modulus determinations. The specimens were compacted in the field and also were prepared in general accordance with ASTM C 593. Deviations from that method involved the use of 6-in. by 12-in. cylinder molds and the use of a 5.5-lb. hammer with a 12-in. free fall instead of 4-in. by 4.6-in. molds and the specified 10-lb. hammer with an 18-in. drop.

To verify satisfactory compactive effort while preparing the 6-in. by 12-in. cylinder molds, wet densities were calculated for all compacted specimens. Samples of the pozzolanic base material also were obtained from selected series of specimens for moisture content determinations. Using these results, dry densities of those specimen were calculated. After compaction, plastic caps were placed on the cylinders and each cylinder was placed in a plastic sample bag and sealed with tape to help prevent loss of moisture. Specimens remained at the jobsite until the final day of placement operations and then were transported to the laboratory in Lexington for destructive testing.

Specimens were cured at ambient temperature in sealed plastic bags in the laboratory. Unconfined compressive strengths were determined in accordance with ASTM C 39. The static chord elastic modulus was determined in accordance with ASTM C 469 (12). Specimens were tested at seven, 14, 28, 56, and 112 days. The results of these analyses are presented in Table 8.

An inspection of the compressive strengths of field compacted specimens contained in Table 8 illustrates the long-term strength gain characteristics of the ponded fly ash-hydrated lime-limestone aggregate base. Average seven-day compressive strengths were only 65 psi. There were no data obtained at seven-days for static chord elastic modulus because of weak samples and fear of damaging the compressometer and dial gages. At 14-days, the compressive strength had increased to an average of 120 psi with a static chord elastic modulus of about 64,000 psi. The 28-day average compressive strength increased to 265 psi. The static chord elastic modulus increased almost tenfold over the 14-day modulus to 573,000 psi. Average values for compressive strength and static chord elastic modulus, at 56 and 112 days, had increased to 645 psi and 1,497,000 psi, and, 1,600 psi and 2,830,000 psi, respectively. Although an attempt was made to simulate proper compactive effort, obvious differences exists between field compacted specimen and field cores. The sparse modulus data presented in Table 8 reflect some of the problems. The 6-in. by 12-in. field compacted specimens often exhibited large numbers of voids on their sides and, therefore, data could not be obtained using the compressometer. As a measure of the compactive effort, the wet density of specimens compacted at optimum moisture content should have been 143.14 pounds per cubic foot.

Kentucky Transportation Center (KTC) personnel visited the project six months after the experimental base was placed and obtained three cores from the pozzolanic base. The core samples were transported to the KTC laboratory for evaluations relative to compressive strength and static chord elastic modulus. The cores were tested at approximately 270 days of age. The average compressive strength of the three field cores was 2,055 psi. Because of sample

TABLE 8. COMPRESSIVE STRENGTH, ELASTIC MODULUS, AND DENSITY OF FIELD COMPACTED 6-in. BY 12-in. SAMPLES

Sample Number	Wet Density (pcf)	Moisture Content (%)	Dry Density (pcf)	Age at Test (days)	Compressive Strength (psi)	Elastic Modulus (psi)
1-1	142.70	-	-	7	80	-
1-2	144.28	-	-	14	130	-
1-3	144.74	-	-	28	325	730,745
5-1	130.78	-	-	7	140*	-
5-2	132.72	-	-	14	-	-
5-3	131.60	-	-	28	275	-
9-1	135.22	-	-	7	-	-
9-2	141.33	-	-	14	135	-
9-3	135.27	-	-	28	260	-
13-1	133.33	-	-	7	130*	-
13-2	135.57	-	-	14	-	-
13-3	130.38	-	-	28	125	-
17-1	144.59	8.6	133.14	7	35	-
17-2	145.00	8.3	133.89	14	140	53,730
17-3	144.28	8.0	133.59	28	275	520,260
21-1	143.88	8.8	132.24	7	40	-
21-2	143.47	9.0	131.62	14	80	52,635
21-3	142.70	8.8	131.16	28	220	299,680
25-1	144.54	8.5	133.22	7	50	-
25-2	142.86	8.6	131.54	14	110	-
25-3	144.44	8.7	132.88	56	715	1,630,830
29-1	145.00	9.0	133.03	7	-	-
29-2	145.56	8.9	133.66	14	135	79,310
29-3	143.62	9.3	131.40	28	330	743,745
33-1	147.41	8.3	136.11	7	50	-
33-2	145.86	8.4	134.56	14	85	70,565
33-3	147.95	7.9	137.12	56	570	1,363,340
37-1	143.88	-	-	7	65	-
37-2	143.47	-	-	14	105	-
37-3	141.07	-	-	28	300	-
41-1	143.62	-	-	7	65	-
41-2	142.96	-	-	14	140	-
41-3	144.08	-	-	112	1,795	3,155,215
45-1	135.47	-	-	7	95	-
45-2	140.62	-	-	14	145	-
45-3	142.65	-	-	112	1,400	2,503,940
50-1	129.62	-	-	7	70	-
50-2	133.33	-	-	14	-	-
50-3	136.90	-	-	28	265	-

NOTE: * indicates less than 2 to 1 length to diameter ratio.

preparation techniques, only one core was tested for static chord elastic modulus. The static chord elastic modulus for this core was 1,670,000 psi (see Figure 9). Results of these analyses are considered more representative of the compressive strength and elastic modulus of the pozzolanic mixture because the tests were performed on actual field cores. The results certainly illustrate the long-term strength gain characteristics associated with the ponded fly ash-hydrated lime-limestone aggregate mixture.

Road Rater Deflection Measurements and Dynamic Analysis

Structural evaluation of the in-place pozzolanic base material was conducted using a Model 400B Road Rater. The Road Rater applies a steady state vibratory load to the pavement structure and records the corresponding deflections at several radial distances from the center of the load. The magnitude of the vibratory load is a function of loading frequency and vibrating mass. The loading limits of the Road Rater are 0 to 2,400-pounds force. A dynamic stiffness may be calculated using the deflection measurements. The dynamic stiffness is calculated by dividing the applied dynamic load by the deflection directly under the load. It may be represented in terms of pounds-force per inch. The dynamic stiffness is a measure of the structural capacity of the material.

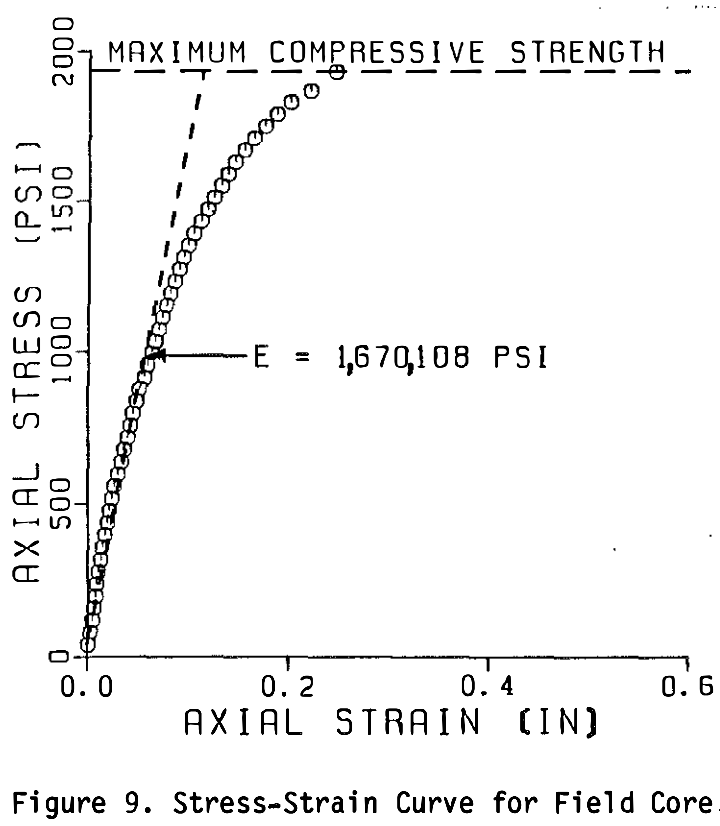

Figure 9. Stress-Strain Curve for Field Core.

