In-Place Recycling and Reclamation of Asphaltic Concrete Pavements in Kentucky

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in cooperation with
Kentucky Transportation Cabinet
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University of Kentucky

Research Report
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16. Abstract
Full-depth reclamation has been defined by the Asphalt Recycling and Reclaiming Association as a "rehabilitation technique in which the full thickness of the asphalt pavement and a predetermined portion of the underlying material (base, subbase, and/or subgrade) is uniformly pulverized, blended and compacted to provide an upgraded, homogeneous material resulting in a stabilized base course." The Kentucky Transportation Cabinet has utilized the full-depth reclamation (FDR) process as a method to address asphalt pavements exhibiting widespread base failures. The FDR process transforms the existing hot mix asphalt (HMA) pavement and underlying granular materials into a stabilized base layer. The stabilized layer is then overlaid with a new HMA surface layer. However, the process of when and how to use the FDR process has not been well defined in Kentucky. The Cabinet commonly uses its Special Note for Cement Stabilized Roadbed as guidance for a stabilized subgrade and is dependent upon the road contractor for a suitable mixture design. The research reported herein presents suggested guidelines to the Kentucky Transportation Cabinet for the design and construction for FDR pavements. Special Notes for Full-Depth Reclamation of Hot Mix Asphalt pavements using cement and asphalt emulsions as stabilizers are presented for consideration. This report, along with the Special Notes, includes a process to identify potential projects for the FDR process, criteria for selecting the stabilizer best suited to the conditions, the optimum thickness of material to be recycled, and the amount of stabilizer to be added.

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Implementation Statement

This research established that full-depth reclamation of asphaltic concrete pavements has been practiced in Kentucky in the absence of guidelines for preconstruction and design activities. Special Notes for construction of pavement subbase layers have been developed and will be implemented to guide the design, construction, and quality control of the full-depth reclamation of asphaltic concrete pavements.

Executive Summary

The objectives of this one-year research study were to assess the potential for implementing in-place asphalt pavement recycling and/or reclamation on low- to medium-volume roadways throughout the Commonwealth of Kentucky. With the exception of using cold milling prior to placing a hot mix asphalt (HMA) overlay, in-place recycling and reclamation of asphalt pavements is rarely practiced in Kentucky. Full-depth reclamation (FDR) of asphaltic concrete pavements is a proven, cost-effective means of rehabilitating a deteriorated pavement structure and is easily implementable. Full-depth reclamation takes a degraded pavement and transforms it into a smooth and consistent structure that, when surfaced, supports the designed traffic requirements. Materials from the existing pavement structure are reused in the construction of the new subbase or base layer, which reduces the amount of material needed to complete projects and lowers construction costs. Pavement geometrics and layer thickness can be maintained during construction because the existing pavement materials are reused. Often, the impacts incurred by the motoring public are less than those associated other rehabilitation techniques. The Kentucky Transportation Cabinet, and the Commonwealth more broadly, will realize the following benefits from implementing full-depth reclamation: reduced environmental stress, as no millings are produced; cost savings due to less material hauling; deferral of maintenance activities; and less severe traffic impacts.

Reclamation of HMA pavements is a viable option when asphaltic concrete pavements exhibit severe cracking or raveling; potholes; high spots or depressions due to base failures; and rutting, shoving, and corrugations.

Many highway agencies and private entities have concluded that adopting FDR yields economic benefits, both during the initial construction phase and across the long-term service life of the pavement. A life cycle cost analysis examining two Kentucky projects confirms that using FDR is clearly preferable to conventional rehabilitation techniques.

Based on the study’s findings and information collected from numerous sources, two draft Special Notes were prepared — the first is a Special Note for FDR-cement, while the second is a Special Note for FDR-emulsified asphalt. Both Special Notes can be found in the report’s appendices. It is recommended that the Kentucky Transportation Cabinet implement the draft specifications on new rehabilitation projects where the existing pavement exhibits severe base failures, cracking or raveling, rutting or shoving, and are in need of rehabilitation. Future projects would implement the guidelines and specifications pertaining to the use of FDR. The guidelines should be utilized to identify suitable projects for FDR, examine material sampling, testing, mixture designs, structural design parameters, and selection requirements for FDR treatment established through preconstruction planning activities. Additionally, quality control/quality assurance testing and monitoring should be conducted to validate the performance of designs. The results of this continuing research may be used to modify the Special Notes and fully develop specifications for FDR design and construction.

