Research Report
KTC 92-17

CONSTRUCTION OF HIGHWAY BASE AND SUBBASE LAYERS CONTAINING RESIDUE FROM AN ATMOSPHERIC FLUIDIZED BED COMBUSTION PROCESS

by

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in cooperation with
Kentucky Transportation Cabinet

and

Federal Highway Administration
US Department of Transportation

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16. Abstract

This report summarizes findings of laboratory and construction evaluations of using residue from an atmospheric fluidized bed combustion (AFBC) process as a component in an experimental road base and subbase application. The base mixture contains pulverized fuel ash, AFBC residue, and limestone aggregates used as bulk filler. The subbase mixture contains AFBC residue and pond ash (ponded fly ash and bottom ash). Mixtures containing various proportions of each component were evaluated in the laboratory relative to maximum dry density, optimum moisture content, and compressive strength development.

Two 750-foot test sections of a 22-foot wide roadway, containing the experimental mixtures, were constructed in May and June 1988. Prior to construction, in-place California Bearing Ratio tests, moisture content determinations and Road Rater deflection tests were performed on the prepared subgrade. During construction of the experimental base and subbase layers, relative compaction and moisture contents of the materials were monitored by nuclear devices. Specimens were compacted for subsequent evaluations. Initial post-construction evaluations included compressive strength development, elastic modulus, Road Rater deflection analyses, and monitoring expansion of the experimental mixtures both in the field and in the laboratory.

17. Key Words

Atmospheric Fluidized Bed Combustion residue, Pond Ash, Fly Ash, Bottom Ash, Unconfined Compressive Strength, Static Chord Modulus of Elasticity, Expansive Characteristics, Highway Road Base and Subbase

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SI[*] (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in.	inches	25.40000	millimetres	mm
ft	feet	0.30480	metres	m
yd	yards	0.91440	metres	m
mi	miles	1.60934	kilometres	km
		AREA		
in.^{2}	square inches	645.16000	millimetres squared	mm^2
ft^2	square feet	0.09290	metres squared	m^2
yd^2	square yards	0.83613	metres squared	m^2
ac	acres	0.40469	hectares	ha
mi^2	square miles	2.58999	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57353	millilitres	ml
gal.	gallons	3.78541	litres	l
ft^3	cubic feet	0.02832	metres cubed	m^3
yd^3	cubic yards	0.76455	metres cubed	m^3
		MASS		
oz	ounces	28.34952	grams	g
lb	pounds	0.45359	kilograms	kg
T	short tons (2000 lb)	0.90718	megagrams	Mg
		FORCE AND PRESSURE		
lbf	pound-force	4.44822	newtons	N
psi	pound-force per square inch	6.89476	kilopascal	kPa
		ILLUMINATION		
fc	foot-candles	10.76426	lux	lx
fl	foot-Lamberts	3.42583	candela/m^2	cd/m^2
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.03937	inches	in.
m	metres	3.28084	feet	ft
m	metres	1.09361	yards	yd
km	kilometres	0.62137	miles	mi
		AREA		
mm^2	millimetres squared	0.00155	square inches	in.^{2}
m^2	metres squared	10.76392	square feet	ft^2
m^2	metres squared	1.19599	square yards	yd^2
ha	hectares	2.47103	acres	ac
km^2	kilometres squared	0.38610	square miles	mi^2
		VOLUME		
ml	millilitres	0.03381	fluid ounces	fl oz
l	litres	0.26417	gallons	gal.
m^3	metres cubed	35.31448	cubic feet	ft^3
m^3	metres cubed	1.30795	cubic yards	yd^3
		MASS		
g	grams	0.03527	ounces	oz
kg	kilograms	2.20462	pounds	lb
Mg	megagrams	1.10231	short tons (2000 lb)	T
		FORCE		
N	newtons	0.22481	pound-force	lbf
kPa	kilopascal	0.14504	pound-force per square inch	psi
		ILLUMINATION		
lx	lux	0.09290	foot-candles	fc
cd/m^2	candela/m^2	0.29190	foot-Lamberts	fl
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8C + 32	Fahrenheit temperature	°F

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[*] SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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EXECUTIVE SUMMARY

Design and construction procedures for the use of an AFBC concrete base and AFBC stabilized pond ash subbase have been demonstrated. This is the first full-scale project in Kentucky wherein AFBC residue and a ponded bottom fly ash, both waste materials, were utilized in constructing stabilized road base and subbase layers. The optimum mixture designs were based upon results of laboratory compressive strength tests. Kentucky flexible pavement design procedures were used to determine thickness requirements for each layer. Structural coefficients of 0.30 and 0.10 were assumed for the AFBC concrete base layer and AFBC stabilized pond ash subbase layer, respectively. The thickness design requirements were 8.0 inches and 12.0 inches for the experimental AFBC concrete layer and AFBC stabilized pond ash layer, respectively. Waste materials utilized constructing the two sections numbered about 1,050 tons. Approximately 460 tons of waste AFBC residue and 590 tons of pond ash were utilized during construction. Difficulties encountered during construction of both experimental sections included homogeneity of the mixtures, consistent moisture contents, and steady production of the mixtures at the concrete batch plant. Production of the mixture could have been accomplished much better by utilizing a pugmill set up near the jobsite as opposed to using a batch plant.

The initial effectiveness of the AFBC concrete mixture and AFBC stabilized pond ash mixture appeared favorable. Compressive strength evaluations of field compacted specimens of the AFBC concrete base mixture indicated average strengths of 1,465 psi at seven days increasing to an average of 4,075 psi after 112 days. The 112-day strengths are comparable to a typical five bag per cubic yard concrete mix. Static chord moduli values were lower than typical concrete indicating less stiffness than typical concrete. The modulus of elasticity averaged 2.20 million psi at seven days and increased to 3.65 million at 112 days. Compressive strength evaluations of AFBC stabilized pond ash specimens indicated average strengths of 375 psi at seven days increasing to 2,345 psi after 112 days. Static chord moduli values of field compacted specimens averaged 0.40 million psi at seven days and increased to 1.55 million psi after 112 days.

Expansion of the experimental mixtures was monitored in the field and in the laboratory. Expansions were less in the field than in the laboratory. The field expansion of the AFBC concrete base was 0.20 percent after 58 days and 0.36 percent after 51 days in the laboratory. The field expansion of the AFBC stabilized pond ash subbase mixture averaged 0.20 percent after 34 days and the laboratory expansion was 0.43 percent after 24 days.

Deflection measurements were obtained within the experimental sections at various stages of construction using the model 400 Road Rater. Deflection measurements were

obtained on the compacted subgrade immediately before placement of the experimental materials and at various times after placement of the experimental AFBC concrete base and AFBC stabilized pond ash subbase mixtures. Analysis of the deflection measurements generally indicated a significant increase in the overall stiffness of the pavement structure due to the addition of the experimental layers. Twenty-eight days after placement of the experimental AFBC concrete base layer, deflection testing established a definite decrease in the dynamic stiffness of the pavement structure. After 82 days the average dynamic stiffness of the pavement structure had decreased by about 34 percent from the peak dynamic stiffness at 14 days. Results of the compressive strength tests and modulus of elasticity tests did not exhibit this substantial decrease in strength. In fact, the AFBC concrete base mixture continued to gain strength throughout the 112-day evaluation period. Deflection measurements taken after placement of the experimental AFBC stabilized pond ash subbase indicated increasing dynamic stiffnesses. Apparently, this material continued to gain strength during the 45-day field evaluation period. Laboratory strength tests also indicated continued strength gain through the 112-day laboratory evaluation period. Still, it must be cautioned that the apparent increase in the overall dynamic stiffness of the pavement structure could be as much the result of temperature changes within the pavement layers, or changing moisture conditions within the subgrade as it could be an actual strengthening over time of the experimental layer.

Previous reported research concluded that prehydrated AFBC residue, pulverized coal fly ash, and aggregate could be used to construct a stabilized base course, provided the AFBC residue had been properly prehydrated prior to its use. The AFBC residue was effectively prehydrated in the laboratory phase of this study. None of the mixtures incorporating the AFBC residue exhibited any expansive characteristics during the laboratory evaluations. However, that success could not be reproduced during the field trial. Apparently, the AFBC residue was not properly hydrated initially or the extended storage period significantly affected the properties of the residue.

Although tests performed on the AFBC residue prior to the beginning of construction indicated a hydration reaction (temperature rise caused by the addition of water), construction of the experimental sections proceeded as planned. Expansion of the materials was expected and gaps were formed in the plastic base and subbase mixture to accommodate the expansion. It appears that both of the mixtures incorporating the AFBC residue possess the capacity for further expansion in the field trial based upon the expansion exhibited by the field compacted specimens. It is uncertain as to the reasons for decrease in the apparent dynamic stiffness of the pavement structure of the AFBC concrete base section but is believed to be the result of the strong expansive forces within the experimental mixture. Because the AFBC stabilized pond ash subbase contains 32 percent AFBC residue, one may expect comparable actions (a decrease in dynamic stiffness) from that section over time.

INTRODUCTION AND BACKGROUND

Kentucky has traditionally been among the leading producers of coal. Kentucky is unique in that it has two distinct coal fields. Coal fields of eastern Kentucky produce low-sulfur, bituminous coals and western Kentucky coal fields produce a higher sulfur bituminous coal. Kentucky is also a large consumer of coal and uses approximately 30 million tons of coal annually at electric generating facilities. Most of these facilities use pulverized coal boilers with electrostatic precipitators for particulate removal. Consequently, by-products in the form of fly ash, flue gas desulfurization sludge, boiler slag, and bottom ash are generated in large quantities. More than three million tons of fly ash are produced annually from Kentucky's coal fired generating plants.

Atmospheric Fluidized Bed Combustion (AFBC) is an advanced combustion process which provides a method of burning high sulfur coal economically and in an environmentally acceptable manner. AFBC is a process where coal is burned in a bed of fine limestone particles. Air is passed through the bed from below and a fire, fed by oil or other fuel, is injected into the bed to heat the coal to ignition temperature. Sulfur dioxide, an undesirable by-product of coal combustion, is captured by calcium oxide formed from the limestone to produce calcium sulfate as a by-product of the AFBC process. Coal ash and spent limestone are drained from the bottom of the bed. Construction and operation of fluidized bed combustion units in Kentucky represent another high volume source of waste material that require disposal. The production of additional waste materials represents a large liability and operating expense to both coal production and processing industries as well as coal consuming industries. The dry calcium sulfate by-product of the AFBC process may be disposed of by conventional methods at substantial costs; however, several studies have indicated that this by-product is useful as an agricultural supplement, road base filler, and as a cement additive [1,2,3].

Calcium sulfate contains appreciable amounts of free lime. Because of this available free lime, residue from the AFBC process when mixed with fly ash from conventional coal burning plants has cement-like properties. Such mixtures have the potential to be used in a variety of applications where a lower strength concrete is suitable, including use as a road base material.

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 materials. Low-strength materials have been used fairly extensively in some areas of the United States as well as abroad. In general, aggregates have been stabilized by adding fly ash and lime to produce a cementitious reaction for construction of stabilized aggregate bases and subbases.

Until recently, the use of stabilized materials in highway and street construction in Kentucky was not often considered as being economically competitive with the area's 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 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 road 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 their 20-MW AFBC pilot plant.

This report describes preliminary engineering, construction, and initial structural evaluations of a stabilized aggregate base course and subbase course wherein residue from the AFBC process was used as a mixture component.

HIGHWAY DESIGN SPECIFICS

The experimental project is a 3,000-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 redesigned highway consists of two 11-foot lanes located in flat to slightly rolling terrain. The

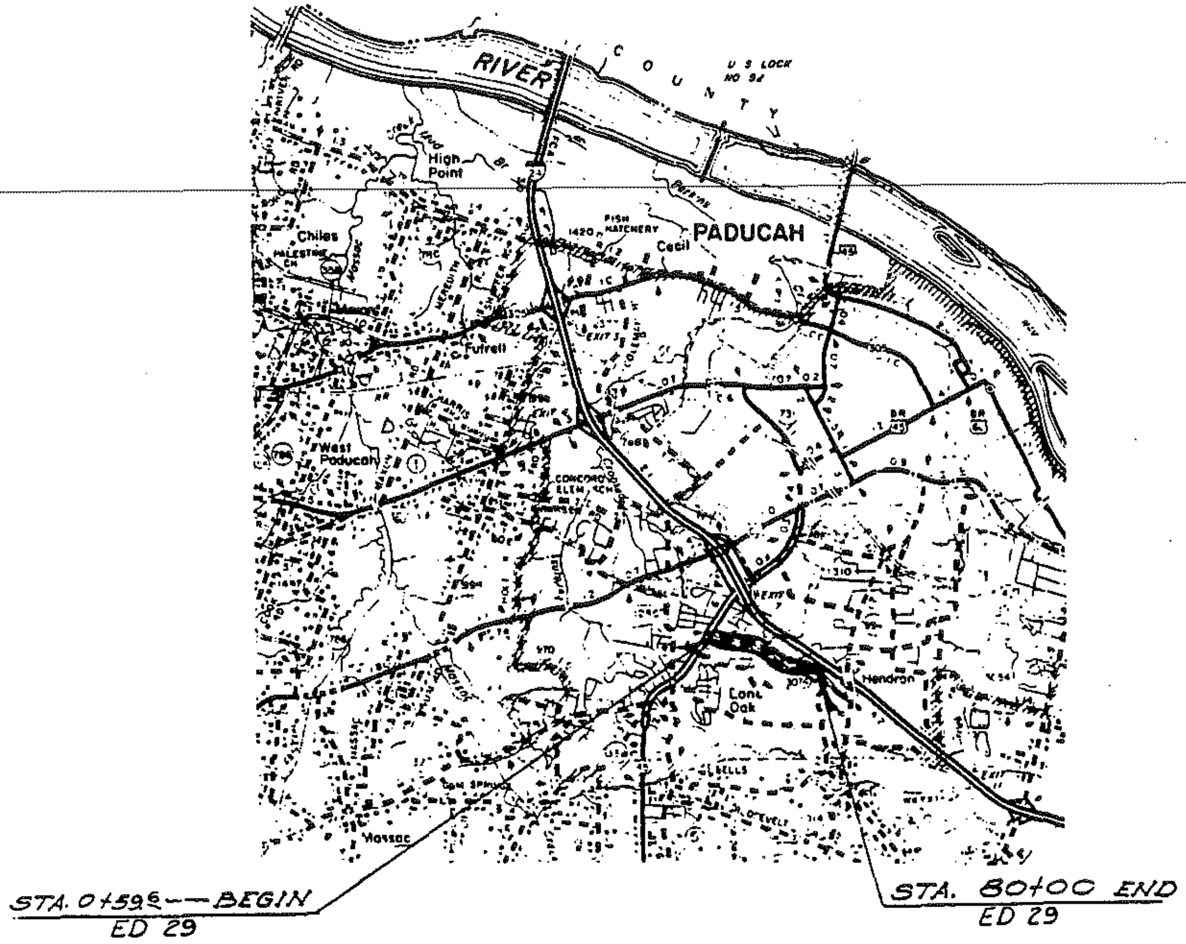


Figure 1. *Location of project.*

highway is crowned and has 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 percent. 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 compacted subgrade. The alternative experimental AFBC concrete base and AFBC stabilized pond ash subbase designs are detailed elsewhere in this report.

Materials Information

The experimental AFBC concrete base mixture consisted of coarse limestone aggregate, AFBC residue and Class F fly ash. The experimental stabilized pond ash subbase mixture consisted of pond ash and AFBC residue. Residue from the AFBC process, and pond ash (bottom ash and fly ash) were supplied by TVA and obtained from TVA's 20-MW

TABLE 1. CHEMICAL CHARACTERISTICS OF AFBC RESIDUE

CHEMICAL COMPOSITION (wt %)		
Moisture Content		0.17
Ash		95.70
Loss on Ignition		2.67
$\text{Carbon}_{\text{total}}$		0.31
$\text{Carbon}_{\text{mineral}}$		0.16
MINERAL ANALYSIS (wt %)		
Silicon Dioxide	SiO_2	4.54
Aluminum Oxide	Al_2O_3	1.36
Iron Oxide	Fe_2O_3	1.80
Magnesium Oxide	MgO	2.08
Sodium Oxide	Na_2O	0.28
Potassium Oxide	K_2O	0.20
Titanium Dioxide	TiO_2	0.07
Sulfur Trioxide	SO_3	32.00
Phosphorus Pentoxide	P_2O_5	0.05
FORMS OF CALCIUM (wt %)		
Calcium Oxide	CaO	32.18
Calcium Sulfate	$CaSO_4$	54.40
Calcium Carbonate	$CaCO_3$	1.33
SPECIFIC GRAVITY		2.67
ABSORPTION (%)		3.23

AFBC pilot plant and adjacent 160-MW coal-fired power plant, were located in McCracken County and within 15 miles of the project site. Table 1 contains the chemical characteristics of the AFBC residue. Figure 2 illustrates a typical sieve analysis for the AFBC residue.

During the laboratory evaluation phase of this study, ponded fly ash was used in the AFBC concrete mixture in order to maximize the amount of by-product material in the mixture. However, just prior to construction TVA personnel requested that a Class F fly ash be used in lieu of the ponded fly ash. The Class F fly ash for the AFBC concrete mixture was supplied by TVA's Kingston Plant located near Nashville, Tennessee. Chemical compositions of the Class F fly ash and pond ash are presented in Table 2. Sieve analyses of the pond ash were performed in accordance with ASTM C 136, "Sieve Analysis of Fine and Coarse Aggregates." Typical sieve analyses of the ponded fly ash and bottom ash are also presented in Figure 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.