Deflection measurements were obtained at various stages of construction. More specifically, deflection measurements were obtained on the compacted subgrade and after placement of the pozzolanic base material. Deflection measurements also were obtained at various times after placement of the asphaltic concrete material. However, for this report, the focus of Road Rater analyses will be limited to the subgrade and pozzolanic base only.

Deflection measurements were made at 50-foot intervals along the centerline of each driving lane and along the centerline of the roadway. Tests were conducted for dynamic loadings of 600-pound force and 1,200-pound force. Mean values of stiffness were calculated for each pass and for both loadings. The deflection measurements were conducted on the compacted subgrade immediately before placement of the pozzolanic base materials and on the pozzolanic base material at various ages. Test were conducted at seven, 14, 28, 42, 52, and 68 days after final placement of the base. The dynamic stiffnesses calculated for each direction at each age are shown in Figure 10. It may be seen from this figure that the application of the pozzolanic base material greatly increased the structural capacity of the roadway.

The long-term strength gain characteristics of the pozzolanic material is further illustrated in Figure 10. Higher dynamic stiffness values are recorded through 42 days. After 42 days, the gain in strength has decreased, as would be expected. It may also be seen that beyond 42 days, there is some variability in the dynamic stiffness. This is most likely due to seasonal changes and the resulting variability in the subgrade materials.

Visual Survey and Rutting Characteristics

The experimental and control sections have been visually surveyed periodically for observable pavement distress since completion of construction. Factors such as pavement rutting and cracking were of principle concern. Overall, both sections are in very good condition. A detailed visual survey was conducted within one year after placement of the asphaltic concrete layers. There was minor cracking observed on the surface of the asphaltic concrete in the experimental section. The hairline longitudinal crack was located within 6 inches of the edge of the pavement and extended about 50 feet. The cracking appeared to be an edge failure and may have occurred before placement of the soil and turf shoulder. The shoulder furnishes structural support to the pavement base and surface courses by serving as a buttress along the pavement's edge. Prolonged absence of the soil and turf shoulder may have contributed to the observed cracking.

Measurements of rutting depth were obtained every 50 feet in both the experimental pozzolanic section and the control section. These results have been tabulated and are listed in Table 9. The magnitude of rutting measured in the westbound lane of the control section was observed to be twice the amount

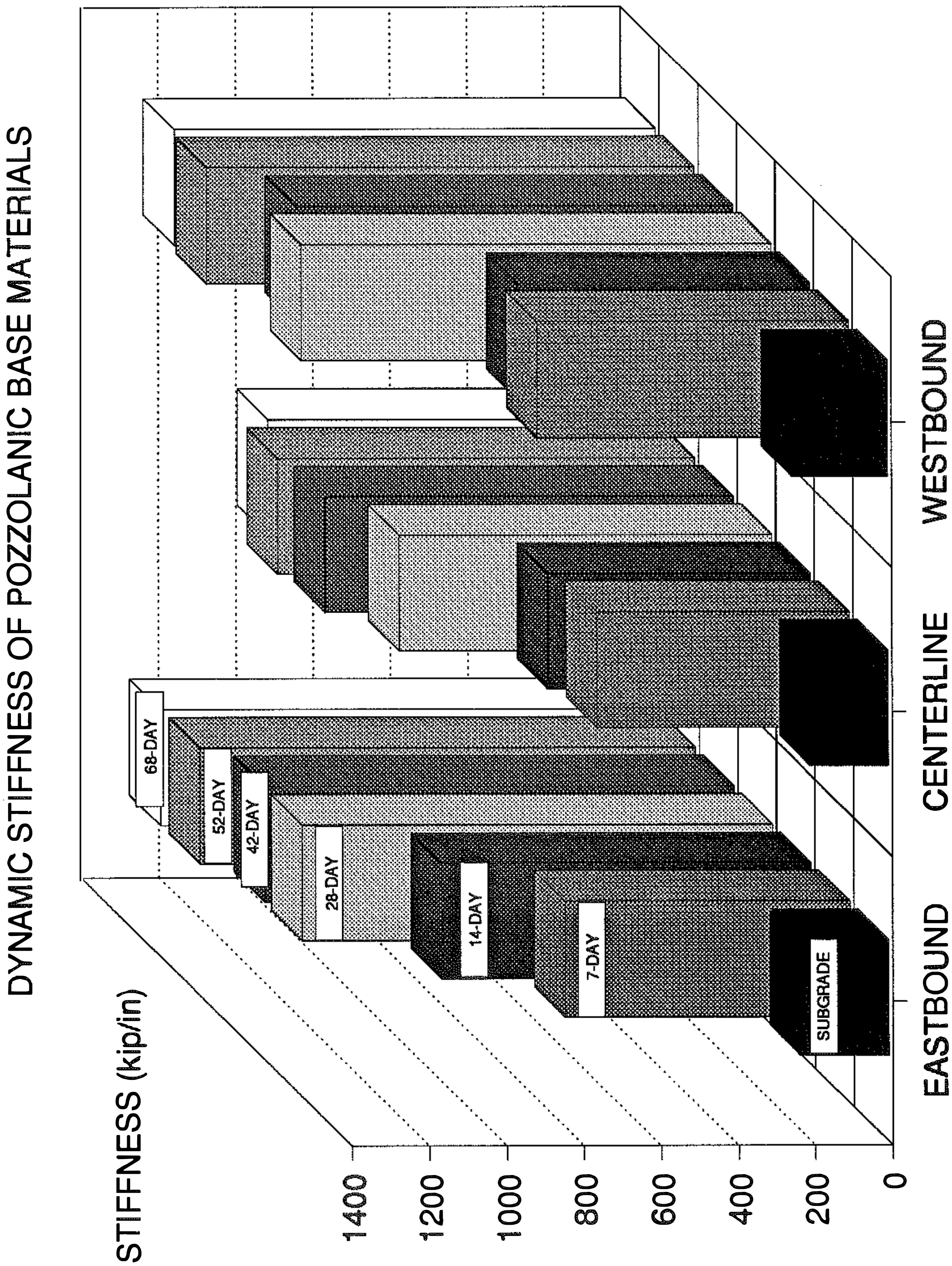

Figure 10. Dynamic Stiffness as a Function of Age.

TABLE 9. RUTTING DEPTHS -- POZZOLANIC AND CONTROL SECTIONS

	POZZOLANIC SECTION					CONTROL SECTION			
	West		East			West		East	
	RWP	LWP	LWP	RWP		RWP	LWP	LWP	RWP
STA.	(in.)	(in.)	(in.)	(in.)	STA.	(in.)	(in.)	(in.)	(in.)
53+00	2/16	2/16	2/16	2/16	68+00	3/16	2/16	2/16	2/16
53+50	1/16	2/16	2/16	1/16	68+50	5/16	4/16	2/16	2/16
54+00	1/16	1/16	1/16	1/16	69+00	6/16	4/16	2/16	2/16
54+50	3/16	1/16	1/16	1/16	69+50	5/16	5/16	2/16	2/16
55+00	2/16	2/16	2/16	1/16	70+00	6/16	4/16	2/16	1/16
55+50	2/16	1/16	2/16	2/16	70+50	7/16	5/16	2/16	1/16
56+00	1/16	1/16	2/16	1/16	71+00	5/16	5/16	2/16	1/16
56+50	2/16	1/16	1/16	1/16	71+50	5/16	2/16	1/16	1/16
57+00	2/16	2/16	1/16	1/16	72+00	3/16	2/16	1/16	1/16
57+50	1/16	1/16	1/16	1/16	72+50	3/16	2/16	2/16	3/16
58+00	2/16	1/16	2/16	1/16	73+00	2/16	4/16	1/16	3/16
58+50	3/16	2/16	3/16	1/16	73+50	3/16	4/16	2/16	2/16
59+00	2/16	1/16	1/16	1/16	74+00	3/16	4/16	1/16	2/16
59+50	2/16	1/16	2/16	1/16	74+50	2/16	3/16	1/16	2/16
Avg.	2/16	1/16	2/16	1/16		4/16	4/16	2/16	2/16

of rutting that was measured in either lane of the experimental section. The rut depths of the pozzolanic section were fairly uniform and averaged 1/16 to 1/8 inch.