1. Introduction and Background

The preservation of existing transportation systems requires methods to rehabilitate and re-construct roadways that reduce congestion during the construction process. There is also a need for more durable pavements that reduce costs for both transportation agencies and the traveling public. In-place recycling and reclamation of asphalt pavements lets highway agencies optimize the value of in-place materials, minimize construction time and traffic flow disruptions, and reduce the number of construction vehicles moving into and out of the construction area. In-place recycling and reclamation is a method whereby an existing deteriorated asphalt pavement is renewed using *in situ* materials in lieu of virgin paving mixtures and materials. In-place recycling and reclamation of asphalt pavements is rarely practiced in Kentucky. More often, rehabilitation of asphalt pavements involves cold milling. These millings are stockpiled and other millings may be used in the hot mix asphalt (HMA) overlay.

Pavement preservation techniques applied at the right time extend the performance life of an asphalt pavement. In-place pavement recycling takes a degraded pavement and transforms it into a smooth and consistent structure that supports traffic requirements. However, if the pavement becomes too deteriorated, pavement preservation techniques do not provide the expected outcome. Because materials from the existing pavement structure are reused to construct the new layer, in-place recycling may reduce the amount of material needed and lower overall costs. Pavement geometrics and layer thickness can be maintained during construction because the existing pavement materials are reused. Often, impacts incurred by the motoring public are less than other rehabilitation techniques.

Pavement recycling and reclamation is not new. A 1996 Federal Highway Administration (FHWA) report stated that recycling asphalt pavement began as early as 1915 (1). However, in recent years the need to utilize in-place materials in highway rehabilitation projects has garnered renewed attention due to the cost and supply of petroleum and aggregate. In-place recycling and reclamation of asphalt pavements serves this need well by making use of *in situ* materials and improving the economics of the construction. Current pavement recycling and reclamation methods include:

- Hot in-place recycling (HIR),
- Cold in-place recycling (CIR), and
- Full-depth reclamation (FDR).

Each pavement recycling and reclamation method addresses different levels of distress. For instance, HIR is used most often when pavement distresses are minimal and there are no structural problems with the pavement. CIR is used when there is a greater degree of non-load-related distresses that may extend farther down into the pavement structure. FDR is the in-place rehabilitation of the entire pavement structure. FDR may also be used for reconstruction, minor profile changes, and lane widening. Distress depth and existing asphalt pavement thickness are typically used to identify the type of in-place recycling method(s) that can economically prolong the serviceability of an asphalt pavement.

NCHRP Report 421 provides details on the use and application of HIR, CIR, and FDR (2). Information presented in this report was collected through a literature review and a survey of state transportation agencies and contractors. Interestingly, for this 2011 report, the Kentucky Transportation Cabinet (KYTC) reported that it had more than 10 years of experience with HIR of asphalt pavements but did less than fifty miles per year. The Cabinet reported using all three HIR methods for asphalt pavements (i.e., surfacing, repaving, and remixing). The Cabinet also disclosed that it had not used CIR and FDR for asphalt pavements but that it would consider using these methods of in-place recycling for routes with average annual daily traffic (AADT) counts under 5,000. In terms of environmental benefits, Kentucky's response noted that using in-place recycling reduced the use of virgin materials and lowered fuel consumption.

Contrary to the information presented in the NCHRP report, the Portland Cement Association has been involved in the FDR of asphalt pavements using cement to stabilize the reclaimed materials in Kentucky at least since 2003. Most of the projects were constructed between 2003 and 2010. More recently, and with renewed efforts, FDR projects have been constructed in Pulaski and Fleming Counties.

2. Methodology

The objectives of this research study were to assess the potential for implementing in-place asphalt pavement recycling and/or reclamation on low- to medium-volume roadways in Kentucky. This study analyzes work that has already been completed in Kentucky and across the United States related to the current practice of in-place recycling and reclamation of asphalt pavements. To address the project objectives Kentucky Transportation Center (KTC) researchers performed a literature search and review to determine current state of the art and state of the practice for various methods used in HMA reclamation and in-place recycling. Researchers also investigated recent projects. Methods for reclamation and in-place recycling reviewed as part of this study included FDR, HIR, and CIR. The literature review focused on current design, construction, and quality control/quality assurance (QC/QA) methods for HMA reclamation and in-place recycling. The literature review specifically addressed the following questions:

- When is HMA reclamation and in-place recycling a viable option?
- What structural credit should be given to the stabilized layer?
- What is the optimal modulus/strength to require for the stabilized layer?

This study also examined past projects in Kentucky with the goal of ascertaining design information and determining the historical performance of as many projects as possible that employed any method of HMA reclamation or in-place recycling. Performance data for the projects were obtained from KYTC's Pavement Management Group. This effort also included a number of site visits by KTC staff to visually inspect the selected projects. Two separate full-depth reclamation projects were forensically investigated to assess the *in situ* strength of the reclaimed asphalt mixture used in the pavement rehabilitation designs. A life cycle cost analysis comparing reclamation/in-place recycling to conventional rehabilitation for HMA pavements was performed using information collected during the investigation of the two, full-depth reclamation projects. A Special Note for Construction for full-depth reclamation of HMA pavements using various means was prepared. This final research report details the results of the study and provides guidance for implementing its findings.

