
Research Report
KTC 93-18

UTILIZATION OF FOSSIL-FUEL
RELATED BY-PRODUCT MATERIALS
FOR HIGHWAY CONSTRUCTION
IN KENTUCKY

by

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in cooperation with
Kentucky Transportation Cabinet

and

Federal Highway Administration
US Department of Transportation

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June 1993



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TRANSPORTATION CABINET
FRANKFORT, KENTUCKY 40622

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November 15, 1993

Mr. Paul E. Toussaint
Division Administrator
Federal Highway Administration
330 West Broadway
Frankfort, Kentucky 40602-0536

SUBJECT: Implementation Statement: KYHPR 87-117, Utilization of Fossil-Fuel Related By-Product Materials for Highway Construction, NCP Code 4E2B5042

Dear Mr. Toussaint:

Research Report KTC 93-18 entitled "Utilization of Fossil-Fuel Related By-Product Materials for Highway Construction In Kentucky" describes analyses undertaken during the course of the study. The objectives of the study were: a) identify by-product materials and sources of materials that may be suitable for use in highway applications; b) conduct laboratory evaluations of mixtures utilizing by-product materials; c) develop specifications for design and construction procedures of pavement structures containing by-product materials; d) plan, design, and monitor construction of a test road(s) involving by-product materials in the pavement surface, base and/or subbase and soil subgrade; e) compare the performance and economics of sections utilizing by-product materials to conventional design and constructed sections; f) assess the positive and negative environmental impacts of using by-product materials in highway construction applications; and, g) develop specifications and recommendations for implementation of by-product materials in highway applications.

This report, the final report for the research study, details the fulfillment of the stated objectives of the research study. By-product materials and sources were identified that were considered suitable for highway applications. By-product materials examined during the course of the study included fly ash, bottom ash, multicone kiln dust, scrubber sludge, and two distinctly different by-products from atmospheric fluidized bed combustion (AFBC) processes. Previous reports issued in conjunction with this study have documented extensive laboratory investigations undertaken to determine engineering properties of individual components of proposed mixtures of by-product materials and of by-product materials combined with conventional construction materials. Materials and construction specifications were developed based on the laboratory evaluations. The interim reports also have documented procedures employed to design experimental test sections involving the by-product materials. The experimental sections constructed and evaluated during the study included: a bituminous surface course containing a bottom ash aggregate as a partial replacement for limestone aggregate; base and subbase courses containing AFBC residue, pond ash, and scrubber sludge; an embankment constructed of pure scrubber sludge; and, a highway soil subgrade modified with residue from an AFBC process and

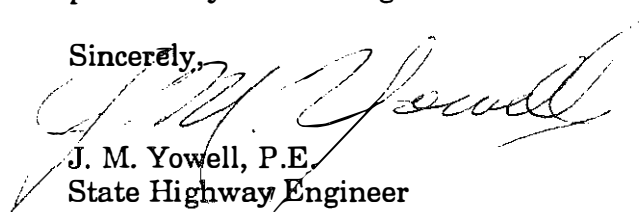
multicone kiln dust, a by-product from the production of lime. The interim reports document construction activities and subsequent monitoring activities. There were no known negative environmental impacts resulting from the use of the by-products materials in the experimental applications. The positive impact resulting from the use of by-product waste materials in highway construction applications is the conservation of valuable natural resources.

Preliminary performance of the field trials has been compared with conventionally designed and constructed sections and documented in the interim reports. The economic viability of using by-product materials in highway applications could not be properly addressed by the study. Although the waste materials were largely supplied for the experimental projects at no cost, the bid price of using the experimental materials apparently always exceeded the bid price of placing the conventional materials. Proven usability of a by-product material may lower the cost somewhat, but transportation costs would necessarily have to be kept to a minimum to make by-product materials used in highway applications economically viable.

Researchers concluded from the results of the field trial applications that some by-product materials are very well suited for highway construction applications. Based upon the experience and knowledge gained during this study, it seems quite probable that comparable, or even extended pavement life may be achieved by using some of the by-product materials. Particularly successful were the field trials involving the use of scrubber sludge in a pavement subbase layer and as an embankment fill material, use of multicone kiln dust for soil subgrade modification, use of bottom ash aggregate in a bituminous surface course, and use of ponded fly ash in lieu of specification fly ash in a stabilized aggregate base layer. Future uses of these materials will be implemented by the Department of Highways where promising and feasible. Specifications developed for design and construction procedures for the use of these by-product materials in pavement structures have proven to be practical approaches to the applications. The Special Notes governing requirements and specifications for use of multicone kiln dust for soil modification, bottom ash aggregate for aggregate replacement in a bituminous surface course, ponded fly ash in lieu of Class F fly ash in a stabilized aggregate base, and scrubber sludge in a subbase are contained in the appendix to this report. Requirements for the use of pure scrubber sludge embankment were not developed by the Kentucky Transportation Center but, rather were developed by Tennessee Valley Authority construction personnel.

Researchers also concluded that the use of the AFBC residues will require additional research before successful uses in highway applications are achieved. It is recommended that further research be conducted specifically to develop satisfactory solutions to the difficulties with the use of the AFBC residues encountered during this research study. Furthermore, it is recommended that monitoring of in-place experimental sections be continued under the long-term monitoring study. Visual distress surveys, sample extractions, and pavement deflections obtained over a period of time will provide valuable information relative to the long-term structural behavior of the experimental field trials. The historical performance and deflection data and analyses will provide specific information relative to the practicality of the design and construction specifications.

Sincerely,



J. M. Yowell, P.E.
State Highway Engineer

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16. Abstract In an effort to increase the utilization of fossil-fuel by product materials in highway construction project, the Kentucky Transportation Cabinet authorized the experimental use of several waste materials. These materials included bottom ashes, fly ash, scrubber sludge, multicone kiln dust, and residues from atmospheric fluidized bed combustion processes. Bottom ash aggregate was used as a partial replacement for the limestone aggregate in a bituminous surface mix. Non-specification fly ash was used in lieu of Class F fly ash in a stabilized aggregate base. Bottom ash stabilized with residue from an atmospheric fluidized bed combustion process was used as a highway subbase layer. Scrubber sludge was used for an embankment construction, Multicone kiln dust and residue from an atmospheric fluidized bed combustion (AFBC) process were used to modify the engineering properties of a soil subgrade. Some of the experimental uses of the waste materials proved quite successful. However, the successes achieved in the laboratory studies were not always duplicated in the field trails and some failures occurred. Principally, uses of residues from the AFBC processes were those that exhibited undesirable performance. Nevertheless, it is believed that economical and effective uses of the AFBC residues in highway construction applications can be achieved by conducting further research on these materials.					
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APPROXIMATE CONVERSIONS TO METRIC UNITS					APPROXIMATE CONVERSIONS FROM METRIC UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH					LENGTH				
in.	inches	25.40000	millimetres	mm	mm	millimetres	0.03937	inches	in.
ft	feet	0.30480	metres	m	m	metres	3.28084	feet	ft
yd	yards	0.91440	metres	m	m	metres	1.09361	yards	yd
mi	miles	1.60934	kilometres	km	km	kilometres	0.62137	miles	mi
AREA					AREA				
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ft ²	square feet	0.09290	metres squared	m ²	m ²	metres squared	10.76392	square feet	ft ²
yd ²	square yards	0.83613	metres squared	m ²	m ²	metres squared	1.19599	square yards	yd ²
ac	acres	0.40469	hectares	ha	ha	hectares	2.47103	acres	ac
mi ²	square miles	2.58999	kilometres squared	km ²	km ²	kilometres squared	0.38610	square miles	mi ²
VOLUME					VOLUME				
fl oz	fluid ounces	29.57353	millilitres	ml	ml	millilitres	0.03381	fluid ounces	fl oz
gal.	gallons	3.78541	litres	l	l	litres	0.26417	gallons	gal.
ft ³	cubic feet	0.02832	metres cubed	m ³	m ³	metres cubed	35.31448	cubic feet	ft ³
yd ³	cubic yards	0.76455	metres cubed	m ³	m ³	metres cubed	1.30795	cubic yards	yd ³
MASS					MASS				
oz	ounces	28.34952	grams	g	g	grams	0.03527	ounces	oz
lb	pounds	0.45359	kilograms	kg	kg	kilograms	2.20462	pounds	lb
T	short tons (2000 lb)	0.90718	megagrams	Mg	Mg	megagrams	1.10231	short tons (2000 lb)	T
FORCE AND PRESSURE					FORCE				
lbf	pound-force	4.44822	newtons	N	N	newtons	0.22481	pound-force	lbf
psi	pound-force per square inch	6.89476	kilopascal	kPa	kPa	kilopascal	0.14504	pound-force per square inch	psi
ILLUMINATION					ILLUMINATION				
fc	foot-candles	10.76426	lux	lx	lx	lux	0.09290	foot-candles	fc
fl	foot-Lamberts	3.42583	candela/m ²	cd/m ²	cd/m ²	candela/m ²	0.29190	foot-Lamberts	fl
TEMPERATURE (exact)					TEMPERATURE (exact)				
°F	Fahrenheit temperature	(°F-32)/1.8	Celsius temperature	°C	°C	Celsius temperature	(1.8°C) + 32	Fahrenheit temperature	°F

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EXECUTIVE SUMMARY

This research report describes analyses undertaken during the course of the study. The objectives of the study were: a) identify by-product materials and sources of materials that may be suitable for use in highway applications; b) conduct laboratory evaluations of mixtures utilizing by-product materials; c) develop specifications for design and construction procedures of pavement structures containing by-product materials; d) plan, design, and monitor construction of a test road(s) involving by-product materials in the pavement surface, base and/or subbase and soil subgrade; e) compare the performance and economics of sections utilizing by-product materials to conventional design and constructed sections; f) assess the positive and negative environmental impacts of using by-product materials in highway construction applications; and, g) develop specifications and recommendations for implementation of by-product materials in highway applications.

This report, the final report for the research study, details the fulfillment the stated objectives of the research study. By-product materials and sources were identified that were considered suitable for highway applications. By-product materials examined during the course of the study included fly ash, bottom ash, multicone kiln dust, scrubber sludge, and two distinctly different by-products from atmospheric fluidized bed combustion (AFBC) processes. Previous reports issued in conjunction with this study have documented extensive laboratory investigations undertaken to determine engineering properties of individual components of proposed mixtures of by-product materials and of by-product materials combined with conventional construction materials. Materials and construction specifications were developed based on the laboratory evaluations. The interim reports also have documented procedures employed to design experimental test sections involving the by-product materials. The experimental sections constructed and evaluated during the study included: a bituminous surface course containing a bottom ash aggregate as a partial replacement for limestone aggregate; base and subbase courses containing AFBC residue, pond ash, and scrubber sludge; an embankment constructed of pure scrubber sludge; and, a highway soil subgrade modified with residue from an AFBC process and multicone kiln dust, a by-product from the production of lime. The interim reports contain documentation of construction activities and subsequent monitoring activities. There were no known negative impacts resulting from the use of the by-products materials in the experimental applications. Positive impacts resulting

from the use of by-product waste materials in highway construction applications are the conservation of valuable *natural* resources.

Preliminary performance of the field trials has been compared with conventionally designed and constructed sections and documented in the interim reports. The economic viability of using by-product materials in highway applications could not be properly addressed by the study. Although the waste materials were supplied for the experimental projects at no cost, the bid price of using the experimental materials would always exceed the bid price of placing the conventional materials. Proven usability of a by-product material may lower the cost somewhat, but transportation costs would necessarily have to be kept to a minimum to make by-product materials used in highway applications, in lieu of natural materials, economically viable.

It was concluded from the results of the field trial applications that some by-product materials are very well suited for highway construction applications. Based upon the experience and knowledge gained through research conducted in this study of the by-product materials utilized for highway applications, it seems quite probable that comparable, or even extended pavement life may be achieved by using some of these by-product materials. Particularly successful were the field trials involving the use of scrubber sludge in a pavement subbase layer and as an embankment fill material, the use of multicone kiln dust as a soil subgrade modifier, and the use of ponded fly ash in lieu of specification fly ash in a stabilized aggregate base layer. Future uses of these materials are recommended where promising and feasible. The specifications developed for the design and construction procedures for the use of these by-product materials in pavement structures are practical techniques to the applications.

It was also concluded that the use of the AFBC residues will require additional research before successful uses in highway applications are achieved. It is recommended that further research be conducted specifically to develop satisfactory solutions to the difficulties encountered during this research study. Furthermore, it is recommended that monitoring of in-place experimental sections be continued under the long-term monitoring study. Visual distress surveys, sample extractions, and pavement deflections obtained over a period of time will provide valuable information relative to the long-term structural behavior of the experimental field trials. The historical performance and deflection data and analyses will provide specific information relative to the practicality of the design and construction specifications formulated during this study and the long-term characteristics of these experimental sections.

INTRODUCTION AND BACKGROUND

Construction materials are becoming more difficult and expensive to produce. Costs of mining and processing crushed stone for aggregates has increased over the years. The same is so for the production of gravels, cements used in concrete, and bituminous materials used for paving materials. Kentucky is one of the nation's leading coal producers and, as a result, there are abundant sources of by-product materials from mining processes. In addition, Kentucky is the home of one of the nation's leading petroleum companies, which produces by-product materials from the distillation of petroleum. The availability of natural resources has resulted in minimal research and development of alternate materials for highway construction. However, as costs of natural materials have risen, so have interests in the use of alternate and sometimes marginal materials in highway, road and street applications.

Pozzolans have been used in cementing materials for centuries. The Greeks and Romans developed pozzolanic cements by blending lime and volcanic ash. Naturally occurring volcanic ashes have properties similar to artificially produced pozzolans from industrial by-products such as fly ash (flue dust), which is a by-product from burning coal. Other pozzolanic materials that may have some potential for applications as stabilizing agents include lime and cement kiln dusts, scrubber sludge, and residues from atmospheric fluidized bed combustion processes. Scrubber sludge and residue from atmospheric fluidized bed combustion processes are by-products of specific procedures designed to minimize air pollution from the burning of fossil fuels. Development of procedures for utilizing by-products from fossil fuel-burning processes serves three functions: use of coal is enhanced since use of by-products from burning and pollution-control processes provides for the management of those by-product materials that otherwise would require disposal; the economy of Kentucky is benefitted by the continued utilization of one of its most important natural resources; and, utilization of by-product materials results in conservation of other valuable natural resources.

Efforts have been made for some time to find worthwhile uses for fly ash in order to convert a material, that might otherwise be an industrial waste, to a profitable product. Fly ash is the fine cinder collected from the flue gasses in force-draft combustion of powdered coal. During 1958, the Kentucky Department of Highways' Materials Research Laboratory, predecessor to the Kentucky Transportation Center, reported on evaluations of fly ash in combination with lime as a soil modifier (1). Researchers determined that the fly ashes investigated would react hydraulically with lime, although to different

degrees, which was essential prior to the evaluation of the materials as soil modifiers. Fly ashes from different sources reacted differently due to variations in fineness. The reactivity of coarser fly ashes was improved by grinding to finer sizes. The researchers concluded that various soils would respond similarly to lime-fly ash modification as they would to portland cement modification except that the rate of strength development would be drastically slower and comparable ultimate strengths might never be reached. Field evaluations were not conducted at that time because of economic considerations. The costs of lime, fly ash, and shipping would have far exceeded the cost of portland cement.

Concurrent with Hardyman's study on lime-fly ash modification, Whitney investigated the use of fly ash as a replacement in portland cement concrete (2). The pozzolanic nature of fly ash suggested not only of providing an inexpensive substitute for more expensive concrete mix ingredients, but possible enhancement of the desirable properties of concrete as well, including a reduction in mixing water. Chemical and physical properties of the fly ash were examined. Compressive and flexural strength, and durability tests were performed on eight different mixtures. Results of tests on mortar cube and briquette specimens, wherein 20 percent of the sand was replaced with fly ash, completed after 60 days of curing indicated that the compressive strength values were almost double that of the control specimens. It was concluded that the fly ash tested could offer an effective and inexpensive substitute for at least some of the sand in air entrained concrete. Further, Whitney concluded that fly ash, as a replacement for up to 25 percent of the cement in air entrained concrete, could provide a material which would be perfectly acceptable for many uses if given curing periods of 28 days or longer. If the use of the fly ash did not require high transportation costs, the fly ash could produce an improved concrete at a lower total expense.

In 1962, the Kentucky Department of Highways initiated a field trial to investigate the use and gain experience in the addition of fly ash to portland cement concrete for pavements (3). A 2.4-mile section of Poplar Level Road, a four-lane highway in Louisville, was selected for the project. The project was divided into three sections; a control section and two experimental sections, one containing 94 and the other 140 pounds of fly ash per cubic yard of pavement concrete. The Department of Highways developed special notes to cover the requirements for the experimental sections. The solid volume of fly ash in excess of that required to replace one bag of cement was considered as fine aggregate. Although not detailed in the report it is estimated, based on the structure's dimensions, that some 355 tons of fly ash, meeting the requirements of ASTM Designation C 350-60T,

were utilized during this field trial. Apparently the only difficulty reported during construction of the pavement was in dispensing the correct amount of fly ash from the hopper, however, that problem was quickly remedied by installing new rollers in the fly ash hopper. Finishers stated that the fly ash concrete had about the same finishing properties as the conventional portland concrete but occasional gumminess or stickiness was encountered when the concrete was not finished immediately after placement.