SUMMARY AND CONCLUSIONS

Design and construction procedures for the use of a ponded fly ash-hydrated lime-limestone aggregate base have been demonstrated. This is the first project in Kentucky wherein ponded fly ash, a waste material, was utilized in constructing a stabilized aggregate road base. Problems encountered during construction included consistency and moisture content of the pozzolanic mixture and production of the material at the concrete batch plant. The lack of a uniform moisture content in materials delivered to the jobsite caused some delay in compacting the pozzolanic base, cutting to proper grade, and applying the bituminous curing seal within the specified time. Production was delayed due to various problems. Failure of a motor on one conveyor belt caused a six-hour delay on the first day of production. Also, delays were encountered because the batch plant operators did not devote full attention to the production of the pozzolanic materials. The batch plant continued producing concrete between batches of the pozzolanic base. The delays at the concrete batch plant suggested that a better set-up for the production of the pozzolanic base material may have been a pugmill set up near the jobsite.

Observed performance of the pozzolanic base relative to the conventional dense graded aggregate base has been favorable. Use of the stress absorbing interlayer membrane eliminated, or at least has delayed, the formation of reflective cracks in the asphaltic concrete due to shrinkage of the pozzolanic base. Compressive strength evaluations indicate low initial strengths but exceptional long-term strength gain. Deflection measurements indicate a significant increase in the overall stiffness of the structure. The magnitudes of deflections for the pozzolanic base material indicate a strong pavement structure even without the benefit of the asphaltic concrete layers. Rutting of the asphaltic concrete layers above the pozzolanic base has been minimal. Rut depths obtained to date for the experimental pozzolanic section and the conventional, or control, section indicate that the control section had nearly twice the amount of rutting when compared to the pozzolanic section.

Based upon these short-term observations, the ponded fly ash-hydrated lime-limestone aggregate base has apparently enhanced overall pavement performance and continued use of these materials should be evaluated as long-term performance data (structural stability and durability, freeze/thaw resistance, etc.,) become available. It is quite probable that pavement life may be extended at reduced costs by using coal by-product waste materials such as ponded fly ash in constructing roadway bases.

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APPENDIX A

Special Note for Experimental Utilization of
Waste Materials in Highway Construction

SPECIAL NOTE FOR
EXPERIMENTAL USE OF WASTE MATERIALS
IN HIGHWAY CONSTRUCTION

I. DESCRIPTION

This work shall consist of furnishing all materials, except experimental materials, and all labor, equipment, and incidentals necessary to complete construction as shown on the plans and in accordance with provisions of the contract documents. Materials which are designated as experimental materials under II.B will be supplied to the Contractor at no cost and will be delivered to the place(s) within the project limits, or reasonably close thereto, designated by the Contractor at no cost for delivery.

All requirements of the Department's Standard Specifications for Road and Bridge Construction shall apply unless specifically modified herein. Section references contained herein are to the Standard Specifications.

II. MATERIALS

A. Conventional Materials. Conventional materials shall include all materials used in construction of the project with the exception of those materials listed herein under B. Experimental Materials. Conventional materials shall meet all requirements of appropriate sections of the Standard Specifications, plans, and proposal.

For this project, hydrated lime, the bituminous curing seal, and the stress-absorbing membrane (SAMI) will be considered conventional materials.

Hydrated lime, when required, shall conform to the requirements of ASTM C 207, Type N, Paragraphs 3, 6, 7.1.1, 10, and 11.

The bituminous material for the curing seal shall be either RS-1, AE-60, SS-1, SS-1h, CRS-1, CSS-1, CSS-1h, or Primer L, conforming to the requirements of Section 806.

B. Experimental Materials. Materials which are designated experimental for this project are:

(1) fly ash,

(2) residue from atmospheric fluidized bed combustion process (AFBC residue), and

(3) ponded bottom ash.

Experimental materials will be supplied and delivered to point(s) of mixing or stockpiling within the project limits or reasonably close thereto designated by the Contractor and at no costs to the Contractor. The Contractor shall inform the Engineer of the location to which the experimental materials are to be delivered at least 2 weeks before the materials will be needed.

The Contractor will not be responsible for ensuring that experimental materials meet physical and/or chemical requirements except the Contractor shall be responsible for pre-hydrating the AFBC residue prior to incorporation in any mixture or placement in the base. Pre-hydration shall be accomplished by the addition of 12 percent, by weight, water to the AFBC residue. The water and AFBC residue shall be thoroughly mixed in a plant meeting requirements of III.A.4 and then permitted to interact for no less than 24 hours prior to use.

III. CONSTRUCTION REQUIREMENTS

A. Plant-Mixed Base.

1. General. The subgrade shall be prepared in accordance with Section 208 and shall be maintained free from irregularities. Where the required thickness is more than 6 inches, the mixture shall be spread and compacted in 2 or more layers of approximately equal thickness, and the maximum compacted thickness of any one layer shall not exceed 6 inches. Work on each layer shall be performed in a similar manner and the surface of the compacted material shall be kept moist or prevented from drying, by a method approved by the Engineer, until covered with the next layer. The second layer may be applied immediately after obtaining satisfactory compaction of the first layer.

When a base course extends under the shoulders, the section under the pavement shall be constructed first and the Contractor may defer the placing of the remaining portion of the base course under the shoulders until after construction of the paved lane. In such a case, the minimum width of initial base construction shall extend 2 feet beyond the paved lane edges. In no case shall construction joints of the base lie underneath the proposed joints of the base or pavement to be superimposed.

2. Seasonal Limitations. The experimental bases shall not be placed between October 1 and March 1.

3. Composition of Experimental Base Mixtures. Compositions of experimental base mixtures will probably be within the following ranges. Job-mix proportions will be based upon laboratory tests and will be furnished to the Contractor prior to start of construction. If the final job-mix proportions require quantities of hydrated lime, OGA, or coarse aggregate outside the ranges shown, payment to the Contractor will be adjusted based on the delivered cost of the material and the actual quantity added or deleted outside the range. No pay adjustment will be made for changes in proportions of experimental materials.

(a) Experimental Section B. Materials for the 8-inch pozzolonic base shall consist of hydrated lime, fly ash, and dense graded aggregate (DGA). The DGA shall conform to requirements of Section 805. Probable composition by weight of the mixture, excluding water, may be within the following ranges:

Ingredients	Range (Percent by Weight)
Fly Ash	6-20
Hydrated Lime	2-10
DGA	74-89

Upon completion of curing as specified under III.A.10 herein, a stress absorbing membrane interlayer (SAMI) shall be placed in accordance with requirements of Special Provision No. 79 (85).

(b) Experimental Section C. Materials for 12-inch lime fly ash-stabilized bottom ash base shall consist of prehydrated AFBC residue, fly ash, and ponded bottom ash. Probable composition by weight of the mixture, excluding water, may be within the following ranges:

Ingredients	Range (Percent by Weight)
AFBC Residue	9-21
Fly Ash	6-12
Ponded Bottom Ash	65-85

In the event sufficient AFBC residue is not available to complete the construction, hydrated lime will be substituted for AFBC residue and compositions shall be altered as directed by the Engineer.

(c) Experimental Section D. Materials for 8-inch AFBC base shall consist of fly ash, pre-hydrated AFBC residue, and size no. 57 coarse aggregate. Coarse aggregate shall conform to the requirements of Section 805. Probable composition by weight of the mixture, excluding water, may be within the following ranges:

Ingredients	Range (Percent by Weight)
Fly Ash	5-10
AFBC Residue	30-40
Coarse Aggregate	40-50

4. *Plant and Equipment*. The equipment for proportioning and mixing shall be subject to approval at all times and shall be maintained so that the mixture is properly mixed and contains the specified amount of cementitious materials and a satisfactory amount of water at all times.