Mixture Designs

Initial evaluations of the stabilized mixtures consisted of determining moisture-density relationships and compressive strength development of compacted specimens. Mixture

TABLE 2: CHEMICAL ANALYSIS OF POND ASH AND CLASS F FLY ASH

		Typical Concentrations (%)		
Element / Parameter		Ponded Fly Ash	Ponded Bottom Ash	Kingston Class F Fly Ash
Moisture Content		Less than 1	9.0	0.38
Loss on Ignition		1.9 - 8.0	5.3	3.42
Fineness		20 - 30	NA	NA
Silicon Dioxide	(SiO_2)	41.0 - 58.0	41.6	51.20
Aluminum Oxide	(Al_2O_3)	18.1 - 28.6	17.7	30.58
Iron Oxide	(Fe_2O_3)	3.9 - 26.0	26.7	8.49
Calcium Oxide	(CaO)	0.8 - 4.5	4.2	8.49
Magnesium Oxide	(MgO)	0.7 - 1.4	0.6	1.52
Sodium Oxide	(Na_2O)	0.2 - 0.6	0.25	0.32
Potassium Oxide	(K_2O)	1.5 - 3.3	NA	3.13
Titanium Dioxide	(TiO_2)	1.0 - 1.9	NA	1.40
Sulfur Trioxide	(SO_3)	0.1 - 2.2	1.5	0.18
Phosphorus Pentoxide	(P_2O_5)	nil - 1.5	NA	0.59
Ph		4.1 - 9.5	NA	NA

NA-Not Analyzed

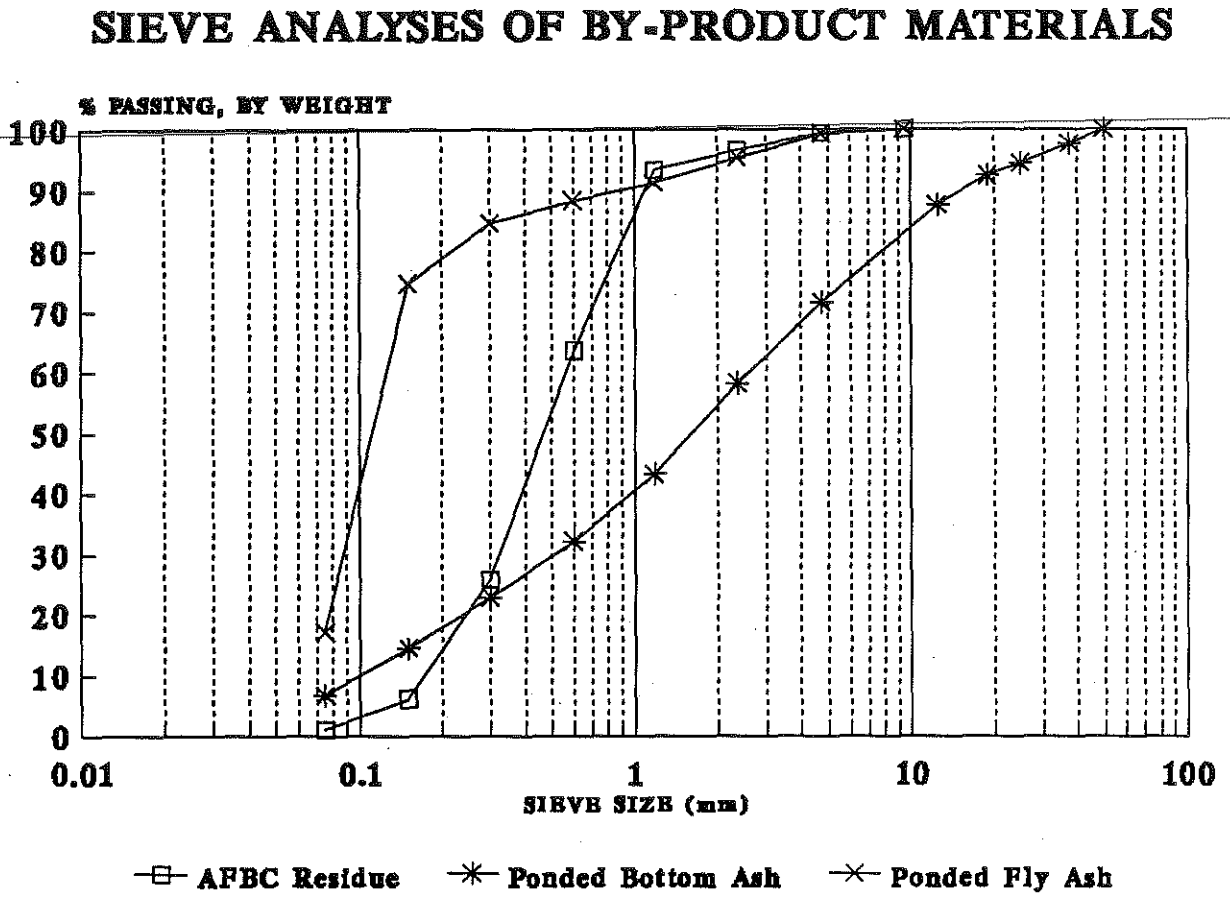


Figure 2. *Average gradation of the by-product materials used in the laboratory study.*

TABLE 3: PROPERTIES OF LIMESTONE AGGREGATE

Gradation			
Sieve Size	Percent Passing	Physical Characteristics	
2"	----	Specific Gravity (SSD)	2.68
1-1/2"	100	Absorption (%)	0.30
1"	99	L. A. Wear (500 revolutions) (%)	20
3/4"	----	Sodium Sulfate Soundness Loss (%)	1-3
1/2"	34		
3/8"	----		
No. 4	2		
No. 8	2		

compositions are summarized in Kentucky Department of Highways' Special Note for Experimental Use of Waste Materials in Highway Construction (see Appendix A).

Proportions for the AFBC concrete base mixture were developed previously during research conducted by Dr. Jerry G. Rose, Professor of Civil Engineering, University of Kentucky [1,4,5], and modified only slightly for this project. The AFBC concrete base mixture initially evaluated in the laboratory consisted of 56 percent No. 57 aggregate, 35 percent AFBC residue, and 9 percent ponded fly ash. The moisture-density relationship and compressive strength development of this mixture are presented in Table 4.

At the request of TVA officials, a Class F fly ash was substituted for the ponded fly ash. The mix design was modified based upon the research conducted by Dr. Rose. The new mix design called for 64 percent No. 57 aggregate, 25 percent AFBC residue, and 11 percent Class F fly ash. Unfortunately, there was not enough time to fully evaluate the amended AFBC concrete mixture prior to the commencement of construction activities. Laboratory evaluations could only assess the moisture-density relationship of the AFBC concrete base mixture and not the compressive strength development of the mixture. The moisture-density relationship for this mixture is presented in Table 4.

Six separate AFBC stabilized pond ash subbase mixtures were evaluated in the laboratory that contained various proportions of pond ash and AFBC residue. Trial mixture designs are summarized in Table 4. The pond ash was designated as coarse fractions (bottom ash) and fine fractions (fly ash). The amount of ponded fly ash in the mixes varied from five to nine percent. The amount of AFBC in the mixes varied from five to 45 percent. Ponded bottom ash varied from 46 to 90 percent of the total mixture. The AFBC residue used in the laboratory study was preconditioned, or prehydrated, by mixing thoroughly with 18 percent water, by weight, and stored in sealed 55-gallon drums until the time that it was combined with other components in the base and subbase mixtures. The AFBC residue must be preconditioned prior to being used in order to prevent excessive heating and expansion from occurring during mixing and also during the early stages of curing [2].

Moisture-density relationships for the mixes were determined in general accordance with ASTM D 1557, Method C, [6]. Deviations from that method involved the use of a 5.5-lb hammer having a 12-inch free fall and 5 lifts were replaced with 3 lifts to better simulate construction compaction efforts. 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. Specimens for evaluating compressive strength development were prepared in general accordance with ASTM C 593, in 4-in by 4.6-in. molds [7]. Specimens were compacted at the optimum moisture content, determined previously for the mixture. The specimens were cured in general

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	No. 57's:	56%	8.5	131.8	04	160
	AFBC:	35%			07	260
	Fly Ash:*	09%			14	615
					28	1,010
1(a)	No. 57's:	64%	8.8	129.6	04	NO DATA
	AFBC:	25%			07	NO DATA
	Fly Ash:	11%			14	NO DATA
					28	NO DATA
2	Bottom Ash:	80%	16.0	100.0	04	80
	AFBC:	14%			07	290
	Fly Ash:*	06%			14	375
					28	565
3	Bottom Ash:	84%	15.4	106.9	04	330
	AFBC:	08%			07	510
	Fly Ash:*	08%			14	490
					28	360
4	Bottom Ash:	76%	14.5	107.8	04	340
	AFBC:	18%			07	310
	Fly Ash:*	06%			14	595
					28	1,335
5	Bottom Ash:	90%	13.4	106.9	04	310
	AFBC:	05%			07	315
	Fly Ash:*	05%			14	360
					28	130
6	Bottom Ash:	60%	16.1	101.8	04	75
	AFBC:	32%			07	435
	Fly Ash:*	08%			14	585
					28	960
7	Bottom Ash:	46%	17.2	100.2	04	250
	AFBC:	45%			07	350
	Fly Ash:*	09%			14	580
					28	905

NOTE: * indicates ponded fly ash.

accordance with ASTM C 593. Specimens were placed in sealed paint cans and cured in a 100° F oven for four, seven, 14, and 28 days. ASTM C 593 also requires submerging samples for four hours prior to compressive strength testing. The specimens were tested in accordance with ASTM C 39 for compressive strength development after removal from the soaking tank [8].

During laboratory evaluations of the experimental mixes, ponded fly ash was utilized in the AFBC concrete mixture in order to maximize the amount of by-product materials in the base mixture. However, just prior to construction TVA officials requested that a Class F fly ash be used instead of the ponded fly ash. The AFBC concrete base mix initially evaluated, containing ponded fly ash, had an optimum moisture content of 8.5 percent and a maximum dry density of 131.8 pcf. The AFBC concrete base mix containing the Class F fly ash had an optimum moisture content of 8.8 percent and a corresponding maximum dry density of 129.6 pcf.

Mix number six was chosen for the optimum mixture design for the AFBC stabilized pond ash subbase because of the consistency of the mix and more uniform compressive strength development. The optimum moisture content and maximum dry density of the mixture was 16.1 percent and 101.8 pcf, respectively. The stated values of optimum moisture content and maximum dry density represent the mean of at least two series of tests performed to determine those relationships. Figures 3 and 4 illustrate typical determinations of the optimum moisture content and maximum dry density for the AFBC concrete base mixture and the AFBC stabilized pond ash subbase mixture, respectively. Average results of moisture-density and unconfined compressive strength determinations for all mixtures are given in Table 4. Appendices B and C contain results of moisture-density determinations and unconfined compressive strength determinations for the AFBC concrete base mixtures and AFBC stabilized pond ash mixtures evaluated, respectively.

Pavement Thickness Design Procedures

Thickness design procedures for flexible pavements in Kentucky have been developed on the basis of a limiting strain-repetitions criterion [9]. 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 could also be applied for thickness design of pozzolanic bases [10]. Thickness design requirements for the AFBC concrete base and AFBC stabilized pond ash subbase

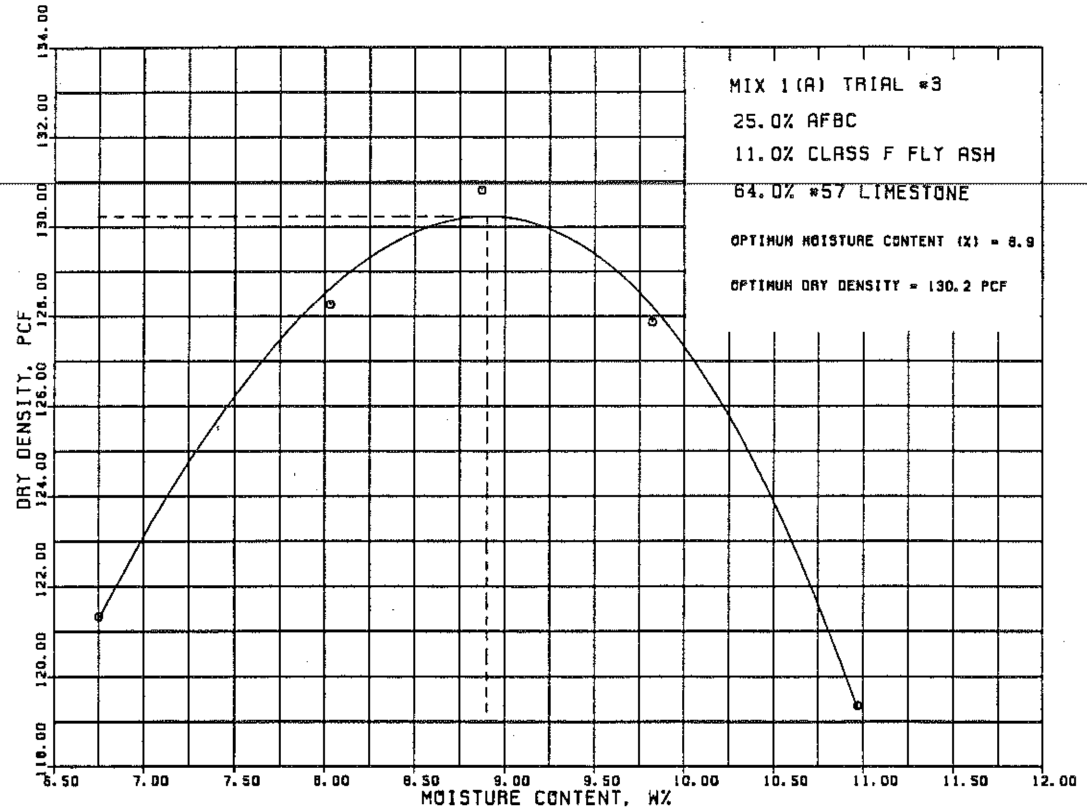


Figure 3. *A typical moisture-density determination for the AFBC concrete base mixture.*

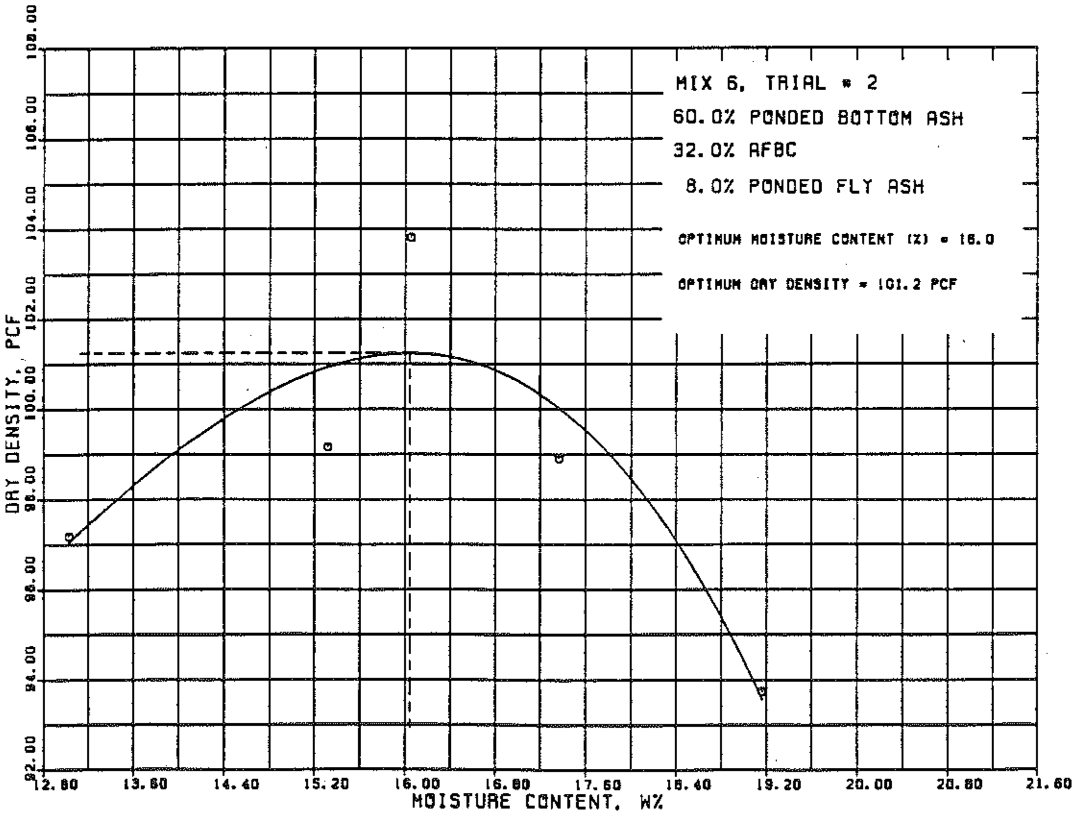


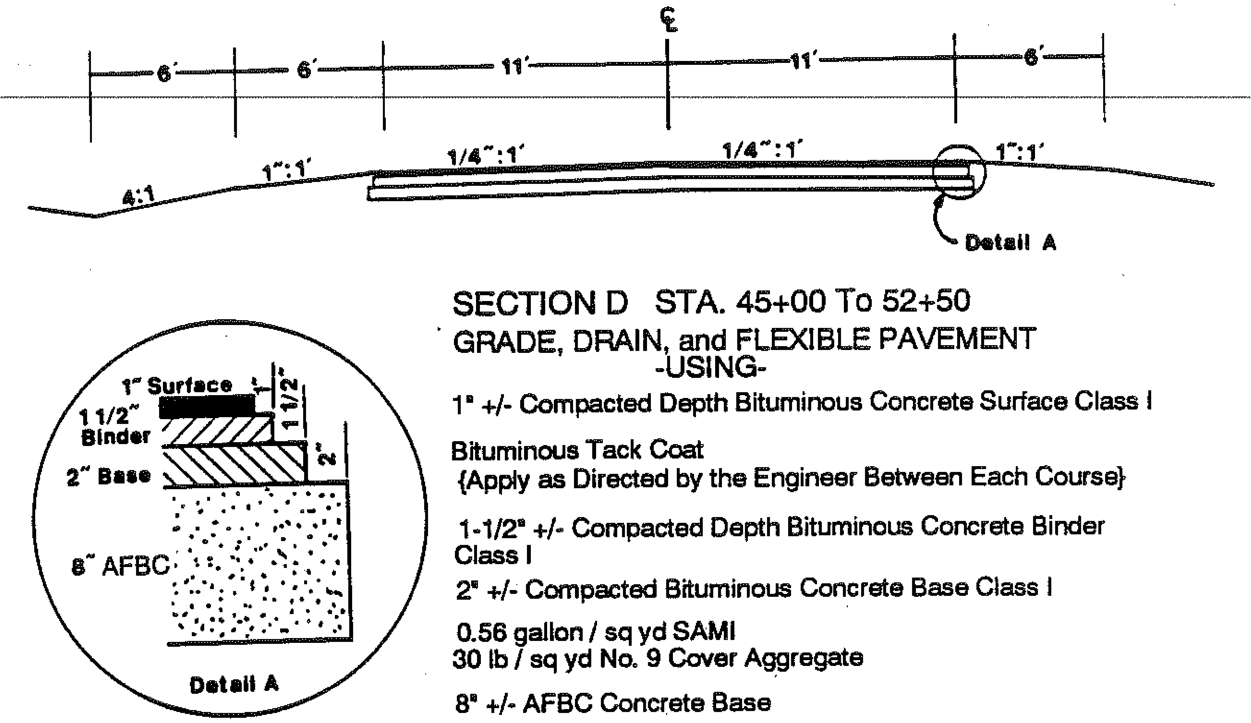
Figure 4. *A typical moisture-density determination for AFBC stabilized pond ash subbase mixture.*

alternates were determined using the Kentucky flexible pavement design procedure to determine thickness requirements of the 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 a structural number for the conventional design determined from the Kentucky procedure [11]. The structural number (SN) was then used in combination with the AASHTO design equation;

$$SN = [a_1 \times d_1] + [a_2 \times d_2] + \dots + [a_n \times d_n] \qquad \{1\}$$

and structural coefficients for asphaltic concrete $a_1 = 0.44$ and $a_2 = 0.30$ for the AFBC concrete base mixture to determine the thickness requirement for the AFBC concrete base. The thickness design requirements based on these analyses indicated an AFBC concrete base thickness of 8.0 inches. A similar analysis was performed to determine the required thickness of the AFBC stabilized pond ash subbase. Structural coefficients used for this analysis were $a_1 = 0.44$ for asphaltic concrete, $a_2 = 0.14$ for crushed stone, and $a_3= 0.10$ for the AFBC stabilized pond ash subbase mixture. The thickness design requirements based on these analyses indicated a crushed aggregate base thickness of 8.0 inches and an AFBC stabilized pond ash subbase thickness of 12.0 inches.

The pavement design of the experimental AFBC concrete base 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. The typical design section for the experimental AFBC concrete base section is shown in Figure 5. The pavement design of the experimental AFBC stabilized pond ash subbase specified a bituminous curing seal to be applied to the subbase material to prevent excessive loss of moisture during the initial cure, 2.0 inches of compacted bituminous concrete base, 1.5 inches compacted bituminous binder, and 1.0 inch compacted bituminous surface. The typical design section for the experimental AFBC stabilized pond ash subbase section is shown in Figure 6. 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. The typical design section for the conventionally constructed section is shown in Figure 7. A schematic diagram detailing locations of the experimental and control sections is given in Figure 8.