Researchers investigated both flexural and compressive strengths and freeze and thaw durability of the fly ash concrete and compared those results to those of the control section. Because a reduction in the water requirement could not be obtained as had been achieved in the laboratory, early compressive strengths of the fly ash concretes were somewhat lower than those of the control mix. However, after three months, the compressive strengths of the fly ash concretes exceeded those of the control mix. Freeze and thaw durability of the fly ash concretes was reported to be excellent after 300 cycles of rapid freezing and thawing. However, after 1,600 cycles, samples from experimental section B (140 pounds fly ash per cubic yard) exhibited poor performance. Five performance surveys, covering four years, were reported. Observations noted during the surveys were recorded on strip maps. Cracks, spalls and pop-outs were noted and summarized in tabular form. Cumulative totals given for cracking, spalls, and pop-outs indicated experimental sections A and B exhibited about 32 and 35 percent more lineal feet of cracking per foot of pavement, respectively, than the control section. Experimental section A exhibited six times the number of spalls and more than double the number of pop-outs than the control section. Experimental section B exhibited four times the number of spalls and only slightly more pop-outs than the control section.

In 1969, another experimental fly ash concrete pavement was placed on a section of the Outer Loop in Jefferson County apparently because performance surveys conducted in 1966 on Poplar Level Road were largely inconclusive (4). However, due to previously poorer freeze and thaw durability of the Experimental B mixtures used on the Poplar Level Road project, only Experimental A mixtures were used. Special Provision 70 was developed in 1969 to cover the requirements of the experimental concrete. The Special Provision required "1.25 barrels of cement and 94 pounds of fly ash per cubic yard." Similar evaluations were conducted, i.e. compressive and flexural strength, durability, etc., during the Outer Loop project. Also, the researcher reported on follow-up inspections of the Poplar Level Road project. Average strengths of specimens cast from mixtures placed at the Outer Loop project were somewhat lower than those obtained during the initial field trial but durability factors were similar. It was stated that the experimental

sections of the Poplar Level Road project, inspected during 1970, contained an appreciably larger number of spalls and pop-outs than did the control section. Based on the two experimental projects, researchers concluded that fly ash may be used as a partial cement replacement for paving concrete. However, no savings in costs were realized on either of the trial projects. Cost data given in the report indicated a unit bid price of \$6.45 per square yard for the fly ash concrete used in the Outer Loop project. During this same time, conventional cement concrete pavements placed within District 5 averaged only \$5.56 per square yard.

Base layers for asphaltic concrete pavements using a mixture of Class F fly ash, lime kiln dust, and limestone aggregate were first constructed during 1982 and 1983 for one arterial street and several residential streets in Fayette County (5). Lime kiln dust is a by-product resulting from the production of lime. Based on the success of these installations, a larger project was conceived wherein approximately 1,114 tons of Class F fly ash and 1,114 tons lime kiln dust were utilized to construct a 1.7-mile segment of Man O' War Boulevard in south Lexington during 1983 and 1984 (6). The experimental section has demonstrated excellent performance for eight years.

Currently, fly ash meeting standard specifications is being used successfully in Kentucky as an additive to subbase courses, soil subgrades, stabilized aggregate bases, and as a cement replacement. Section 844 of the Kentucky Department of Highways' Standard Specifications for Road and Bridge Construction covers the general specifications for Class F grade and Class C grade fly ash. Requirements for fly ash used in portland cement concrete pavements are contained in Section 501 of the Standard Specifications. Class F fly ash and Class C fly ash may be used to reduce the quantity of cement, except in Type 1P cement, up to a maximum of 20 percent and 30 percent, respectively, of the minimum cement content. Fly ash use in structural concretes is covered in Section 601. Use of fly ash in stabilized aggregate bases is detailed in Special Provision Number 70D [91]. The total amount of coal fly ash being utilized annually in Department of Highways' projects is estimated to be 25,000 tons.

Blast-furnace slag, a by-product of iron and steel making processes, has been an approved aggregate since the 1930's and approximately 40,000 tons are currently used annually. Another waste product evaluated in the early 1960's was wet-bottom boiler slag (7). Wet-bottom boiler slag is a furnace ash or cinder derived from coal-fired power plants. The main features of the slag aggregate were sharp edges, irregular shape, hardness, and glassy appearance; these being features which impart skid-resistance to a pavement

surface. During 1961, the Division of Maintenance constructed a 1,000-foot test strip on Poplar Level Road for the purpose of evaluating a seal coat containing wet-bottom boiler slag. The aggregate used on the job was obtained from the Clifty Creek Power Plant in Madison, Indiana. Two mixtures were evaluated, the difference being the addition of neoprene rubber latex to the RS-2 emulsion binder. On the basis of the performance of the test section containing the neoprene rubber latex over about a one-week period, engineers with the Maintenance Division decided to seal the approaches and deck of the Clarke Memorial Bridge. The seal coat was placed in October 1961. The aggregate was applied at the rate of 24 pounds per square yard and the emulsion at the rate of 0.3 gallon per square yard. Approximately 300 tons of the wet-bottom boiler slag were used in the seal coat application. In October 1962, a slurry seal was placed on the southbound shoulder of the North-South Expressway in Louisville as a demonstration of wet-bottom boiler slag as a slurry aggregate (8).

In August 1964, wet-bottom boiler slag from the Tennessee Valley Authority's (TVA) Paradise Steam Generating Plant was used on an experimental basis in a 1.25-inch course of Class I, Type A bituminous concrete (9). A Special Note for the experimental use of wet-bottom boiler slag in Class I, Type A, bituminous concrete pavement was developed for the field trial. The Special Note required that 40 percent of the aggregate total, both fine and coarse, be slag aggregate from TVA's plant. A laboratory investigation into the feasibility of using the slag aggregate as a substitute for the natural sand normally required in high-type surface course mixtures preceded the field trial. The most significant hinderance to direct use of the slag aggregate was determined to be its gradation. Between 75 to 90 percent of the slag aggregate was found to exist within the No. 8 to No. 50 sieve range. The maximum amount of No. 8 to No. 50 material, allowed in a Type A surface by Kentucky Department of Highways' (KDOH) Specifications in force at that time, was 51 percent. In the experimental surface, the proportion of No. 8 to No. 50 material was about 50 percent, just at the upper limit of the specification. There were no reported production or placement difficulties. The average coefficient of friction was reported to be 0.50 approximately two weeks after placement of the experimental surface. Researchers were quite satisfied with the construction and initial performance of the experimental surface but concluded that should the slag aggregate be crushed to a more uniform gradation, its utilization in the transportation area would be greatly enhanced. As recently as 1988, more than 20,000 tons of wet-bottom boiler slag were utilized as an additive to surface wearing courses and shoulder seal coats. Unfortunately, the major supplier of this material has found that greater profits are realized when the material is marketed elsewhere as granular roofing materials.

In 1983, the Center conducted a laboratory analysis of flue gas desulfurization sludge (scrubber sludge) and pond ash for potential application as a highway subbase and/or embankment material (10). The laboratory study confirmed that scrubber sludge from the Big Rivers Power Plant in Sebree, in combination with pond ash from the same plant, could be used for either application. During 1984, the optimum laboratory mix design of scrubber sludge and pond ash was used to construct a subbase layer of the Sebree Bypass, KY 494, in Webster County. The amount of waste material used in the experimental project could not be determined. The performance of the subbase has been outstanding. The constructed base material apparently has had no adverse effects upon the environment and future use of this mixture was recommended. However, for economical utilization, it remains essential to have the project very near the source of the waste material to minimize transportation costs. Cost savings derived from the use of scrubber sludge mixtures result largely from a reduction in thicknesses of more expensive base and surface course materials. It was surmised that the most economical use for scrubber sludge would be for low-fatigue roads in areas near the plant producing the waste material.

Research Report UKTRP 87-15 describes the development and implementation of a no-cement concrete mixture containing pulverized fuel ash and previously hydrated atmospheric fluidized bed combustion residue (AFBC), (both from the Tennessee Valley Authority's Shawnee Power Plant, near Paducah), combined with conventional limestone aggregate to form a highway road base (11). The report presents a summary of laboratory evaluations and the application of those results to the design of a roadway base, construction, evaluation and performance of the pilot application of this material used as a base for a thin bituminous pavement. The total volume of AFBC residue utilized was approximately 32 cubic yards. Costs estimates were not available because the project was constructed using Tennessee Valley Authority (TVA) personnel and the construction materials were contributed by TVA for the pilot application. Staff members from TVA's Performance Evaluation Section assured Kentucky Transportation Center (KTC) staff personnel that the AFBC material used in this manner was environmentally safe. The test section performed admirably with no cracking or deterioration observed. Deflection analyses indicated superior strength of the experimental base material relative to that exhibited by conventional, unbound, crushed stone, base materials. The mixture was recommended for further use.

As evidenced by the previous discussion, the Kentucky Department of Highways has long been a strong proponent of research to determine engineered uses of waste materials in

highway applications. Further research was deemed necessary to investigate the performances of previously constructed sections wherein waste by-products have been utilized in the construction process. Moreover, subsequent research is necessary to develop procedures for design of pavement structures wherein by-product materials are utilized. The impetus for this study was the desire to document performance of experimentally constructed sections and to identify existing by-product materials that might be suitable for highway applications.

The stated objectives for the research study were: a) to identify by-product materials and sources of materials that may be suitable for highway applications, b) conduct laboratory evaluations of mixtures comprised of by-product materials or by-product materials combined with conventional materials, c) plan, design, and monitor construction of a test road(s) involving by-product materials in the pavement surface, base, subbase, or subgrade layers, d) assess the positive and negative environmental impacts of using by-product materials in highway construction, e) compare the performance of experimentally constructed sections relative to that of conventionally constructed sections, f) develop specifications and recommendations for implementation for the utilization of by-product materials in highway applications, and g) develop specifications for design and construction procedures of pavement structures containing by-product waste materials.

To identify by-product materials that would be suitable for highway applications, research personnel performed an extensive literature search in an effort to obtain and review pertinent information relative to the use of by-products in highway applications. Determining sources of suitable by-product materials for use in highway applications was achieved by surveying specific industries within Kentucky. The survey focused on those industries producing by-product waste materials that resulted from the production or consumption of fossil fuels. Based upon results of the review of applicable literature and responses from the targeted industries to the survey of suitable waste materials, a number of products and experimental uses were proposed. The waste materials used during the research study included pond ash, scrubber sludge, residue from two atmospheric fluidized bed combustion (AFBC) processes, and multicone kiln dust. These by-product materials were utilized to construct pavement surface, base, and subbase layers and to modify soil subgrade layers. Construction of the experimental projects was contingent upon the availability of construction funding. A prerequisite to the experimental construction of pavement sections containing by-product materials also was that the transportation of the by-product materials be accomplished both effectively and economically.

SUMMARY OF THE EXPERIMENTAL USES OF BY-PRODUCT MATERIALS

Several of the waste materials used experimentally in the highway applications were used successfully and some uses resulted in failures. Following is a brief description and summary for new and existing experimental projects evaluated during this research study on the utilization of by-product materials in highway construction. Locations of the experimental applications are depicted graphically in Figure 1.

BITUMINOUS SURFACE MIXTURE CONTAINING BOTTOM ASH AGGREGATE

The primary objective of this research effort was to evaluate the design and performance of a dry bottom ash used as a substitute for a portion of the limestone aggregate in a bituminous surface mixture (12). The dry bottom ash used in this project was supplied by Kentucky Power Company's Big Sandy Plant located near Louisa, Kentucky. A number of tests were performed by the Division of Materials' Central Laboratory of the Kentucky Department of Highways to determine the physical attributes of the ponded bottom ash material.

The physical tests performed on stockpiled bottom ash materials included sieve analysis, specific gravity, soundness, absorption, wear, and sand equivalent value. Sieve analyses indicated that 90 percent of the stockpiled bottom ash was finer than 1/2 inch. The Special Note developed for the experimental bituminous surface mixture required oversized material be scalped from the aggregate prior to entering the bituminous mixing plant. Saturated surface dry specific gravities ranged from 2.04 to 2.32. Losses of the bottom ash, determined by the sodium sulfate soundness test, ranged from two to six percent. Absorption of the bottom ash aggregate was variable and ranged from 0.2 percent to 2.7 percent. One bottom ash sample was evaluated for wear loss in the Los Angeles abrasion test. That sample had losses of 20 percent after 200 revolutions and 40 percent after 500 revolutions. The sand equivalency value of the bottom ash ranged from 73 to 90.

Kentucky Department of Highways' methods were used to design a bituminous mixture containing bottom ash aggregate, limestone aggregate, and natural sand. Tests were conducted to determine levels of strength, stability, air void content and other design

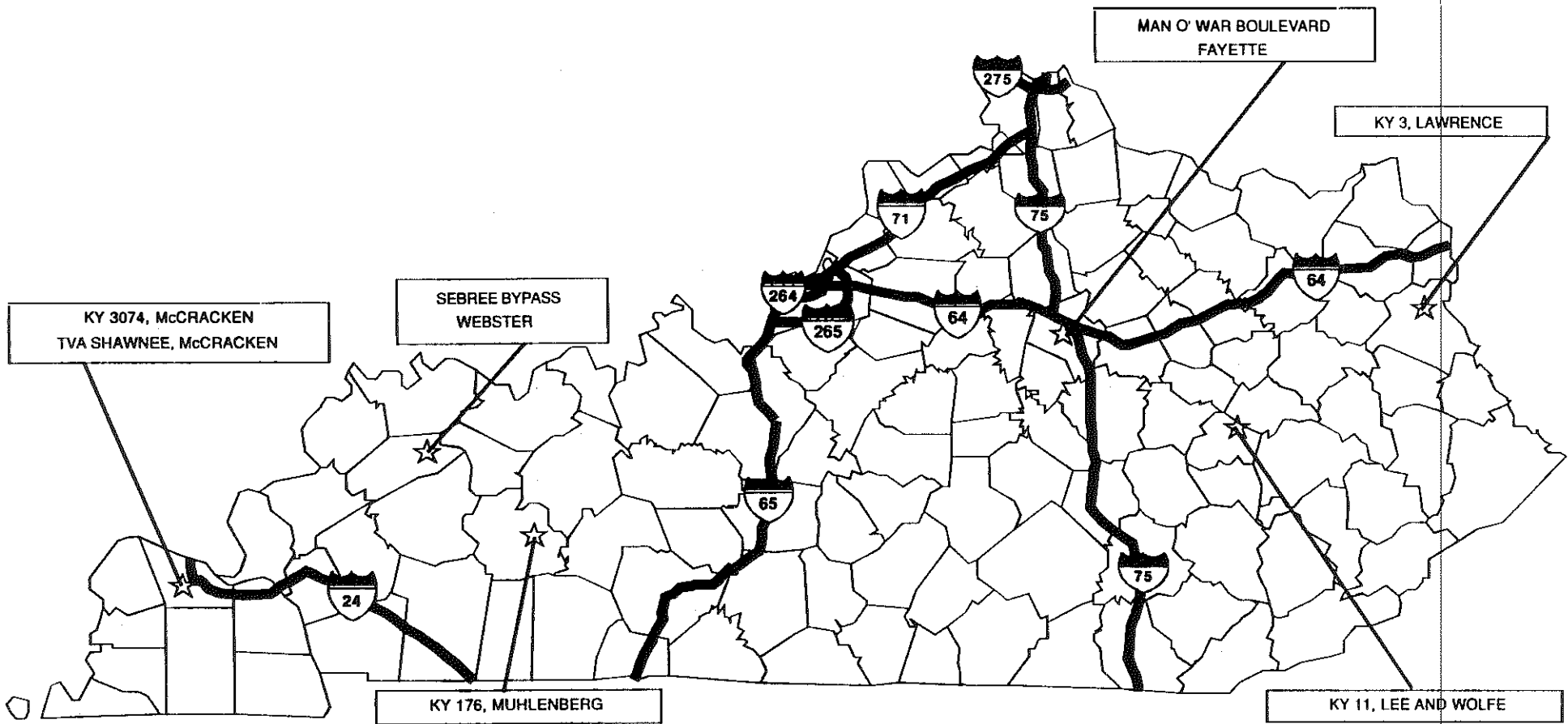


Figure 1. *Project locations of experimental applications of by-product materials for highway construction.*

parameters of the mixture. Aggregate tests performed on the bottom ash prior to combining the material with limestone aggregate and natural sand aggregate indicated a saturated surface dry specific gravity of 2.00 and an absorption of 8.7 percent. It is unknown why this sample had a higher absorption value than values determined previously. The Special Note required a mixture of 40 percent size No. 8 limestone aggregate, 40 percent bottom ash, with larger particles scalped from the aggregate, and 20 percent natural sand aggregate. Marshall mix design tests were completed by the Division of Materials' Central Laboratory. Results of the bituminous mix design indicated a unit weight of 130.5 lbs/ft³ for the mixture. The optimum asphalt content was recommended to be 8.5 percent. The effective asphalt content was 7.9 percent. Air voids comprised 3.8 percent of the mixture. Specific gravity of the bituminous mixture was 2.18. The flow was 0.08 inch. Stability, at the optimum asphalt content, was 1,900 pounds. Splitting tensile strength tests indicated a retained tensile strength value of 81.7 percent.