3. Literature Review Summary

The Asphalt Recycling and Reclaiming Association (ARRA) identifies five (5) broad categories of asphalt pavement recycling and reclaiming methods (3). These methods are:

1. Hot Recycling
2. Cold Planing or Milling (CP)
3. Hot In-Place Recycling (HIR)
4. Cold Recycling (CR)
5. Full-Depth Reclamation (FDR)

Highway paving contractors in Kentucky routinely perform hot recycling. Hot recycling involves mixing recycled asphalt pavement (RAP) with virgin aggregates and asphalt binder in a central mixing plant. A recycling agent may be added depending upon the mix design requirements. Hot recycling is the most widely used asphalt recycling method and while the Asphalt Pavement Alliance estimates that nearly 100 million tons of RAP are produced each year worldwide, 95% of the material is reused or recycled (4). Kentucky contractors utilize hot recycling in the placement of many HMA courses. Current specifications for the use of RAP in HMA courses are contained within Section 409 of the current edition of Kentucky's Standard Specifications for Road and Bridge Construction.

Cold planing, or milling, is the removal of a predetermined depth of asphaltic concrete to a specified grade and cross slope. Cold planing is unique in that the action restores transverse and longitudinal profiles before placement of an HMA surface course or a pavement preservation treatment. The milling action is accomplished using a cold planer with a rotary cutting drum. Upon completion of the milling activity, a traversable surface remains that may be treated with another recycling method, or simply tacked and overlaid with an HMA surface course. Current specifications for removing existing pavement layers by milling and texturing are contained within Section 408 of the current edition of Kentucky's Standard Specifications for Road and Bridge Construction.

Hot in-place recycling consists of heating, and thereby softening, the existing asphalt pavement. The surface is then scarified with spring-loaded tines, augered, or milled to specified depths. The scarified pavement is then mixed thoroughly, placed, and compacted. The equipment associated with the recycling process can stretch out over several hundred feet. Conversations with the Executive Director with the Plantmix Asphalt Industry of Kentucky (PAIKY) revealed that HIR of asphalt pavement is not typically performed in Kentucky. Similarly, cold recycling, which entails recycling the asphalt pavement without heating it, is not typically utilized by Kentucky's asphalt paving community.

Full-depth reclamation is a process of rehabilitating an old asphalt pavement. The entire pavement structure, including the old pavement surface, the bound base courses, any unbound granular bases, and perhaps some of the subgrade, is pulverized or ground up into essentially a uniform particle size. The pulverized material is blended and re-compacted to form a new uniform base for the new pavement surface. Various compounds can be used to bind this material together, such as heated asphalt binders, various asphalt emulsions, cement, fly ash, lime, and water (5). Mechanical methods can also be used — for example the addition of granular material to alter the gradation to obtain better compaction and density.

Pavement conditions that are suitable for the FDR process include (3, 10, 11):

- Flexible pavements and unpaved roads,
- Renewing deteriorated roads by incorporating existing materials,
- Severely cracked or raveled roads,
- Roads with high spots or depressions due to underlying layers,
- Roads with many potholes, and
- Roads with plastic deformations (rutting, shoving, and corrugations).

Some advantages of FDR include:

- Provides a good foundation structure,
- Increases stiffness of the base materials, thereby reducing deflections from traffic,
- Reduces subgrade stresses, helping to prevent issues such as cracking and potholes,
- Produces a moisture-resistant layer, reducing intrusion,
- Reduces potential of pumping of subgrade fines,
- Increases capacity,
- Extends service life, and
- Improves serviceability (7, 10).

Some agencies (8) limit FDR to low-volume roads (1 million ESALs per design life) and to a total depth of 12 inches (normally six to nine inches). Many agencies require a minimum two-inch overlay above the reclaimed base. Structural layer coefficients for FDR layers generally range from 0.15 to 0.25 for FDR-cement stabilized and 0.20 to 0.30 for FDR-bituminous stabilized (3, 7, 9, 21).

a. Pre-Construction and Design

Most highway agencies require a pre-design and construction investigation of the current pavement structure. Nearly all agencies require the collection of cores. The number of cores is usually determined by the project's length. Once gathered, cores are cataloged. The depth of the various pavement layers is noted. Gradation analysis is required on each layer, including the subgrade soil. A mix design is developed for the combined layers. The laboratory tests most often required are moisture content, sieve analysis, hydrometer analysis, CBR, and liquid and plastic limits (8).