SECTION D STA. 45+00 To 52+50
GRADE, DRAIN, and FLEXIBLE PAVEMENT
-USING-

1" +/- Compacted Depth Bituminous Concrete Surface Class I

Bituminous Tack Coat
{Apply as Directed by the Engineer Between Each Course}

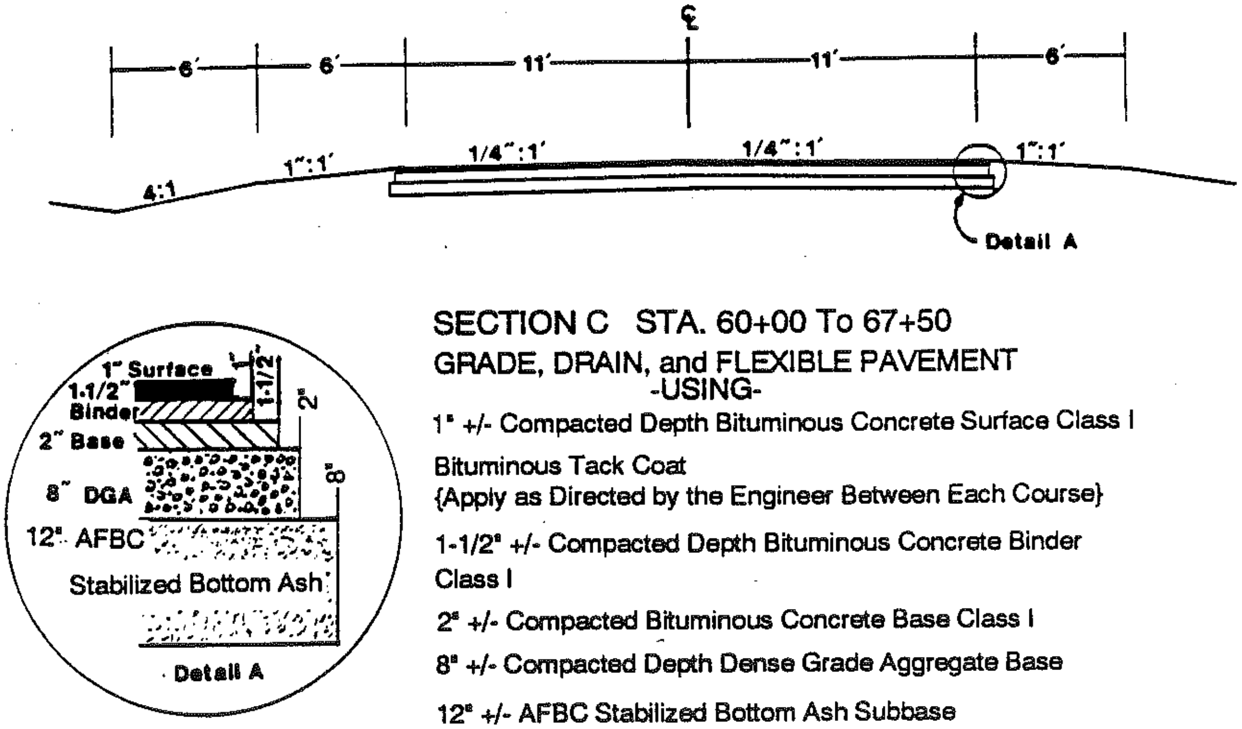
1-1/2" +/- Compacted Depth Bituminous Concrete Binder Class I

2" +/- Compacted Bituminous Concrete Base Class I

0.56 gallon / sq yd SAMI
30 lb / sq yd No. 9 Cover Aggregate

8" +/- AFBC Concrete Base

Figure 5. *Typical section and detail for the AFBC concrete base section.*



SECTION C STA. 60+00 To 67+50
GRADE, DRAIN, and FLEXIBLE PAVEMENT
-USING-

1" +/- Compacted Depth Bituminous Concrete Surface Class I

Bituminous Tack Coat
{Apply as Directed by the Engineer Between Each Course}

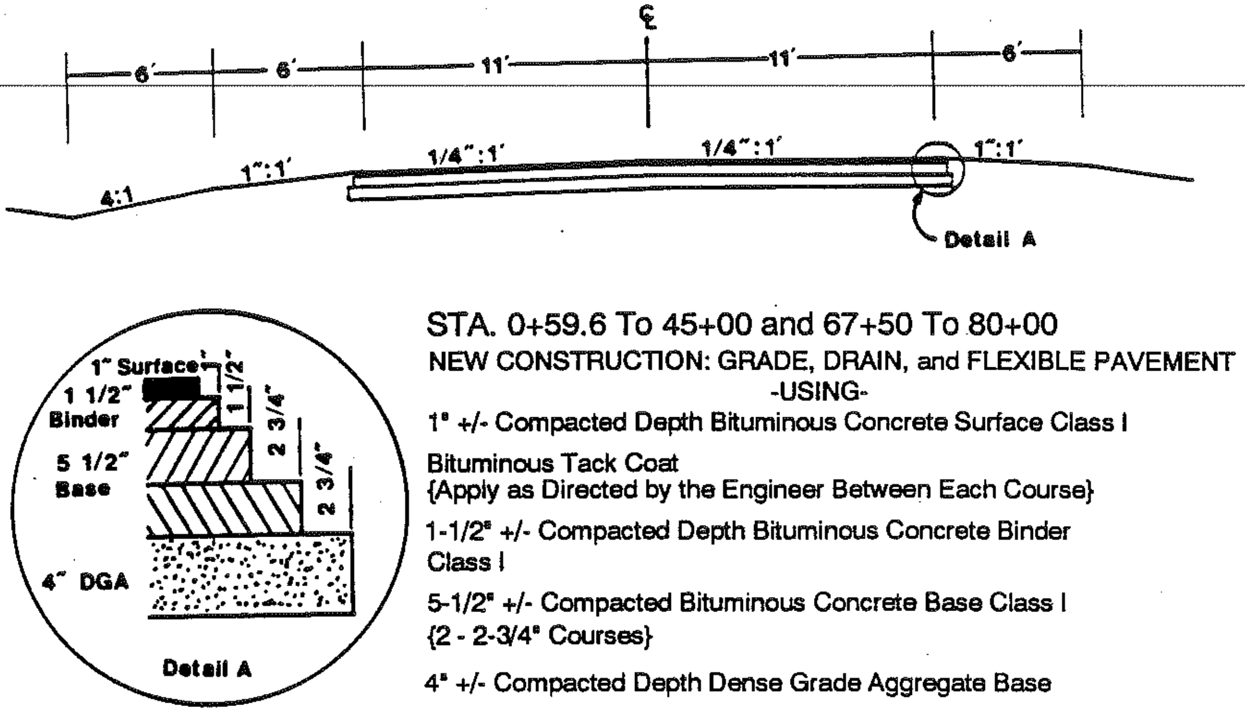
1-1/2" +/- Compacted Depth Bituminous Concrete Binder Class I

2" +/- Compacted Bituminous Concrete Base Class I

8" +/- Compacted Depth Dense Grade Aggregate Base

12" +/- AFBC Stabilized Bottom Ash Subbase

Figure 6. *Typical section and detail for the AFBC stabilized pond ash subbase section.*



STA. 0+59.6 To 45+00 and 67+50 To 80+00

NEW CONSTRUCTION: GRADE, DRAIN, and FLEXIBLE PAVEMENT
-USING-

1" +/- Compacted Depth Bituminous Concrete Surface Class I

Bituminous Tack Coat
{Apply as Directed by the Engineer Between Each Course}

1-1/2" +/- Compacted Depth Bituminous Concrete Binder Class I

5-1/2" +/- Compacted Bituminous Concrete Base Class I
{2 - 2-3/4" Courses}

4" +/- Compacted Depth Dense Grade Aggregate Base

Figure 7. *Typical section and detail for the control section.*

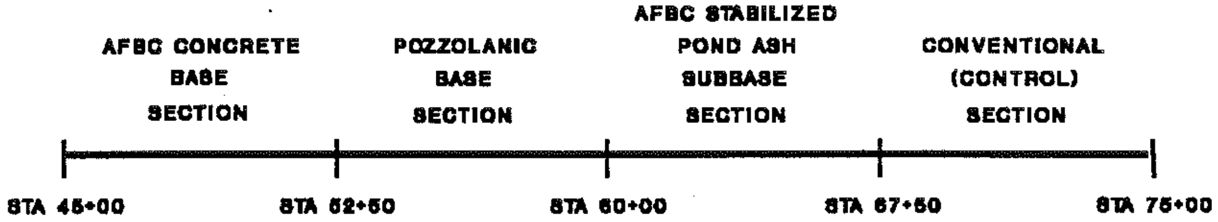


Figure 8. *Schematic detailing location of experimental and control sections.*

CONSTRUCTION PROCEDURES

The project, McCracken County SSP 073 3074 000-002, was 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, except that the tests were performed on the soil in its actual in-situ condition [12]. Measurement of subgrade strength was also by the Clegg Impact Test using the Clegg Impact Soil Tester [13]. Moisture content of the soil for these tests was determined in accordance with ASTM D 2216 [14]. Values of California Bearing Ratio (CBR) for each method of determination and corresponding subgrade moisture content are contained in Table 5. The in-situ bearing strength as determined by the ASTM D 1883 method, and moisture content of the subgrade materials were neither uniform nor consistent. The subgrade of the AFBC concrete base section had an average in-situ CBR of 24 and ranged from six to 43. The moisture content of the subgrade in the AFBC concrete base section averaged 8.3 percent and ranged from 6.3 percent to 10.3 percent. The subgrade of the AFBC stabilized pond ash subbase section had an average in-situ CBR of 12 and ranged from one to 22. The subgrade moisture content in the AFBC stabilized pond ash section averaged 16.2 percent and ranged from 6.5 percent to 40.4 percent. The average in-situ CBR and subgrade moisture content values in the control section averaged 33 percent and 14.6 percent, respectively.

AFBC Concrete Base Section -- STA 45+00 to STA 52+50

Placement of the experimental AFBC concrete base began May 18, 1988. Construction requirements are summarized in Kentucky Department of Highways' Special Note for Experimental Use of Waste Materials in Highway Construction (see Appendix A). Components of the AFBC concrete base material 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 plant. Plant equipment included all components and accessories for stabilization-type mixing plants deemed necessary for proper performance.

Because of a materials handling and storage problem, prehydration of the AFBC residue just prior to its use, as is desirable, was not feasible. Questions then arose to the possibility of preconditioning the AFBC residue in advance and storing it. Since similar methods had been employed in the laboratory evaluations, (preconditioned AFBC residue had been stored in sealed 55-gallon drums for several months prior to being used without exhibiting any detrimental effects), it was thought that storing the preconditioned AFBC residue in a warehouse would be satisfactory. Therefore, it was recommended that the AFBC residue be preconditioned with 18 percent water, by weight, and stored in a warehouse prior to being used in the base and subbase mixtures. Apparently, most of

TABLE 5: SUMMARY OF SUBGRADE CONSTRUCTION INFORMATION

Station Number	Moisture Content (%)	In-Situ California Bearing Ratio	
		ASTM D-1883	Clegg Hammer
AFBC Concrete Base Section			
47+50 LT	10.3	43	37
49+00 LT	6.3	30	49
50+50 RT	7.0	06	03
52+00 RT	9.9	18	11
AFBC Stabilized Pond Ash Section			
61+00 LT	10.2	12	18
62+50 RT	10.1	22	17
64+00 LT	40.4	01	02
65+50 RT	6.5	11	18
67+00 LT	13.6	14	10
Control Section			
68+50 RT	15.5	07	08
70+00 LT	11.6	77	33
71+50 RT	11.1	46	32
73+00 LT	16.6	19	10
74+50 RT	18.0	16	05

the prehydrated AFBC residue was stored in the warehouse for several months prior to being used in the mixtures.

To check the condition of the AFBC residue, KTC personnel visited the storage warehouse in March, 1988 and obtained samples for evaluation. Tests at that time indicated that the previously preconditioned AFBC residue would react; generating heat when water was added to it. The AFBC residue had apparently repossessed some of its initial properties while being stored in the warehouse or either was not properly preconditioned initially. Results of the impromptu tests indicated that some expansion of the mixtures would be experienced. A decision was made to use the AFBC residue in its present state, as opposed to prehydrating the material again, and to form gaps in the plastic base and subbase layers that would accommodate expected expansion of the mixture. Preliminary, short-term laboratory data indicated expansion could range up to one percent for the selected mixtures.

The No. 57 aggregate used in the mixture was stockpiled without protection and the Class F fly ash was pumped from a pneumatic truck to a storage silo. The AFBC residue and No. 57 aggregate were loaded onto an aggregate conveyor belt at prevailing moisture contents and transported to the mixer. The Class F fly ash 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 D contains information relative to production times and material quantities used during construction of the AFBC concrete base.

The blended base material was transported approximately 15 miles to the paving site in dump trucks. The base material was end dumped into and spread by a conventional aggregate spreader box pushed by a bulldozer. The 8.0 inches of base material was placed in two equal lifts and compacted using a steel-wheeled vibratory roller having a minimum weight of 10 tons (see Figure 9). A motor grader was used to trim the material to proper grade. Two days were required to complete placement of the base material. Summaries of the calculated material quantities for production of the AFBC concrete road base are listed in Table 6.

The AFBC concrete base materials were placed on Wednesday and Thursday, May 18 and 19, 1988, respectively. On the first day of production, a 4-inch lift was placed in the eastbound lane for a distance of 750 feet followed by a 4-inch lift in the westbound lane, again for a distance of 750 feet. The second course of the AFBC concrete base material had to be placed the following day because of a breakdown at the batch plant. After the batch plant broke down, the contractor was requested to water the surface of the plastic AFBC concrete base before leaving the jobsite and prior to beginning work the following day. There was immediate concern that delamination between layers might occur. At the end of the first production day, gaps approximately 4 feet in width were formed at 250-foot intervals to allow for expected expansion of the AFBC concrete base mixture (see Figure 10).

During construction, placement and compaction operations proceeded relatively smoothly. The number of truck loads delivered to the jobsite on Wednesday was 30, or about 437 tons of material. The first load contained approximately 11 percent moisture and was

Figure 9. *Placing and compacting the first lift of the experimental AFBC concrete base mixture.*

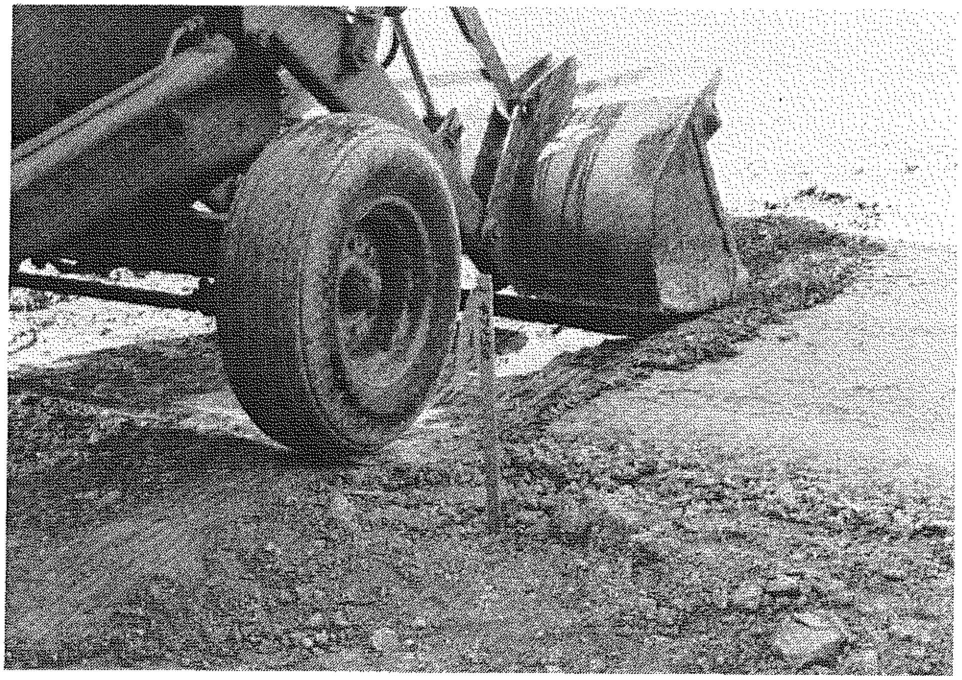


Figure 10. *Cutting gaps in the first lift of the AFBC concrete base.*

spread out very thinly by a road grader. The second load was much more consistent, but still contained excess moisture. The load was thinly spread by the road grader over a distance of about 15 feet in both eastbound and westbound lanes. Twenty-two truck loads, or about 343 tons of material, were delivered to the jobsite on Thursday. The amount of material delivered Thursday was not sufficient to complete the second lift throughout the entire 750-foot experimental section. The Resident Engineer for the project recommended that the second lift be stopped at STA 52+00 and the remaining 50 feet of the second lift be constructed using conventional bituminous base materials. At the end of the second production day, the 4-foot wide gaps were re-formed to allow for the anticipated expansion of the AFBC concrete base mixture.

Overall, the consistency of the mix appeared to be fairly uniform. There were, however, some material segregation and excess moisture observed in a few 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 delayed compaction of the base mixture.

A compaction requirement of no less than 100 percent of laboratory dry density was specified for the AFBC concrete base construction. In-place densities of the compacted AFBC concrete base material were determined by nuclear gages using applicable Kentucky Department of Highways' Test Methods [15]. A total of 16 measurements were made to determine density and moisture content. A summary of construction density measurements is presented in Table 7. As illustrated in Table 7, all measurements taken on both the first and second lifts exceeded the specified 100 percent of maximum dry density.

TABLE 6. AFBC CONCRETE BASE MATERIAL QUANTITIES

Material	Quantity (Tons)	Percent of Total (%)
Coarse Limestone	458.64	63.9
Class F Fly Ash	77.67	10.8
AFBC Residue	181.62	25.3
Totals	717.93	100.0

TABLE 7: SUMMARY OF DENSITIES FOR AFBC CONCRETE BASE CONSTRUCTION

Station Number	Offset	Course	Moisture Content (%)	Field Density (% of maximum)
45+80	RT 5’	first	8.8	105.9
45+80	RT 5’	first	10.5	103.4
48+10	RT 5’	first	9.6	103.5
51+35	RT 7’	first	9.8	104.9
45+35	LT 2’	first	9.3	104.4
51+00	LT 7’	first	10.5	104.9
52+35	RT 7’	first	9.1	104.2
45+10	Lt 2’	second	9.9	105.9
45+75	RT 6’	second	9.6	103.9
46+60	LT 3’	second	10.5	105.1
48+05	RT 2’	second	8.5	102.5
48+90	RT 8’	second	8.1	101.6
49+02	LT 3’	second	6.6	105.9
50+40	RT 4’	second	9.6	106.7
51+50	RT 9’	second	8.9	102.6
51+50	LT 5’	second	9.5	101.9

A 5-hour time limit between mixing and completion of compaction was specified. It was also intended that all trimming and fine grading be accomplished during the 5-hour period. Although a 5-hour time limit between mixing and completion of compaction was specified, in those locations where loads were placed that contained excess moisture, the experimental AFBC concrete base remained plastic for several hours. A bituminous curing seal was required to be placed over the compacted AFBC concrete base to prevent excess evaporation of moisture from the 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. The contractor placed the bituminous curing seal that afternoon. The asphalt distributor would often rut the plastic base when placing the curing membrane. Figure 11 shows the surface of the completed AFBC concrete base.