The one-inch experimental bottom ash surface was placed on State Route 3 from milepost 21.9 to 22.9 on October 13 and 14, 1987. The site map of this project is shown in Figure 2. Approximately 539 tons of the experimental surface were placed. Due to a lack of

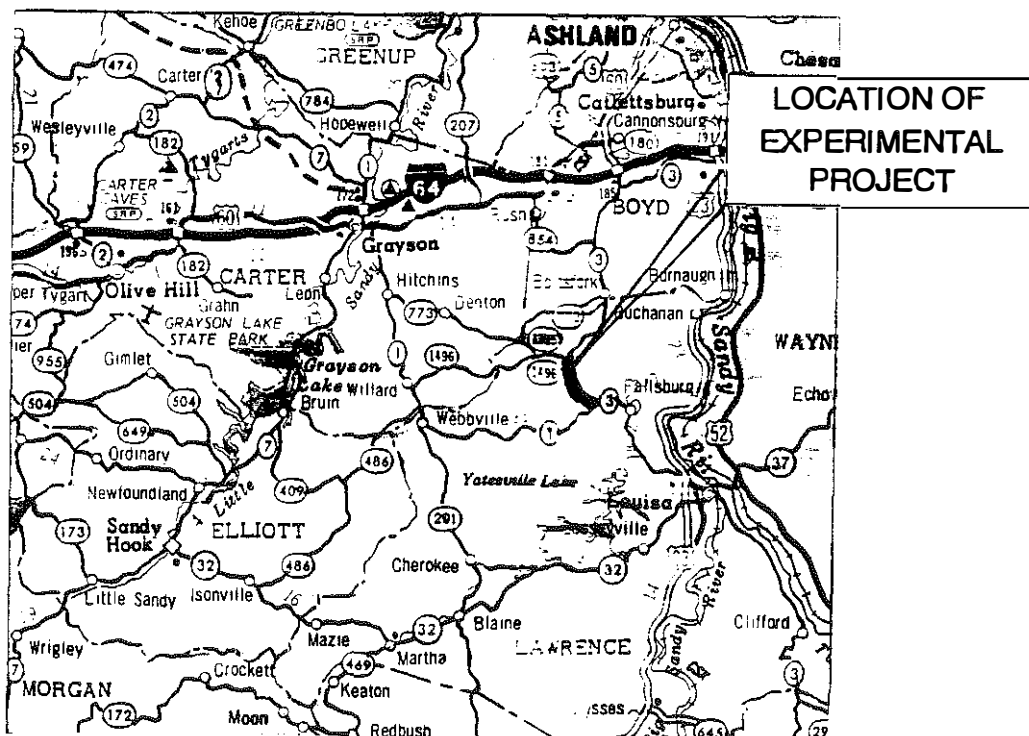


Figure 2. Location of KY Route 3 project in Lawrence County.

communication between Kentucky Transportation Center personnel and Kentucky Department of Highways personnel, construction of the experimental overlay was not observed by research personnel. Kentucky Department of Highways personnel did not suggest any significant problems with the production of the experimental mixture or placement of the experimental material.

Asphalt extractions and aggregate sieve analyses were performed on samples obtained during construction. Results of those tests indicated extracted asphalt contents ranging from 8.5 percent to 8.7 percent and averaging 8.6 percent. Extracted aggregate gradations were within the tolerances allowed for the job-mix formula for the experimental bottom ash surface mixture. There were no subsequent laboratory testing of the experimental bottom ash surface mixture performed by the Kentucky Department of Highways or by the Kentucky Transportation Center.

Kentucky Transportation Center personnel conducted visual surveys to assess the condition and performance of the experimental bottom ash surface and to compare these aspects with the conventional Class I surface. Reflective cracks in the asphaltic concrete surface of both the experimental and control sections were visible above joints and cracks of the old portland cement concrete pavement. Deterioration of the experimental and control pavements in the vicinity of the reflective cracks appeared to be comparable in both sections. No significant rutting was observed in the experimental section during the survey period. The experimental bottom ash surface did exhibit considerable aggregate popouts and some ravelling throughout the section. Generally, the experimental surface exhibited a rough texture throughout the section which persisted during the evaluation period.

Skid tests were performed by the Pavement Management Unit of the Kentucky Department of Highways to compare the frictional characteristics of the experimental surface with the conventional bituminous surface. The skid test results demonstrated the excellent frictional characteristics of the experimental bottom ash surface. Although traffic volumes were nearly three times higher in the experimental section, the experimental bottom ash surface and the conventional Class I bituminous surface had similar skid numbers.

The performance of this successful project has demonstrated that bottom ash aggregate may be effectively substituted for a portion of the coarse aggregate in a bituminous surface mixture. The combination of bottom ash aggregates with limestone and natural

sand aggregate appeared to actually improve the overall performance of a bituminous surface mixture, especially with respect to its skid resistant properties. Dry bottom ashes are angular and have a very porous surface which supports the concept that bottom ash used in a bituminous surface mixture course may improve its skid resistant properties. Because of the absorptive characteristics of bottom ash aggregate, nearly 50 percent more asphalt is required in the mixture. The increased asphalt content results in a higher unit bid price for the bituminous concrete material. Nevertheless, bottom ash represents a large potential source of high-friction, nonpolishing aggregates for use as an aggregate substitute in a bituminous surface mixture and increased utilization of bottom ash aggregate is recommended. With the success of this experimental application, it is quite probable that unit prices of bituminous concrete mixtures containing bottom ash aggregates will decrease to the point that the mixture is an economically viable alternative to conventional bituminous limestone mixtures especially in areas having abundant supplies of bottom ash.

SOIL SUBGRADES MODIFIED WITH ATMOSPHERIC FLUIDIZED BED COMBUSTION RESIDUE AND MULTICONE KILN DUST

Research Report KTC 93-4 described laboratory evaluations, construction procedures and short-term performance of field trials involving admixture modification of several sections of highway soil subgrade on KY Route 11, (13). The site map of this project is shown in Figure 3. Four admixtures were used during construction including Type 1P cement, hydrated lime, and two waste by-products: atmospheric fluidized bed combustion residue (AFBC) and multicone kiln dust (MKD). The AFBC residue was provided at no cost by the Ashland Oil Company and is a by-product resulting from the conversion of crude oil to gasoline. The MKD was provided at no cost by the Dravo Lime Company and is a by-product resulting from the production of lime. A 1,000-foot section of the highway soil subgrade was constructed using conventional procedures without admixture modification. All admixture types, except Type 1P cement, were used on an experimental basis. Therefore, the Type 1P cement admixture was used to compare to the experimental soil modifiers and the untreated soil subgrade section was used as the control section for the project.

An extensive laboratory testing program was used to determine the suitability of using the waste by-product materials as soil modifiers. The laboratory testing program consisted of determining select engineering properties of the soil in an untreated, or

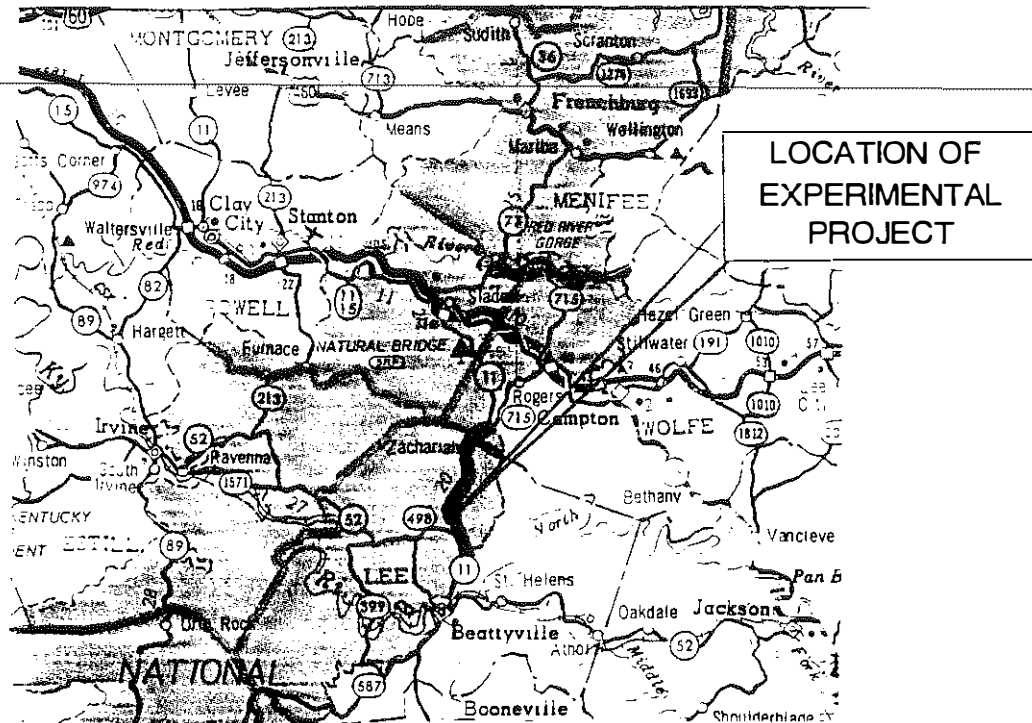


Figure 3. Site map showing location of KY Route 11 in Lee and Wolfe Counties.

natural state, and in a state altered by the chemical admixtures. Index tests were performed, moisture-density relationships were determined, and bearing ratio tests and swell tests were performed. Laboratory procedures used to determine the optimum percentage of each admixture were described.

A laboratory procedure was used to determine the optimum percentage of chemical admixture to add to a given soil type. Typically, when the optimum percentage of admixture is added to a given type of soil, the maximum unconfined compressive strength is obtained. An increase in the percentage of admixture above the optimum amount does not significantly increase the unconfined compressive strength properties of the modified soil. The optimum amount of Type 1P cement necessary to achieve the maximum unconfined compressive strength was determined to be around ten to 12 percent. A value of ten percent was used for one subgrade modification section and a value of seven percent was used for another section. The laboratory strength of the soil-cement specimens was six to seven times greater and ten to 11 times greater than untreated soil specimens remolded from stockpile Stations 273+00 and 574+00, respectively. The unconfined compressive strength of soil-cement specimens ranged from about 265 psi to 470 psi and the unconfined compressive strength of the natural soil specimens was about 40 psi. The optimum amount of hydrated lime for soil modification, based on the

maximum unconfined compressive strength, was around six or seven percent. A value of seven percent was used for construction. The laboratory strength of the soil-hydrated lime specimens was about 100 psi. The unconfined compressive strength of the natural soil specimens was about 40 psi. The optimum amount of AFBC residue for soil modification was around six percent. A value of seven percent was used constructing two experimental sections. The laboratory strength of the soil-AFBC spent lime specimens was about 160 psi. The unconfined compressive strength of the natural soil specimens was about 40 psi. The optimum amount of multicone kiln dust for soil modification was about eight to ten percent. A value of ten percent was used to construct the experimental section. The laboratory strength of the soil-MKD specimens was about 170 psi. Although there were no unconfined strength tests performed on the soil stockpiled at Station 334+00 with which to compare the laboratory strength of MKD modified soil specimens it may be safe to assume, based on the characteristics of the soil, that the unconfined compressive strength of the soils at this location would have been comparable to those determined from the other stockpiled soils, i.e., 40 psi.

Index properties and soil classifications were generally improved when the natural soil was mixed with the chemical admixtures. The most significant changes in the index properties of the soils occurred when Type 1P cement was added to the soil. Some improvement in the index properties was observed when hydrated lime was mixed with the soils. The AFBC spent lime produced mixed results with respect to soil index properties. A slight reduction was observed in the percentage of clay particles when the AFBC was mixed with the soils. However, the plasticity index showed little or no change. The index properties of soils modified with the waste by-product MKD were not investigated prior to construction.

Based on laboratory unconfined compression tests and CBR tests, all four admixtures significantly improved the shear strength and bearing strength of the soils at the study site. It was determined that as the percent hydrated lime and AFBC spent lime increased, the maximum dry density and optimum moisture content obtained from standard compaction procedures decreased and increased, respectively. During construction, the volume change that occurred when the natural soils were mixed with these admixtures required that the finished subgrades be trimmed significantly to obtain design grade elevation. Conversely, as the percent Type 1P cement and MKD added to the soils increased, no significant changes were observed in the maximum dry density or optimum moisture content.

Construction requirements for AFBC residue roadbed modification, MKD roadbed modification and lime roadbed modification were presented in the appendices of Research Report KTC 93-4. The Special Note for Construction for the AFBC residue roadbed modification and MKD roadbed modification were developed by engineers specifically for this project. As with the initial use of any material, there were some difficulties encountered at the beginning of construction of the AFBC spent lime modified subgrade. Principally, there appeared to be little control in the amount of AFBC spent lime or water being placed. Because of the fine-grained nature of the AFBC spent lime, the material flowed much like a liquid and extra effort was devoted to constructing windrows along the edge of the shoulders to contain the AFBC residue. The soil mixing machines performed exceptionally well. The pulverization requirement was easily met after one pass with the pulverizing machine and the mellowing period required for the AFBC residue roadbed modification and the MKD roadbed modification was waived. Initially, inspectors had difficulties getting correct moisture readings using the nuclear density device. After the problem was identified, the inspectors determined the actual moisture content by applying a moisture-content correction factor. The incorporation of the AFBC spent lime into the soil caused significant volume change. Nearly four inches of the subgrade had to be trimmed in order to obtain proper grade elevation but trimming was easily accomplished 24 to 30 hours after final compaction. The subgrade subcontractor did not experience further troubles while constructing the remaining modified subgrade sections.

Investigations relative to the engineering properties of the modified soil subgrades continued during construction of the modified subgrade. Field testing consisted of moisture content/dry density tests for construction compliance, and in-place bearing capacity tests, moisture content tests and Road Rater deflection tests performed on the subgrade both before and after modification with chemical admixtures. Based on 84 nuclear density tests conducted on all sections of KY 11, the relative compaction averaged 98.2 percent with a standard deviation of +/- 2.6 percent. Since specifications required that all field dry densities be 95 percent of maximum dry density, all subgrade sections were compacted according to the dry density specification. With regard to the moisture content, compaction specifications required that the field moisture content be no less than the optimum moisture content nor more than five percent above optimum moisture. The average value of the differences between measured moisture contents in the field and specified optimum moisture contents was -0.2 percent. This means that generally the subgrades were compacted at moisture contents just slightly dry of the optimum moisture content.

In-place bearing ratio tests were performed throughout the test site on the natural soil prior to admixture modification. Attempts were made to repeat these tests after a period of seven days. Unfortunately, the attempt met with little success and tests were only performed after seven days within the AFBC sections. Results of the tests on the untreated soil indicated very high bearing capacities and correspondingly low moisture contents. In-place bearing ratio tests performed on the soil-AFBC spent lime modified section confirmed that the bearing capacity of the chemically modified subgrade had increased by about 36 percent above the value of the untreated subgrade. However, the moisture content determined in conjunction with the tests indicated a decrease in the moisture content of about 13 percent. The decrease in moisture content was attributed to incorrect moisture readings initially obtained with the nuclear device. Analysis of Road Rater deflection tests conducted before subgrade modification and seven days after modification provided initial indication of the benefits of chemical admixture modification. The mean moduli estimated from the Road Rater tests were 24,000 psi for the untreated subgrade. Modification with Type 1P cement increased the estimated subgrade modulus to 137,000 psi. Modification of the soils with hydrated lime increased the estimated subgrade modulus to only 46,000 psi. The two waste by-products also proved beneficial with regard to increasing the shear strength of the natural soil. Modification of the soil with AFBC residue increased the estimated subgrade modulus to about 75,000 psi and modification with MKD increased the estimated subgrade modulus to 93,000 psi.

After construction, monitoring of the experimental and control sections continued. The initial post-construction analysis involved re-examining the expansive characteristics of the soil-AFBC spent lime mixture. Approximately two months after construction of the soil-AFBC spent lime subgrades, severe differential swell or heave of the pavement surface was noted. The preconstruction laboratory evaluation of the swell characteristics indicated swell of 3.1 percent when seven percent AFBC residue was combined with the natural soil. The natural soil exhibited 3.9 percent swell. Additional specimens of the soil-AFBC mixture were evaluated. A specimen remolded from a bag sample obtained from a trench that was opened to investigate the subgrade heave had less than one percent swell during the CBR test. Specimens were remolded using soils obtained from stockpiles and excessive quantities of the AFBC residue. It was determined that the volumetric swell of the remolded specimens containing 15 to 30 percent AFBC residue (by weight of the dry soil) ranged between 24 and 27 percent. Based on this investigation, it was concluded that the amount of AFBC residue mixed with the natural soil at locations where differential heave had occurred exceeded the specified seven percent necessary for soil modification. Primary and secondary swell characteristics were noted. A model was

developed to estimate the time at which primary swell of the soil-AFBC spent lime mixture would be completed and the magnitude of swell that could be expected to occur during the secondary swell phase.