The Texas Department of Transportation (TxDOT) has developed detailed testing methods to assist in the pre-construction and design of FDR projects. However, its methods require hundreds of pounds of testing materials and weeks of testing time. In 2012, it began the process of simplifying pre-construction and design procedures (10). The Pennsylvania Department of Transportation (PennDOT) also has a detailed pre-construction procedure for materials testing (9):

- Pavement Distress Survey
    - Distresses
    - Thickness of layers

- Drainage
- Lab Testing
    - Subgrade: CBR, LL, PL, gradation, moisture content, classification
    - Top Layers: Gradation, AC content
- Establish Depth of Reclamation
    - Based on Distress
    - Field/Lab Tests
    - Required Capacity
- Design FDR mix and process
    - Is mechanical stabilization needed?
        - Yes – Reclaim/Pulverize, add water, mix, grade, compact
        - No – Determine type and amount of chemical additive
            - Reclaim/Pulverize, add chemical, mix, grade, compact
- Test Results
    - *In situ* density
    - FWD
    - Field CBR.

PennDOT produced a chart for selecting the proper stabilizing agent. The selection of the stabilizing agent is a function of soil type, the percent of material passing the #200 sieve, and the plasticity index (9). The PennDOT chart is reproduced in Table 1. A similar chart is contained in the *Basic Asphalt Recycling Manual* and is reproduced in Table 2 (3). The sand equivalency of the material to be reclaimed is also considered when determining the proper stabilization agent.

Table 1 Correlation of Stabilization Additive as a Function of Soil Type, Percent Passing No. 200 Sieve, and Plastic Index.

Percent Passing No.200	Plastic Index	Stablizer	Soil Type													
			Granular Material								Silt-Clay Material					
			Well-graded gravel	Poorly graded gravel	Silty gravel	Clayey gravel	Well-graded sand	Poorly graded sand	Silty sand	Clayey sand	Silt, Silt with sand	Lean clay	Organic silt/Organic lean clay	Elastic silt	Fat clay, fat clay with sand
			GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH
			A-1-a	A-1-a	A-1-b	A-1-b or A-2-6	A-1-b	A-3 or A-1-b	A-2-4 or A-2-5	A-2-6 or A-2-7	A-4 or A-5	A-6	A-4	A-5 or A-7-5	A-7-6
<25	<6	Bituminous													
	<10	Cement													
	>10	Lime													
>25	<10	Cement													
	10-30	Lime													
	>30	Lime+cement													

Table 2 Stabilizing Agent Selection Guide for FDR Mixtures Including RAP (ARRA, 2015)

Material Type - Including RAP	Well Graded Gravel	Poorly Graded Gravel	Silty Gravel	Clayey Gravel	Well Graded Sand	Poorly Graded Sand	Silty Sand	Clayey Sand	Silt, Silt with Sand	Lean Clay	Organic Silt/Organic Lean Clay	Elastic Silt	Fat Clay, Fat Clay with Sand
USCS[2]	GW	GP	GM	GC	SW	SP	SM	SC	ML	CL	OL	MH	CH
AASHTO[3]	A-1-a	A-1-a	A-1-b	A-1-b A-2-6	A-1-b	A-3 or A-1-b	A-2-4 or A-2-5	A-2-6 or A-2-7	A-4 or A-5	A-6	A-4	A-5 or A-7-5	A-7-6
Emulsified Asphalt SE > 30 or PI < 6 and P200 < 20%	X	X	X	X	X	X	X						
Foamed Asphalt PI< 10 and P200 5 to 20%	X		X	X	X		X						
Cement, CKD or Self-Cementing Class C Fly Ash PI<20 S04 < 3000 ppm	X	X	X	X	X	X	X	X	X	X			
Lime/LKD PI > 20 and P200 > 25% S04 < 3000 ppm								X		X		X	X

P200 = Percent passing No. 200 (0.075 mm) sieve; SE = Sand equivalent (AASHTO T-176 or ASTM D2419); PI = Plasticity Index (AASHTO T-90 or ASTM D4318)

[1] Additives may also be used in combination with a stabilizing agent to optimize performance of the FDR section

[2] *USCS: Unified Soil Classification System, ASTM D2487*

[3] *AASHTO: American Association State Highway Transportation Officials, AASHTO M 145*

For low volume roads, some highway agencies (8) have a simple standard design of four inches of HMA on the FDR base. Most agencies that attempt to design the asphalt layer thickness that goes on top of the reclaimed layer use the fall weight deflectometer (FWD) to calculate a modulus or determine a layer coefficient.