Either a separate weigh batch increment type plant or a continuous volumetric proportioning type plant may be used, at the Contractor's option, for plant mixing. The equipment shall include all the components and accessories for stabilization-type mixing plants deemed necessary for proper performance and, depending upon the type of equipment, may include scales, variable speed motors, electronic and/or mechanical sensors to detect volume changes, a separate silo for each cementitious material storage, precise feeders for materials, interlocking actuators to control the simultaneous flow and stoppage of the ingredient materials, and any other items that may be necessary in order to produce an acceptable mixture.

All cementitious materials to be weighed at batch type plants shall each be weighed on scales separate from the aggregate batching scales, except that if a compartment for pre-mixed cementitious materials is contained within the aggregate hopper and the pre-mixed cementitious material for each batch is weighed prior to the weighing of the aggregate, the pre-mixed material may be weighed on the aggregate scale.

If cementitious materials are pre-mixed, all ingredients shall be dry, or the pre-mixing shall not be performed until immediately before batching.

When the mixing plant is not a batch type equipped so that the material can be accurately weighed for each batch, then a daily check shall be made to determine the quantity of cementitious material being used. This may require 2 or more silos for storing cementitious materials, cessation of plant operation for the time required to make the determination, weighing of partially unloaded materials shipments, and/or other approved methods.

The Contractor shall provide the necessary equipment and devices to check the proportioning of materials to ensure the mixture uniformly conforms to the job-mix proportions. This check will be made twice daily, or more often if deemed necessary by the Engineer.

Continuous volumetric plants shall be equipped with feeding and metering devices which will add the aggregate and cementitious materials into the plant in the specific quantities. Feeding equipment or procedures that do not consistently produce a reasonably uniform mixture shall be modified or replaced. The water supply system shall be equipped with positive cut-off control which will stop the flow of water simultaneously with any stoppage in the flow of aggregate into the pugmill.

5. *Mixing.* Water shall be added to the mixture in sufficient quantity, and mixing shall continue until all component materials are evenly distributed through the mass and a uniform unchanging appearance is obtained.

6. *Transporting and Spreading.* Each load shall be covered to reduce the loss of moisture in transit when the time between loading the vehicle and spreading the mixture exceeds 30 minutes. Material shall be deposited on a moist subgrade by approved spreading equipment. Depositing and spreading the mixed materials on the roadbed shall commence at the point farthest from the point of loading and shall progress continuously as far as practical without breaks. No hauling shall be done over the completed base course except as necessary to place the succeeding layer of base or pavement. Dumping in piles upon the subgrade will not be permitted except when special equipment which distributes the material uniformly is used and is approved by the Engineer.

The mixture shall be spread to such width and thickness that, after compacting, the finished base will conform to the required grade and cross section. The mixture shall be spread by self-propelled equipment which will produce a smooth uniform depth of material ready for compaction. Further manipulation or trimming of the mixture by graders or other equipment is undesirable and will not be allowed as a part of the normal placing and spreading operation. However, small and infrequent areas needing correction or further spreading because of adverse conditions for the spreading equipment or other justifiable reasons may be corrected immediately after placement with a minimum amount of manipulation, or the mixture shall be removed and replaced at no cost to the Department.

Base material to be placed on areas inaccessible to mechanical spreading equipment may be spread by other methods approved by the Engineer.

7. Compaction and Finishing. Immediately upon completion of each portion of spreading operations, the material shall be thoroughly compacted. Moisture shall be maintained at a level sufficient to facilitate compaction. Initial and final rolling shall be performed by compaction equipment which will produce the required density and surface finish within the time limit specified below.

All high spots on the finished surface of the final layer outside of the specified tolerance shall be trimmed to within the specified tolerance. The excess material shall be removed and disposed of as directed by the Engineer immediately after trimming and before any further rolling. Trimmed areas shall be wetted as directed and shall be rolled. Rolling shall be performed in such a manner as to avoid the formation of irregularities, and the finished surface shall be true to the required grade and cross section.

Areas inaccessible to rollers shall be compacted by means of pneumatic tampers or other compacting equipment which produces the required density.

The finished experimental bases shall be compacted to a density no less than 100 percent of the maximum density determined by KM 64-511.

The in-place density of each course will be determined by nuclear gages or by KM 64-512.

No more than 5 hours shall elapse between the time water is added to the combined materials and the time of completion of final compaction of the base. Any mixture that has not been compacted and finished shall not remain undisturbed for more than 30 minutes.

When a second course is required, it shall be placed as soon as practical after completion of the first course, and on the same work day as the first course. When the Contractor elects to work multiple shifts, the second course shall be placed during the same shift that the first course is placed.

It is intended that all trimming and fine grading be accomplished during the 5 hours mentioned previously, and that trimming of the completed base be limited to occasional minor irregularities.

When it is determined that the specified density has not been obtained during compaction, the mixture may be dampened and thoroughly remixed and recompacted provided the recompaction can be completed the same day of initial mixing at the plant. When the recompaction is not completed the same day, the materials shall be removed and replaced with new stabilized material.

8. Joints. At the end of each day's work and when base operations are delayed or stopped for more than 2 hours, a construction joint shall be made by trimming the end of the compacted material to a vertical face. The same procedure shall be followed in trimming longitudinal edges where the abutting course is to be placed. The interval between a transverse construction joint in the top course and one in the bottom course of the stabilized base shall be no less than 25 feet nor more than 50 feet.

9. *Tolerances*.

(a) Surface Tolerance. The top surface of the experimental bases shall be smooth and uniform and shall not deviate more than 1/2 inch from the specified cross section at any point and shall not deviate from the specified longitudinal grade more than 3/8 inch in 10 feet at any location. When final grading is to be performed by an automatic grading machine, the base shall be trimmed to such accuracy that the succeeding base or pavement courses will meet their respective specified surface and thickness tolerances.

The Contractor shall furnish all devices necessary to check the surface, such as stringline, straightedges, etc., and the labor necessary to handle the devices.

When the completed base is found to deviate from the designated tolerances the deviations shall be corrected after the curing period, by leveling and wedging with an approved bituminous concrete mixture. This corrective work shall be performed at no cost to the Department.

(b) Thickness Tolerance. The base course will be checked for proper thickness after compaction. The Contractor shall refill all test holes with approved mixture and adequately compact the material at no additional expense to the Department.

No base with a deficiency in thickness greater than 1/2 inch will be accepted.

10. *Curing*. The completed experimental bases shall be protected against drying by covering with a bituminous curing seal. The curing seal will be required only for the top layer of the experimental bases.

The curing seal shall be applied as soon as possible, but no later than 24 hours after completion of finishing operations. The finished base shall be kept moist until the curing seal is applied. When the bituminous material is applied, the surface of the base shall be dense, free from loose extraneous material, and shall contain sufficient moisture to prevent penetration of the bituminous material.

The curing seal shall consist of the bituminous material specified and shall be uniformly applied to the surface of the completed experimental base course at the rate of approximately 1.2 pounds per square yard with approved distributing equipment. The actual rate of application of bituminous material will be determined by the Engineer. Application temperature of the bituminous material shall be as specified in Section 407.07. The curing seal shall be applied in sufficient quantity to provide a continuous membrane over the base.

No traffic or equipment other than curing equipment will be permitted on the finished base until completion of 7 satisfactory curing days, unless permitted by the Engineer. A satisfactory curing day shall be any day when the temperature of the completed base does not fall below 50°F. If traffic is permitted on the seal, a sand blanket shall be applied at no cost to the Department. If any damage occurs to the curing seal prior to the completion of curing, the damaged area shall be immediately resealed at the Contractor's expense.

B. Maintenance and Protection. Traffic on the completed base should be held to the minimum necessary to complete the work. Areas subjected to traffic shall be rechecked for grade and cross section and necessary corrections made, and any damaged areas repaired as directed, before the succeeding course is constructed.

Any damage to the base by hauling or other means at any time shall be repaired with an approved bituminous concrete mixture at no cost to the Department.