Wheel track rutting in the westbound lane near station 48+50 was the result of placing the curing membrane too soon. To prevent the occurrence of reflective cracking in the asphalt layers, known to be associated with pozzolanic bases, a polymerized emulsion was used with 9M limestone chips (3/8-inch maximum) to construct a stress relief layer approximately 1/2 inch thick the day following application of the curing membrane [16]. 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.

AFBC Stabilized Pond Ash Subbase Section -- STA 60+00 to STA 67+50

Placement of the experimental AFBC stabilized pond ash subbase began June 9, 1988. Construction requirements for the AFBC stabilized pond ash subbase are also summarized in Kentucky Department of Highways' Special Note for Experimental Use of Waste Materials in Highway Construction (see Appendix A). Components of the AFBC stabilized pond ash subbase material were blended at the Federal Materials Corporation's concrete batching plant.

The AFBC residue and the pond ash were loaded onto an aggregate conveyor belt at their prevailing moisture contents and transported to the batch mixer. The amount of mixing water required for optimum conditions was generally estimated and the proper amount of water required for blending was also estimated based upon the appearance of the mixture at the jobsite. Appendix E contains information relative to production times and material quantities used to construct the 12-inch AFBC stabilized pond ash subbase.

The blended subbase material was transported to the paving site in covered dump trucks. The subbase material was end dumped into and spread by a conventional aggregate spreader box pushed by a bulldozer. The 12.0 inches of base material were placed in two equal lifts and compacted using a steel-wheeled vibratory roller having a minimum weight of 10 tons. A motor grader could not be used to trim the material to proper grade primarily due to the consistency of the mixture. Because an 8.0-inch layer of dense graded aggregate was to be placed above the subbase layer, engineers allowed greater tolerances in the grade elevations required for the subbase layer. Scheduling difficulties at the concrete batch plant made it necessary to complete placement of the subbase material over a three day period. Summaries of calculated material quantities for production of the AFBC stabilized pond ash subbase are listed in Table 8.

Figure 11. *The plastic AFBC concrete base was easily rutted when the curing seal was applied.*

TABLE 8. AFBC STABILIZED POND ASH SUBBASE MATERIAL QUANTITIES

Material		Quantity (Tons)	Percent of Total (%)
Pond Ash			
	Fly Ash	67.74	7.8
	Bottom Ash	523.52	60.3
AFBC Residue		277.13	31.9
	Totals	868.39	100.0

The AFBC stabilized pond ash subbase material was placed on Thursday, Friday, and Saturday, June 9, 10, and 11, 1988, respectively. On the first day of production, the initial load was very wet and was spread thinly over the prepared subgrade using the road grader (see Figure 12). The second load appeared to be near optimum moisture but was also spread thinly and shaped by the road grader. The third load was end dumped into the aggregate spreader box and normal construction techniques were followed thereafter. A 6-inch lift was placed in the eastbound lane for an approximate distance of 385 feet. At this point, the paving train was placed in the westbound lane and a 6-inch lift was placed in the westbound lane, again for a distance of about 385 feet. Twenty and one-half loads, or about 319 tons of the subbase mixture, were delivered on the first day. Figure 13 depicts the placement of the westbound lane. The placement operations continued steadily when materials were available. Production times for Thursday's placement were from around noon to nearly 8:00 pm. Approximately 11 percent water was added to the subbase mixture at the plant. The construction crew assembled shortly after noon on Friday. The first 6-inch course of the AFBC stabilized pond ash subbase material was completed in the eastbound and westbound lanes. Seventeen loads, or about 271 tons of material, were placed. Production times for Friday began about noon and ended around 9:30 pm. The construction crew reassembled at about 5:30 am Saturday, June 11, to complete placement of the experimental subbase. The first load was batched at the concrete plant at 5:40 am. The paving train began placing the second lift in the eastbound lane at Station 60+00. A water truck wetted the surface of the first lift prior to placement of the second lift in an attempt to prevent delamination between lifts even though most of the initial lift had been placed two days earlier. Production of the experimental subbase mixture at the batch plant was continuous. The paving train had very few delays. Twenty-four loads, or about 372 tons of material, were delivered to the construction site and placed before 1:00 pm that afternoon.

At the end of the day, when all material was placed and compacted, a bituminous curing seal was placed over the compacted AFBC stabilized pond ash subbase to prevent excess moisture evaporating from the 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. However, apparently because it was Saturday afternoon, the construction crew applied the curing seal immediately after the compactor had completed compacting an area. Figure 14 shows placement operations continuing in the eastbound lane after the curing seal had been sprayed in the adjacent area of the westbound lane. The curing seal was placed in the eastbound lane before the material could gain adequate strength to support the vehicle applying the seal. Figure 15 illustrates the result of this action. Deep ruts were formed in the plastic subbase material that was placed near station 66+50 in the eastbound lane.

Figure 12. *A road grader was used to spread the first two loads of the AFBC stabilized pond ash subbase mixture.*

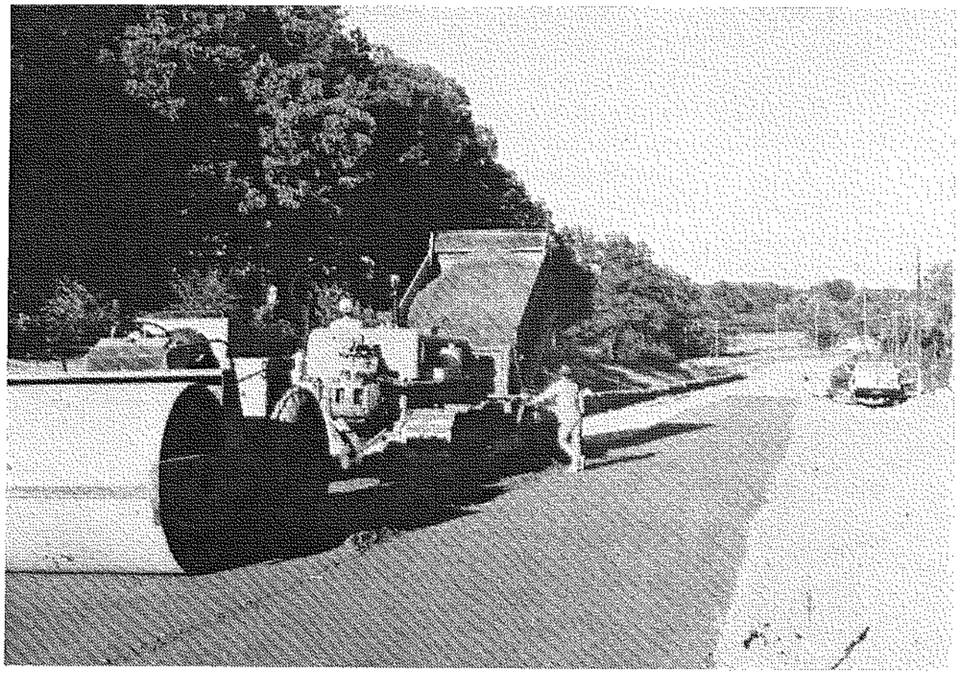


Figure 13. *Placement of the experimental AFBC stabilized pond ash subbase.*

Figure 14. *Placement operations continued in the eastbound lane after the curing membrane had been applied in the westbound lane.*

Figure 15. *Deep ruts formed in the plastic subbase mixture when the curing seal was placed too soon after completing compaction.*

Because results of the impromptu preconditioning study conducted to determine the condition of the AFBC residue had indicated that some expansion may be experienced, a decision was made to form gaps in the plastic AFBC stabilized pond ash subbase in similar fashion to those formed in the AFBC concrete base material. On Monday, June 13, the construction crew returned to the jobsite and attempted to excavate 4-foot wide gaps in the subbase material. However, the AFBC stabilized pond ash subbase had hardened to such an extent that the crew found even a 2-foot wide gap was nearly impossible to make using the small backhoe machine.

For the overall production of the AFBC stabilized pond ash subbase, the consistency of the mixture appeared to be fairly uniform after adjustments were made based on the appearance of the initial loads. There was, however, some excess moisture observed in some, but not all, of the loads. The initial loads of the day's production most often contained excess moisture and later loads were often nearer to the optimum moisture content after adjusting the amount of water added to the mixture based on the appearance of the mixture at the jobsite. The additional moisture in the initial loads delayed compaction.

A compaction requirement of no less than 100 percent of the laboratory dry density was also specified for the AFBC stabilized pond ash subbase layer. In-place densities of the compacted subbase material were determined by nuclear gages using applicable Kentucky Department of Highways' Test Methods. A total of 12 measurements were made to determine density and moisture content. A summary of construction density measurements is contained in Table 9. After the number of compactor passes to achieve satisfactory density was determined, all measurements taken on both first and second lifts exceeded the specified 100 percent of maximum dry density.

EVALUATIONS

During and after construction, investigations relative to the engineering properties of the experimental mixtures continued. While constructing the two sections, specimens were compacted at the jobsite for verification of densities. A limited number of moisture content samples also were obtained from the mixtures. Field compacted specimens were transported to the laboratory, cured under ambient conditions in sealed plastic sample bags, and subjected to destructive testing. Specifically, test specimens of the base and

TABLE 9: SUMMARY OF DENSITIES FOR AFBC STABILIZED POND ASH SUBBASE CONSTRUCTION

Station Number	Offset	Course	Moisture Content (%)	Field Density (% of maximum)
61+21	RT 6'	first	16.4	97.8
61+21	RT 6'	first	17.6	99.6
61+21	RT 6'	first	16.7	102.2
64+05	LT 2'	first	15.6	103.2
67+00	LT 6'	first	14.5	100.7
67+25	RT 3'	first	16.7	102.8
60+25	RT 4'	second	14.3	101.8
60+35	RT 1'	second	14.9	103.2
62+15	RT 6'	second	16.1	102.5
62+20	LT 8'	second	14.3	105.7
64+50	RT 4'	second	16.3	100.7
64+60	LT 8'	second	15.6	107.0

subbase mixtures were evaluated for compressive strength, static chord modulus of elasticity, and expansion. Additionally, field inspections were conducted to document the condition of the experimental base and subbase sections. Visual surveys were performed to observe instances of cracking and other distresses. Optical surveys were made to determine the expansion of the experimental mixtures. Road Rater deflection surveys were performed on compacted subgrade and cured base and subbase layers.

Density, Moisture, Compressive Strength and Modulus of Elasticity

Specimens of the experimental base and subbase mixtures were compacted at the jobsite during construction for laboratory evaluations. 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 evaluated for compressive strength development. However, while transporting the specimens to the laboratory, the specimens slumped and no tests were attempted on these samples. Six-inch by 12-in. plastic cylinder molds also were utilized in making specimens for compressive strength and elastic moduli 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.

To verify satisfactory compactive effort while preparing the 6-in. by 12-in. cylinder molds, wet densities were calculated for all compacted specimens. 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 evaluation. All specimens were cured in the laboratory at ambient temperatures in sealed plastic bags until they were tested. Unconfined compressive strengths of the specimens were determined in accordance with ASTM C 39. Static chord elastic modulus was determined in accordance with ASTM C 469 [17].

AFBC Concrete Base Mixture

The field compacted specimens of the AFBC concrete base mixture were tested at seven, 14, 28, 56, and 112 days. Results of these analyses are presented in Table 10. Average values of compressive strength and elastic modulus of field compacted specimens presented in Table 11 illustrate the long-term strength gain characteristics of the AFBC concrete base mixture. Average seven-day compressive strengths were 1,465 psi. Seven-day static chord elastic moduli values averaged 2.20 x 10^6 psi. At 14-days, the compressive strength had increased to an average of 2,130 psi with a static chord elastic modulus of about 2.80 x 10^6 psi. The 28-day average compressive strength increased to 2,725 psi and the static chord elastic modulus average value increased to 2.90 x 10^6 psi. Average values for compressive strength and static chord elastic modulus, at 56 and 112 days, had increased to 3,580 psi and 3.15 x 10^6 psi, and, 4,075 psi and 3.65 x 10^6 psi, respectively. Figure 16 graphically illustrates the strength development of the field compacted specimens.

TABLE 10. COMPRESSIVE STRENGTH, ELASTIC MODULUS, AND DENSITY OF AFBC CONCRETE BASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Number	Wet Density (pcf)	Moisture Content (%)	Dry Density (pcf)	Age at Test (days)	Compressive Strength (psi)	Elastic Modulus (psi x 10^6)
			SPECIMENS MADE MAY 18,1988			
3-1	146.4	--	--	7	1,310	1.85
3-2	146.4	--	--	14	1,680	3.05
3-3	144.9	--	--	28	2,895	3.05
6-1	145.2	--	--	7	1,485	2.70
6-2	144.3	--	--	14	2,885	2.75
6-3	147.3	--	--	112	4,210	3.35
9-1	146.1	--	--	7	1,540	2.10
9-2	147.6	--	--	14	2,070	2.80
9-3	146.4	--	--	28	2,975	3.10
15-1	145.2	--	--	7	1,865	2.50
15-2	146.1	--	--	14	2,410	2.60
15-3	144.6	--	--	28	2,790	2.95
18-1	147.6	--	--	7	1,805	2.50
18-2	146.4	--	--	14	2,280	2.95
18-3	147.9	--	--	56	4,095	3.25
21-1	146.1	--	--	7	1,415	--
21-2	147.6	--	--	14	2,140	--
21-3	147.3	--	--	56	4,030	3.40
24-1	148.2	--	--	7	1,625	2.50
24-2	147.0	--	--	14	2,090	2.90
24-3	147.0	--	--	28	3,135	2.85
27-1	146.7	--	--	7	1,415	2.60
27-2	149.7	--	--	14	1,820	1.55
27-3	147.6	--	--	112	4,165	3.90

TABLE 10 (continued). COMPRESSIVE STRENGTH, ELASTIC MODULUS, AND DENSITY OF AFBC CONCRETE BASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Number	Wet Density (pcf)	Moisture Content (%)	Dry Density (pcf)	Age at Test (days)	Compressive Strength (psi)	Elastic Modulus (psi x 10^6)
			SPECIMENS MADE MAY 19,1988			
31-1	145.2	--	--	7	1,400	2.10
31-2	144.3	--	--	14	2,010	2.45
31-3	145.2	--	--	28	2,155	2.70
35-1	146.4	--	--	7	1,025	1.55
35-2	145.2	--	--	14	1,480	2.25
35-3	146.1	--	--	28	2,055	2.35
39-1	144.6	--	--	7	1,615	2.30
39-2	145.8	--	--	14	2,530	2.90
39-3	146.1	--	--	56	3,945	3.50
43-1	146.1	--	--	7	900	1.20
43-2	145.8	--	--	14	1,965	2.65
43-3	145.8	--	--	112	3,850	3.75
47-1	144.9	--	--	7	1,695	2.55
47-2	145.2	--	--	14	2,485	3.15
47-3	145.2	--	--	28	3,075	3.35
51-1	146.7	--	--	7	1,415	1.95
51-2	146.7	--	--	14	1,940	--
51-3	145.8	--	--	56	2,260	2.45

The attempt to simulate proper compactive effort while preparing field specimen was successful. As a measure of the compactive effort, the wet density of the AFBC concrete base specimens compacted at optimum moisture content would have been 141.0 pounds per cubic foot. Wet densities of the 6-in. by 12-in. AFBC concrete base specimen averaged 146.2 pcf, or 103.7 percent of maximum density. Densities of the AFBC concrete base layer, determined with nuclear density devices, averaged 104.2 percent of the maximum density.

TABLE 11. AVERAGE, BY AGE, OF COMPRESSIVE STRENGTH AND STATIC CHORD ELASTIC MODULUS OF AFBC CONCRETE BASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Age (days)	7	14	28	56	112
No. of Samples Tested for a Given Age	14	14	7	4	3
Average Compressive Strength (psi)	1,465	2,130	2,725	3,580	4,075
Range of Compressive Strengths (psi)	900-1,865	1,480-2,885	2,055-3,135	2,260-4,095	3,850-4,210
Average Elastic Modulus (psi x 10^6)	2.20	2.65	2.90	3.15	3.65
Range of Elastic Moduli (psi x 10^6)	1.20-2.70	2.25-3.15	2.35-3.35	2.45-3.50	3.35-3.90

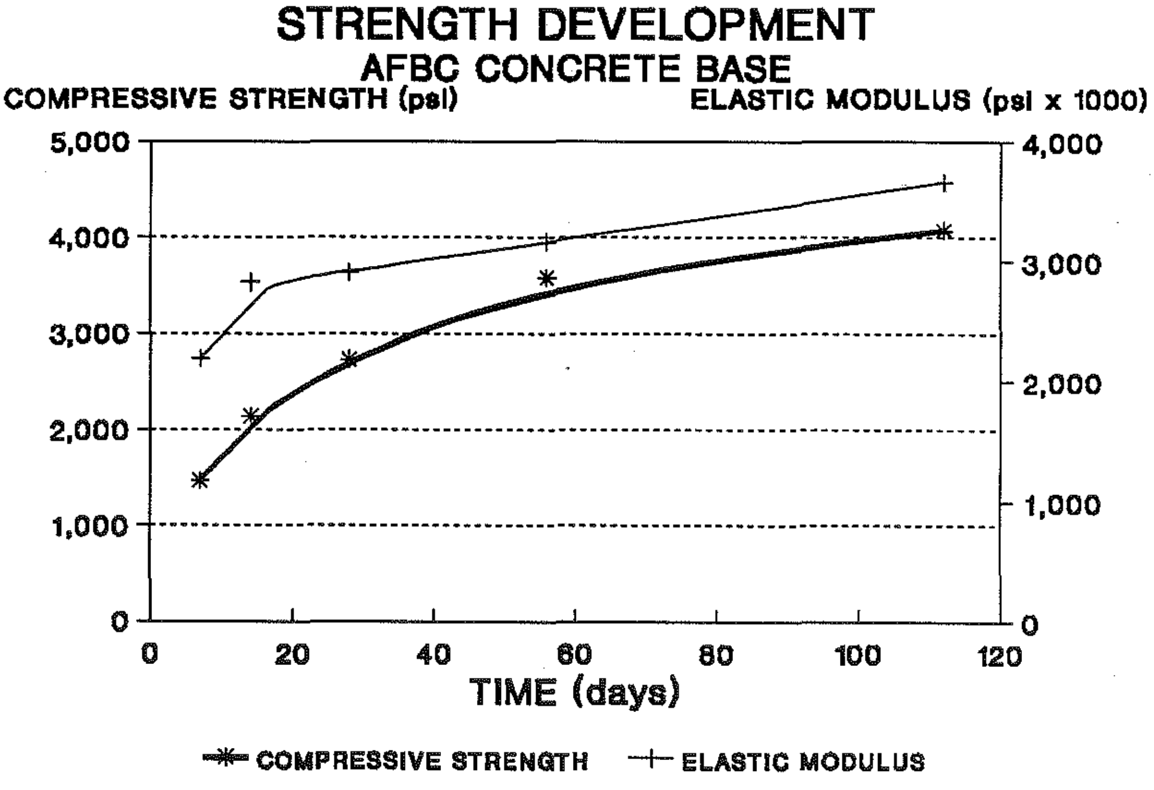


Figure 16. *Strength development properties of AFBC concrete base mixture.*

Specimens of the AFBC stabilized pond ash subbase mixture also were tested at seven, 14, 28, 56, and 112 days. Results of these analyses are presented in Table 12. Average values of compressive strengths and elastic moduli of field compacted AFBC stabilized pond ash subbase specimens presented in Table 13 illustrate the strength gain properties of the AFBC stabilized pond ash subbase mixture. The average seven-day compressive strength was 375 psi. Seven-day static chord elastic moduli values averaged 0.40 x 10^6 psi. At 14-days, the compressive strength had increased to an average value of 800 psi and the static chord elastic modulus had increased to 0.80 x 10^6 psi. The 28-day average compressive strength increased to 1,480 psi and the static chord elastic modulus average value increased to 1.15 x 10^6 psi. Average values for compressive strength and static chord elastic modulus, at 56 and 112 days, had increased to 1,780 psi and 1.30 x 10^6 psi, and, 2,345 psi and 1.55 x 10^6 psi, respectively. Figure 17 graphically illustrates the strength development of the field compacted AFBC stabilized pond ash subbase specimens.