Performance monitoring of the chemically modified subgrade soils included performing in-place bearing capacity tests on the subgrades, obtaining undisturbed samples to analyze in the laboratory relative to unconfined compressive strength, moisture content, and soil classification, monitoring pavement elevations for swell attributes, and performing Road Rater deflection measurements on the completed pavement structure. Additional in-place CBR tests were performed during 1988, 1989 and 1991 to determine the benefits of subgrade modification with the waste by-products. The most extensive evaluation of the modified soil subgrade layers was performed in 1991. A comparison of the bearing capacity and moisture content of the treated layer and the underlying untreated layer was made. For reasons that cannot be explained, results of in-place CBR tests performed during 1989 were much lower for all soil-admixture types than results obtained during the other two test dates, though the moisture contents were relatively constant for each testing period.

Results of in-situ bearing capacity tests on the soil-AFBC sections performed in 1988 and 1991 were comparable and indicated an average CBR of about 27 and an average moisture content of about 28 percent. The untreated soil layer beneath the treated layer had an average CBR and moisture content of four and 22.5 percent, respectively, during 1991. Based on the results of the in-situ field tests, it appears that bearing capacity and moisture content of the soil-AFBC spent lime mixture has stabilized. The AFBC spent lime modified soil subgrade appears to be sustaining elevated shear strength values at very high moisture contents. The Type 1P cement, hydrated lime and MKD modified soil subgrades appear to be continuing to gain strength with time. The multicone kiln dust modified soil subgrade had an average CBR of about 96 and an average moisture content of about 16 percent during 1991. The bearing capacity increased about 50 percent over the 1988 value. The moisture content also increased above the 1988 value but was similar to the 1989 value of 18.2 percent. The untreated soil layer below the MKD-treated layer had an average CBR and moisture content of six and 19.2 percent, respectively, during the 1991 test. The untreated section had an average CBR of eight and moisture content of about 15 percent in 1991.

Laboratory evaluations of the Shelby tube samples included performing unconfined compressive strength tests, determining moisture content, dry density and determining

soil classifications of the extruded specimens. The Shelby tubes were difficult to push through the treated soil layer. Specimens that were obtained were difficult to extrude in the laboratory and many were disturbed, and even destroyed, during the extrusion process. Values obtained for the unconfined compressive strength during the laboratory evaluations were not considered to be representative of the true character of either the treated or untreated soils. Unconfined compressive strength results also were inconclusive because of the limited number of test specimens. Values of the dry density of the modified soils were largely obtainable for only the soil-AFBC spent lime modified subgrade section. The dry density of soil-AFBC spent lime specimens averaged 89.8 pcf and 94.9 pcf, respectively, during the 1989 and 1991 investigations. These values are substantially less than values recorded during construction and are a direct result of the volumetric swell that the soil-AFBC mixture underwent after construction. The untreated soils beneath the AFBC modified soils had a dry density of about 119 pcf during both years. Results of index tests performed on extruded shelly tube specimens indicated that the all chemically modified soils were generally classified as SM in the Unified Classification System and soil from the untreated layer was classified as CL.

Based on pavement elevations, no significant swell occurred in the subgrade sections stabilized with Type 1P cement, hydrated lime or the waste material MKD. Laboratory swell tests also revealed that there was no swelling associated with Type 1P cement or hydrated lime and that these two admixtures actually reduced the swelling of the natural soils. However, the soil-AFBC spent lime modified subgrade swelled significantly. Significant swell or heave, of the pavement placed on the two soil-AFBC sections occurred shortly after construction and after a period of heavy rain in the region. The swelling nature of this material, when mixed with the natural soils, was not expected since such a small quantity was to be mixed with the subgrade soils. It was concluded that the humps that formed on the pavement surface were caused by the combination of excessive amounts of the AFBC spent lime admixture and an insufficient amount of water being added in those areas where the subgrade heaved. The excessive amount of AFBC spent lime most likely occurred when the spreader trucks stopped and started while distributing the admixture. Similarly, the water trucks deposited more water in some areas than others because they often became bogged down or stuck. Typically, the width of the transverse humps on that occurred on the pavement surface was the same as the width of the spreaders.

The experimental and control sections were visually surveyed periodically for observable pavement distress since the completion of construction. Factors such as rutting and

cracking were of principal concern. Overall, all of the chemically modified subgrade sections are in good condition and exhibiting excellent performance. With the exception of one area within the soil-AFBC section near Station 563+00, no significant pavement distresses have been observed to date. Pavement rutting characteristics were monitored during the study. On average, the deepest rutting occurred in the control section. The absence of significant pavement rutting in the chemically modified subgrade sections is illustrative of the benefits of chemical admixture subgrade modification.

Elastic moduli, as estimated from non-destructive Road Rater deflection tests, indicated substantial improvement after the fine-grained soils were modified with the all chemical admixture types. Based on the results of the Road Rater tests performed on the natural soil subgrade and the modified soil subgrade after seven days, the waste by-products AFBC spent lime and MKD improved the stiffness of the soil subgrade threefold and fourfold. Modification with Type 1P cement provided appeared to provide the highest moduli values. Analyses of subsequent deflection tests performed with the Road Rater to quantify the long-term benefits of the admixture modification indicated that each chemically modified subgrade section continues to exhibit higher strengths than the untreated control section. The cement modified subgrade sections continued to exhibit the largest increase in strength above the strength realized in the untreated control section. However, the strength of the soil-hydrated lime subgrade section had surpassed that of the soil-MKD and soil-AFBC spent lime modified subgrade sections. The deflection analyses also indicated an increase in subgrade strength with time for all sections including the untreated section. Because a three-layer solution was employed to analyze the Road Rater deflection data collected during the evaluation period, elastic moduli values of the chemically modified subgrade layers were not specifically determined.

It was concluded that the AFBC spent lime admixture enhanced the overall bearing capacity characteristics of the natural soil. However, the construction procedures employed by the subcontractor could not prevent excessive amounts of the AFBC residue from being mixed with the natural soil. Future use of the AFBC spent lime for soil subgrade modification was not recommended because of the extremely expansive nature of the waste by-product. Further research is recommended to identify and control the mechanism that causes the swelling of the soil-AFBC spent lime mixtures.

It also was concluded that multicone kiln dust waste material, when used as a soil modifier, provides increased shear strength properties above those of the natural soil. Results of the in-situ field tests also indicate that the soil-MKD layer appears to be

of the AFBC concrete base mixture was based upon unconfined compressive strength tests and optimization of three mix variables: volume of water needed for prehydrating the AFBC residue; the fly ash to AFBC residue ratio; and, the amount of coarse aggregate. 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.

Because of a materials handling and storage problem, prehydration of the AFBC residue at the site prior to its use was not feasible. Questions then arose relative to the effectiveness of preconditioning the AFBC residue in advance and storing it. Since similar methods had been employed during the laboratory evaluations, it was thought that storing the preconditioned AFBC residue in a warehouse would be acceptable. To check the condition of the AFBC residue, KTC personnel visited the storage facility in March, 1988 and obtained samples for evaluation. Tests at that time indicated that the AFBC residue that apparently had been preconditioned and stored for several months prior to the visit by KTC personnel was reactive; that is, the material would generate heat when water was added to it. The AFBC residue had evidently regained some of its initial properties while being stored in the warehouse or was not properly prehydrated initially. Whatever the reason, results of impromptu tests performed on the residue prior to its use in construction indicated that some expansion of the mixtures containing the residue would occur. A decision was made to use the AFBC residue in its existing condition, as opposed to prehydrating the residue again, and to form gaps in the plastic base and subbase layers of sufficient width in an effort to accommodate the one or two percent expansion that was expected to occur.

Mixture Designs

Proportions for the optimum AFBC concrete base mixture had been developed previously by Dr. Jerry G. Rose, Professor of Civil Engineering, University of Kentucky, and were modified only slightly for this project. The optimum AFBC concrete base mixture evaluated in the laboratory initially contained 56 percent No. 57 limestone aggregate, 35 percent AFBC residue and nine percent ponded fly ash. At the request of TVA officials, a Class F fly ash was substituted for the ponded fly ash and the mixture proportions were adjusted based upon previous research conducted by Dr. Rose. The altered mixture design for the AFBC concrete base was comprised of 64 percent No. 57 limestone aggregate, 25 percent AFBC residue, and 11 percent Class F fly ash. Unfortunately, there

was not enough time to determine the 28-day compressive strength of the AFBC concrete base mixture prior to the commencement of construction activities. Laboratory evaluations could only assess the moisture-density relationship of the amended mixture. The revised AFBC concrete mixture had an optimum moisture content of 8.8 percent and a maximum dry density of 129.6 pcf.

The design of the ponded fly ash-hydrated lime-dense grade aggregate (pozzolanic) base mixture was based upon 28-day compressive strength development. Three mixtures were evaluated that contained various proportions of ponded fly ash, hydrated lime, and DGA. The amount of ponded fly ash varied from six to 11 percent. Hydrated lime in the mixtures varied from three to five percent and the amount of DGA varied from 84 to 91 percent. The optimum mixture design for the pozzolanic base contained 11 percent ponded fly ash, five percent hydrated lime, and 84 percent DGA. The pozzolanic mixture used had an optimum moisture content of 9.6 percent and a maximum dry density of 130.6 pcf. The 28-day compressive strength of the pozzolanic mixture was 780 psi.

Similar analyses were performed to develop the optimum design for the AFBC stabilized pond ash subbase mixture. Six separate mixtures were evaluated in the laboratory that contained various proportions of pond ash and AFBC residue. The pond ash was designated as coarse fractions (bottom ash) and fine fractions (fly ash). The amount of ponded fly ash in the mixtures was varied from five to nine percent. Ponded bottom ash varied from 46 to 90 percent of the total mixture. The amount of AFBC residue in the mixes varied from five to 45 percent. The mixture chosen for use as the subbase mixture exhibited uniform consistency and compressive strength development during the laboratory evaluations. The optimum AFBC stabilized pond ash mixture consisted of 60 percent ponded bottom ash, 32 percent AFBC residue, and eight percent ponded fly ash. The AFBC stabilized pond ash mixture had an optimum moisture content of 16.1 percent and a maximum dry density of 101.8 pcf. The 28-day compressive strength of the AFBC stabilized pond ash mixture was 960 psi.

Pavement Thickness Designs

Kentucky flexible pavement design procedures were used to determine thickness requirements of the AFBC concrete base, pozzolanic base, and AFBC stabilized pond ash subbase layers. AASHTO structural coefficients of 0.30, 0.28 and 0.10 were assumed for the AFBC concrete base layer, pozzolanic base layer, and AFBC stabilized pond ash subbase layer, respectively. The thickness design requirements were 8.0 inches, 8.0

inches, and 12.0 inches for the experimental AFBC concrete base layer, pozzolanic base layer, and AFBC stabilized pond ash subbase layer, respectively. The pavement design for the experimental AFBC stabilized pond ash subbase section included a bituminous curing seal above the subbase layer and a crushed aggregate base thickness of 8.0 inches. The pavement design of the experimental sections also specified 2.0 inches of compacted bituminous concrete base, 1.5 inches compacted bituminous binder, and 1.0 inch compacted bituminous concrete surface. Additionally, the pavement design for the AFBC concrete base section and pozzolanic section included a stress relief layer to minimize the occurrence of reflective cracking.

Construction

Prior to construction of the experimental sections, KTC personnel performed in-situ bearing capacity tests and Road Rater deflection tests on the prepared subgrade. During construction, KTC personnel monitored construction activities and prepared field compacted specimens for laboratory evaluations. Department of Highways' personnel were responsible for determining conformance to the standard construction specifications and special notes for the experimental project. The experimental base and subbase layers were placed using conventional equipment, typically an aggregate spreader box pushed by a small bulldozer. Difficulties documented during construction of the experimental base and subbase layers included consistency and moisture content of the mixtures and production of the materials at the concrete batch plant that was used to produce the mixtures. The lack of a uniform moisture content in materials delivered to the jobsite caused some delay in compacting the base and subbase materials and cutting the materials to proper grade. A compaction requirement of no less than 100 percent of the laboratory dry density was specified for the experimental base and subbase layers. Satisfactory densities were easily achieved during construction. Four-foot wide gaps were formed in the plastic AFBC concrete base material to accommodate the expected expansion. Gaps were also formed in the AFBC stabilized subbase layer, but not until two to three days after placement of the bituminous curing seal. Because the mixture had firmly set, formation of the gaps was quite difficult. The stress relief layer on the AFBC concrete base and pozzolanic base and the bituminous curing seal on the subbase was required to be placed no later than 24 hours after completion of compaction activities. The allotted time to place the stress relief layer and the curing seal was apparently disregarded because the contractor generally placed them immediately upon completion of compaction. This action resulted in the formation of several deep ruts in the still-plastic base and subbase layers.

Production of the AFBC concrete base mixture was satisfactory but less than ideal. Two days were required to complete placement of the 750-foot length of the AFBC concrete base. Because the AFBC concrete base mixture was placed in two lifts, the occurrence of delamination between lifts was thought possible. Production of the pozzolanic mixture and AFBC stabilized pond ash mixture was very sporadic and three days were required to complete placement of each section. Production was delayed due to various problems. Failure of a motor on one conveyor belt caused a six-hour delay on the first day of production of the pozzolanic mixture. Also, delays were encountered because the batch plant operators continued producing concrete between batches of the base and subbase mixtures. The pozzolanic base mixture was placed in one lift to eliminate the possibility of delamination and to expedite the construction process. However, because the AFBC stabilized pond ash subbase mixture was placed in two, six-inch lifts, there was a high probability that delamination would occur. Because of the delays at the concrete batch plant, it was concluded that a better set-up for production of the mixtures would have been a pugmill set up near the jobsite. Waste materials utilized constructing the three sections totaled approximately 1,138 tons. Approximately 460 tons of waste AFBC residue and 678 tons of pond ash were utilized constructing the three experimental sections incorporating AFBC residue and pond ash in the pavement structure.

Post Construction Laboratory and Field Evaluations

Despite the observed construction difficulties, the initial effectiveness of the experimental base and subbase layers appeared favorable. Compressive strength evaluations of field compacted six-inch by 12-inch 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 and increased 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. The attempt to simulate proper compactive effort while preparing the field compacted specimens was successful. The wet densities of the field compacted AFBC concrete base specimens averaged 146.2 pcf, or 103.7 percent of the maximum density determined in the laboratory.

Average seven-day compressive strengths of the pozzolanic base mixture were only 65 psi. The seven-day specimens were so weak that no data were obtained for the static chord modulus of elasticity for fear of damaging the compressometer and dial indicators. After 14 days, the compressive strength of the field compacted specimens of the pozzolanic

mixture had increased to 120 psi. The average 14-day static chord modulus of elasticity was 64,000 psi. The 28-day average compressive strength increased to 265 psi. The static chord elastic modulus increased almost tenfold over the 14-day modulus to 573,000 psi. Average values for compressive strength and static chord elastic modulus, at 56 and 112 days, had increased to 645 psi and 1,497,000 psi and 1,600 psi and 2,830,000 psi, respectively. Although an attempt was made to simulate proper compactive effort while preparing the field compacted specimens of the pozzolanic mixture, the average of the wet densities of the field compacted base specimens was 140.7 pcf, or 98.0 percent of the laboratory maximum wet density. While the average wet density of the field compacted specimens may appear close to the laboratory value, the wet densities of the field specimens ranged from 129.6 pcf, or about 90.5 percent of the maximum wet density to 147.9 pcf, or 103.4 percent of the laboratory maximum wet density. Of the 39 specimens prepared in the field, 19 equaled or exceeded the laboratory maximum wet density of 143.1 pcf.

Compressive strength evaluations of AFBC stabilized pond ash specimens indicated average strengths of 375 psi at seven days and increasing significantly to 2,345 psi at 112 days. These strengths were only slightly greater than the 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 attempt to simulate proper compactive effort while preparing the field compacted specimens of the AFBC stabilized pond ash mixture was not successful. The wet densities of the field compacted subbase specimens averaged 114.7 pcf, or 97.0 percent of the maximum wet density. None of the 42 compacted specimens of the subbase mixture equaled or exceeded the maximum wet density.

The base and subbase layers containing AFBC residue were optically monitored periodically for length change prior to the placement of the asphaltic concrete layers. Field compacted specimens of the AFBC concrete base mixture and the AFBC stabilized pond ash subbase mixture also were monitored in the laboratory for expansive characteristics. The magnitude of the expansion of the experimental mixtures was less in the field than that observed 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.

Structural attributes were evaluated by obtaining deflection measurements on the experimental layers with a Model 400B Road Rater. Deflection measurements were obtained at various stages of construction. 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, pozzolanic 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 base and subgrade 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, field compacted specimens of the AFBC concrete base mixture continued to gain strength throughout the 112-day laboratory evaluation period.

Deflection tests were conducted over a 68-day period on the experimental pozzolanic base layer. Analyses of these data indicated higher dynamic stiffnesses through 42 days. After 42 days, the rate of the strength gain appeared to decrease. There were some variations in the deflections after 42 days but the overall trend of the dynamic stiffness was to increase. These variations were attributed to either temperature changes within the pozzolanic layer or changing moisture conditions within the subgrade. The results of compressive strength and static chord modulus of elasticity tests of field compacted specimens of the pozzolanic base mixture also indicated a substantial increase in strength. Field compacted specimens of the pozzolanic 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 experimental pozzolanic base and AFBC stabilized pond ash subbase layers, or changing moisture conditions within the subgrade as it could be an actual strengthening over time of the experimental layers.