The Virginia Department of Transportation (12) conducted research on three state routes where FDR was utilized to rehabilitate asphalt pavements. Each route was tested using ground penetrating radar (GPR) to obtain layer thicknesses and the FWD to back calculate resilient modulus and layer coefficients. One interesting result of this research was that it may not be possible to calculate layer coefficients of the FDR layers immediately after construction when using asphalt emulsions or foamed asphalt. Over a period of two years, most of the layer coefficients more than doubled — apparently due to the ageing of the asphalt.

b. Construction

There are four basic steps in completing an FDR project (3). They are:

1. Pulverization,
2. Stabilization,
3. Shaping, and
4. Compaction.

A 1997 paper published in the *Journal of Asphalt Paving Technologists* describes the FDR equipment typically used in the pulverization step (15).

> "The pulverization and mixing operations normally are with large and high horsepower (up to 485 kW/650 HP) road reclaiming machines such as the Caterpillar RM-350, RMI RS-500B, or RS-650, the Wirtgen WR-2500, or Hamm Raco 550. However, for projects with thicker asphalt sections 200mm (8") or more, and a base capable of supporting the equipment, the FDR may be completed with a cold in-place recycling "train." The train consists of a cold milling machine towing trailer mounted screens/crushing and mixing plants."

Recent advances in milling and pulverizing equipment include larger machines. For example, a machine capable of pulverizing a full-lane width has up to 1,200 HP while a half-lane machine has up to 800HP. Also, most modern equipment is equipped with lasers to monitor grade and cross slope and can maintain surfaces to within ± 5mm (0.2 in.) of target grade or slope.

Pulverization depth is usually between six and ten inches. The cutting head is between eight and 14 feet wide. The cutting head is mounted with carbide teeth to perform the cutting. Maximum cutting depth is approximately 18 inches.

Stabilization consists of mixing in the chosen additive or water into the pulverized surface, or of adding and mixing in aggregate to change the gradation, thereby providing a more suitable material.

Shaping is accomplished with a grader. Care must be taken to grade to the appropriate or specified cross slope. In addition, the longitudinal grade must meet specifications.

The FDR material must be compacted to a predetermined moisture content and density. Depending on the gradation of the FDR material, a steel drum roller or a sheepsfoot roller may be used. Gradation and moisture content dictate the type of roller used.

In some cases, two passes are made with the reclaiming equipment and the reclaimed material is compacted and graded/shaped after each pass.

Construction of FDR should not proceed in rainy weather (3).

c. Specifications

Specifications are generally defined as a method or performance type. Specifications can also be a combination of the two. A method specification outlines a procedure to execute the work without specifying the final result. A performance specification prescribes a final result without specifying a procedure for obtaining that result.

CALTRANS (California Transportation Department) has a very broad, all-encompassing, specification for FDR construction (11). The specification includes a number of material and equipment requirements, construction methods, inspection protocols, QC/QA standards, acceptance requirements, measurement procedures, and payment instructions. The agency's specification requires some performance requirements and some method protocols.

South Carolina has a specification for determining the job mix formula (JMF) for all FDR projects. As a method specification, it itemizes specific steps in the protocol (13).

In 2012, TxDOT made several changes to their specifications for FDR. These recommendations were informed by research. Significant changes to the TxDOT FDR specification included:

- More predesign testing,
- Use of the FWD in the design phase,
- A "pull-off" test to help determine the best tack material to bond new asphalt to the FDR layer, and
- Modifying the temperature requirement to avoid freezing temperatures during construction.

Colorado has a detailed method specification for FDR construction (5). The major items in that specification include:

- Temperature requirements for when the work may proceed;
- A requirement for a "first-pass" phase of pulverization, grading, and compacting;
- A requirement for a "second-pass" phase of pulverization, grading, and compacting;
- Requirements for the recycling train, including capabilities of the equipment used;
- A general specification on the type of compactors used; and
- A smoothness requirement.

In 2011, the FHWA sponsored research that was conducted by the South Dakota School of Mines and Technology and the South Dakota Transportation Department to develop specifications or protocols for developing mix designs for FDR materials (14). Four types of FDR materials were tested:

- Unstabilized FDR,
- FDR-stabilized and Portland cement (PC) and fly ash (FA),
- FDR-stabilized with asphalt emulsion (AE) and asphalt emulsion plus lime (AE + Lime), and
- FDR-stabilized with foamed asphalt plus Portland cement (foamed asphalt + PC).

PennDOT has a detailed method specification for FDR construction (9). In addition, the agency has developed guidelines for FDR projects including all preliminary planning, design, and testing work. The guidelines for preliminary work include:

- Determining the suitability of a road as an FDR candidate,
- Sampling and testing,
- Determining the appropriate FDR techniques and material,
- FDR mix design development,
- Project planning,
- Project construction and quality control measures, and
- Final surfacing.

PennDOT's method specification contains requirements pertaining to the following:

- Materials to be used,
- Pulverization equipment,
- Compaction and grading equipment,
- Curing and protection,
- Surface tolerances, and
- QC/QA Program.