Although simulation of proper compactive effort was attempted while making the field compacted specimens, specimen densities were only 97.0 percent of the maximum density. Wet densities of AFBC stabilized pond ash subbase specimens compacted at optimum moisture content should have been about 118.2 pounds per cubic foot. AFBC stabilized pond ash specimens had an average density of 114.7 pcf. Field densities of the subbase layer, determined with nuclear density devices, averaged 103.0 percent of the maximum density (excludes first two measurements taken to determine the appropriate number of passes).

Post-Construction Condition Surveys

Several trips were made to the test site to document the condition of the experimental base and subbase layers. The asphaltic concrete layers were not placed immediately after placement of the base and subbase layers so that researchers would have the opportunity to monitor the condition of the experimental layers and the expansive characteristics of each mixture. There were significant changes that occurred within both sections prior to the time the asphaltic concrete layers were placed. Figure 18 is a typical view of the experimental section containing the AFBC concrete base mixture. The photograph was taken approximately seven weeks after placement of the base material. The view is

TABLE 12. COMPRESSIVE STRENGTH, ELASTIC MODULUS, AND DENSITY OF AFBC STABILIZED POND ASH SUBBASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Number	Wet Density (pcf)	Moisture Content (%)	Dry Density (pcf)	Age at Test (days)	Compressive Strength (psi)	Elastic Modulus (psi x 10^6)
SPECIMENS MADE JUNE 9,1988						
2-1	115.1	--	--	7	285	0.30
2-2	115.1	--	--	14	705	0.75
2-3	114.2	--	--	28	1,370	--
6-1	116.9	--	--	7	365	--
6-2	116.2	--	--	14	815	0.80
6-3	117.4	--	--	28	1,465	1.30
11-1	114.1	--	--	7	250	0.20
11-2	115.1	--	--	14	630	0.70
11-3	115.7	--	--	28	1,320	1.05
15-1	116.0	--	--	7	360	0.30
15-2	117.6	--	--	14	865	0.80
15-3	116.5	--	--	28	1,595	1.10
18-1	117.0	--	--	7	365	0.35
18-2	116.1	--	--	14	845	0.70
18-3	116.7	--	--	28	1,595	1.25
SPECIMENS MADE JUNE 10,1988						
26-1	115.9	--	--	7	310	0.35
26-2	115.0	--	--	14	770	0.85
26-3	115.0	--	--	56	1,815	1.45
31-1	115.4	--	--	7	280	0.30
31-2	115.7	--	--	14	815	0.75
31-3	115.0	--	--	112	2,570	1.60
34-1	113.9	--	--	7	295	0.35
34-2	115.0	--	--	14	810	0.70
34-3	113.4	--	--	112	1,940	1.50

TABLE 12 (continued). COMPRESSIVE STRENGTH, ELASTIC MODULUS, AND DENSITY OF AFBC STABILIZED POND ASH SUBBASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Number	Wet Density (pcf)	Moisture Content (%)	Dry Density (pcf)	Age at Test (days)	Compressive Strength (psi)	Elastic Modulus (psi x 10^6)
			SPECIMENS MADE JUNE 10,1988			
39-1	112.4	--	--	7	415	0.45
39-2	112.0	--	--	14	735	0.80
39-3	112.6	--	--	56	1,485	1.10
43-1	115.0	19.0	96.6	7	545	0.55
43-2	114.0	18.2	96.5	14	840	0.95
43-3	115.2	18.8	97.0	112	2,435	1.55
47-1	110.6	17.9	93.8	7	345	0.45
47-2	110.0	17.7	93.4	14	655	0.75
47-3	111.1	16.7	95.2	56	1,625	1.25
51-1	113.8	20.4	94.5	7	495	0.50
51-2	115.0	20.7	95.3	14	965	0.85
51-3	115.1	20.4	95.6	28	1,545	1.15
55-1	115.6	20.0	96.3	7	580	0.60
55-2	114.4	19.3	95.9	14	870	1.25
55-3	113.7	18.5	95.9	112	2,440	1.60
59-1	114.0	21.4	93.9	7	335	0.50
59-2	114.2	21.8	93.8	14	875	0.80
59-3	113.5	21.7	93.3	56	2,205	1.40

looking eastward from beginning Station 45+00. Figure 19 shows longitudinal cracking along the centerline, longitudinal wheel-track rutting, and segregation of the mixture in some areas. Longitudinal centerline cracking was most evident from about Station 45+00 to the expansion gap formed at Station 47+50 and also from Station 50+00 to Station 51+00. Figure 20 is a close-up view of the longitudinal centerline crack and one of the few transverse cracks observed near Station 50+15.

Figure 21 is a typical view of the completed AFBC stabilized pond ash section approximately four weeks after placement. The photograph was taken near beginning

TABLE 13. AVERAGE, BY AGE, OF COMPRESSIVE STRENGTH AND STATIC CHORD ELASTIC MODULUS OF AFBC STABILIZED POND ASH SUBBASE MIXTURE (FIELD COMPACTED SAMPLES)

Sample Age (days)	7	14	28	56	112
No. of Samples Tested for a Given Age	14	14	6	4	4
Average Compressive Strength (psi)	375	800	1,480	1,780	2,345
Range of Compressive Strengths (psi)	250-580	630-965	1,320-1,595	1,485-2,205	1,940-2,570
Average Elastic Modulus (psi x 10^6)	0.40	0.80	1.15	1.30	1.55
Range of Elastic Moduli (psi x 10^6)	0.20-0.60	0.70-1.25	1.05-1.30	1.10-1.45	1.50-1.60

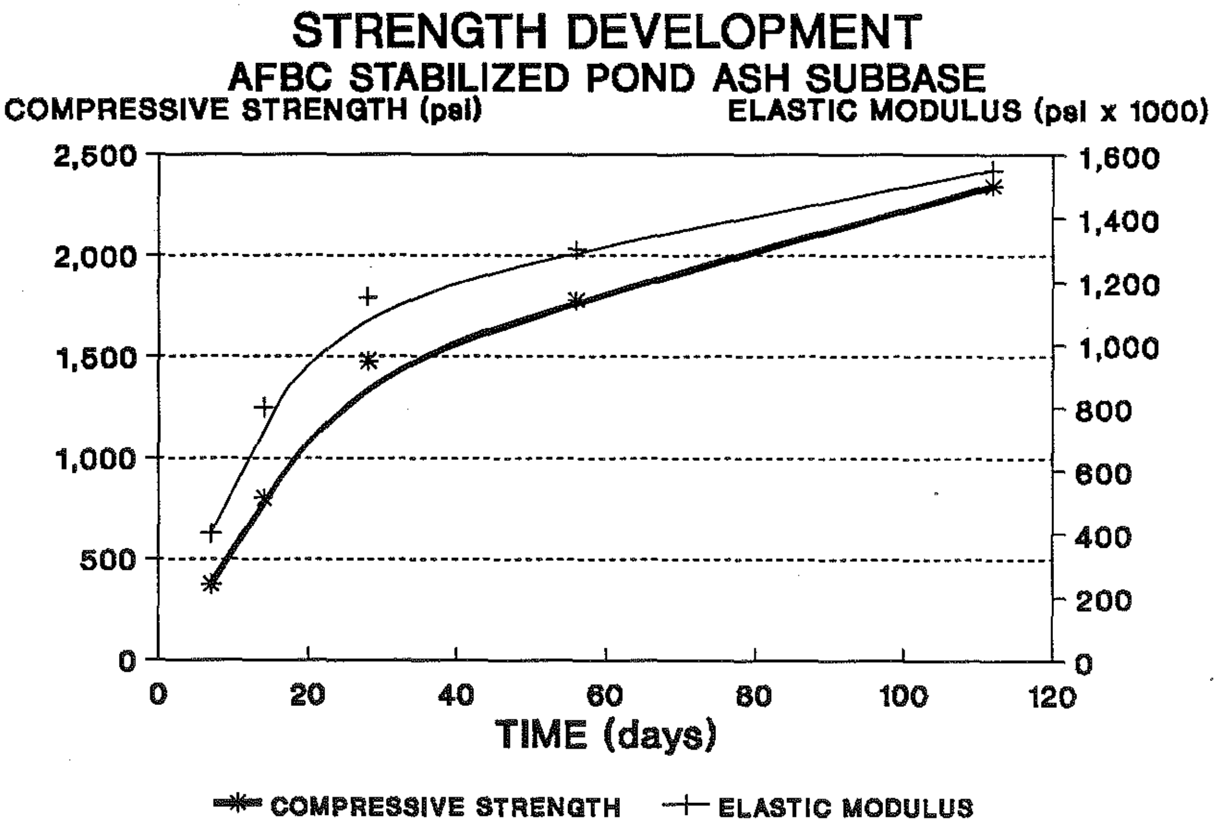


Figure 17. *Strength development properties of the AFBC stabilized pond ash subbase mixture.*

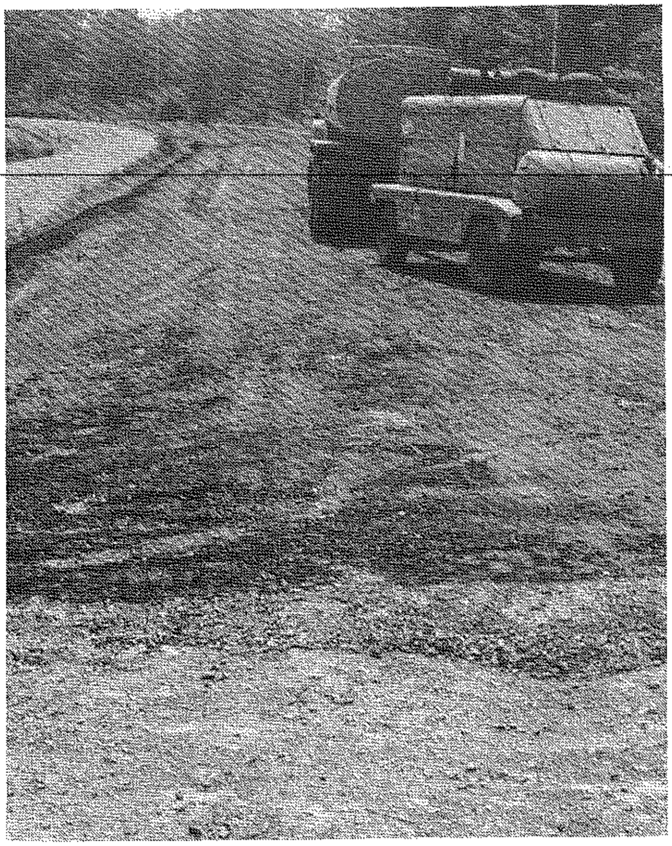


Figure 18. *Experimental AFBC concrete base section seven weeks after placement.*

Figure 19. *Longitudinal centerline cracking and wheel-track rutting in the AFBC concrete base section.*

Figure 20. *Longitudinal and transverse cracking observed in the AFBC concrete base section.*

Figure 21. *Experimental AFBC stabilized pond ash subbase section four weeks after placement.*

Station 60+00 looking eastward. Delamination between the first and second lift is evident in the lower left corner of the figure. Figure 22 is a close-up view of the trench at Station 62+50. Note the disbonding between lifts as well as the sloughing off of the subgrade material into the trench. Shown in the photograph of Figure 23, taken near Station 63+00, is a longitudinal centerline crack that occurs for most of the section and a transverse crack. Figure 24 is a close-up view of the surface of the AFBC stabilized pond ash subbase near Station 64+00. Note the extensive amount of map cracking.

Expansive Characteristics of the Experimental Mixtures

Expansion of the experimental base and subbase layers was monitored optically prior to placement of the asphaltic concrete layers. Survey pins were grouted into the base and subbase material. Hubs were established on each side of the roadway, thereby establishing a line of sight. Length changes were determined using a transit to observe a ruler and measuring from the center of the survey pin to the line of sight. Expansion of the 6-in. by 12-in. field compacted samples was monitored in the laboratory. Results of the expansion analyses for each experimental mixture are discussed below.

AFBC Concrete Base Mixture

The AFBC concrete base mixture was monitored periodically for length changes. Survey pins were grouted into the hardened base material near the expansion gaps, which were formed in the plastic base material (see Figure 25). The survey pins were set and initial base line data were obtained on May 23, 1988. Additional readings were obtained during the months of June and July, and prior to placement of the asphaltic concrete layers. Movement of the experimental AFBC concrete base layer can be seen in Figure 25 in the form of a wave formed on the surface of the subgrade. Results of the field measurements are contained in Table 14. Observations of field expansion were made over a 58-day period. The field expansion of the AFBC concrete base equaled 0.20 percent after the 58-day monitoring period.

Field compacted samples were measured in the laboratory to determine expansive characteristics of the AFBC concrete base materials (see Figure 26). Initial measurements were obtained on May 23, 1988. Additional measurements were obtained prior to testing the specimens for compressive strength and static chord modulus of elasticity at the cured ages of 14, 28, 56 and 112 days. Therefore, expansion was

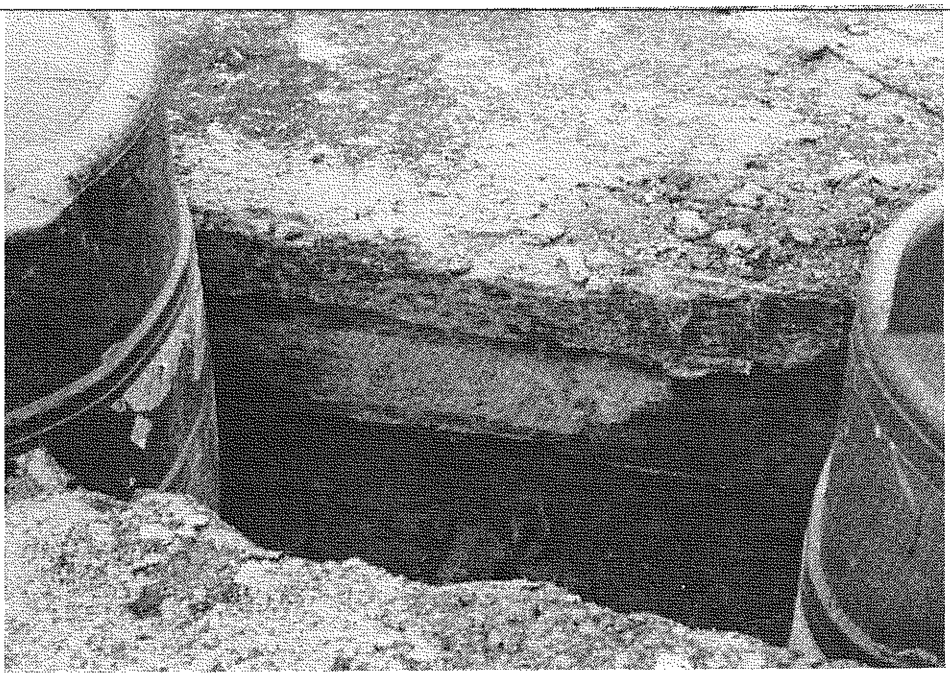


Figure 22. *Delamination was evident in the trenched areas of the AFBC pond ash subbase.*

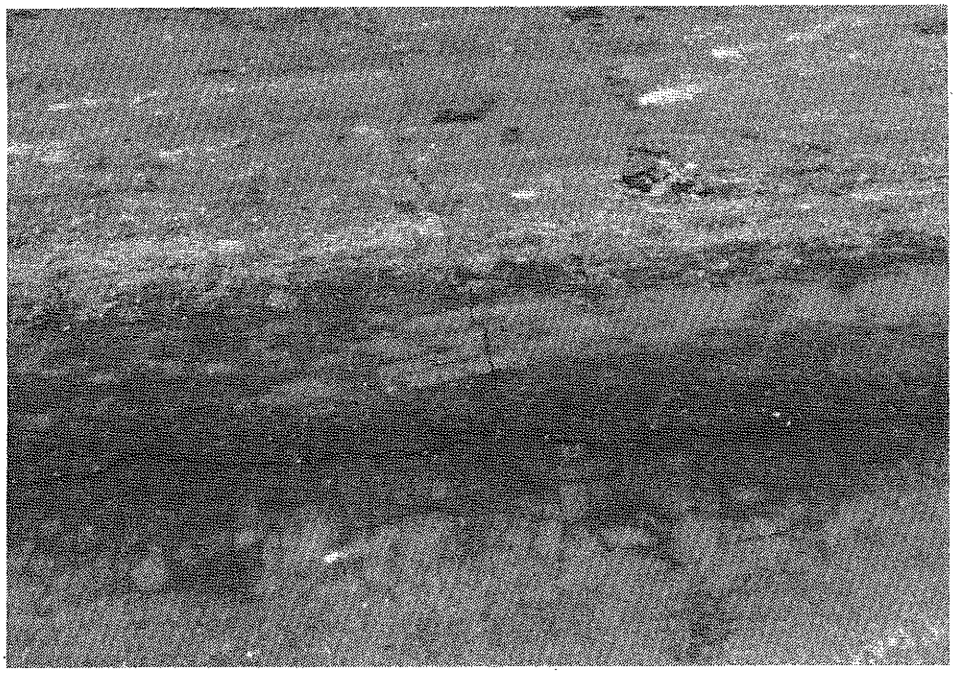


Figure 23. *Longitudinal and transverse cracking observed in the AFBC stabilized pond ash subbase section.*

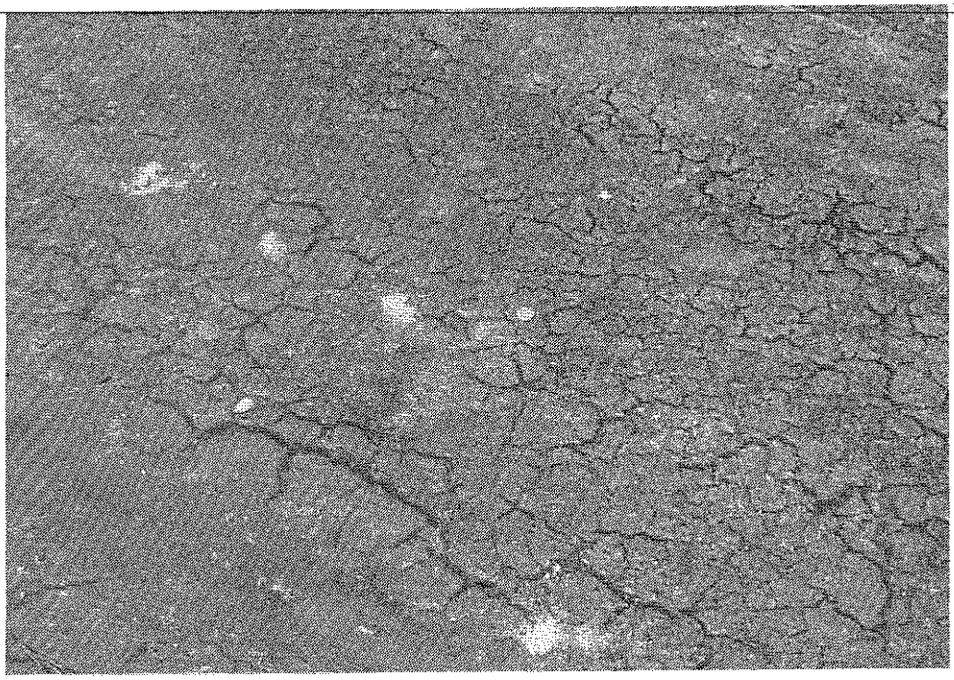


Figure 24. *Map cracking was prominent in the AFBC stabilized pond ash subbase section.*