Interim Conclusions

Previous research reported by others concluded that prehydrated AFBC residue, pulverized coal fly ash, and aggregate could be used to construct a stabilized base course, provided the AFBC residue was properly prehydrated prior to its use. The AFBC residue used in this study was effectively prehydrated during the laboratory phase of the study. Mixtures containing AFBC residue that was prehydrated in the laboratory did not exhibit any expansive characteristics during the subsequent evaluations. However, that success was not duplicated during the field trial. Specimens made in the laboratory, just prior to construction of the experimental base and subbase layers, containing AFBC residue that was prehydrated at the concrete batch plant and stored for several months prior to the commencement of construction, revealed expansive characteristics of the mixtures. It was thought that 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 Dr. John Minnick, "the longer the storage period, the more detrimental effect carbonation is expected to have on the quality of the AFBC residue." Air from the atmosphere most likely reacted with the hydroxides in the AFBC residue and converted them to carbonates. This action had a detrimental result upon the mixtures containing residue from the AFBC process.

Although tests performed on the AFBC residue that was prehydrated at the batch plant indicated a hydration reaction (temperature rise caused by the addition of water),

construction of the experimental sections proceeded as planned. An attempt was made to accommodate the anticipated material expansion by forming gaps in the plastic base and subbase materials. Construction of the experimental layers using conventional equipment was generally acceptable when materials were available. Materials with the proper moisture content were placed and compacted with no apparent difficulties. The only readily apparent construction difficulty was cutting the materials to grade and the impatience displayed by the construction contractor in placing the stress relief layers and the bituminous curing seal. Production of the experimental mixtures was hindered because concrete batching operations were alternated with production of the experimental mixtures. Producing the mixture with a pugmill set up near the jobsite would have been preferable to the batch plant operation. This is true also of the AFBC prehydration process. It would have been more appropriate to prehydrate the AFBC residue just one or two days prior to mixing it with the other materials in the experimental mixtures.

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 achieved. However, that was not the case with either the pozzolanic base mixture or the AFBC stabilized pond ash mixture. Compressive strength and static chord elastic moduli evaluations generally indicated low initial strengths but exceptional strength gain for all of the experimental mixtures. It appeared that both of the mixtures incorporating the AFBC residue possessed the potential for further expansion in the field trial application based upon expansions of field compacted specimens observed in the laboratory. The initial performance of the pozzolanic base was superior to the other experimental base and subbase layers that contained residue from the AFBC process.

It was uncertain as to the cause for the observed decreases in the apparent dynamic stiffnesses of the pavement structure of the AFBC concrete base section but was hypothesized to be the result of the continued expansion and fairly extensive cracking of the experimental base layer. Because the AFBC stabilized pond ash subbase contained 32 percent of the AFBC residue by weight, similar actions (a decrease in dynamic stiffness) from that section were expected as time passed. Deflection measurements obtained on the pozzolanic base indicated continued gains in the dynamic stiffness of the structure although the rate of gain decreased with the passage of time.

Summary of Performance Evaluations

Previous reports described the preliminary engineering and design, construction details, and initial performance of three experimental sections. Subsequent performance surveys

and measurements performed as part of this research effort consisted of distress surveys, obtaining dynamic deflections and performing data analyses, pavement rutting characteristics, and strength and durability measurements of field cores obtained from the experimental base and subbase layers (16).

Shortly after the bituminous base and binder layers were placed at the experimental site, humps were observed on the pavement surface within the sections that had incorporated residue from the AFBC process in the mixtures. During the three-year evaluation period, the humps required approximately ten millings. Expansion of the base and subbase mixtures that contained the AFBC residue was so immense that the backfilled materials were eventually squeezed from the gaps and milled away. The areas near the expansion gaps required repeated maintenance to prevent the sections from being a traveling hazard to the public. Dynamic deflection tests performed on the experimental sections indicated gradual deterioration of the pavement structure during the evaluation period. This was especially true of the AFBC concrete base layer. The two sections containing residue from the AFBC process exhibited the greatest depth of pavement rutting. Compression tests of cored field specimens also indicated a gradual deterioration of the base and subbase materials during the three-year period. After continual milling and patching operations and visible deterioration of the pavement structure, the base and subbase sections incorporating residue from the AFBC process were judged to be failed experiments. The sections were removed and replaced with conventional construction materials.

The remaining experimental section containing the pozzolanic (ponded fly ash-hydrated lime-dense grade aggregate) base demonstrated superior performance during the evaluation period. Only one transverse and one, short longitudinal reflective crack were observed. Other than the reflective cracks caused by shrinkage known to be associated with pozzolanic bases, no significant distresses were noted. Analysis of the deflection data obtained within this section indicated exceptional structural integrity for the pozzolanic base layer. Rutting measurements indicated less rutting occurred in the bituminous layers of the experimental pozzolanic section than was observed in the conventionally designed and constructed control section. Unconfined compressive strength tests substantiated the excellent and consistent strengths of the experimental pozzolanic mixture.

Conclusions and Recommendations

The base and subbase layers containing residue from the AFBC process were classified as failures because of the poor performance demonstrated by the sections. The poor

performance was due to a number of circumstances but the excessive expansion that the base and subbase mixtures underwent was the principal reason for the resulting pavement distresses and ultimately, the failure of the sections. The Special Note for Construction, developed for the waste materials utilized in this project, required that the AFBC residue be prehydrated prior to its use. Prehydration of the residue from the AFBC process is necessary to eliminate, or minimize the inherent expansive properties of the residue. Because of materials handling and storage problems, the materials handler prehydrated the AFBC residue several months prior to construction and stored it in a warehouse. KTC representatives obtained a sample of the prehydrated AFBC residue from the storage warehouse prior to the construction date. That sample had a hydration reaction when water was added to it and thus, it was known that the material would swell when placed in the mixtures. It is believed that either the AFBC residue initially was not prehydrated according to specifications or the extended storage period somehow adversely affected the properties of the residue. Nevertheless, officials involved with the study proceeded with the construction and the AFBC residue was used. It was thought that the expected expansion could be accommodated by placing gaps in the plastic base and subbase layers. This response to the expansive properties of the materials was not successful and the two experimental sections subsequently failed. The experimental base and subbase layers containing the expansive AFBC residue likely should not have been constructed without prehydrating the AFBC residue again. The AFBC residue continued to cause extensive pavement distress throughout the evaluation period. Public clamor over the apparent waste of taxpayer monies on the failed experiment was quite harsh. The KDOH suffered through a public relations nightmare due to the failed experiment. However, the experiment was a learning experience.

Use of the AFBC residue from the Shawnee Power Plant in highway base and subbase layers, or as a subgrade modifier, may be feasible at some point in the future but should not be permitted unless techniques can be developed and used that will absolutely guarantee elimination or, at the very least, minimization of the expansive nature of the AFBC residue. The successes obtained during the laboratory studies must be transmittable to field trial applications. One possibility could be prehydration of the AFBC residue within one or two days prior to its use. A pugmill set up near the construction site would permit prehydration activities to take place only a few days before the commencement of construction activities. The pugmill would also permit mixture components to be batched at a more suitable rate than achieved during this experiment. Future experiments should be conducted in an effort to effectively utilize the

by-product materials from the atmospheric fluidized bed combustion process in highway construction applications.

The excellent performance of the experimental pozzolanic base layer clearly demonstrated that a non-specification fly ash, a waste material, may be successfully substituted in stabilized aggregate base construction for the specification-grade fly ash that meets standard requirements for Class F or Class C fly ash. It was recommended that KDOH officials allow the substitution of non-specification fly ashes for specification grade fly ash in stabilized aggregate bases on a limited basis and perform additional detailed performance and cost comparisons to validate any advantages of this practice. Current KDOH Special Provision No. 70D (91) for stabilized aggregate bases governs probable compositions for hydrated lime-fly ash-DGA mixtures.

MONITORING ACTIVITIES OF EXISTING APPLICATIONS OF BY-PRODUCT MATERIALS

Monitoring of three existing facilities wherein by-product materials were utilized in experimental projects was conducted. These experimental projects were constructed prior to the commencement of this research study but were included in the field evaluation phase of the study. The applications included stabilized aggregate base and subbase layers.

Pozzolanic Base Layer on Man O'War Boulevard, Fayette County

Pozzolanic bases comprised of a Class F fly ash-lime kiln dust-aggregate mixture were constructed during 1982 for several local streets in Lexington, Kentucky (5). Lime kiln dust is a by-product resulting from the production of lime. After achieving moderate success with these smaller projects, and in conjunction the Federal Highway Administration's Demonstration Project Number 59, a pozzolanic base design was selected to be constructed on a portion of Man O'War Boulevard in Lexington (6). A site map showing the location of the Demonstration 59 project is contained in Figure 5. For Kentucky's fly ash demonstration project, the pozzolanic stabilized base material consisted of 10.0 inches of a mixture of eight percent fly ash, eight percent lime kiln dust, and 84 percent limestone aggregate material. A bituminous curing membrane material was applied to the base course immediately after placement to facilitate curing by slowing moisture loss and facilitating the absorption of heat. A minimum compressive strength of 600 psi was required at seven days when samples were prepared and cured

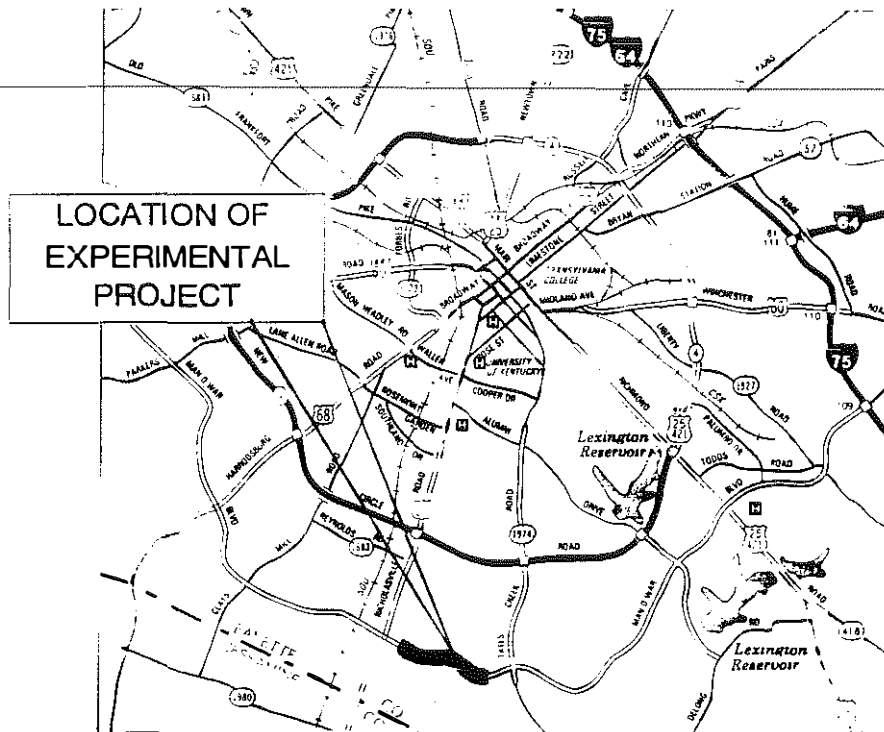


Figure 5. *Location of Demonstration Project Number 59 in Fayette County.*

according to KDOH Special Provision 70(79) - Fly Ash Stabilized Bases. A bituminous stress-absorbing membrane interlayer consisting of 3/8-inch size aggregate, emulsified asphalt, and a polymer additive was applied with the expectation that reflective cracking in the asphaltic concrete surfacing would be minimized. A thickness of four inches asphaltic concrete was placed as the final phase of pavement construction.

The demonstration project was a 1.7-mile section of Man O'War Boulevard in southern Fayette County extending from Nicholasville Road (US 27) eastward to Tates Creek Pike (KY 1974). The design average daily traffic was 14,000 vehicles per day with approximately two percent trucks. The original design for the arterial collector called for two 12-foot lanes with turning lanes where needed. Terrain over the section is generally flat to slightly rolling. The highway is crowned with curb and gutter drainage facilities located on either side of the roadway. Four alternate pavement designs were included in the bid proposal. Alternate pavement thickness designs were determined on the basis of 500,000 Equivalent Axleloads and a CBR 5 subgrade material. Bids were received on only two of the four alternates. The bid for a full-depth asphaltic concrete design exceeded the bid of \$2,200,000 for the pozzolanic base alternate by only \$3,000.

The Class F fly ash for the mixture was obtained from Kentucky Utilities Company's E. W. Brown Station located in Burgin, Kentucky. The fly ash source was located within 40

miles of the project site. Lime kiln dust (baghouse lime) was supplied by Dravo Lime Company located near Maysville, Kentucky. The lime kiln dust source was located within 100 miles of the project site. Specimens of the experimental mixture were prepared in general accordance with ASTM C 593 in 4-inch by 4.6-inch molds for evaluation of compressive strength and modulus of elasticity. Deviations from that method involve the use of a 5.5-lb. hammer and a 12-inch free fall instead of the specified 10-lb. hammer and 18-in. drop.

Materials submitted to KTC for analyses indicated a maximum dry density of 145.0 pcf and optimum moisture content of 6.6 percent for the proposed design when tested in accordance with ASTM D 698. Unconfined compressive strengths were determined in accordance with ASTM C 39. The static chord elastic modulus was determined by method ASTM C 469. Various curing conditions were utilized in an effort to determine how curing conditions affect the strength parameters of the pozzolanic mixture. Specimens cured seven days in a 100°F oven in a sealed container and soaked prior to testing had an average unconfined compressive strength of 2,100 psi and an average elastic modulus value of about 150,000 psi. Unconfined compressive strength values for the twelve specimens ranged from 1,630 psi to 2,760 psi. Elastic modulus values for the twelve specimens ranged from about 75,000 psi to 300,000 psi.

Elastic layer concepts were applied to formulate the thickness design of pozzolanic base layer. Thickness design requirements for the pozzolanic base alternate were determined by first using the Kentucky flexible pavement design procedure to determine thickness requirements of conventional materials (asphaltic concrete and crushed limestone). AASHTO structural coefficients of $a_1 = 0.44$ for asphaltic concrete and $a_2 = 0.14$ for crushed stone were used to determine the structural number for the conventional design. This structural number (SN) was then used in combination with the AASHTO design equation $SN = [a_1 \times d_1] + [a_2 \times d_2]$ and a structural coefficient of $a_1 = 0.44$ for the asphaltic concrete layer and an assumed structural coefficient of $a_2 = 0.28$ for the pozzolanic base material to determine the thickness requirement for the pozzolanic base layer.

Preparation of the soil subgrade was completed in September 1984. Subgrade moisture, density, and laboratory and in-situ California Bearing Ratio (CBR) information were obtained after compaction of the soil. Subgrade density measurements and moisture determinations were made using nuclear instruments. Values of CBR's of remolded field samples were obtained in accordance with Kentucky Method 64-501-80. Measurement of

in-situ subgrade strength was in general accordance with ASTM D 1883, except that the tests were performed on the soil in its actual in-situ condition. Moisture content of the soil for the in-situ CBR test was determined in accordance with ASTM D 2216. The pozzolanic base material was blended in a continuous volumetric-proportion pugmill. Lime kiln dust was fed dry from a silo onto an aggregate belt. Conditioned fly ash was stockpiled without protection and loaded into the feeder bin at the prevailing moisture content. Occasionally, problems were encountered with clumping of the fly ash which would prevent uniform flow through the bin opening. Dense graded limestone aggregate materials were also loaded into the feeder bin at prevailing moisture contents. The amount of mixing water required for optimum conditions was computed and the proper amount of water required for blending was added accordingly. The blended base material was transported approximately ten miles to the paving site by dump truck.

The pozzolanic base materials were end dumped into and spread by a conventional aggregate spreader box pushed by a small bulldozer. A motor grader was used to distribute the base material around preformed concrete curb and gutter at intersecting roads. The 10.0 inches of base material was placed in two equal lifts and compacted using steel-wheeled vibratory rollers having a minimum weight of ten tons. A compaction requirement of 102% of laboratory dry density was specified for the pozzolanic base. During construction, fewer than 30 percent of the nuclear density tests met this requirement. The average density was only 100.3 percent of the required density of 145.0 pcf. The standard deviation of the density was 1.6 percent. After compaction, a motor grader was used to trim the base material to grade. When the proper elevation grade was achieved, the bituminous curing seal was placed. Because of the occurrence of reflective cracking at the earlier project, a change order was executed for application of a rubber-asphalt stress-absorbing membrane interlayer (SAMI). Scheduling difficulties prevented its use and, instead, a CRS-2S polymer emulsion was used with No. 9m limestone chips (3/8 inch maximum) to construct a stress relief layer approximately 1/2 inch thick. Application rate of the limestone chips was about 27 pounds per square yard. The stress relief layer was applied to the 10.0-inch pozzolanic base material from Station 400+06.50 to Station 437+78.25 and from Station 452+78.25 to Station 490+50.00. A 1,500-foot section in the center of the demonstration project did not receive the stress relief layer. Asphalt pavement construction was begun approximately three weeks after placement of the pozzolanic base material. Placement of the lime kiln dust-fly ash-limestone aggregate base was completed by October 1984. Placement of asphaltic concrete layers was completed by mid-November, 1984. Final inspection and acceptance of the project resulted in January, 1985.