It is intended that the experimental base courses shall be completely covered with the specified base and pavement courses before the work is suspended for the winter months. The Contractor shall make every reasonable effort to accomplish this objective. When the experimental base is not completely covered with the specified base and pavement, the Contractor shall be responsible for determining and performing any further work necessary to protect and maintain the uncompleted work during the winter months. The Contractor shall perform any work necessary to acceptably repair or restore the uncompleted work before the beginning of Spring paving operations. When extra materials, methods, and construction techniques are determined to be necessary to protect, maintain, and repair any portion of the uncompleted work, the cost of such extra materials, methods, and techniques shall be borne by the Contractor. All work necessary to protect, maintain, or repair the experimental base courses shall be subject to the approval of the Engineer.

C. Conventional Base and Pavement Construction. Conventional base and pavement courses shall be constructed as specified elsewhere in the contract.

IV. METHOD OF MEASUREMENT

Eight-inch Pozzolonic Base, 12-inch Lime Fly Ash-Stabilized Bottom Ash Base, and 8-inch AFBC Base will each be measured in square yards complete and accepted. The width will be the width shown on the plans, and the length will be measured horizontally along the centerline of each experimental section.

Water used for dampening the subgrade, mixing with the mixtures, or for maintaining moisture in the base during shaping and compacting will not be measured for payment, but will be considered incidental to the base.

Bituminous material for the curing seal will be weighed in accordance with Section 109.

Measurement and payment for conventional materials shall be as specified elsewhere in the contract.

V. BASIS OF PAYMENT

The accepted quantities of 8-inch Pozzolonic Base, 12-inch Lime Fly Ash-Stabilized Bottom Ash Base, 8-inch AFBC Base, and Bituminous Curing Seal will be paid for at their respective contract unit prices, which shall be full compensation for all labor, materials, hauling, equipment, and incidentals necessary to complete the work specified herein.

Payment will be made under:

Pay Item	Pay Unit
B-inch Pozzolonic Base	Square Yard
12-inch Lime Fly Ash-Stabilized Bottom Ash Base	Square Yard
B-inch AFBC Base	Square Yard
Bituminous Curing Seal	Ton

April 21, 1987

APPENDIX B

Moisture-Density Relationships
and
Unconfined Compressive Strength
of
Pozzolanic Mixtures

Moisture-Density Relationships

MIX No. 1.

Mixture Proportions:

Ponded Fly Ash:	9%
Hydrated Lime:	4%
Dense Graded Aggregate:	87%

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial No. 1	9.4	133.0
Trial No. 2	8.9	134.2
Average	9.2	133.6

MIX No. 2.

Mixture Proportions:

Ponded Fly Ash:	11%
Hydrated Lime:	5%
Dense Graded Aggregate:	84%

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial No. 1	9.9	131.9
Trial No. 2	9.2	129.7
Average	9.6	130.8

MIX No. 3.

Mixture Proportions:

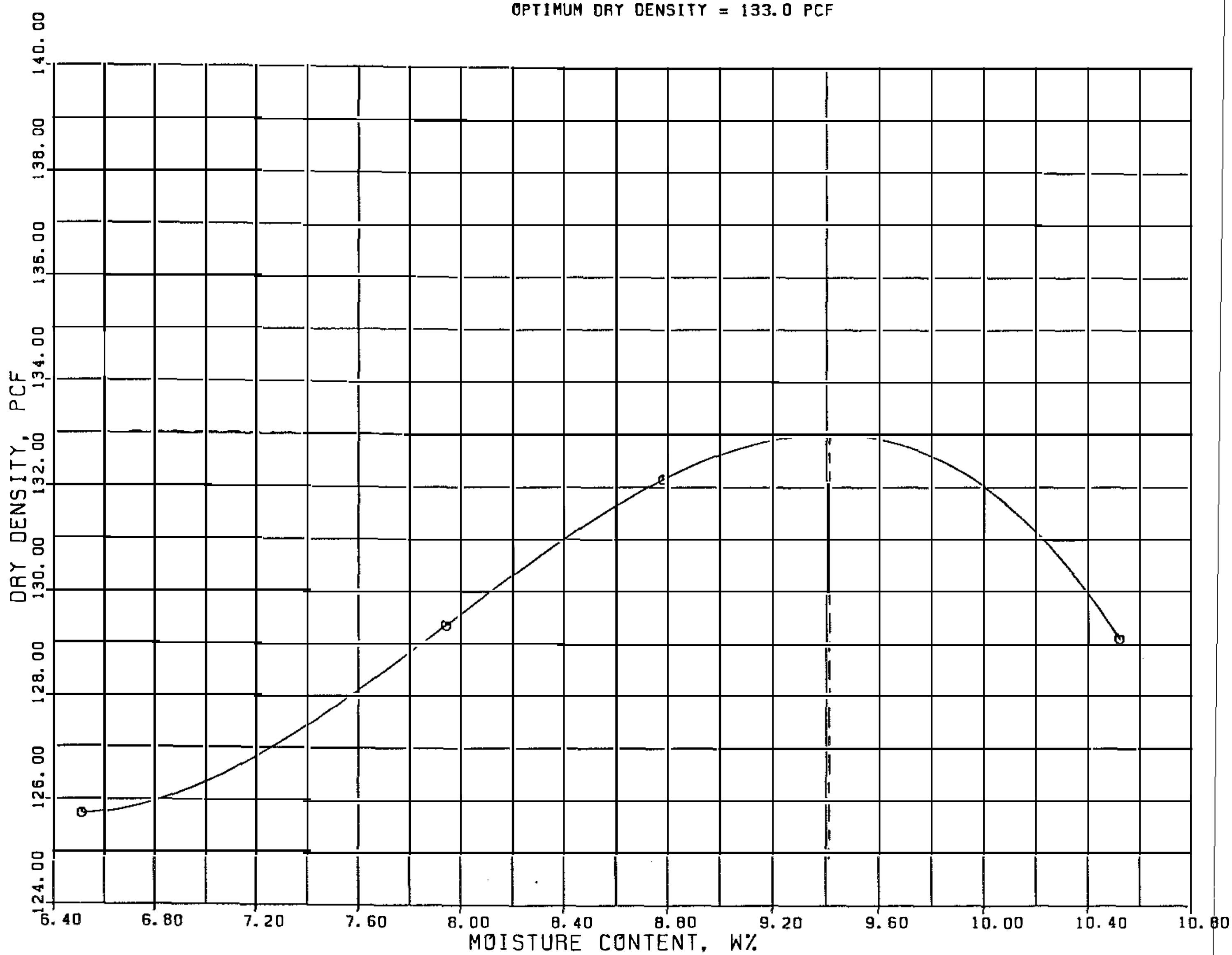
Ponded Fly Ash:	6%
Hydrated Lime:	3%
Dense Graded Aggregate:	91%

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial No. 1	8.5	135.4
Trial No. 2	8.8	134.6
Trial No. 3	8.0	135.7
Average	8.4	135.2