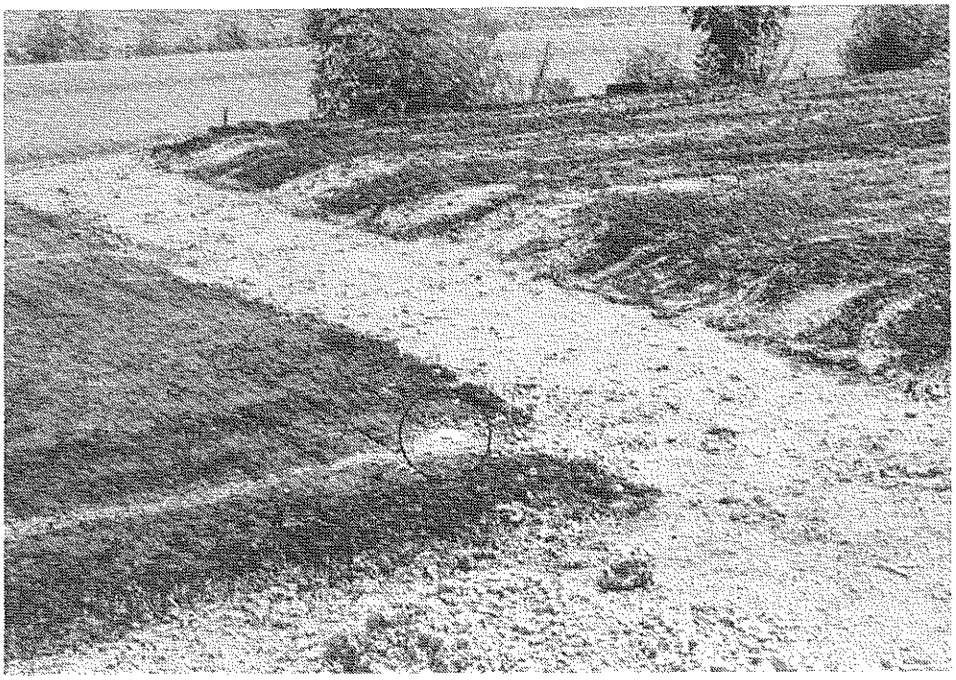


Figure 25. *Survey pins were grouted into the AFBC concrete base layer. Expansion of the base layer is evidenced by the wave formed on the surface of the subgrade.*

TABLE 14. FIELD EXPANSION CHARACTERISTICS OF EXPERIMENTAL BASE AND SUBBASE MIXTURES

Survey Date	Average East (ft)	Average Centerline (ft)	Average West (ft)	Overall Average Expansion (ft)	Percent Expansion (%)
AFBC Concrete Base (STA 45+00 to STA 52+50)					
5/23/88	0.000	0.000	0.000	0.000	0.000
6/01/88	0.445	0.445	0.460	0.453	0.060
6/10/88	0.865	0.805	0.835	0.835	0.111
6/16/88	0.910	0.910	0.835	0.885	0.118
7/06/88	1.172	1.215	1.104	1.164	0.155
7/15/88	1.141	1.470	1.540	1.384	0.184
7/20/88	1.154	1.630	1.620	1.468	0.196
AFBC Stabilized Pond Ash Subbase (STA 60+00 to STA 67+50)					
6/16/88	0.000	0.000	0.000	0.000	0.000
7/11/88	0.996	1.022	1.112	1.043	0.139
7/15/88	1.340	1.320	1.430	1.363	0.182
7/20/88	1.430	1.500	1.600	1.510	0.201

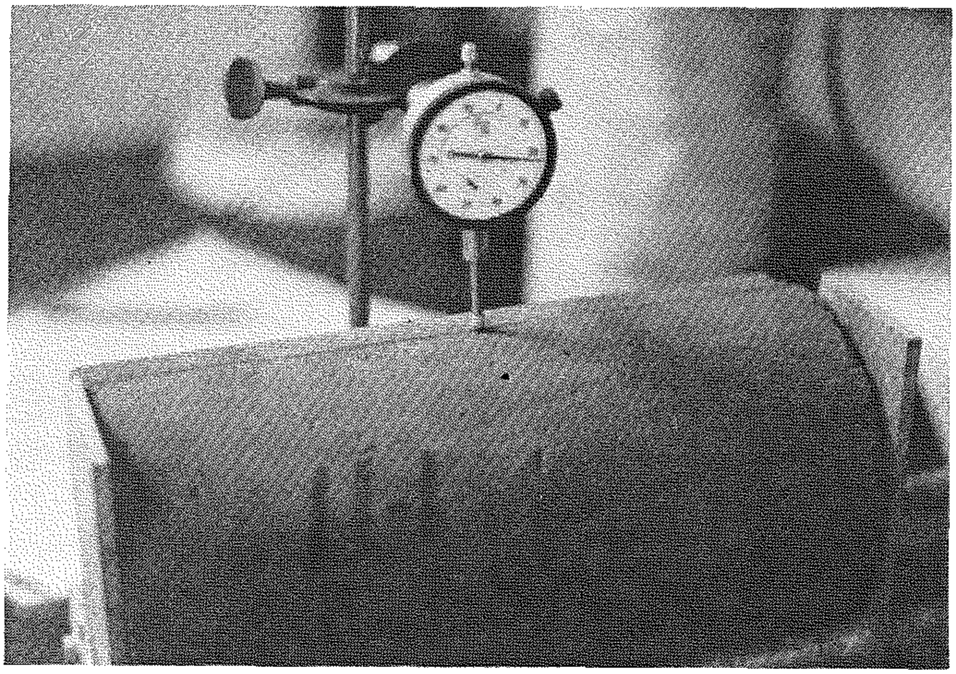


Figure 26. *Laboratory measurement of cylinder expansion.*

measured after nine days for specimens broken at 14 days. There were no measurements obtained at seven days. Results of laboratory observations are contained in Table 15. Laboratory expansions were much greater than field expansions. This fact may be attributable to the curing conditions. After initial readings were obtained, the laboratory specimens remained sealed in plastic bags until the time they were tested for compressive strength and elastic modulus. Expansion of specimens cured 56 days (measured 51 days after initial readings were obtained) in the laboratory was approximately 0.36 percent. This compares to field expansions after 53 days of 0.18 percent. Total laboratory expansion of specimen tested at 112-days age was 0.59 percent.

AFBC Stabilized Pond Ash Subbase Mixture

The AFBC stabilized pond ash subbase mixture also was monitored periodically for length changes. Survey pins were grouted into the hardened base material near the expansion gaps, which were formed in the plastic base material. The survey pins were set and initial base line data were obtained on June 16, 1988. Additional readings were obtained during the remaining month of June and in July. Measurements were made using procedures similar to those used in the AFBC concrete section. Figure 27 gives an

Figure 27. *Expansion of the AFBC stabilized pond ash mixture crushed the orange safety barrels that were placed in the trench.*

TABLE 15. LABORATORY EXPANSION CHARACTERISTICS OF EXPERIMENTAL BASE AND SUBBASE MIXTURES

AFBC Concrete Base Mixture					
Sample Age (days)	7	14	28	56	112
Time from Initial Measurement (days)	No Data	9	23	51	107
No. of Samples Tested for a Given Age	No Data	14	4	4	3
Average Expansion (%)	No Data	0.05	0.08	0.36	0.59
Range of Expansion (%)	No Data	0.02-0.13	0.00-0.17	0.18-0.98	0.00-0.98

AFBC Stabilized Pond Ash Subbase Mixture					
Sample Age (days)	7	14	28	56	112
Time from Initial Measurement (days)	3	10	24	52	108
No. of Samples Tested for a Given Age	14	14	6	4	4
Average Expansion (%)	0.14	0.27	0.43	0.51	0.62
Range of Expansion (%)	(-)0.02-0.43	(-)0.08-0.42	0.23-0.73	0.42-0.62	0.38-0.75

indication of the magnitude of the expansion of the AFBC stabilized pond ash subbase mixture. Differential expansion between the first and second lifts is evident in Figure 28. Results of field expansion measurements for this section are also contained in Table 14. Observations of field expansion were made only over a 34-day period. The field expansion of the AFBC stabilized pond ash subbase amounted to 0.20 percent after the 34-day monitoring period indicating the possibility for much higher expansions than those observed in the AFBC concrete section.

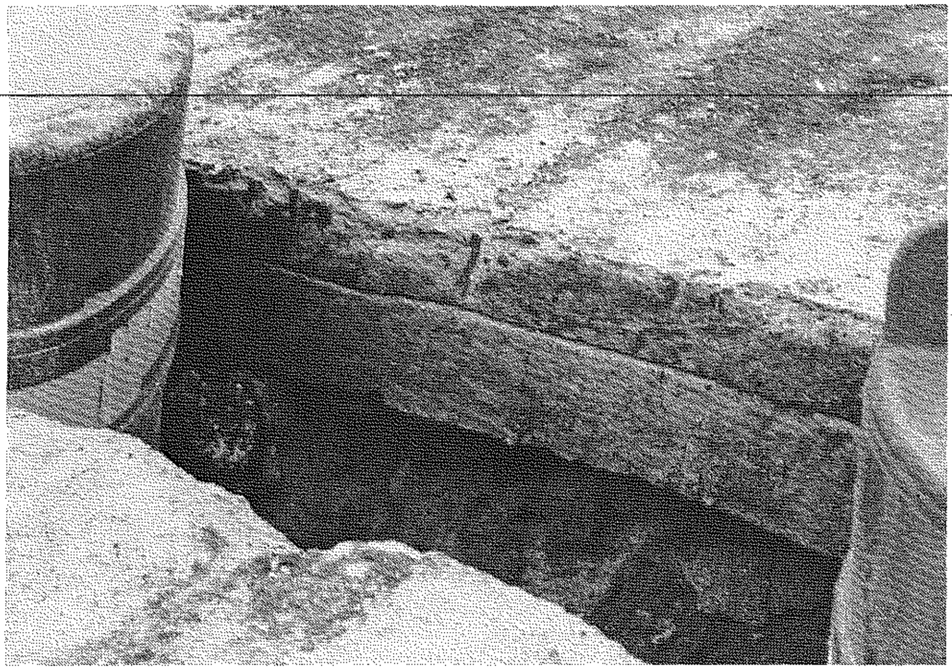


Figure 28. *Differential expansion between the first and second lifts of the AFBC stabilized pond ash mixture was observed in the trenched areas.*

Field compacted samples of the AFBC stabilized pond ash mixture also were measured in the laboratory to determine their expansive characteristics. Initial measurements of the cylinders were obtained on June 13, 1988. Additional measurements were obtained prior to testing the specimens for compressive strength and static chord modulus of elasticity at the cured ages of seven, 14, 28, 56 and 112 days. Therefore, expansion was measured after three days for specimens broken at seven-days age.

Results of laboratory expansion observations are contained in Table 15. Again the laboratory expansions were much greater than observed field expansions. Expansion of laboratory specimens cured 28 days (measured 24 days after initial readings were obtained) in the laboratory was approximately 0.43 percent. This compares to field expansion after 25 days of only 0.18 percent. Total laboratory expansions of specimen tested at 112-days age was similar to the AFBC concrete base material and averaged 0.62 percent.

Road Rater Deflection Measurements and Dynamic Analysis

Structural evaluation of the in-place experimental base and subbase materials 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. Dynamic stiffness may be defined as the dynamic load applied to the pavement divided by the recorded deflection directly beneath the load. It is generally expressed in units of force per unit of displacement (pounds-force per inch). The dynamic stiffness may be utilized as a relative appraisal of the structural condition of the pavement system. Relative comparisons may be made from one location to another or from one point in time to another point in time. Dynamic stiffness is not a measure of the elastic modulus of the pavement structure or the elastic modulus of any given layer, therefore it is not intended to be used as inputs to layer elastic analyses.

Deflection measurements were obtained at various stages of construction. Specifically, deflection measurements were obtained on the compacted subgrade immediately before placement of the experimental materials and at various times after placement of the experimental AFBC concrete base and AFBC stabilized pond ash subbase mixtures. 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.

AFBC Concrete Base Section

Deflection measurements were performed on the compacted subgrade on May 17, 1987 immediately before placement of the AFBC concrete base layer and on the base layer at various ages. Tests were performed on the experimental base layer seven, 14, 21, 28, 42, 56, 66 and 82 days after placement. The dynamic stiffness of the subgrade and experimental AFBC concrete base layer, calculated for each test direction and at each age, is shown in Figure 29. The experimental base layer increased the general dynamic stiffness of the pavement structure nearly 400 percent at seven days to about 789,000 pounds-force per inch. The overall dynamic stiffness of the pavement structure continued to increase through 14 days and had an average dynamic stiffness of 915,000 pounds-force per inch. After that time, results of the deflection analyses indicated variable dynamic behavior with increasing age. These variations were attributed to either temperature changes within the pavement layers or changing moisture conditions within the subgrade. However, after 28 days, results of the deflection testing activity demonstrated a definite decrease in the dynamic stiffness of the pavement structure. After 82 days, the average dynamic stiffness was determined to be about 603,000

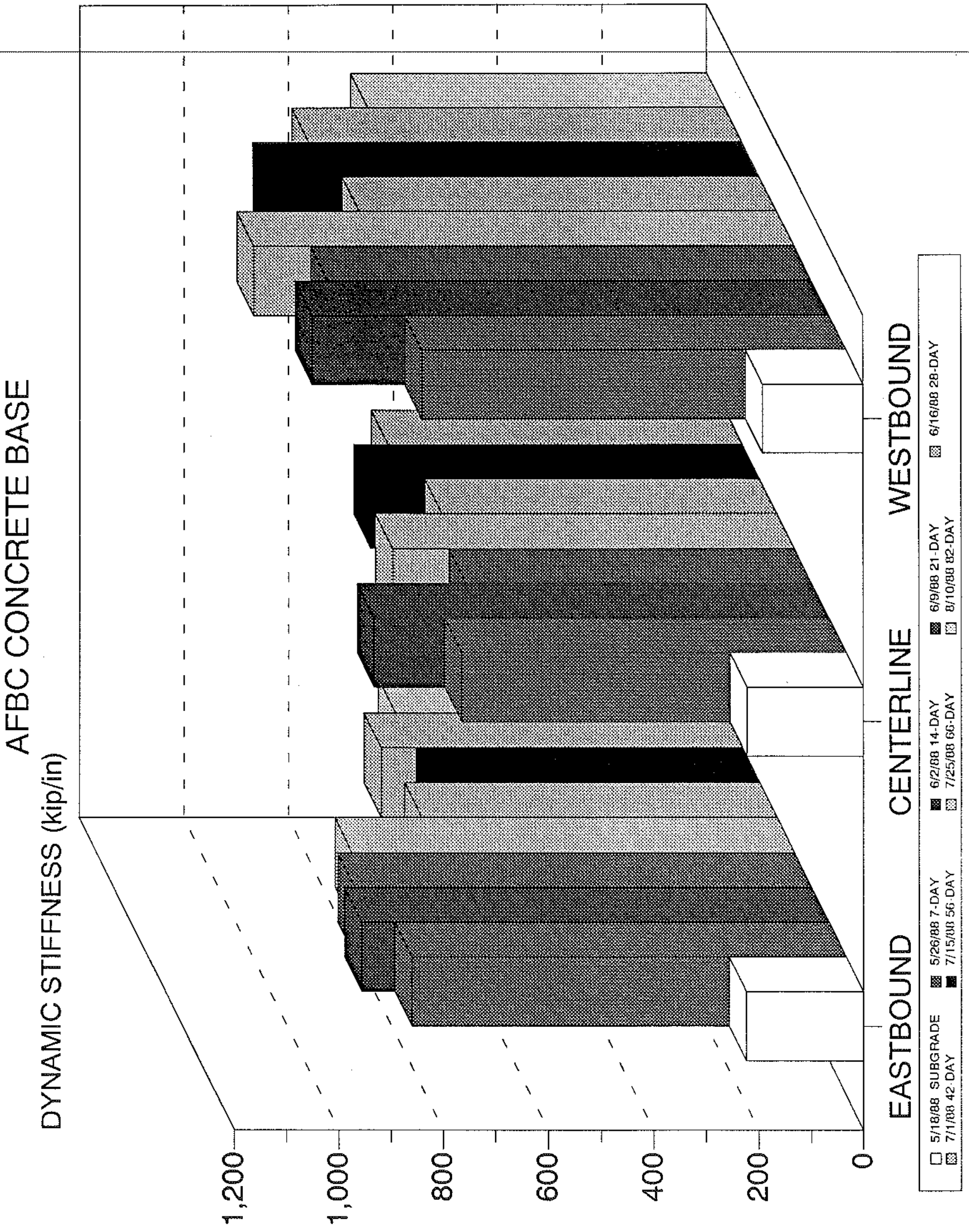


Figure 29. *Dynamic stiffness as a function of age of the AFBC concrete base.*

pounds-force per inch, a decrease of 34 percent from the peak dynamic stiffness at 14 days. It is uncertain as to the cause for decrease in the apparent dynamic stiffness of the pavement structure but it is believed to be due primarily to the expansion and resulting cracking of the experimental base material.

AFBC Stabilized Pond Ash Subbase Section

Tests were conducted at seven, 21, 35, and 45 days after final placement of the AFBC stabilized pond ash subbase mixture. The dynamic stiffnesses calculated for each direction at each age are shown in Figure 30 for the AFBC stabilized pond ash subbase section. The experimental subbase layer substantially increased the dynamic stiffness of the pavement structure. The subgrade stiffness was estimated to be 230,000 pounds-force per inch just prior to the placement of the experimental subbase material. After the subbase layer was allowed to cure for seven days, the pavement structure had a dynamic stiffness of about 730,000 pounds-force per inch. Road Rater deflections at an age of 21 days had increased indicating a structure of decreased stiffness. However, readings obtained 35 and 45 days after placement resulted in calculated averages of the dynamic stiffness of the section to be 708,000 and 749,000 pound-force per inch, respectively. Apparently, the experimental AFBC stabilized pond ash subbase material continued to gain strength during the 45-day time period. However, it must be cautioned that the increased dynamic stiffness could be a result of temperature changes within the pavement layers or changing moisture conditions within the subgrade.