During and after construction, investigations relative to the engineering properties of the fly ash stabilized aggregate base continued. Laboratory compacted field materials were cured under various conditions and subjected to destructive testing. Cores of the pozzolanic base were obtained and tested for compressive strength at varying ages. Road Rater deflection surveys were performed on compacted subgrade, cured base material, and asphaltic concrete layers. Visual distress surveys were performed to assess the condition of the pavement.

Specimens made from field materials for evaluation of compressive strength and modulus of elasticity were prepared. Moisture-density relationships were determined. Unconfined compressive strengths and static chord elastic moduli were determined. There were some differences between compressive strengths and elastic moduli of laboratory compacted samples and field cores. These differences were attributed directly to the degree of compaction obtained during construction. Only 29% of the field densities obtained during construction met the required compaction of 102% of the laboratory dry density. Because compaction requirements were not always met, differences in the compressive strengths and elastic moduli of laboratory compacted specimens and field cores can be expected.

An inspection of the compressive strength data of field specimens exemplified the long-term strength gain characteristics of a lime kiln dust-fly ash-aggregate base. The average compressive strength of cores obtained and tested after 14 days was 725 psi. This average increased to about 1,735 psi at 65 days and to 2,335 psi at about 525 days.

Deflection measurements were obtained at various stages of construction. More specifically, deflection measurements were obtained after compaction of the subgrade but before placement of the pozzolanic base material, and at various intervals after placement of the asphaltic concrete material. An inspection of deflection data presented indicates a considerable reduction of deflection after placement of the pozzolanic base material. One series of deflection measurements was obtained after completion of all construction activities. Back-calculation of specific elastic layer moduli indicate that the moduli of the pozzolanic base material is most likely within a range of 5×10^5 to 1×10^6 psi.

This experimental project has been visually surveyed periodically for observable pavement distresses since completion of construction activities. Factors such as rutting and cracking were of principle concern. Overall, the pavement has demonstrated excellent performance. The most notable distresses observed were shrinkage cracks appearing

around most curb inlet drains. There was a distinct pattern to the cracking of the asphaltic concrete located around those drains that exhibited cracking. The geometric design of the curb inlet drains appeared to prevent proper compaction of the pozzolanic base layer in the vicinity of the drains. Field observations during the construction phase indicated that the contractor did not exert any effort to provide proper compaction around the curb inlet boxes (i.e., use of a pneumatic tamping device). Visual surveys indicated that fine debris accumulated in the gutter area near some curb inlet drains and vegetation was growing there. The obstruction in the gutter area caused water to flow out onto the traffic lane. The overflow water infiltrated the experimental base by seeping through the shrinkage cracks and the longitudinal joint at the curb gutter pavement interface. This action caused minor fatigue damage of the pavement, in the form of alligator cracking, in the area immediately adjacent to the drain inlet. Seven transverse reflective cracks were documented in the sections receiving the stress relief interlayer. However, of particular interest was the amount of reflective cracking in the section not receiving the stress relief interlayer. The 1,500-foot section contained three transverse cracks which principally, extended from curb to curb. Subsequent visual surveys indicated increased incidence of reflective cracking in the section not having the stress relief interlayer. Due to the relative increase in the amount of reflective cracking, it was concluded that the stress relief interlayer minimized reflective cracking of the bituminous pavement.

Scrubber Sludge and Pond Ash Combined for Highway Subbase Layer, Sebree Bypass, Webster County

During 1983, a laboratory analysis of flue gas desulfurization sludge (scrubber sludge) and pond ash was conducted to assess the potential of the materials for use as a highway subbase and/or embankment material (10). The laboratory study confirmed that scrubber sludge from the Big Rivers Power Plant in Sebree, in combination with pond ash from the same plant, could be used for either application. Analyses completed on pure scrubber sludge as an embankment material indicated that embankments 20 feet or less in height could be constructed with side slopes no greater than 3.5:1. For embankments greater than 20 feet, it was found that the side slopes should be 4:1 or flatter. It was stressed that scrubber sludge as an embankment material would only be economical when suitable fill materials were not available at or near the fill site.

The optimum laboratory mix design of 20 percent scrubber sludge and 80 percent pond ash was selected to construct an experimental subbase. The seven-day compressive

strength of the mixture was 150 psi. The design modulus of elasticity was determined to be 18,000 psi. Elastic layer theory was used to determine thickness requirements on the basis of elastic layer theory and laboratory-determined engineering properties. Results of these analyses suggested a pavement subbase thickness of 16 inches, aggregate base thickness of eight inches, and asphaltic concrete thickness of 6-1/2 inches.

Construction of the experimental pavement system on the Sebree Bypass, KY 494, in Webster County, utilizing the scrubber sludge and pond ash mixture began in July 1984 and was completed by October 1984 (see Figure 6). Prior to construction, samples were obtained from the stockpiled materials and tested for moisture contents. Target values of optimum moisture content and maximum dry density were obtained by compacting a mixture of 80 percent pond ash and 20 percent scrubber sludge. The target values for the optimum moisture content and maximum dry density were 11.0 percent and 132.8 pcf, respectively. It was originally intended to use belt feeders and a pug mill to blend the materials in the desired proportions. However, the scrubber sludge in its stabilized condition was so cohesive, it would not feed properly with the available equipment. To facilitate blending, the materials were proportioned by volume and mixed on the ground using front-end loaders. The final mixture was obtained by feeding the blend into an unheated conventional asphalt plant mixer and adding water to obtain the optimum moisture content. Although this method resulted in a fairly uniform moisture content, the mixture still did not seem completely homogeneous. Scrubber sludge appeared to form

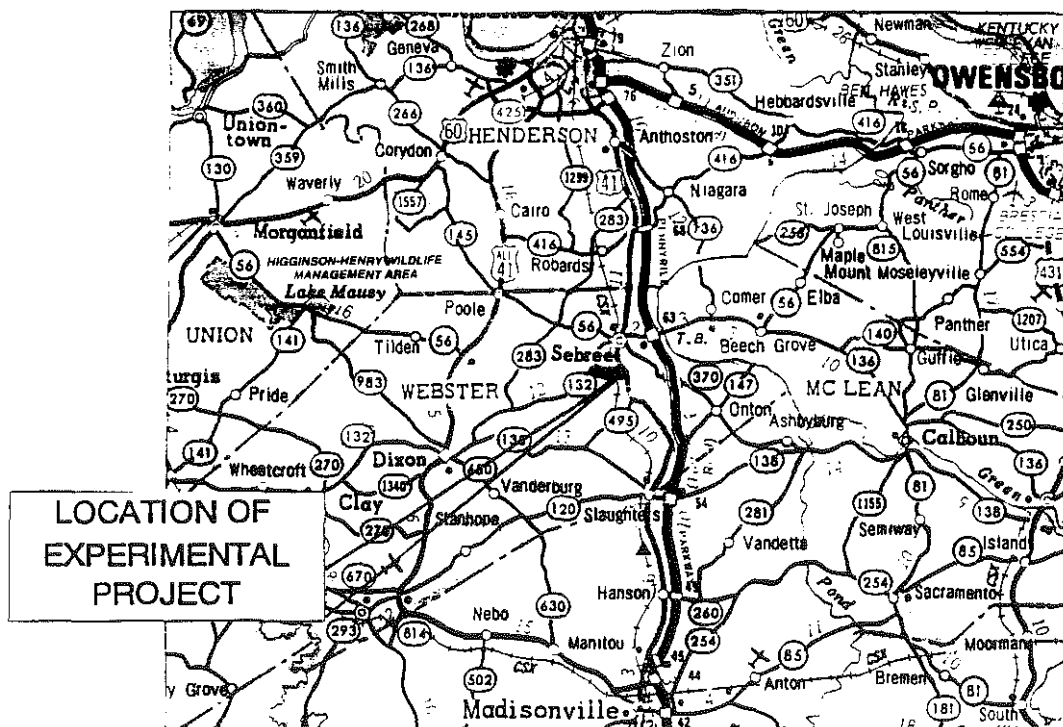


Figure 6. Location of Sebree Bypass project in Webster County.

pockets in the mixture. The scrubber sludge pond ash mixture was placed using a conventional aggregate spreader box. The experimental subbase materials were placed in three lifts of four to six inches each for a total depth of 16 inches. Density and moisture content were monitored using nuclear density meters. Moisture was added at the plant if necessary. Typically, results from the field moisture-density tests compared favorably with those obtained in the laboratory. As each layer was placed the material at the surface appeared to dry quickly, producing discontinuities in the homogeneity of the subbase course. There were pockets of almost pure scrubber sludge, which has a much higher capacity for retaining water. Overall, however, staff personnel concluded that the experimental subbase material was very workable and appeared, when compacted, to possess the expected design characteristics.

Periodic visual surveys and deflection tests were conducted at the Sebree Bypass site in conjunction with this study. Attempts were made to obtain field core specimens. Unfortunately, analyses of the deflection data were not performed and field core specimens could not be obtained. Nevertheless, the visual condition of the roadway has proven to be exceptional. There were some minor surface distresses observed which evidently were due to pond ash contaminating the bituminous surface mixture. The contamination resulted in a few popouts and staining of the surface. Notwithstanding these obstacles, the performance of the pavement overlying the experimental subbase materials has been outstanding to date and future uses of the scrubber sludge and pond ash mixture could be viable solutions to the use of naturally occurring materials. However, economic evaluations indicated that a scrubber sludge and pond ash mixture could only be economically attractive when transportation costs remain minimal.

Experimental Field Trial of AFBC Concrete Base Layer, Shawnee Power Plant, McCracken County

This experimental field trial was the inaugural use of a roadway base comprised of AFBC residue, Class F fly ash, and limestone coarse aggregate (see Figure 7). Preliminary laboratory evaluations and the application of those results to the design and construction of the roadway base have been documented (11). Evaluation and performance of the pilot application of this material used as a base for a thin bituminous pavement have also been presented (17). The total volume of AFBC residue utilized was approximately 32 cubic yards. Costs estimates were not available because the project was constructed using Tennessee Valley Authority (TVA) personnel and the construction materials were contributed by TVA for the pilot application. Staff members from TVA's Performance

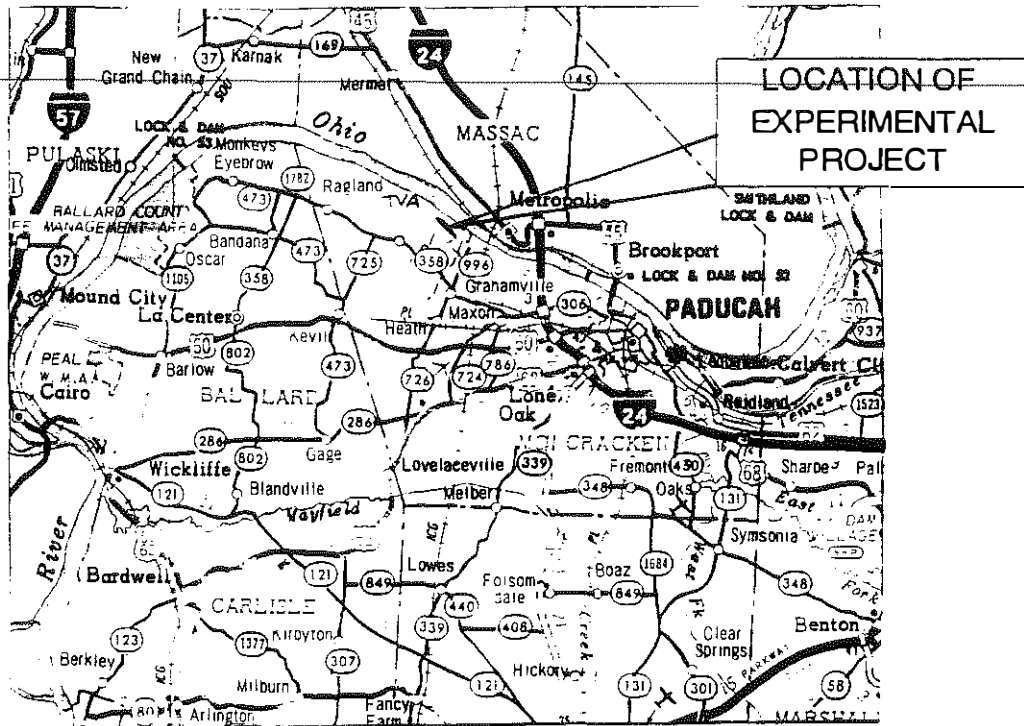


Figure 7. Project location at Shawnee Power Plant in McCracken County.

Evaluation Section assured Kentucky Transportation Center (KTC) staff personnel that the AFBC material used in this manner was environmentally safe.

Two experimental test sections were constructed contiguously to one another. One experimental section contained a mixture of pulverized fuel ash, atmospheric fluidized bed combustion residue, and conventional limestone aggregate. The second section contained a similar mixture but with a small amount of cement substituted for a portion of the limestone aggregate. Both experimental sections were constructed to a total nominal thickness of nine inches. The designed section included six inches of the experimental base mixture overlaid with three inches of asphaltic concrete.

The test sections containing the experimental mixtures were constructed in November 1985. Construction of the base layer was somewhat difficult as problems did occur. When the materials were blended at the batch plant, some material would invariably stick to the inside of the mixer. Placement of the material with a bulldozer appeared to be satisfactory but there was little control over the depth of the materials. The materials appeared to be placed wet of optimum and the mixtures could not immediately be compacted using the smooth-wheeled vibratory roller. The base mixtures hardened rapidly and proper grade was not attained. It was recommended that in the future, the

materials be blended in a pug mill, placed slightly dry of optimum with a conventional aggregate spreader and compacted with a smooth-wheeled vibratory roller. Proper grade should be obtained before leaving the jobsite. A bituminous curing seal is necessary to ensure proper curing of the base material.

The sections were monitored for performance over a three year period. Evaluations included strength determinations of the mixtures, Road Rater deflection testing and visual observations. Results of destructive testing activities generally indicated higher compressive strengths and elastic moduli for field compacted specimens than laboratory compacted specimens when cured under similar conditions. This was due to slight differences in mixture proportions, compaction methods, and moisture available for hydration of the mixtures. The average compressive strengths of specimens compacted in the field and cured at room temperatures for 28 days were 2,570 psi for the mixture containing a small amount of cement and 1,480 psi for no-cement mixture. However, specimens prepared in the laboratory of the no-cement mixture had higher compressive strength values than mixture containing cement. Those values were 1,025 psi and 2,275 psi, respectively, for mixture containing cement and the no-cement mixture. Similar differences between specimens molded in the field and laboratory compacted specimens were noted for values of elastic moduli. The average elastic modulus value of specimens compacted in the field was 830,000 psi for mixture containing cement and 510,000 psi for the no-cement mixture. Laboratory prepared specimens had average moduli values of 385,000 for the mixture containing cement and 750,000 for no-cement mixture.

Destructive testing of field core specimens validated results of the laboratory study. Compressive strengths and moduli values were higher for the field core specimens obtained from the no-cement mixture. Core specimens tested at 268 days age indicated an average compressive strength and elastic modulus value of 3,995 psi and 720,000 psi, respectively, for mixture containing cement. Field core specimens from the section containing the mixture without cement had average compressive strength and elastic modulus values of 5,320 psi and 770,000 psi, respectively, at 268 days. Core specimens from the section which had cement in the mixture, tested at 573 days age, indicated an average compressive strength and elastic modulus of 3,985 psi and 1,450,000 psi, respectively. Field core specimens from the section with the no cement mixture had average compressive strength and elastic modulus values of 3,825 psi and 2,170,000 psi, respectively, at 573 days.

Results of the deflection testing activities indicated the pavement structure containing the base material without cement had a lower stiffness than the section containing cement. It was estimated from the deflection analyses that the stiffness of the pavement

structure within the section having the base material containing cement was approximately 44 percent greater than the stiffness of the pavement structure where cement was excluded from the mixture.

It was concluded, based upon the performance observations and evaluation activities, that both experimental mixtures would be suitable for use as a road base material. The test sections performed well with no cracking, rutting or deterioration observed. Both mixtures of the experimental road base materials were marginally as strong as typical concrete but had lower elastic moduli than typical concrete. Results of this study indicated that the pulverized fuel ash-atmospheric fluidized bed combustion residue-limestone aggregate mixture would serve well as an alternative road base material. Evaluation of the use of the experimental mixtures as a road base material provided valuable insight into its use.