87% OGA, 9% FLYASH, 4% LIME

OPTIMUM MOISTURE CONTENT (%) = 9.4

OPTIMUM DRY DENSITY = 133.0 PCF

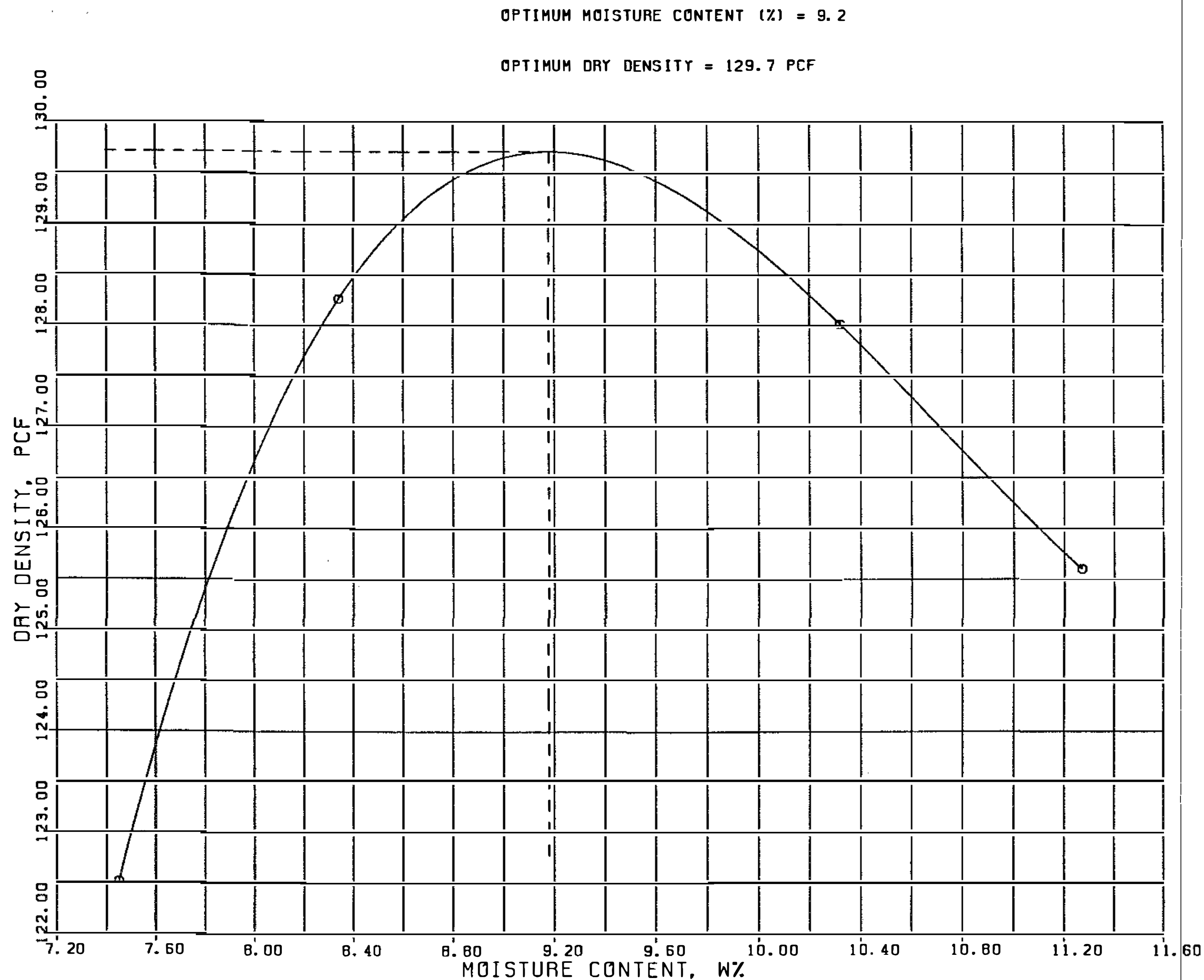


87% DGA, 9% FLYASH, 4% LIME

OPTIMUM MOISTURE CONTENT (%) = 8.9

OPTIMUM DRY DENSITY = 134.2 PCF

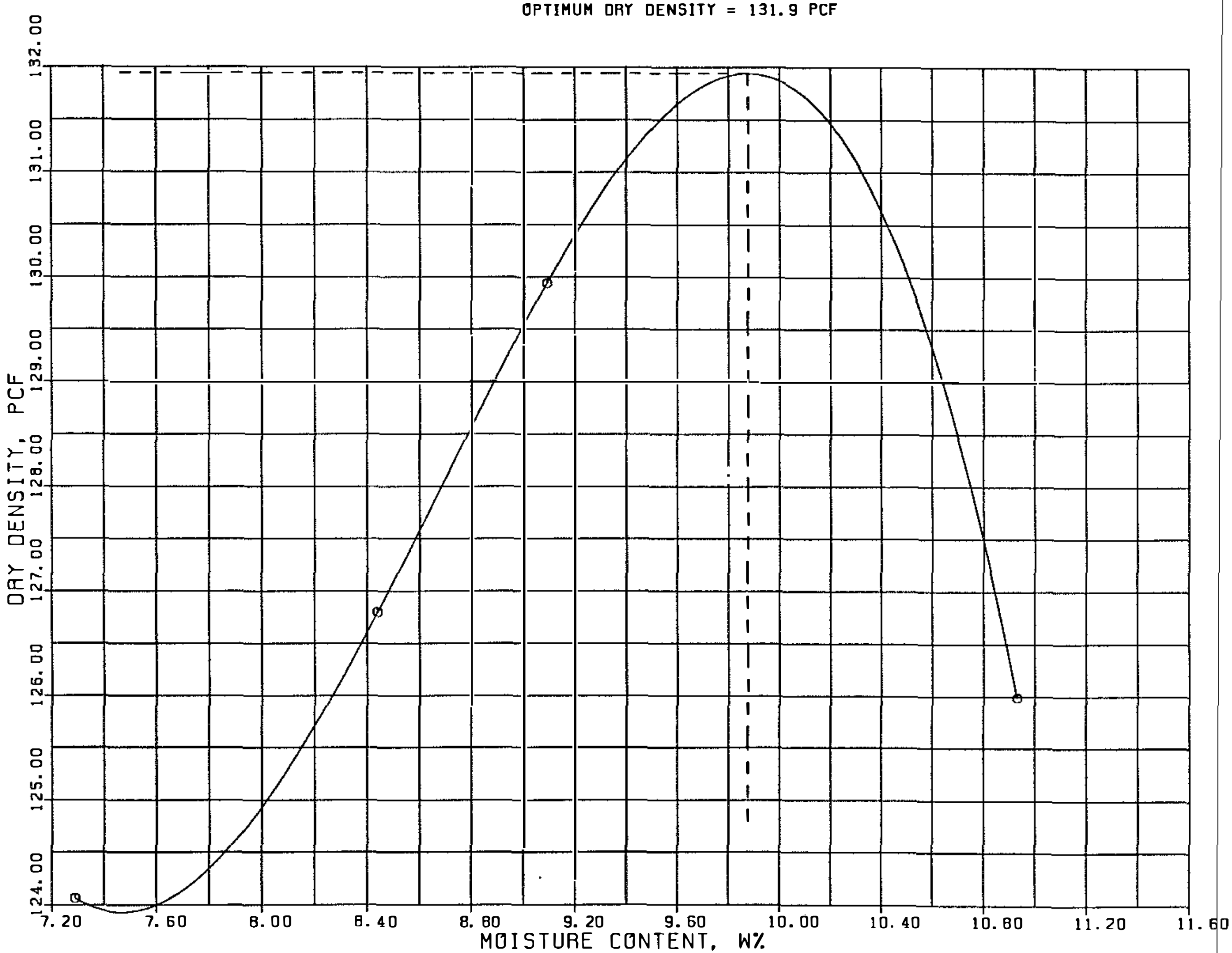
84% DGA, 11% FLYASH, 5% LIME

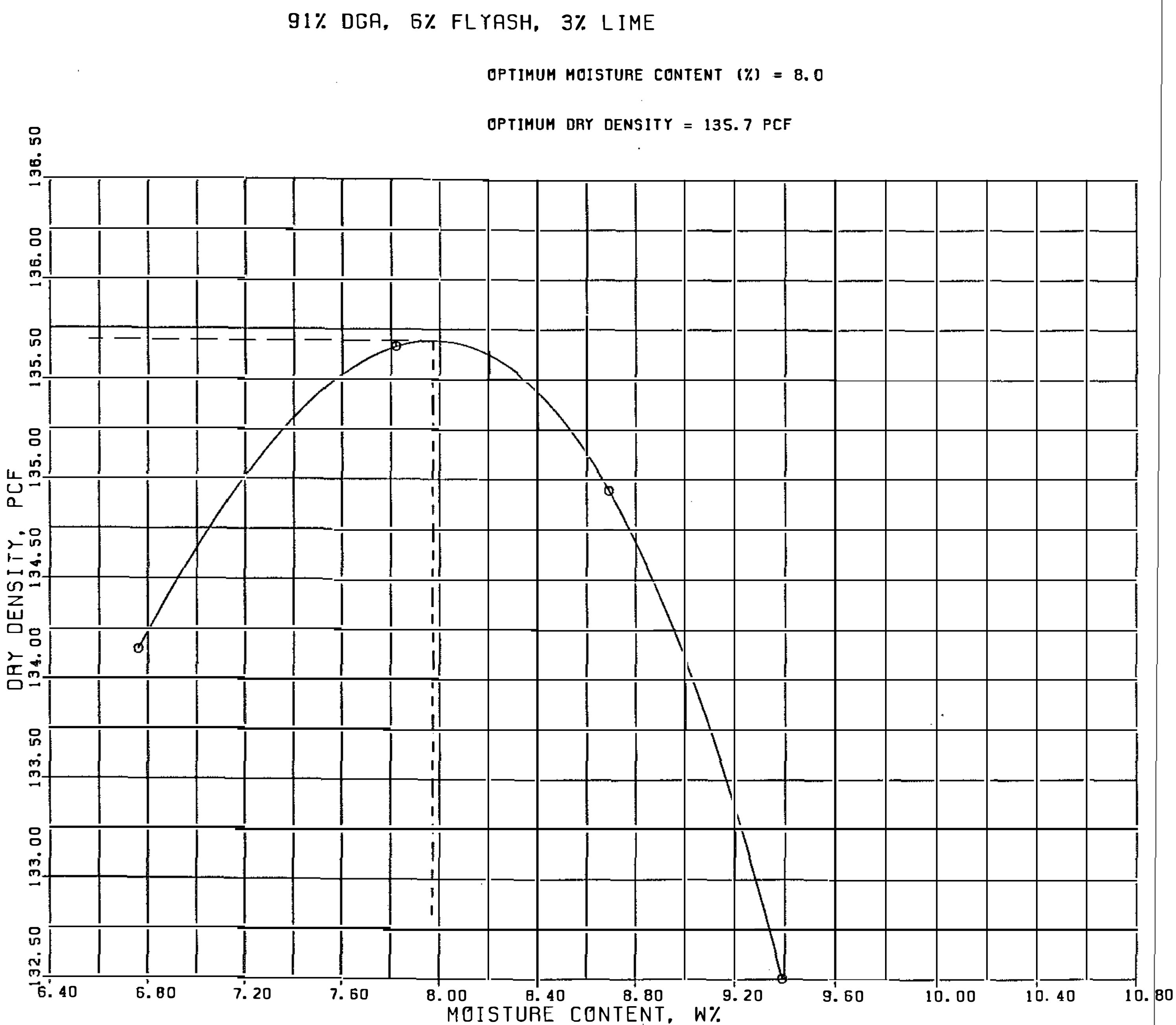


84% DGA, 11% FLYASH, 5% LIME

OPTIMUM MOISTURE CONTENT (%) = 9.9

OPTIMUM DRY DENSITY = 131.9 PCF

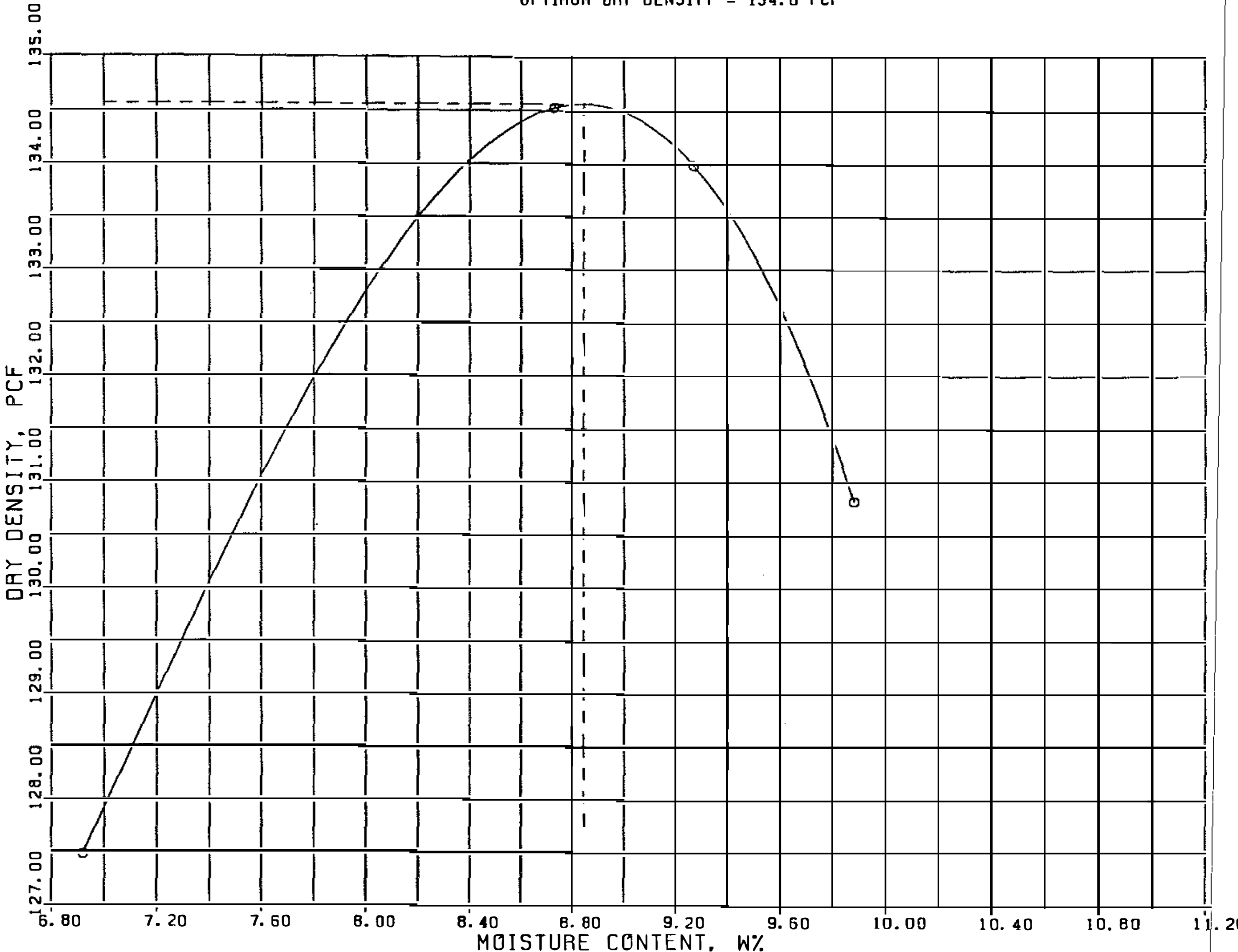



91% DGA, 6% FLYASH, 3% LIME
OPTIMUM MOISTURE CONTENT (%) = 8.0
OPTIMUM DRY DENSITY = 135.7 PCF
DRY DENSITY, PCF
136.50
136.00
135.50
135.00
134.50
134.00
133.50
133.00
132.50
6.40
6.80
7.20
7.60
8.00
8.40
8.80
9.20
9.60
10.00
10.40
10.80
MOISTURE CONTENT, W%

91% DGA, 6% FLYASH, 3% LIME

OPTIMUM MOISTURE CONTENT (%) = 8.8

OPTIMUM DRY DENSITY = 134.6 PCF



91% DGA, 6% FLYASH, 3% LIME

OPTIMUM MOISTURE CONTENT (%) = 8.5

OPTIMUM DRY DENSITY = 135.4 PCF

Unconfined Compressive Strength

MIX No. 1.

Mixture Proportions:

Ponded Fly Ash: 9%
Hydrated Lime: 4%
Dense Graded Aggregate: 87%

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. All samples soaked 4-hrs. prior to testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)	Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{6-4}	4	170	A_{6-14}	14	685
B_{6-4}	4	150	B_{6-14}	14	505
C_{6-4}	4	*	C_{6-14}	14	*
	Average	160		Average	595
A_{6-7}	7	*	A_{6-28}	28	695
B_{6-7}	7	*	B_{6-28}	28	640
C_{6-7}	7	305	C_{6-28}	28	750
	Average	305		Average	695

NOTE: * indicates that sample was unable to be evaluated after 4-hour soak.