SUMMARY

Design and construction procedures for the use of an AFBC concrete base and AFBC stabilized pond ash subbase have been demonstrated. The AFBC concrete mixture design was based upon compressive strength tests and the optimization of three mix variables: the volume of water needed for prehydrating the AFBC residue; the fly ash to AFBC residue ratio; and, the amount of coarse aggregate. Mixture design for the AFBC concrete mixture included 64 percent No. 57 aggregate, 25 percent AFBC residue, and 11 percent Class F fly ash. Similar analyses were performed to develop the optimum design for the AFBC stabilized pond ash mixture. The mixture chosen for use as the subbase mixture exhibited uniform consistency and compressive strength development during the laboratory evaluations. The AFBC stabilized pond ash mixture consisted of 60 percent ponded bottom ash, 32 percent AFBC residue, and eight percent ponded fly ash.

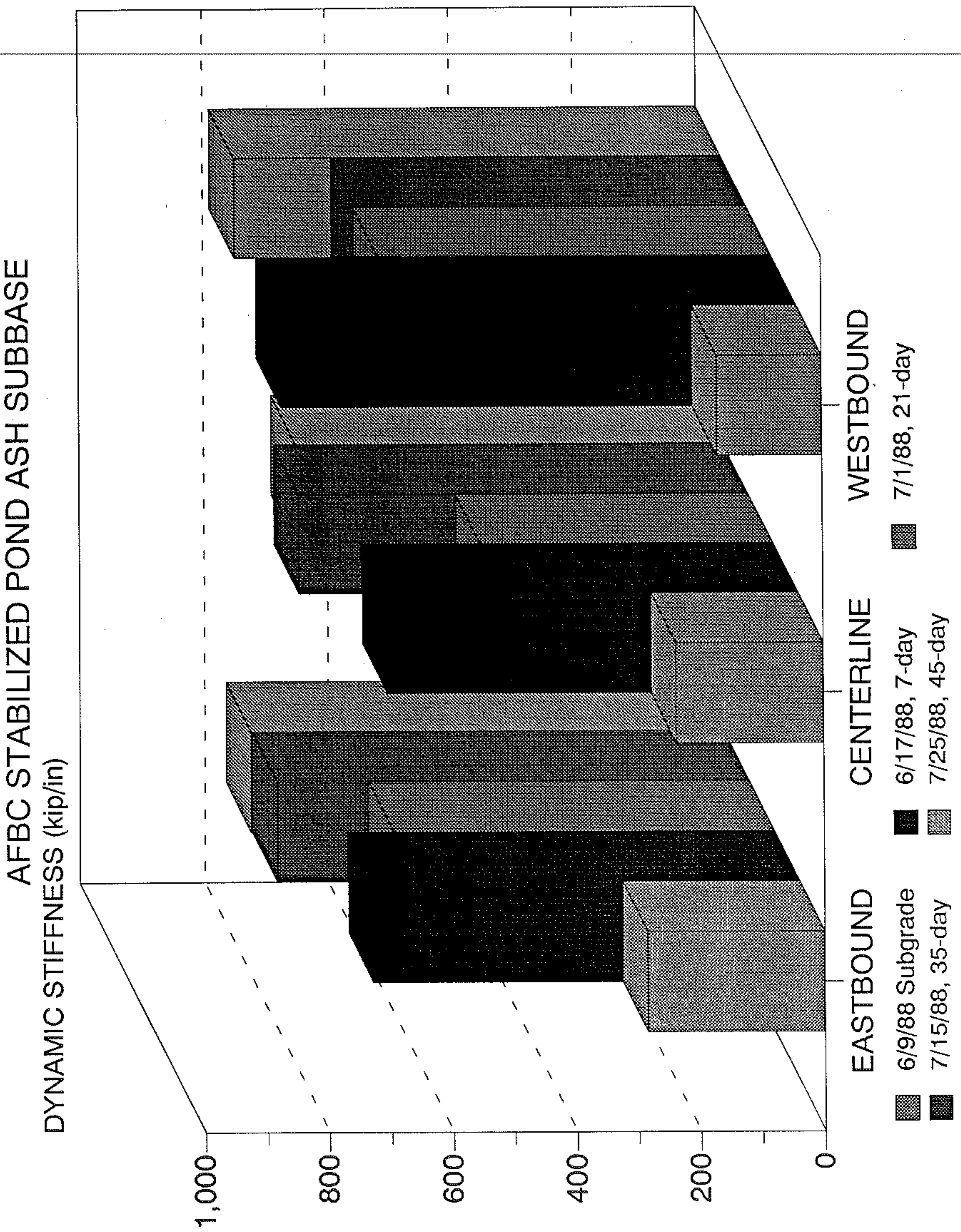


Figure 30. *Dynamic stiffness as a function of age of the AFBC stabilized pond ash subbase.*

Kentucky flexible pavement design procedures were used to determine thickness requirements of the AFBC concrete base and AFBC stabilized pond ash subbase layers. AASHTO structural coefficients of 0.30 and 0.10 were assumed for the AFBC concrete base layer and AFBC stabilized pond ash subbase layer, respectively. The thickness design requirements were 8.0 inches and 12.0 inches for the experimental AFBC concrete layer and AFBC stabilized pond ash layer, respectively.

Difficulties encountered during construction of both experimental sections included homogeneity of the mixtures, consistent moisture in the mixture, and steady production of the mixtures at the concrete batch plant. Segregation was apparent in many of the loads. The lack of uniform moisture from one load to the next caused delays in compaction and cutting the materials to proper grade. Application of the bituminous curing seal occurred prematurely in both sections. Production of the AFBC concrete base was satisfactory. However, production of the AFBC stabilized pond ash mixture was very sporadic. The primary reason for the extended delays was the fact that the concrete batch plant personnel chose not to devote full attention to the production of the subbase materials but continued to batch concrete. This action often resulted in excessive moisture in the subbase mixture. Production times given in Appendix E exemplify this problem. Waste materials utilized constructing the two sections totaled approximately 1,050 tons. Approximately 460 tons of waste AFBC residue and 590 tons of pond ash were utilized constructing the two experimental sections incorporating AFBC residue in the pavement structure.

The initial effectiveness of the AFBC concrete base and AFBC stabilized pond ash subbase appeared favorable. Compressive strength evaluations of field compacted specimens indicated average strengths of 1,465 psi at seven days for the AFBC concrete base mixture. The compressive strength averaged 4,075 psi at 112 days. The 112-day strengths are comparable to a typical five bag per cubic yard concrete mix. Static chord elastic moduli values were lower than typical concrete. The static chord modulus of elasticity averaged 2.20 million psi at seven days increasing to 3.65 million at 112 days. There were no strength data obtained during the laboratory phase of the study from laboratory compacted specimens incorporating the Class F fly ash with which to compare the field data. Compressive strength evaluations of AFBC stabilized pond ash specimens indicated average strengths of 375 psi at seven days and significantly increasing to 2,345 psi at 112 days. These strengths were only slightly greater than compressive strengths obtained for laboratory compacted specimens during the laboratory phase of the study. Static chord modulus of elasticity values of field compacted specimens averaged 0.40 million psi at seven days and increased to 1.55 million psi at 112 days.

The magnitude of the expansion of the experimental mixtures was less in the field than in the laboratory. The field expansion of the AFBC concrete base equaled 0.20 percent after 58 days. Expansion of field compacted AFBC concrete base specimens, cured in the laboratory, averaged 0.36 percent after 51 days and 0.59 percent after 112 days. Field expansion of the AFBC stabilized pond ash subbase also averaged 0.20 percent, but after only 34 days of monitoring. Compacted specimens of the AFBC stabilized pond ash, cured in the laboratory, expanded 0.43 percent after 24 days and averaged 0.62 percent expansion after 108 days.

Deflection measurements were obtained at various stages of construction using the model 400 Road Rater. Deflection measurements were obtained on the compacted subgrade immediately before placement of the experimental materials and at various times after placement of the experimental AFBC concrete base and AFBC stabilized pond ash subbase mixtures. Analysis of the deflection measurements generally indicated a significant increase in the overall stiffness of the pavement structure due to the addition of the experimental layers. Analysis of deflection tests conducted over an 82-day period on the experimental AFBC concrete base layer indicated the dynamic stiffness of the experimental layer appeared to peak after 14 days. There were some variations in the deflections after 14 days but the overall trend of the dynamic stiffness was to decrease. The variations were attributed to either temperature changes within the pavement layers or changing moisture conditions within the subgrade. After 82 days, the average dynamic stiffness of the pavement structure had decreased 34 percent below the peak dynamic stiffness at 14 days. The results of compressive strength and static chord modulus of elasticity tests of field compacted specimens did not show a substantial decrease in strength. In fact, the AFBC concrete base mixture continued to gain strength throughout the 112-day laboratory evaluation period.

Deflection tests were performed up through 45 days after final placement of the AFBC stabilized pond ash subbase mixture. Again, the experimental subbase layer substantially increased the dynamic stiffness of the pavement structure. The subgrade stiffness was estimated to be 230,000 pounds-force per inch just prior to the placement of the experimental subbase material. The subbase layer was tested after a seven-day curing period. The pavement structure had a dynamic stiffness of about 730,000 pounds-force per inch at that time. Deflections after 21 days were higher than the seven-day deflections, indicating a less rigid structure. However, deflection readings taken 35 and 45 days after placement indicated increasing dynamic stiffnesses. This indicates that the experimental AFBC stabilized pond ash subbase material continued to gain strength during the 45-day evaluation period. Laboratory strength tests also indicated continued strength gain throughout the 112-day laboratory evaluation period. Still, it must be cautioned that the apparent increase in the overall dynamic stiffness of the pavement structure could be as much the result of temperature changes within the pavement layers, or changing moisture conditions within the subgrade as it could be an actual strengthening over time of the experimental layer.

CONCLUSIONS

This was the first full-scale project in Kentucky wherein AFBC residue and a ponded bottom fly ash, both waste materials, were utilized to construct stabilized road base and subbase layers. The following conclusions are based upon the short-term observations.

1. Previous reported research concluded that prehydrated AFBC residue, pulverized coal fly ash, and aggregate could be used to construct a stabilized base course, provided the AFBC residue is properly prehydrated prior to its use. The AFBC residue used in this study was effectively prehydrated during the initial laboratory phase of the study. Mixtures incorporating the AFBC residue that was prehydrated in the laboratory did not exhibit any expansive characteristics during the laboratory evaluations. However, that success could not be reproduced during the field trial. Specimens made in the laboratory prior to the construction of experimental base and subbase layers, using AFBC residue which was prehydrated at the batch plant several months before construction commenced, exhibited expansive characteristics when combined with aggregate, fly ash, and water. Apparently, either the AFBC residue was not properly prehydrated at the batch plant or the extended storage period significantly affected the properties of the residue. According to Minnick, "the longer the storage period, the more detrimental effect carbonation is expected to have on the quality of the residue," [2]. Air from the atmosphere reacts with the hydroxides, converting them to carbonates.

2. Although tests performed on the AFBC residue that was prehydrated at the batch plant several months prior to commencement of construction activities indicated a hydration reaction (temperature rise caused by the addition of water), construction of the experimental sections proceeded as planned. Accommodation of anticipated material expansion was attempted by forming gaps in the plastic materials. Construction of the experimental base and subbase layers was generally

acceptable when materials were available. Materials with the proper moisture content were placed and compacted with no difficulties. The only readily apparent construction difficulty was cutting the materials to grade and the anxiousness displayed by the construction contractor to place the SAMI and bituminous curing seal. Production of the experimental mixtures was hampered because concrete batching operations were alternated with production of the experimental mixtures. Production of the mixture could have been accomplished much better by utilizing a pugmill set up near the jobsite. This is true also of the AFBC prehydration process. It would have been far better to prehydrate the AFBC residue one or two days prior to mixing it with the other materials in the experimental mixtures.

3. Field preparation of specimens for compressive strength and elastic modulus determinations using modified procedures was moderately successful. Successful compaction of the AFBC concrete base mixture in the 6-inch by 12-inch molds was satisfactorily achieved. However, that was not the case with the AFBC stabilized pond ash mixture.

4. It appears that both of the mixtures incorporating the AFBC residue possess the capacity for further expansion in the field trial based upon the expansion of field compacted specimens realized in the laboratory.

5. It is uncertain as to the cause for the decrease in the apparent dynamic stiffness of the pavement structure of the AFBC concrete base section but is believed to be the result of the continued expansion and substantial cracking of the experimental base material. Because the AFBC stabilized pond ash subbase contains 32 percent AFBC residue, comparable actions (a decrease in dynamic stiffness) from that section may also be expected over time.

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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, DGA, 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
8-inch Pozzolonic Base	Square Yard
12-inch Lime Fly Ash-Stabilized Bottom Ash Base	Square Yard
8-inch AFBC Base	Square Yard
Bituminous Curing Seal	Ton

April 21, 1987

APPENDIX B

Moisture-Density Relationships
and
Unconfined Compressive Strength Development
of
AFBC Concrete Base Mixture

Moisture-Density Relationships

MIX No. 1

Mixture Proportions, (%):

Ponded Fly Ash:	09
AFBC Residue:	35
No. 57 Limestone Aggregate:	56

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial 1	7.4	134.8
Trial 2	8.8	133.0
Trial 3	9.4	127.6
AVERAGE	8.5	131.8

MIX No. 1(a)

Mixture Proportions, (%):

Class F Fly Ash:	11
AFBC Residue:	25
No. 57 Limestone Aggregate:	64

	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial 1	8.4	128.4
Trial 2	9.1	130.1
Trial 3	8.9	130.2
AVERAGE	8.8	129.6

Unconfined Compressive Strength

MIX No. 1

Mixture Proportions, (%):

Ponded Fly Ash:	09
AFBC Residue:	35
Ponded Bottom Ash:	56

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{1-4}	4	100
B_{1-4}	4	205
C_{1-4}	4	180
AVERAGE		160
A_{1-7}	7	*
B_{1-7}	7	270
C_{1-7}	7	250
AVERAGE		260

Curing Conditions:

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

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{1-14}	14	555
B_{1-14}	14	545
C_{1-14}	14	745
AVERAGE		615
A_{1-28}	28	1,060
B_{1-28}	28	985
C_{1-28}	28	990
AVERAGE		1,010

NOTE: * indicates value was indeterminable.

APPENDIX C

Moisture-Density Relationships
and
Unconfined Compressive Strength Development
of
AFBC Stabilized Pond Ash Subbase Mixture

Moisture-Density Relationships

MIX No. 2

Mixture Proportions, (%):

Ponded Fly Ash: 06
AFBC Residue: 14
Ponded Bottom Ash: 80

MIX No. 3

Mixture Proportions, (%):

Ponded Fly Ash: 08
AFBC Residue: 08
Ponded Bottom Ash: 84

MIX No. 4

Mixture Proportions, (%):

Ponded Fly Ash: 06
AFBC Residue: 18
Ponded Bottom Ash: 76

	MIX No. 2		MIX No. 3		MIX No. 4	
	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial 1	16.3	100.3	16.5	112.9	15.6	108.5
Trial 2	15.6	99.7	14.3	100.9	13.3	107.1
AVERAGE	16.0	100.0	15.4	106.9	14.5	107.8

Moisture-Density Relationships

MIX No. 5

Mixture Proportions, (%):

Ponded Fly Ash: 05
AFBC Residue: 05
Ponded Bottom Ash: 90

MIX No. 6

Mixture Proportions, (%):

Ponded Fly Ash: 08
AFBC Residue: 32
Ponded Bottom Ash: 60

MIX No. 7

Mixture Proportions, (%):

Ponded Fly Ash: 09
AFBC Residue: 45
Ponded Bottom Ash: 46

	MIX No. 5		MIX No. 6		MIX No. 7	
	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	Maximum Dry Density (pcf)
Trial 1	13.4	106.9	16.0	101.2	16.7	100.1
Trial 2	--	--	16.2	102.4	17.7	100.2
AVERAGE	13.4	106.9	16.1	101.8	17.2	100.2

Unconfined Compressive Strength

MIX No. 2

Mixture Proportions, (%):

Ponded Fly Ash:	06
AFBC Residue:	14
Ponded Bottom Ash:	80

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Samples not soaked prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{2-4}	4	80
B_{2-4}	4	*
C_{2-4}	4	*
AVERAGE		80
A_{2-7}	7	310
B_{2-7}	7	270
C_{2-7}	7	290
AVERAGE		290

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{2-14}	14	330
B_{2-14}	14	445
C_{2-14}	14	355
AVERAGE		375
A_{2-28}	28	545
B_{2-28}	28	565
C_{2-28}	28	585
AVERAGE		565

NOTE: * indicates value was indeterminable.

Unconfined Compressive Strength

MIX No. 3

Mixture Proportions, (%):

Ponded Fly Ash:	08
AFBC Residue:	08
Ponded Bottom Ash:	84

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{3-4}	4	325
B_{3-4}	4	340
C_{3-4}	4	320
AVERAGE		330
A_{3-7}	7	485
B_{3-7}	7	525
C_{3-7}	7	515
AVERAGE		510

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Samples not soaked prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{3-14}	14	515
B_{3-14}	14	510
C_{3-14}	14	445
AVERAGE		490
A_{3-28}	28	285
B_{3-28}	28	270
C_{3-28}	28	530
AVERAGE		360

Unconfined Compressive Strength

MIX No. 4

Mixture Proportions, (%):

Ponded Fly Ash:	06
AFBC Residue:	18
Ponded Bottom Ash:	76

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{4-4}	4	345
B_{4-4}	4	*
C_{4-4}	4	335
AVERAGE		340
A_{4-7}	7	390
B_{4-7}	7	290
C_{4-7}	7	250
AVERAGE		310

NOTE: * indicates value was indeterminable.

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Samples not soaked prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{4-14}	14	695
B_{4-14}	14	445
C_{4-14}	14	650
AVERAGE		595
A_{4-28}	28	1,595
B_{4-28}	28	1,225
C_{4-28}	28	1,180
AVERAGE		1,335

Unconfined Compressive Strength

MIX No. 5

Mixture Proportions, (%):

Ponded Fly Ash:	05
AFBC Residue:	05
Ponded Bottom Ash:	90

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Four-day and 28-day samples soaked 4-hours prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{5-4}	4	230
B_{5-4}	4	415
C_{5-4}	4	285
AVERAGE		310^{*}
A_{5-7}	7	295
B_{5-7}	7	340
C_{5-7}	7	315
AVERAGE		315

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{5-14}	14	395
B_{5-14}	14	330
C_{5-14}	14	350
AVERAGE		360
A_{5-28}	28	120
B_{5-28}	28	120
C_{5-28}	28	150
AVERAGE		$130^{\wedge}$

NOTE: * samples absorbed 4.4% water, average by weight, during 4-hour soak.
^ samples absorbed 7.3% water, average by weight, during 4-hour soak.

Unconfined Compressive Strength

MIX No. 6

Mixture Proportions, (%):

Ponded Fly Ash:	08
AFBC Residue:	32
Ponded Bottom Ash:	60

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Four-day and 14-day samples soaked 4-hours prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{6-4}	4	70
B_{6-4}	4	75
C_{6-4}	4	85
AVERAGE		75*
A_{6-7}	7	385
B_{6-7}	7	380
C_{6-7}	7	540
AVERAGE		435

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{6-14}	14	670
B_{6-14}	14	580
C_{6-14}	14	505
AVERAGE		585^
A_{6-28}	28	890
B_{6-28}	28	1,080
C_{6-28}	28	910
AVERAGE		960

NOTE: * samples absorbed 5.7% water, average by weight, during 4-hour soak.
^ samples absorbed 5.1% water, average by weight, during 4-hour soak.

Unconfined Compressive Strength

MIX No. 7

Mixture Proportions, (%):

Ponded Fly Ash:	09
AFBC Residue:	45
Ponded Bottom Ash:	46

Curing Conditions:

All samples sealed in gallon paint cans and cured in 100°F oven. Four-day, seven-day and 28-day samples soaked 4-hours prior to destructive testing.