Scrubber Sludge as an Embankment Material, KY 176, Muhlenberg County

An embankment constructed of pure scrubber sludge was constructed on the Drakesboro to Paradise Road in Muhlenberg County to eliminate a vertical sag curve by raising the elevation of the existing pavement (see Figure 8). The constructed embankment was approximately 15 feet at its highest point. The Tennessee Valley Authority requested to

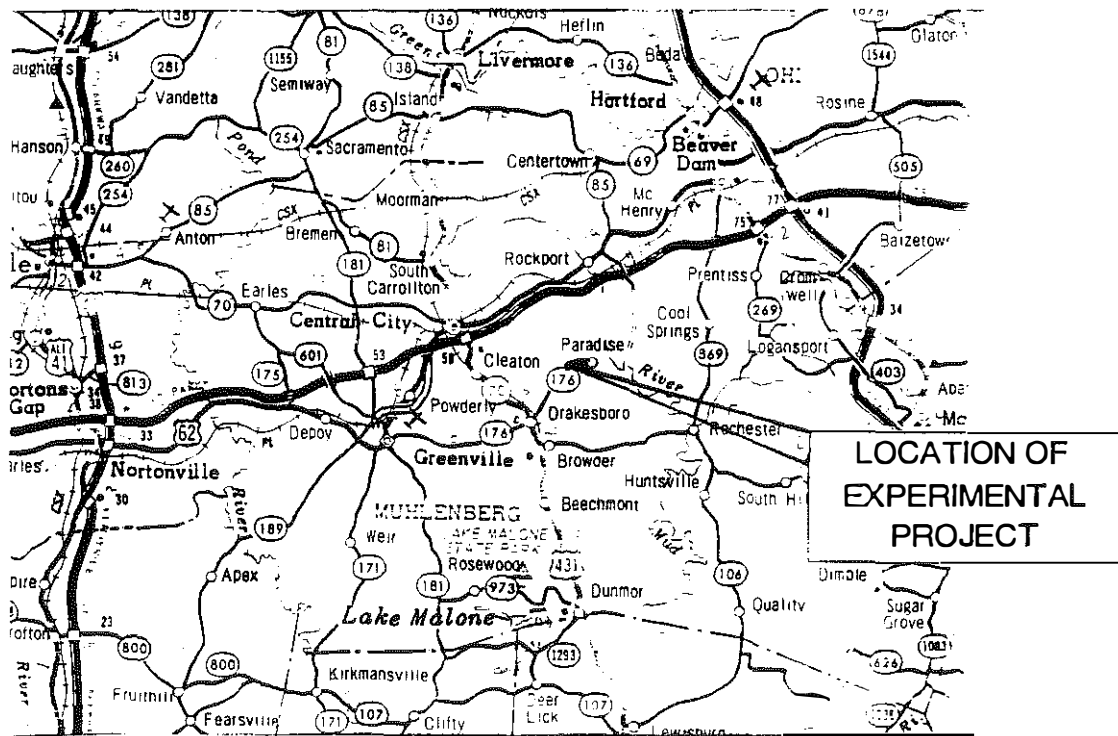


Figure 8. Project location on KY Route 176 in Muhlenberg County.

use pure scrubber sludge (oxidized) produced at the Paradise Steam Plant to construct the embankment. Construction of the embankment and related construction detour ultimately consumed about 140,000 cubic yards of scrubber sludge material which were stockpiled on the TVA reservation.

Evaluations of the use of 100 percent scrubber sludge as an embankment material were performed and recommendations presented to KDOH officials. The evaluations included determining the optimum moisture content and maximum dry density relationship of the sludge material, specific gravity, grain size distribution, Atterberg limits, and soil classification. Samples also were prepared for consolidated-undrained and unconsolidated-undrained triaxial tests.

A TVA representative supplied the initial sample for the evaluations. After the sample was transported to the KTC laboratory, technicians removed a small amount of the sample for moisture content determination. The sample was obtained from the center and at approximately 2/3 of the total depth of the material contained in a five-gallon bucket. After allowing the sample to dry overnight, the natural moisture content was determined to be 26.7 percent. Immediately after obtaining the moisture content sample, procedures were initiated to determine the moisture/density relationship of the material. Optimum moisture content and maximum dry density were determined using a polynomial fitting program. A smoothing technique was used to eliminate localized changes in concavity. The first trial established an optimum moisture content of 31.2 percent and a maximum dry density of 83.7 pounds per cubic foot, (pcf). A second determination was performed the following day to verify results of the first trial. Procedures used for the second trial were identical to the first trial. The natural moisture content of the material was 25.3 percent. Results from the second moisture/density trial indicated an optimum moisture content of 29.9 percent and a maximum dry density of 87.4 pcf. A third series of tests was performed using the same procedures as was used previously. The natural moisture content of the scrubber sludge material was 17.6 percent. Results from the third moisture/density trial indicated an optimum moisture content of 32.2 percent and a maximum dry density of 84.4 pcf.

While determining the moisture/density relationship of the scrubber sludge material, technicians also investigated other properties of the material including specific gravity, grain size distribution, Atterberg Limits, and soil classification by the Unified and AASHTO classification systems. Specific gravity was determined in accordance with ASTM standards. A dispersing agent (four percent Calgon) had to be used to prevent the

scrubber sludge from rapid set in the specific gravity flask. The specific gravity of the material was determined to be 2.89. The grain size distribution and hydrometer analysis indicated that nearly 93 percent of the material is silt size. The test for Atterberg Limits found the material to be non-plastic and the scrubber sludge was classified as CL by the Unified Classification System and A-4 (0) by the AASHTO Classification System.

Samples for consolidated-undrained triaxial tests, with pore pressure measurements, and unconsolidated-undrained triaxial tests were prepared using results from the third moisture/density trial, (32.2 percent optimum moisture content and 84.4 pcf dry density). Samples were compacted to 95 percent of the optimum density. Results of the triaxial analyses of consolidated-undrained samples indicated a cohesion value of 1,322.0 psf and a friction angle equal to 39.2°. Results of the triaxial analyses of unconsolidated-undrained samples indicated a cohesion value of 1,027.7 psf and a friction angle equal to 41.8°.

Results from the laboratory testing activities indicated that the design submitted by TVA engineers was satisfactory based upon the shear strength properties of the scrubber sludge material provided by TVA representatives. Because the scrubber sludge did not come from the stockpile that was to be used during construction of the embankment, another series of tests were performed using materials obtained from the actual stockpile of scrubber sludge that was proposed for use.

Three bag samples obtained by KDOH personnel were submitted to the KTC laboratory for comparative analysis. The bag samples were identified as A, B, and C. Initial moisture contents were 31.2 percent, 27.6 percent, and 29.3 percent for samples A, B, and C, respectively. Moisture/density relationships were determined for each bag sample. Moisture-density relationships were determined using procedures identical to those used during the initial analysis. Sample A had an optimum moisture content of 36.0 percent and a maximum density of 83.8 pcf. Sample B had an optimum moisture content of 31.2 percent and a maximum density of 87.1 pcf. Sample C had an optimum moisture content of 34.6 percent and a maximum density of 86.4 pcf.

Triaxial tests were performed on samples prepared from each bag using the average of results obtained from moisture-density determinations, (33.9 percent optimum moisture content and 85.8 pcf dry density). Samples for consolidated-undrained triaxial tests, with pore pressure measurements, were compacted to 95 percent of the optimum density. Results of the consolidated-undrained triaxial analyses of three samples prepared from

Bag A indicated a cohesion value of 755.4 pounds per square foot, psf, and a friction angle equal to 35.9°. Samples prepared from Bag B indicated a cohesion value of 0 psf and a friction angle of 37.8° and samples prepared from Bag C had a cohesion value of 0 psf and a friction angle equal to 41.2°.

Samples also were tested at the Division of Materials' Geotechnical Group relative to optimum moisture-maximum dry density determination, triaxial test, grain size analysis, soil classification, specific gravity, and California Bearing Ratio (CBR). The scrubber sludge had a optimum moisture content of 34.0 percent and a maximum dry density of 83.0 pcf. Two triaxial tests were conducted and indicated cohesion values of 0 psf, and friction angles of 40.5° and 42.4°.

Results from the additional analyses of the scrubber sludge material compare favorably with the initial results. Because results of tests performed on scrubber sludge material from the stockpile proposed to be used for the embankment construction were comparable to earlier test results, it was recommended to KDOH officials that construction of the embankment be permitted as designed.

A TVA construction crew built the embankment with actual construction proceeding swiftly. The job foreman indicated that the scrubber sludge material went in very tight and compacted well at a moisture content of about 28 percent. Pumping of the scrubber sludge occurred at moisture contents above 28 percent. Target densities were easily achieved. The scrubber sludge was placed and compacted in lifts approximately two-feet thick. A two to four-foot thickness of soil was placed above the scrubber sludge as required by the design. The pavement structure included a 13-inch thickness of crushed stone, six inches of bituminous base, and one inch bituminous surface. Only periodic visual surveys have been conducted at the site. Preliminary results indicate excellent performance of the constructed embankment and roadway.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The objectives for this research study were: to identify by-product materials and sources of materials that may be suitable for highway applications; conduct laboratory evaluations of mixtures comprised of by-product materials or by-product materials combined with conventional materials; plan, design, and monitor construction of a test

road(s) involving by-product materials in the pavement surface, base, subbase, or subgrade layers; assess the positive and negative environmental impacts of using by-product materials in highway construction; compare the performance of experimentally constructed sections relative to that of conventionally constructed sections; develop specifications and recommendations for implementation for the utilization of by-product materials in highway applications; and, develop specifications for design and construction procedures of pavement structures containing by-product waste materials.

This report, the final report for the research study, details the fulfillment the stated objectives of the research study. By-product materials and sources were identified, through a review of literature and industry survey, that were considered suitable for highway applications. By-product materials examined during the course of the study included fly ash, bottom ash, multicone kiln dust, scrubber sludge, and two distinctly different by-products from AFBC processes.

Previous reports issued in conjunction with this study have documented extensive laboratory investigations undertaken to determine engineering properties of individual components of proposed mixtures of by-product materials and of by-product materials combined with conventional construction materials. Materials and construction specifications were developed based on the laboratory evaluations. The reports also have documented procedures employed to design experimental test sections involving by-product materials. The experimental sections included a surface course containing bottom ash aggregate as a partial replacement for the limestone aggregate; base and subbase courses containing AFBC residue, pond ash, and scrubber sludge; an embankment constructed of pure scrubber sludge; and, a highway soil subgrade modified with residue from and AFBC process and multicone kiln dust. The project reports contain documentation of construction activities and subsequent monitoring activities. There were no known negative impacts resulting from the use of the by-products materials in the highway construction applications. Positive impacts from using by-product waste materials in highway construction applications are reductions in the land area associated with disposal and conservation of other valuable resources. Performance of the field trials has been compared with conventionally designed and constructed sections and reported. The conventionally designed and constructed sections served as control sections and oftentimes were constructed contiguous to the experimental test sections.

The economic viability of using by-product materials in highway applications could not be properly addressed by the study. Although the waste materials were supplied for the projects at no cost, the bid price of using the experimental materials would exceed the bid price of placing the conventional materials. For example, a three percent increase in

the asphalt content of the bituminous surface mix containing bottom ash aggregate resulted in a \$10.00 increase in the unit bid price for a ton of the experimental bituminous surface mix, even though 40 percent of the bituminous surface mixture was a waste material supplied to the contractor for the project at no cost and the increased asphalt content would have added only about \$4.35 to the unit cost. This example exemplifies the contractor's risk associated with the use of experimental materials. Proven usability of a by-product material may lower the cost somewhat, but transportation costs would necessarily have to be kept to a minimum to make by-product materials used in highway applications, in lieu of natural materials, economically viable.

Based upon the experience and knowledge gained through research of the by-product materials utilized in this study for highway applications, it appears quite probable that comparable, or even extended pavement life may be achieved by using some of these by-product materials. Particularly successful were the field trials involving the use of scrubber sludge in a pavement subbase layer and as an embankment fill material, the use of multicone kiln dust as a soil subgrade modifier, and the use of ponded fly ash in lieu of specification fly ash in a stabilized aggregate base layer. Future use of these by-product materials in these applications are recommended where considered feasible. The specifications developed in the Special Notes for the design and construction procedures for the use of these by-product materials in pavement structures are practical approaches to the applications and could be used in the future without significant modifications. The Special Notes have been reproduced in Appendix A of this report.

However, problems were encountered with both uses of residues from the AFBC processes. Only the two uses of the AFBC residue from the Shawnee Power Plant were considered as complete failures. The obstacles to the successful use of the materials could possibly be eliminated or, at least, minimized. Undoubtedly, with suitable, documentable, pretreatment of the AFBC residue from the Shawnee Power Plant combined with the use of a pug mill, a successful field application of the laboratory mixture design would have transpired. Likewise, adequate construction controls during the application of the Ashland Oil AFBC residue as a soil modifier may have eliminated or minimized the non-uniform vertical swell of the modified soil subgrade. The use of the AFBC residue on KY Route 11 may now be considered a success because after the initial problems occurred, analyses of the AFBC modified soils indicated cessation of the primary swell characteristics of the modified soils after a short period. These analyses also indicated only minor secondary swell characteristics of the AFBC modified soils. Since the two experimental sections were milled and overlaid, they have demonstrated excellent performance to date. The AFBC modified soil maintains elevated bearing capacity and shear strength properties when compared to the untreated soil.

It may be concluded from the results of the field trial applications that some by-product materials are very well suited for highway construction applications. It may also be concluded that uses of the AFBC residues will require additional research and stricter construction controls before successful uses in highway applications are achieved. Therefore, it is recommended that supplementary research be conducted to specifically identify solutions to the difficulties encountered during the experimental field trials. It also is recommended that monitoring of in-place experimental sections be continued under the long-term monitoring study. Visual distress surveys, sample extractions, and pavement deflections obtained over a period of time will provide valuable information relative to the long-term structural behavior of the experimental field trials. The historical performance and deflection data and analyses will provide specific information relative to the practicality of the design and construction specifications developed as a result of this study and the long-term performance characteristics of these experimental sections.

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APPENDIX

SPECIAL NOTES

USE OF BY-PRODUCT MATERIALS IN HIGHWAY CONSTRUCTION

SPECIAL NOTE
for
MKD ROADBED STABILIZATION
(Experimental)

I. DESCRIPTION

This work shall consist of roadbed stabilization constructed by uniformly mixing multi-cone kiln dust (MKD) with the roadbed soil, and the resulting mixture moistened and compacted to the lines, grades, thicknesses, and cross sections as specified in the contract. Section references herein are to the Department's Standard Specification for Road and Bridge Construction.

II. MATERIALS

The MKD shall be the by-product of Dravo Lime Company's Maysville, Kentucky plant.

Bituminous material for the curing seal shall be as either RS-1, AE-60, SS-1, SS-1h, CRS-1, CSS-1, CSS-1h, or primer L, and shall meet the requirements of Section 806.

Water shall be obtained from a source approved by the Engineer.

III. CONSTRUCTION REQUIREMENTS

A. Temperature and Weather Limitations.

During seasons of probable freezing temperatures, no MKD shall be applied unless the temperature is at least 40°F in the shade and rising, or between October 1 and March 31.

B. Equipment.

Hauling equipment shall be the same type equipment normally used for hauling portland cement. Any modification to the hauling equipment, or any additional equipment, that may be necessary to load the MKD at Dravo Lime Company's terminal without producing objectionable dust is the responsibility of the Contractor.

Any machine, combination of machines, or equipment, which will produce the completed stabilized roadbed meeting the requirements for pulverizing soil, distributing MKD, applying water, mixing materials, compacting, finishing, and providing protection and cover, as controlled by these specifications may be used upon approval by the Engineer. The machines and equipment used shall be maintained in a satisfactory operating condition at all times during use.

C. Job-Site Storage.

MKD may be stored on the project up to 3 days in approved hauling vehicles. Weatherproof storage facilities shall be provided if longer term storage is necessary. In no event shall the MKD be stored longer than 60 days.

D. Preparation of Existing Roadway.

Before proceeding with other construction operations, the roadway shall be graded and shaped to conform to the grades, lines, and cross section required for the completed roadway.

Before stabilization begins, the elevation of the subgrade shall be approved by the Engineer to allow for anticipated volume increase when the MKD is added. The subgrade shall conform to the +/- 1/2 inch tolerance specified in Section 208.03 of the Standard Specifications both before and after stabilization. After stabilization, the Engineer may make such minor adjustments in plan grades as he deems necessary.

E. Application of MKD.

The characteristics of the soils actually encountered in the subgrade may affect the quantity of MKD necessary or desirable. The Department reserves the right to increase or decrease the quantity of MKD used, if deemed necessary by the Engineer.

MKD shall be spread at the required rate by equipment which will uniformly distribute the material without excessive loss. Due to the experimental nature of the use of MKD, the application rate may vary from 5% to 10% by volume as directed by the Engineer.

MKD (dry) shall not be applied during periods of high winds which cause excessive loss of material.

No traffic or equipment shall be permitted on the spread MKD other than that required for spreading, watering, or mixing.

The MKD shall be prepared, transported, distributed, and mixed with the soil in a manner that will not cause injury, damage, discomfort, or inconvenience to individuals or property.

F. Mixing.

(1) *Test Section.* When mixing begins, the contractor shall construct a test section at least 100 feet long and one traffic lane wide, to demonstrate the acceptability of his equipment and methods, and to provide a check on the resulting finish grade elevation. Changes in equipment or methods, or the initial grade elevations, shall be made as needed based on results of the test section. If changes in methods or equipment are made during the project, additional test sections may be required.

(2) *Primary Mixing.* The optimum moisture content specified will be determined by the Engineer in accordance with KM 64-511 on mixtures of MKD and representative soil samples taken from the base material to be processed. Two-thirds of the specified quantity of MKD shall be spread and immediately thoroughly mixed into the soil for the full depth of treatment. Immediately after dry mixing, water shall be added to the mixture so the moisture content is no less than optimum, nor more than optimum plus 5%. The primary mixing operation shall be completed within four hours after application of MKD. At this time, the result shall be a homogeneous, friable mixture free from clods or lumps exceeding 2 inches in size.