The specifications KTC researchers examined are very similar in form and content. Most combine method and performance specifications. All specify the type of materials to be used, including the materials to be reclaimed, and the additive necessary to bind reclaimed materials. All note some tests performed on the materials, such as moisture-density, moisture susceptibility, gradation, and soil classification (15).

A number of agencies require performance resilient modulus (M_r) tests (or its calculation). Several specifications also require the FWD, which is used to calculate M_r and/or structural number (SN).

All specifications contain instructions and requirements for construction operations, including the description of the phases of the operations. The types of equipment used for different construction are often specified and described, including requirements of the reclaiming "train." Curing times and paving temperatures are also specified in most of the specifications (16).

Testing requirements for QC/QA programs are described in all the specifications. Many specifications also listed requirements for maintenance of traffic operations.

d. Economics of FDR and Life Cycle Cost Analysis (LCCA)

Many highway agencies and private entities have concluded that FDR presents economic advantages during the initial construction phase and across the long-term service life of the pavement. One study reported by the Portland Cement Association (19) highlights the economic and environmental benefits of FDR construction over conventional construction techniques. The following comparisons were reported in its study.

- Number of Trucks Needed — FDR (12), Conventional (180),
- New Roadway Materials Needed (tons) — FDR (300), Conventional (4500),
- Materials Landfilled (cu. yd.) — FDR (0), Conventional (2700), and
- Diesel Fuel Consumed (gal.) — FDR (500), Conventional (3000).

Although particulars of the construction operations and the dimensions of the project are unknown, the average numbers reported demonstrate significant economic and environmental benefits. Johnson and Bland (17) reported that the typical cost per square yard of FDR ranges from $8 to $12. They observed also that pavement patching typically costs approximately $45 per square yard. Based on their analysis, they concluded that anytime a pavement requires more than 15 to 20 percent patching, it is more economical to use FDR for rehabilitation.

Although the initial cost benefits of FDR construction over conventional construction techniques are easily determined, it is much more challenging to quantify its long-term benefits. To calculate the long-term costs and benefits of FDR versus conventional construction and rehabilitation, a life-cycle cost analysis (LCCA) can be used. There are two variants of LCCA — network-level and project-level analysis. A network-level LCCA analyzes a complete network of highway sections to determine the best spending strategy over the entire network. A project-level LCCA analyzes the repair, maintenance, or rehabilitation strategy for a single highway section. This study is concerned with project-level LCCA only. Hereafter, in this report, any mention of LCCA refers to project-level analysis.

The FHWA has published one of the better-known methods for conducting an LCCA analysis (18, 20). Its procedure consists of seven basic steps:

- *Establish alternative pavement design strategies for the analysis period* (mill and fill, rebuild, overlay, FDR);
- *Determine performance periods and activity timing,* (evaluate the service life of each strategy);
- *Estimate agency costs* (calculate the unit cost of each construction or maintenance strategy and the number of units involved);
- *Estimate user costs* (must know Average Daily Traffic, percent daily trucks, average speed, cost per truck delay, and cost per auto delay);

- *Develop expenditure stream diagrams* (which illustrate the amount and timing of expenditures);
- *Compute net present value (NPV)* (convert all future expenditures to today's dollars); and
- *Analyze results and reevaluate design strategies*.

Determining the timing of rehabilitation and/or maintenance schedules can be difficult if good historical records are not available. Often, published data are used to estimate schedules. An example LCCA is presented in Appendix A for two Kentucky projects. A 20-year design life was assumed for the analysis. From an economic perspective, the LCCA results show the FDR option for pavement rehabilitation clearly wins out over conventional rehabilitation techniques.

4. Full-Depth Reclamation Projects in Kentucky

Since 2003, the Kentucky office of the Portland Cement Association has been involved in the FDR of asphalt pavements using cement to stabilize the reclaimed materials. Most projects were constructed between 2003 and 2010 (Figure 1). More recently, and with renewed efforts, FDR projects have been constructed in Pulaski and Fleming Counties. Most of the projects identified in Figure 1 were small projects typically performed by local forces. No design information was available for these projects. For instance, the project in Franklin County was completed in the spring of 2006 by the Franklin County Road Department (FCRD)[1]. The Trigg and Lyon County projects occurred on United States Forest Service roads in Land Between the Lakes National Recreation Area. Another project targeted Kentucky Route 175 in Muhlenberg County[2], which suffered damage after a new coal mine opened in the area. KYTC required the coal company to fix the road. The coal company contracted with the Mount Carmel Stabilization Group out of Mount Carmel, Illinois, to repair the roadway using FDR with cement. Researchers were unable to obtain design information from the Mount Carmel Stabilization Group.