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{7-4}	4	210
B_{7-4}	4	255
C_{7-4}	4	280
AVERAGE		250*
A_{7-7}	7	335
B_{7-7}	7	340
C_{7-7}	7	380
AVERAGE		350#

Sample Number	Age at Test (days)	Maximum Compressive Strength (psi)
A_{7-14}	14	530
B_{7-14}	14	675
C_{7-14}	14	540
AVERAGE		580
A_{7-28}	28	855
B_{7-28}	28	920
C_{7-28}	28	935
AVERAGE		905^

NOTE: * samples absorbed 4.4% water, average by weight, during 4-hour soak.
samples absorbed 4.0% water, average by weight, during 4-hour soak.
^ samples absorbed 3.1% water, average by weight, during 4-hour soak.

APPENDIX D

Production Times
and
Material Quantities

AFBC Concrete Base

DATE: <u>May 18, 1988</u>

Batch Number	Elapsed Time of Batching (min.)	Interval between Batches (min.)	Weight of No. 57 Aggregate (lb.)	Weight of AFBC Residue (lb.)	Weight of Class F Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent No. 57 Aggregate (%)	Percent AFBC Residue (%)	Percent Class F Fly Ash (%)
1	4	31	18,360	9,100	3,141	30,601	197	60.0	29.7	10.3
2	2	55	11,520	5,520	1,953	18,993	177	60.7	29.1	10.3
3	3	9	11,360	4,540	1,953	17,853	175	63.6	25.4	10.9
4	3	39	13,860	5,240	2,343	21,443	228	64.6	24.4	10.9
5	3	10	18,380	7,160	3,147	28,687	305	64.1	25.0	11.0
6	3	9	18,200	7,340	3,135	28,675	304	63.5	25.6	10.9
7	2	6	9,260	3,460	1,560	14,280	167	64.8	24.2	10.9
8	1	20	9,060	3,680	1,560	14,300	152	63.4	25.7	10.9
9	3	7	18,540	7,020	3,126	28,686	306	64.6	24.5	10.9
10	2	23	18,300	7,160	3,144	28,604	304	64.0	25.0	11.0
11	5	7	18,340	7,140	3,126	28,606	306	64.1	25.0	10.9
12	7	5	18,520	6,980	3,147	28,647	304	64.6	24.4	11.0
13	6	20	18,340	7,140	3,126	28,606	304	64.1	25.0	10.9
14	3	5	18,360	7,220	3,123	28,703	304	64.0	25.2	10.9
15	6	5	18,500	7,000	3,126	28,626	304	64.6	24.5	10.9
16	6	8	18,360	7,120	3,135	28,615	306	64.2	24.9	11.0
17	2	23	18,620	6,940	3,129	28,689	305	64.9	24.2	10.9

DATE: May 18, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of No. 57 Aggregate (lb.)	Weight of AFBC Residue (lb.)	Weight of Class F Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent No. 57 Aggregate (%)	Percent AFBC Residue (%)	Percent Class F Fly Ash (%)
18	4	5	18,220	7,260	3,129	28,609	305	63.7	25.4	10.9
19	8	7	18,360	7,100	3,135	28,595	306	64.2	24.8	11.0
20	3	6	18,340	7,160	3,141	28,641	307	64.0	25.0	11.0
21	3	8	18,400	7,100	3,126	28,626	306	64.3	24.8	10.9
22	6	15	18,580	6,920	3,147	28,647	305	64.9	24.2	11.0
23	3	7	18,200	7,280	3,162	28,642	304	63.5	25.4	11.0
24	4	6	18,160	7,340	3,129	28,629	305	63.4	25.6	10.9
25	4	6	18,340	7,220	3,123	28,683	304	63.9	25.2	10.9
26	2	20	18,320	7,160	3,123	28,603	304	64.0	25.0	10.9
27	3	5	18,380	7,120	3,147	28,647	306	64.2	24.9	11.0
28	3	5	18,480	6,980	3,129	28,589	304	64.6	24.4	10.9
29	4	6	18,300	7,160	3,126	28,586	304	64.0	25.0	10.9
30	3	-	18,300	7,200	3,123	28,623	304	63.9	25.2	10.9
AVERAGE	4	13	17,142	6,759	2,924	26,824	280	63.9	25.2	10.9
STD. DEV.	2	12	2,835	1,130	485	4,390	50	1.0	1.2	0.2
PRODUCTION FOR DAY (lbs.)			514,260	202,760	87,714	804,734	70,198			

DATE: May 19, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of No. 57 Aggregate (lb.)	Weight of AFBC Residue (lb.)	Weight of Class F Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent No. 57 Aggregate (%)	Percent AFBC Residue (%)	Percent Class F Fly Ash (%)
1	0	51	18,300	7,240	3,123	28,663	306	63.8	25.3	10.9
2	3	8	18,360	7,240	3,162	28,762	306	63.8	25.2	11.0
3	5	4	18,240	7,160	3,135	28,535	304	63.9	25.1	11.0
4	3	29	18,360	7,360	3,138	28,858	305	63.6	25.5	10.9
5	3	7	18,320	7,220	3,123	28,663	304	63.9	25.2	10.9
6	4	8	18,300	7,180	3,147	28,627	304	63.9	25.1	11.0
7	2	7	18,320	7,260	3,138	28,718	297	63.8	25.3	10.9
8	4	19	18,320	7,220	3,162	28,702	296	63.8	25.2	11.0
9	3	5	18,320	7,160	3,144	28,624	296	64.0	25.0	11.0
10	2	79	18,320	7,020	3,141	28,481	298	64.3	24.6	11.0
11	22	71	18,360	7,100	3,123	28,583	297	64.2	24.8	10.9
12	2	6	18,360	7,260	3,138	28,758	296	63.8	25.2	10.9
13	4	6	18,340	7,240	3,129	28,709	288	63.9	25.2	10.9

DATE: May 19, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of No. 57 Aggregate (lb.)	Weight of AFBC Residue (lb.)	Weight of Class F Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent No. 57 Aggregate (%)	Percent AFBC Residue (%)	Percent Class F Fly Ash (%)
14	5	6	18,320	7,160	3,144	28,624	288	64.0	25.0	11.0
15	6	10	18,320	9,580	3,141	31,041	288	59.0	30.9	10.1
16	11	6	18,300	7,160	3,144	28,604	288	64.0	25.0	11.0
17	8	8	18,320	7,120	3,132	28,572	288	64.1	24.9	11.0
18	3	7	18,360	6,920	3,135	28,415	288	64.6	24.4	11.0
19	4	25	18,300	7,200	3,132	28,632	288	63.9	25.1	10.9
20	2	6	18,340	7,240	3,159	28,739	288	63.8	25.2	11.0
21	4	0	18,220	7,260	3,144	28,624	288	63.7	25.4	11.0
22	27	-	18,320	7,160	1,701	27,181	163	67.4	26.3	6.3
AVERAGE	4	18	18,319	7,294	3,074	28,687	289	63.9	25.4	10.7
STD. DEV.	2	22	35	507	300	605	28	1.3	1.2	1.0
PRODUCTION FOR DAY (lbs.)			403,020	160,460	67,635	631,115	53,108			

APPENDIX E

Production Times
and
Material Quantities

AFBC Stabilized Pond Ash Subbase

DATE: June 9, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
1	9	12	8,900	4,470	540	13,910	121	64.0	32.1	3.9
2	2	7	8,340	4,476	1,260	14,076	220	59.2	31.8	9.0
3	7	3	8,360	4,458	1,180	13,998	212	59.7	31.8	8.4
4	2	23	8,320	4,476	1,260	14,056	212	59.2	31.8	9.0
5	2	3	8,320	4,440	1,240	14,000	212	59.4	31.7	8.9
6	2	5	8,360	4,464	1,180	14,004	214	59.7	31.9	8.4
7	3	3	8,320	4,455	1,500	14,275	213	58.3	31.2	10.5
8	6	8	8,360	4,473	1,100	13,933	212	60.0	32.1	7.9
9	2	4	8,540	4,449	960	13,949	202	61.2	31.9	6.9
10	1	4	8,600	4,452	860	13,912	201	61.8	32.0	6.2
11	2	1	8,760	4,467	680	13,907	180	63.0	32.1	4.9
12	3	9	8,340	4,452	1,140	13,932	180	59.9	32.0	8.2
13	2	2	8,360	4,458	1,320	14,138	180	59.1	31.5	9.3
14	3	4	8,320	4,464	1,160	13,944	180	59.7	32.0	8.3
15	2	2	8,320	4,446	1,500	14,266	180	58.3	31.2	10.5

DATE: June 9, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
16	3	10	8,440	4,443	1,240	14,123	180	59.8	31.5	8.8
17	5	1	8,360	4,464	1,280	14,104	180	59.3	31.7	9.1
18	5	3	8,340	4,476	1,260	14,076	180	59.2	31.8	9.0
19	5	1	8,320	4,455	1,140	13,915	180	59.8	32.0	8.2
20	3	2	8,320	4,467	1,340	14,127	180	58.9	31.6	9.5
21	9	12	8,400	4,458	1,100	13,958	180	60.2	31.9	7.9
22	14	18	8,440	4,479	1,000	13,919	180	60.6	32.2	7.2
23	3	5	8,480	4,464	980	13,924	182	60.9	32.1	7.0
24	2	4	8,940	4,449	500	13,889	182	64.4	32.0	3.6
25	7	3	8,660	4,488	780	13,928	181	62.2	32.2	5.6
26	7	10	8,600	4,488	1,060	14,148	182	60.8	31.7	7.5
27	2	3	8,500	4,482	940	13,922	180	61.1	32.2	6.8
28	7	6	8,320	4,491	1,440	14,251	181	58.4	31.5	10.1
29	12	5	8,840	4,470	600	13,910	180	63.6	32.1	4.3
30	12	48	8,320	4,482	1,140	13,942	182	59.7	32.1	8.2

DATE: June 9, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
31	10	3	8,440	4,485	1,000	13,925	181	60.6	32.2	7.2
32	8	4	8,360	4,482	1,360	14,202	180	58.9	31.6	9.6
33	7	3	8,440	4,491	1,020	13,951	180	60.5	32.2	7.3
34	8	4	8,360	4,488	1,540	14,388	180	58.1	31.2	10.7
35	7	3	8,400	4,488	1,040	13,928	180	60.3	32.2	7.5
36	9	4	8,600	4,488	1,400	14,488	180	59.4	31.0	9.7
37	7	3	9,740	4,488	0	14,228	180	68.5	31.5	0.0
38	8	5	8,320	4,482	1,120	13,922	180	59.8	32.2	8.0
39	7	3	8,560	4,491	980	14,031	180	61.0	32.0	7.0
40	11	3	8,480	4,482	980	13,942	180	60.8	32.1	7.0
41	8	-	8,340	4,467	1,120	13,927	180	59.9	32.1	8.0
AVERAGE	6	6	8,484	4,470	1,079	14,033	186	60.5	31.9	7.7
STD. DEV.	3	8	258	15	298	145	16	1.9	0.3	2.1
PRODUCTION FOR DAY (lbs.)			347,840	183,288	44,240	575,368	63,639			

DATE: June 10, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
1	3	1	8,340	4,476	1,100	13,916	181	59.9	32.2	7.9
2	2	40	8,400	4,467	1,060	13,927	180	60.3	32.1	7.6
3	3	3	8,320	4,479	1,120	13,919	181	59.8	32.2	8.0
4	2	68	8,360	4,458	1,080	13,898	180	60.2	32.1	7.8
5	2	3	8,340	4,464	1,120	13,924	182	59.9	32.1	8.0
6	4	4	8,320	4,446	1,240	14,006	181	59.4	31.7	8.9
7	12	3	8,360	4,452	1,100	13,912	180	60.1	32.0	7.9
8	2	3	8,340	4,455	1,320	14,115	182	59.1	31.6	9.4
9	5	0	8,480	4,446	1,080	14,006	180	60.5	31.7	7.7
10	2	7	8,360	4,440	1,160	13,960	180	59.9	31.8	8.3
11	4	4	8,440	4,458	1,000	13,898	180	60.7	32.1	7.2
12	3	4	8,560	4,461	940	13,961	180	61.3	32.0	6.7

DATE: June 10, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
13	3	0	8,340	4,452	1,120	13,912	180	59.9	32.0	8.1
14	6	18	8,400	4,470	1,200	14,070	180	59.7	31.8	8.5
15	5	0	8,340	4,479	1,120	13,939	180	59.8	32.1	18.0
16	13	8	8,420	4,488	1,020	13,928	180	60.5	32.2	7.3
17	32	5	8,480	4,473	960	13,913	180	61.0	32.1	6.9
18	8	26	8,440	4,488	1,000	13,928	180	60.6	32.2	7.2
19	6	4	8,580	4,488	860	13,928	182	61.6	32.2	6.2
20	4	11	8,600	4,485	860	13,945	181	61.7	32.2	6.2
21	2	1	8,320	4,479	1,120	13,919	180	59.8	32.2	8.0
22	8	6	8,360	4,488	1,140	13,988	182	59.8	32.1	8.1
23	8	65	8,480	4,500	1,000	13,980	180	60.7	32.2	7.2
24	18	3	8,600	4,500	1,300	14,400	181	59.7	31.3	9.0

DATE: June 10, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
25	13	3	8,420	4,512	1,320	14,252	182	59.1	31.7	9.3
26	9	2	8,640	4,443	820	13,903	180	62.1	32.0	5.9
27	8	8	8,580	4,488	940	14,008	180	61.3	32.0	6.7
28	3	4	8,320	4,476	1,340	14,136	180	58.9	31.7	9.5
29	6	10	8,440	4,464	1,000	13,904	181	60.7	32.1	7.2
30	2	3	8,480	4,479	1,100	14,059	180	60.3	31.9	7.8
31	4	3	8,520	4,500	960	13,980	182	60.9	32.2	6.9
32	3	3	8,380	4,449	1,180	14,009	181	59.8	31.8	8.4
33	5	2	8,420	4,455	1,180	14,055	181	59.9	31.7	8.4
34	6	2	8,340	4,515	1,160	14,015	181	59.5	32.2	8.3
35	5	-	8,580	4,560	1,000	14,140	180	60.7	32.2	7.1
AVERAGE	6	10	8,431	4,475	1,086	13,993	181	60.3	32.0	7.8
STD. DEV.	6	16	96	24	129	108	1	0.8	0.2	0.9
PRODUCTION FOR DAY (lbs.)			295,100	156,633	38,020	489,753	52,865			

DATE: June 11, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
1	17	3	8,400	4,497	1,200	14,097	181	59.6	31.9	8.5
2	2	3	8,560	4,476	900	13,936	182	61.4	32.1	6.5
3	2	2	8,420	4,467	1,040	13,927	180	60.5	32.1	7.5
4	2	12	8,360	4,473	1,120	13,953	180	59.9	32.1	8.0
5	5	3	8,340	4,443	1,260	14,043	180	59.4	31.6	9.0
6	4	4	8,320	4,461	1,200	13,981	180	59.5	31.9	8.6
7	2	1	8,340	4,458	1,260	14,058	180	59.3	31.7	9.0
8	3	13	8,940	4,452	620	14,012	180	63.8	31.8	4.4
9	2	3	8,320	4,455	1,260	14,035	180	59.3	31.7	9.0
10	2	54	8,340	4,470	1,100	13,910	182	60.0	32.1	7.9
11	2	1	8,340	4,479	1,100	13,919	181	59.9	32.2	7.9
12	2	2	8,320	4,476	1,240	14,036	180	59.3	31.9	8.8
13	3	1	8,460	4,443	1,040	13,943	180	60.7	31.9	7.5
14	2	12	8,460	4,461	1,080	14,001	182	60.4	31.9	7.7
15	2	4	8,460	4,491	1,060	14,011	180	60.6	32.1	7.6
16	2	2	8,380	4,443	1,160	13,983	180	59.9	31.8	8.3
17	2	2	8,320	4,446	1,240	14,006	183	59.4	31.7	8.9

DATE: June 11, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
18	3	1	8,400	4,461	1,060	13,921	181	60.3	32.0	7.6
19	2	1	8,440	4,440	1,100	13,980	183	60.4	31.8	7.9
20	2	10	8,400	4,446	1,140	13,986	180	60.1	31.8	8.2
21	2	3	8,420	4,458	1,140	14,018	180	60.1	31.8	8.1
22	2	3	8,400	4,455	1,160	14,015	174	59.9	31.8	8.3
23	1	4	8,400	4,461	1,100	13,961	180	60.2	32.0	7.9
24	1	4	8,340	4,443	1,140	13,923	180	59.9	31.9	8.2
25	2	4	8,580	4,476	900	13,956	180	61.5	32.1	6.4
26	2	24	8,440	4,482	1,100	14,022	180	60.2	32.0	7.8
27	2	1	8,320	4,446	1,180	13,946	182	59.7	31.9	8.5
28	3	2	8,540	4,473	1,000	14,013	181	60.9	31.9	7.1
29	2	1	8,520	4,461	940	13,921	182	61.2	32.0	6.8
30	1	2	8,360	4,458	1,160	13,978	181	59.8	31.9	8.3
31	2	1	8,480	4,449	1,060	13,989	183	60.6	31.8	7.6
32	2	14	8,420	4,458	1,080	13,958	180	60.3	31.9	7.7
33	1	1	8,440	4,452	1,040	13,932	181	60.6	32.0	7.5
34	2	2	8,400	4,440	1,200	14,040	180	59.8	31.6	8.3

DATE: June 11, 1988

Batch Number	Elasped Time of Batching (min.)	Interval between Batches (min.)	Weight of Ponded Bottom Ash (lb.)	Weight of AFBC Residue (lb.)	Weight of Ponded Fly Ash (lb.)	Total Weight of Dry Materials (lb.)	Amount of Water Added (gal.)	Percent Bottom Ash (%)	Percent AFBC Residue (%)	Percent Ponded Fly Ash (%)
35	4	0	8,380	4,449	1,140	13,969	180	60.0	31.8	8.2
36	3	1	8,320	4,449	1,240	14,009	180	59.4	31.8	8.9
37	2	2	8,480	4,458	1,060	13,998	180	60.6	31.8	7.6
38	6	13	8,480	4,482	1,100	14,062	180	60.3	31.9	7.8
39	3	5	8,380	4,470	1,220	14,070	180	59.6	31.8	8.7
40	8	5	8,400	4,497	1,160	14,057	180	59.8	32.0	8.3
41	2	1	8,380	4,485	1,180	14,045	180	59.7	31.9	8.4
42	4	3	8,320	4,467	1,220	14,007	180	59.4	31.9	8.7
43	6	2	8,440	4,494	1,040	13,974	182	60.4	32.2	7.4
44	6	6	8,460	4,470	1,120	14,050	182	60.2	31.8	8.0
45	4	1	8,440	4,485	1,100	14,025	180	60.2	32.0	7.8
46	5	31	8,360	4,515	1,100	13,975	180	59.8	32.3	7.9
47	12	4	8,460	4,497	1,020	13,977	183	60.5	32.2	7.3
48	7	-	8,420	4,473	1,140	14,033	180	60.0	31.9	8.1
AVERAGE	3	6	8,419	4,465	1,109	13,993	181	60.2	31.9	7.9
STD. DEV.	3	9	100	18	112	46	1	0.7	0.2	0.8
PRODUCTION FOR DAY (lbs.)			404,100	214,341	53,220	671,661	72,318			