After primary mixing, the MKD-treated layer shall be shaped to the approximate cross section and lightly compacted to minimize evaporation loss. The surface shall be crowned so as to properly drain.

(3) *Preliminary Curing (mellowing).* Following primary mixing, the stabilized layer shall be allowed to cure for at least 48 hours, to permit the MKD and water to break down or mellow the clay clods. The characteristics of the soil, temperature, and rainfall may influence the curing period necessary. The actual curing time shall be as determined by the Engineer, and final mixing and pulverizing shall not be performed

until permitted by the Engineer. During preliminary curing, the surface of the material shall be kept moist by continuous sprinkling or other approved method to prevent drying and cracking.

(4) *Final Mixing and Pulverizing.* Immediately after completion of the preliminary curing, the remaining one-third of the MKD shall be spread and the stabilized layer shall again be completely mixed and pulverized to the full depth of stabilization. Final mixing shall continue until all clods are broken down so that 100%, exclusive of rock particles, will pass a one-inch sieve and at least 60% will pass a No. 4 sieve. Additional water shall be added if necessary so the moisture content of the completed and compacted roadbed is between optimum and optimum plus 5%.

(5) *Exceptions.* Upon the approval by the Engineer, the Contractor may construct a test section to demonstrate that the entire quantity of MKD can be added, acceptably mixed, and the pulverization requirement in paragraph (4) above can be met in one operation. If the demonstration is successful, the preliminary curing and final mixing steps can be eliminated.

G. Compaction and Surface Finish.

Prior to the beginning of compaction, and as a continuation of the mixing operations, the mixture shall be thoroughly loosened to its full depth. The mixture shall then be uniformly compacted for its full depth, to the specified density. Sheep's foot rollers will be required if the depth of treatment exceeds 8 inches. During compaction, the surface of the stabilized roadbed shall be reshaped to the approximate crown and grade.

The mixture shall be compacted to at least 95% of the maximum density obtained by KM 64-511. Density determinations will be made in the field by KM 64-512 or by nuclear gages.

After the mixture is compacted, the surface of the roadbed shall be reshaped, at optimum moisture content, to the required lines, grades, and cross section.

The moisture content of the material must be maintained at no less than its specified optimum during all finishing operations. The surface compaction and finishing for the specified width of stabilized roadbed shall be done in a manner to produce, a smooth, closely-knit surface, free from cracks, ridges or loose material; and the finished surface shall conform to the required crown, grade, and line.

The density of all the stabilized roadbed will be determined by the Engineer each day. Any portion of the roadway which does not meet the specified density shall be reconstructed to meet these specifications.

The average thickness of the roadway construction during one day shall be within 1/2 inch of the thickness shown on the plans, except that the thickness at any one place may be within 3/4 inch of that shown on the plans. Where the average thickness shown by the measurements in that day's construction is not within the specified tolerances, the Contractor will be required to reconstruct that day's work or portion of day's work at his sole expense.

After curing is completed, Department representatives will take samples from the stabilized roadbed. The Contractor shall cooperate with the Department's representatives, and shall not place succeeding pavement courses until the samples have been taken.

H. Curing and Protection.

After the roadbed has been finished as specified herein, it shall be protected against drying for 7 calendar days by applying a bituminous curing seal.

The curing seal shall be applied as soon as possible, but no later than 24 hours after completion of finishing operations. The finished roadbed shall be kept moist, by continuous sprinkling if necessary, until the curing seal is applied. When the bituminous material is applied, the surface of the roadbed 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 at the rate of approximately 1.6 pounds per square yard with approved distributing equipment. The actual rate and application temperature of bituminous material will be determined by the Engineer. The curing seal shall be applied in sufficient quantity to provide a continuous membrane over the roadbed.

No traffic or equipment other than curing equipment will be permitted on the finished surface 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 any damage occurs to the curing seal prior to completion of curing, the damaged area shall be immediately resealed at the Contractor's expense.

If the bituminous material is still tacky or sticky after the 7-day curing period has ended, and trucks are allowed to haul over the sticky material, a sand blotter material shall be applied at a rate of approximately 5 pounds/square yard, when required by the Engineer. The sand blotter shall be furnished and applied at the Contractor's expense, except when necessary to maintain public traffic.

Other acceptable curing materials or methods may be used upon written permission, at no change in cost to the Department.

Any finished portion of the roadbed, which is traveled by equipment used during construction of an adjoining section, shall be protected in a manner to prevent the equipment from marring or damaging the completed work.

When at any time the air temperature may be expected to reach freezing, sufficient protection against freezing shall be given the roadbed for 7 calendar days after placement.

It is intended that the stabilized roadbed shall be completely covered with the specified pavement courses before work is suspended for the winter months. The Contractor shall make every reasonable effort to accomplish this objective. When the stabilized roadbed is not completely covered by the specified pavement courses, 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, not a part of the specified construction 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 stabilized roadbed shall be subject to the approval of the Engineer.

I. Opening to Traffic.

Local traffic and construction equipment may be permitted to use completed portions provided the roadbed has hardened sufficiently to prevent marring or damaging of the surface by such usage, and provided that the cover for protection and curing specified in Section 304.11 is not impaired. Only pneumatic-tired construction equipment shall be permitted to operate over the completed work.

After the 7-calendar day curing period, all traffic will be permitted to use completed portions provided the roadbed has hardened sufficiently to prevent damage to the surface by traffic.

J. Maintenance.

The Contractor will be required to maintain the entire roadway within the limits of his contract in a condition satisfactory to the Engineer, for the duration of the contract. Maintenance shall include immediate repairs of any defects that may occur either before or after the stabilized roadbed is completed, which work shall be done by the Contractor at his own expense and repeated as often as necessary to keep the roadway continuously intact. Repairs shall completely restore the uniformity of the surface and durability of the repaired portion.

IV. METHOD OF MEASUREMENT

Multi-cone kiln dust (MKD) will be measured in tons for the quantity actually incorporated into the completed work.

All water used will be considered incidental to the work and will not be measured for pavement.

The stabilized roadbed will be measured in square yards of stabilized base actually constructed and accepted.

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

V. BASIS OF PAYMENT

The accepted quantities of MKD will be paid for at the contract unit price per ton, the accepted quantities of stabilized roadbed will be paid for at the contract unit price per square yard, and the accepted quantities of bituminous curing seal will be paid for at the contract unit price per ton, which payment shall be full compensation for all labor, equipment, materials, and incidentals necessary to complete the work as specified in the contract.

Payment will be made under:

<u>PAY ITEM</u>	<u>PAY UNIT</u>
MKD	Ton
MKD Stabilized Roadbed	Square Yard
Bituminous Curing Seal	Ton

August 27, 1987

SPECIAL NOTE
for
Bituminous Concrete Surface, Class I
(Experimental)

An experimental section shall be constructed on this project utilizing bottom ash aggregate from the Kentucky Power Company, Big Sandy Plant, near Louisa, Kentucky. The test section shall be approximately one mile in length and shall be placed between M.P. 19 and 25 as directed by the Engineer.

The Kentucky Power Company will offer up to 700 tons free of charge for use in the experimental test section. The Contractor shall make arrangements for obtaining the material by contacting:

Arthur H. Hill, Plant Manager
Kentucky Power Company
Big Sandy Plant
U.S. Route Number 23
P.O. Box 400
Louisa, Kentucky 41230
Phone (606) 686-2415

The bottom ash shall be made available from stockpiles located on plant property in an area known as Horseford Hollow which is located approximately 1/4 mile west of U.S. Route Number 23 at the location of the plant generating units. A plant service road leads from U.S. Route Number 23 to the stockpile area. Bottom ash shall be loaded from specific stockpile locations mutually agreed to by representatives of the Department and Big Sandy plant personnel. The Contractor will be responsible for loading his trucks at the designated plant stockpiles which may be accessed Monday through Friday (except holidays) 8:00 A.M. - 4:30 P.M. The Contractor will be required to execute a "Bottom Ash Purchase Agreement" and forward it to the Big Sandy Plant prior to obtaining the bottom ash.

Since the deposit may vary considerably in gradation, the Contractor shall stockpile the estimated quantity (maximum of 700 tons) for the experimental section at the bituminous mixing plant at least two weeks prior to starting work on the experimental section. The Contractor shall build the stockpile in layers and observe other normal precautions to blend and mix the aggregate prior to charging cold feeds in order to obtain a reasonably uniform gradation. The bottom ash contains some oversized material which must be scalped off prior to entering the bituminous mixing unit.

It is expected the test section will consist of a blend of approximately 50 percent bottom ash and approximately 50 percent of the standard aggregates utilized on the remainder of the project. The proportioning shall be as directed by the Engineer.

Contrary to the Special Note for Bituminous Pavements, the target asphalt content for the Class I Surface (experimental) shall be 10.0 percent. Quantities for Bituminous Concrete Surface, Class I (Experimental) are based on 95 psy/inch.

Any unforeseen circumstances which occur which makes construction of the experimental section impractical shall result in construction of the entire project utilizing Class I surface with standard aggregates.

SPECIAL NOTE
for
USE OF PONDED FLY ASH IN A
STABILIZED AGGREGATE BASE
(Experimental)

I. DESCRIPTION

This work shall consist of furnishing all materials, labor, equipment, and incidentals necessary to complete construction as shown on the plans and in accordance with provisions of the contract documents. 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.

Whenever a stabilized aggregate base is used, a stress absorbing membrane interlayer (SAMI) or other means to prevent development of bond between the stabilized aggregate base and subsequent pavement layers shall be used. When a SAMI is specified, the current edition of Special Provision No. 79, Stress Absorbing Membrane Interlayer (SAMI), shall apply to the contract.

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.

Dense Graded Aggregate, hydrated lime, bituminous curing seal, and the stress absorbing membrane interlayer (SAMI) will be considered conventional materials.

Dense Graded Aggregate (DGA) shall conform to the requirements of Section 805.

Hydrated lime 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 as either AE-60, SS-1, SS-1h, CRS-1, CSS-1, CSS-1h, or primer L, conforming to the requirements of Section 806.

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

- (1) ponded fly ash

The ponded fly ash material will be supplied and delivered to point(s) of mixing or stockpiling within the project limits or reasonably close thereto designated by the Contractor. The Contractor shall inform the Engineer of the location to which the ponded fly ash is to be delivered at least 2 weeks before the material will be needed.

The Contractor will not be responsible for ensuring that ponded fly ash materials meet physical and/or chemical requirements.

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 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 base shall not be placed between October 1 and March 1.

3. *Composition of Experimental Base Mixture.* Composition of the experimental base mixture 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 the start of construction. If the final job-mix proportions require quantities of hydrated lime or DGA 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.

Materials for the pozzolanic base shall consist of hydrated lime, ponded fly ash, and dense graded aggregate (DGA). Probable composition by weight of the mixture, excluding water, may be within the following ranges:

<u>Ingredients</u>	<u>Range (Percent by Weight)</u>
Ponded 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, current edition.

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 and 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 compaction, 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 materials 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 off 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 base 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.

Not 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 base 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 grades 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 stringlines, 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 base 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 base.

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 the bituminous material will be determined by the Engineer. Application temperature of the bituminous material shall be as specified in subsection 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 completion of curing, the damaged area shall be immediately resealed at the Contractor's expense.

B. Stress Absorbing Membrane Interlayer (SAMI). The entire surface of the experimental base, on which the contract requires construction of pavement; miscellaneous items such as curbs, curb and gutter, paved medians, etc.; or paved shoulders; shall receive a stress absorbing membrane interlayer (SAMI), or other bond-breaking layer when specified in the contract. Materials and construction requirements for the SAMI are covered in Special Provision No. 79, current edition. Requirements for other types of bond-breaking layers shall be as specified elsewhere.

C. 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 course 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 of 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 course shall be subject to the approval of the Engineer.

IV. METHOD OF MEASUREMENT

Stabilized aggregate base containing ponded fly ash will be measured in accordance with Section 109.

Water used for dampening the subgrade, mixing with the mixture, 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.

VII. BASIS OF PAYMENT

The accepted quantities of the experimental stabilized ponded fly ash-hydrated lime-dense graded aggregate 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:

<u>Pay Item</u>	<u>Pay Unit</u>
Stabilized Aggregate Base containing Ponded Fly Ash	Ton
Bituminous Curing Seal	Ton

June 30, 1993

SPECIAL NOTE
for
16-INCH COMPACTED SUBBASE CONSISTING OF
SCRUBBER SLUDGE AND POND ASH
(Experimental)

Reconstruction of KY 494
Martin Brown Road (Sebree Bypass), Webster County

I. DESCRIPTION

This special note shall be applicable to materials and construction requirements for a 16-inch compacted subbase for the above-referenced project from Station 26+08 to Station 128+00.

The subbase material shall consist of an intimate mixture of 20 percent scrubber sludge and 80 percent pond ash, by weight. The materials are located within the bounds of the Big Rivers Power and Electric Corporation's property.

II. MATERIALS AND MIXING

The scrubber sludge and pond ash shall be thoroughly and uniformly mixed in a twin shaft pugmill type mixer located in the immediate vicinity of the source of the materials, unless another type of mixer and/or another location of mixing are/is approved. The pugmill and other equipment related to the mixing operation shall be of sufficient capacity to provide a continuous supply of mixture required at the job site. Ingredient materials shall be stockpiled and permitted to dry to a degree such that specified density is obtained; however, materials shall not be permitted to dry to the extent that materials harden prior to mixing. Mixing shall be performed in such a manner as to produce mixtures having component materials evenly distributed throughout the mass and being of uniform unchanging appearance. Separate feeds may be necessary to achieve uniform blending. Mixing equipment and procedures are subject to approval by the Engineer.

The proportion of each material shall be maintained during production within +/- 2.0 percent of the specified percentages.

The Contractor shall ensure that these materials are handled, stockpiled, transported, and placed so as to avoid contamination of water supplies, and to conform to all applicable Federal, State or local requirements relative to water pollution.

III. TRANSPORTING

The mixture shall be transported in such manner as to deliver the mixture to the job site without loss or segregation. Each truck load shall be covered with a heavy canvas sheet.

IV. SPREADING, COMPACTING, AND FINISHING

The subbase materials shall be spread and compacted on the prepared subgrade in layers not to exceed 6 inches compacted thickness. The mixture shall be deposited on a moist subgrade by approved spreading equipment. ~~Depositing and spreading the mixture 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 subbase course except as necessary to place the succeeding layer of the subbase or base and 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 compaction, the finished subbase will conform to the required grade and cross section.

Subbase materials placed on areas inaccessible to mechanical spreading equipment may be spread by other methods approved by the Engineer. 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 on the final layer outside of the specified tolerance shall be trimmed off within the specified tolerance prior to placing any material thereon. 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 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 subbase shall be compacted to at least 95 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.

Not more than 2-1/2 hours shall elapse between the time the ingredients are mixed and the time of completion of final compaction of the layer. Any mixture that has not been compacted and finished shall not remain undisturbed for more than 30 minutes.

It is intended that all trimming and fine grading be accomplished during the 2-1/2 hours mentioned above, and that trimming of the completed and cured subbase be limited to occasional irregularities.

At the end of each day's work and when subbase 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 surface of the top of the subbase 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 grades more than 3/8 inch in 10 feet at any location. When final grading is to be performed by an automatic grading machine, the subbase shall be trimmed to such accuracy that the succeeding subbase and/or base or surface courses will meet their respective specified surface and thickness tolerances. The Contractor shall

furnish all devices necessary to check the surface, such as stringlines, straightedges, etc., and the labor necessary to handle the devices.

When the subbase is found to deviate from the tolerances, the deviations shall be corrected after the ~~7-calendar-day curing period, by leveling and wedging with an approved bituminous concrete mixture.~~ This corrective work shall be performed at no cost to the Department.

The subbase course will be checked for proper thickness after compaction. The Contractor shall refill all test holes with approved mixture and adequately compact the material.

No subbase deficiency in thickness greater than 1/2 inch will be accepted.

No traffic or equipment will be permitted on the finished surface 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 does not fall below 50°F.

Traffic on the completed subbase 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 subbase 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 subbase 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 subbase is not completely covered with the specified courses, the Engineer will then determine the extent of any further work necessary to protect and maintain the uncompleted work during the winter months and until the beginning of spring paving operations. When extra materials, methods, and construction are determined to be necessary to the project, maintain and repair of any portion of the uncompleted work, the cost of such extra materials, methods, and techniques shall be borne by the Contractor.

V. WEATHER LIMITATIONS

Subbase mixtures shall not be placed between the period of October 1 through April 30.

VI. METHOD OF MEASUREMENT

The subbase mixtures will be weighed in accordance with Section 109 of the Department's Standard Specifications for Road and Bridge Construction.

Water used to maintain moisture to facilitate compaction will be considered incidental to the work and will not be measured for separate payment.

VII. BASIS OF PAYMENT

Payment for the accepted quantities at the contract unit prices shall be full compensation for all labor, equipment, materials, hauling, and incidentals necessary to complete the work specified herein.

Payment will be made under:

Pay Item

Pay Unit

Scrubber Sludge - Pond Ash Subbase

Ton

September 6, 1983