Staff with FCRD have observed that the project highlighted in "The Link" newsletter did not perform as anticipated primarily due to the presence of a previously undetected natural spring. The water from the spring was detrimental to the stabilized layer, resulting in base failures reappearing in the treated areas. However, the technique has been used successfully elsewhere by the FCRD to repair areas exhibiting base failures. By all accounts, the KY 175 work was completed successfully and performed as expected.

[1] http://www.kyt2.com/assets/files/uploads/link_newsletter_Summer_2006.pdf
[2] http://mtcsg.com/wp-content/uploads/2013/06/KY-175-Muhlenberg-County-FDR-Case-Study.pdf

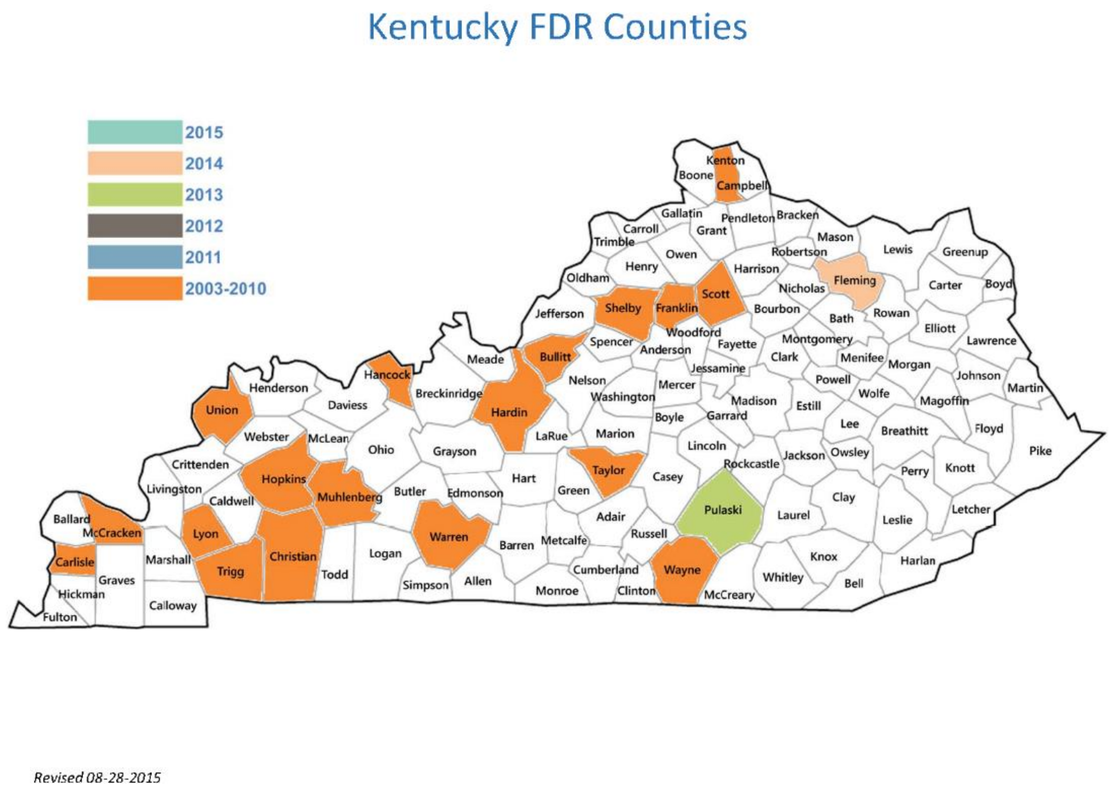

Figure 1 Kentucky Counties with at least one full-depth reclamation project. (Graphic provided by Kentucky Ready-Mix Concrete Association).

The most recent contracts issued by KYTC utilizing full-depth reclamation techniques were located in Pulaski and Fleming Counties. The Pulaski County project on KY 80 extended eastward from its intersection with US 27 to its intersection with KY 914 and was completed in 2013. The Mount Carmel Stabilization Group performed the soil stabilization work for this project and Hinkle Contracting Company served as the general contractor. Originally, the project was slated for FDR, but based on available information it appears that all layers of the asphalt pavement were milled and the subgrade was chemically modified with cement in accordance with the Special Note for Cement Stabilized Roadbed and Section 208 of Kentucky's Standard Specifications for Road and Bridge Construction, "Chemically Stabilized Roadbed." Figure 2 depicts a core sample from KY 80's completed pavement structure. The core does not appear to contain reclaimed asphalt paving material in its lower portion. Because of uncertainty over the construction process and the use of FDR activities, the Pulaski County project was not investigated further.

a. KY Route 3301, District 9, Fleming County

Two separate FDR projects were constructed in Fleming County, both located on Flemingsburg-Beechburg Road, KY 3301. Kentucky Route 3301 is a rural secondary route with an AADT of 437 vehicles per day and zero percent trucks. These FDR projects offered researchers background design information, limited performance information, and the opportunity to forensically investigate the FDR materials. The following sections provide information on the two projects. Specific data are contained in the appendices at the end of this report.