Unconfined Compressive Strength

MIX No. 2.

Mixture Proportions:

Ponded Fly Ash:	11%
Hydrated Lime:	5%
Dense Graded Aggregate:	84%

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100^{o}F oven. All samples soaked 4-hrs. prior to testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{7-4}	4	*
B_{7-4}	4	*
C_{7-4}	4	*
	Average	*
A_{7-7}	7	230
B_{7-7}	7	265
C_{7-7}	7	290
	Average	260

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{7-14}	14	525
B_{7-14}	14	500
C_{7-14}	14	585
	Average	535
A_{7-28}	28	770
B_{7-28}	28	830
C_{7-28}	28	735
	Average	780

NOTE: * indicates that sample was unable to be evaluated after 4-hour soak.

Unconfined Compressive Strength

MIX No. 3.

Mixture Proportions:

Ponded Fly Ash: 6%
Hydrated Lime: 3%
Dense Graded Aggregate: 91%

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100^{O}F oven. All samples soaked 4-hrs. prior to testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{8-4}	4	*
B_{8-4}	4	*
C_{8-4}	4	*
	Average	*
A_{8-7}	7	155
B_{8-7}	7	180
C_{8-7}	7	330
	Average	220

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{8-14}	14	505
B_{8-14}	14	380
C_{8-14}	14	445
	Average	445
A_{8-28}	28	670
B_{8-28}	28	680
C_{8-28}	28	600
	Average	650

NOTE: * indicates that sample was unable to be evaluated after 4-hour soak.

APPENDIX C

Production Times
and
Material Quantities

DATE: June 1, 1988

Batch Number	Duration Time of Batching (min.)	Interval Between Batches (min.)	Weight of Aggregate (lb.)	Weight of Hydrated Lime (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Aggregate (%)	Percent Hydrated Lime (%)	Percent Ponded Fly Ash (%)
1	25	244	23,580	1,392	3,020	27,992	230	84.2	5.0	10.8
2	3	36	23,580	1,389	2,980	27,949	120	84.4	5.0	10.6
3	8	17	23,560	1,389	3,220	28,169	80	83.6	4.9	11.4
4	1	23	14,080	1,389	0	15,469	102	91.0	9.0	0.0
5	7	13	23,580	1,413	3,180	28,173	101	83.7	5.0	11.3
6	10	15	23,500	1,407	2,960	27,867	100	84.3	5.1	10.6
7	23	28	23,520	1,410	3,060	27,990	100	84.0	5.0	11.0
8	14	6	23,520	1,401	2,940	27,861	101	84.4	5.0	10.6
9	5	6	23,540	1,392	3,060	27,992	100	84.1	5.0	10.9
10	16	18	23,520	1,398	2,860	27,778	120	84.7	5.0	10.3
11	15	3	23,540	1,404	2,940	27,884	100	84.4	5.0	10.6
12	4	5	23,500	1,389	3,060	27,949	102	84.1	5.0	10.9
13	23	9	23,520	1,395	3,040	27,955	121	84.1	5.0	10.9
14	3	19	23,760	1,389	2,620	27,769	140	85.6	5.0	9.4
15	9	-	23,620	1,401	2,900	27,921	100	84.6	5.0	10.4
Average	11	31	22,928	1,397	2,789	27,115	114	84.7	5.3	10.0
St. Dev.	8	60	2,366	8	758	3,114	34	1.7	1.0	2.7

DATE: June 3, 1988

Batch Number	Duration Time of Batching (min.)	Interval Between Batches (min.)	Weight of Aggregate (lb.)	Weight of Hydrated Lime (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Aggregate (%)	Percent Hydrated Lime (%)	Percent Ponded Fly Ash (%)
1	7	22	23,560	1,353	2,780	27,693	175	85.1	4.9	10.0
2	3	10	23,420	1,347	3,220	27,987	141	83.7	4.8	11.5
3	9	10	23,500	1,347	3,540	28,387	141	82.8	4.7	12.5
4	10	7	23,600	1,356	2,960	27,916	149	84.5	4.9	10.6
5	3	7	24,540	1,359	2,320	28,219	161	87.0	4.8	8.2
6	3	8	23,480	1.347	3,160	27,987	162	83.9	4.8	11.3
7	3	33	23,520	1,347	3,100	27,967	160	84.1	4.8	11.1
8	7	8	23,840	1,353	3,260	28,453	162	83.8	4.8	11.5
9	2	9	23,560	1,347	2,980	27,887	160	84.5	4.8	10.7
10	7	9	23,440	1,350	3,320	28,110	160	83.4	4.8	11.8
11	9	7	23,260	1,347	3,320	27,927	160	83.3	4.8	11.9
12	10	20	23,520	1,356	3,280	28,156	160	83.5	4.8	11.6
13	4	9	23,540	1,347	3,120	28,007	162	84.1	4.8	11.1
14	8	8	23,660	1,350	2,880	27,890	160	84.8	4.8	10.3
15	6	14	23,460	1,371	3,320	28,151	161	83.3	4.9	11.8
16	6	9	23,700	1,353	3,060	28,113	160	84.3	4.8	10.9
17	5	10	23,560	1,347	3,120	28,207	160	84.1	4.8	11.1
18	11	14	23,840	1,350	3,520	28,710	160	83.0	4.7	12.3
19	5	5	23,440	1,353	3,100	27,893	147	84.0	4.9	11.1
20	12	10	23,540	1,347	3,140	28,027	144	84.0	4.8	11.2
21	6	6	23,520	1,371	2,940	27,831	144	84.5	4.9	10.6
22	28	-	23,500	1,362	3,300	28,162	144	83.5	4.8	11.7
Average	7	11	23,591	1,353	3,125	28,068	156	84.1	4.8	11.1
St. Dev.	5	6	243	7	256	221	9	0.8	0.0	0.9

DATE: June 4, 1988

Batch Number	Duration Time of Batching (min.)	Interval Between Batches (min.)	Weight of Aggregate (lb.)	Weight of Hydrated Lime (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Aggregate (%)	Percent Hydrated Lime (%)	Percent Ponded Fly Ash (%)
1	3	7	23,300	1,347	3,080	27,727	160	84.0	4.9	11.1
2	7	14	23,680	1,350	3,060	28,090	137	84.3	4.8	10.9
3	4	7	23,820	1,347	3,440	28,607	137	83.3	4.7	12.0
4	9	9	23,500	1,347	3,000	27,847	137	84.4	4.8	10.8
5	3	5	23,840	1,356	4,220	29,416	136	81.0	4.6	14.3
6	11	24	23,560	1,350	2,920	27,830	137	84.7	4.9	10.5
7	7	8	23,540	1,359	3,740	28,639	153	82.2	4.7	13.1
8	2	15	23,260	1,350	3,520	28,130	136	82.7	4.8	12.5
9	9	5	23,560	1,353	3,940	28,853	137	81.7	4.7	13.7
10	6	23	23,580	1,350	2,960	27,890	138	84.5	4.8	10.6
11	9	6	23,540	1,347	3,140	28,027	138	84.0	4.8	11.2
12	8	4	23,420	1,359	3,180	27,959	137	83.8	4.9	11.4
13	4	4	23,920	1,350	2,580	27,850	130	85.9	4.8	9.3
14	6	19	23,520	1,350	3,140	28,010	128	84.0	4.8	11.2
15	5	8	23,380	1,353	3,080	27,813	130	84.1	4.9	11.1
16	5	4	23,340	1,356	3,460	28,156	128	82.9	4.8	12.3
17	10	5	23,600	1,353	2,980	27,933	129	84.5	4.8	10.7
18	5	6	23,340	1,350	3,320	28,010	129	83.3	4.8	11.9
19	9	8	23,520	1,347	3,260	28,127	128	83.6	4.8	11.6
20	13	-	23,500	1,347	3,600	28,447	128	82.6	4.7	12.7
Average	7	9	23,536	1,351	3,281	28,168	136	83.6	4.8	11.6
St. Dev.	3	6	173	4	375	413	8	1.1	0.1	1.2