Figure 2 Pavement core obtained from the Pulaski County KY 80 Project. (Photograph courtesy of Neil Ryan, Mount Carmel Stabilization Group)

i. KY 3301 2014 Project

The 2014 project (Contract Identification 143223) was completed in fall 2014 and extended from Mile Point 3.43 to Mile Point 5.0, near the intersection with Botkins Lane (Figure 3). The 2014 project included FDR throughout its entire length and width. Pavement coring done by KYTC personnel established the existing asphalt pavement thickness as approximately 8-1/2 inches. The project design called for a layer of reconstructed base material 12 inches thick produced through FDR and overlaid with 1-1/2 inches of Class 2 asphalt surface using a 0.38D stone and a PG 64-22 binder. Eaton Asphalt Paving Company, Incorporated, was the winning bidder and priced the FDR work at \$2.75 per yd^2. In lieu of a specification or special note for FDR on asphalt pavement, the contract included a Special Note for Cement Stabilized Roadbed. The special note required incorporating 12 inches of the existing roadway material (asphalt, stone, and soil). The FDR process used 6% cement by weight at 110 lbs./ft^3, two (2) pounds of asphalt curing seal per square yard, and five (5) pounds of sand per square yard for a blotter. The project quantities specified in the bid proposal were 17,794 yd^2 for FDR, 529 tons of cement, 18 tons of asphalt curing seal, and 44 tons of sand for the blotter.

Figure 3 Map of KY 3301 Project. Mile Point 5.00 is at the Intersection with Botkins Ln. (Google Maps 2017)

Before starting the FDR, and contrary to Section 208 of the 2012 Standard Specifications for Road and Bridge Construction, KYTC assigned the contractor responsibility for supplying the Department the analysis used to determine the optimum moisture content and maximum density of the existing roadbed. Results of the analysis were used as the benchmark during the actual mixing process. Materials sampling and mix analysis for this project were performed by Thelen Associates. Sampling was conducted to a depth of one foot. The optimum moisture content of the mixture containing milled asphalt, aggregate, soil, and 6% cement was found to be 7.2% with a maximum dry density of 130.5 lbs./ft^3. A summary table of the proctor tests is presented in Appendix B.

ii. KY 3301 2015 Project

The second project on KY 3301 (Contract Identification 153223) extended from Mile Point 0.0 at the intersection of KY 57 to Mile Point 3.43 at Beechburg (see Figure 3). It was completed in 2015. This project contained areas identified for base failure repair using conventional methods. The conventional base failure repair technique included excavating to a depth 14 inches below the existing asphalt surface level and backfilling the excavated area with eight (8) inches of #2 stone wrapped in a Class IV geotextile fabric, two (2) inches dense graded aggregate, and four (4) inches of compacted Class 2 Asphalt Base 1.00 PG 64-22. Initially, the pavement section from mile point 0.00 to 0.234 was slated for conventional rehabilitation, but after construction began a change order was issued to include FDR within the area.

Available data for these projects were gathered, reviewed, and are reported herein. The data included information from KYTC's Pavement Management Group, construction inspection reports, and field forensic investigations. The field investigations included structural evaluations of the FDR sections using the Center's FWD and obtaining core specimens for laboratory assessment. Results of the post-construction assessment activities are presented in the appendices and discussed herein.

b. LCMS Pavement Performance Data

Researchers obtained pavement performance data from KYTC's Pavement Management Group. The data included rutting, cracking, and International Roughness Index (IRI) determinations obtained using a laser crack measurement system (LCMS). Data for KY 3301 were available for two collection dates — July 2014 and September 2016. The July 2014 data were collected before the rehabilitation of KY 3301 began. A second set of performance condition data was collected in 2016, one and two years after the separate rehabilitation projects were completed. The data were sorted within the beginning and ending mile points of the two different projects (i.e., the 2014 project extended from Mile Point 3.43 to Mile Point 5.00 and the 2015 project extended from Mile Point 0.00 to 3.43). Tables C1 and C2 in Appendix C present summary LCMS data for the 2014 and 2015 projects, respectively. Table C1 shows LCMS data prior to any roadway rehabilitation activities (July 2014) and almost two (2) years after their completion (September 2016). Cracking and rutting remained minimal and IRI values were reasonable for the rural secondary route. Similarly, Table C2 presents LCMS data collected before and after rehabilitation. Cracking and rutting were minimal and IRI values were reasonable one year after rehabilitation.

c. Falling Weight Deflectometer Data Collection and Analysis

Falling Weight Deflectometer — deflection testing was performed with a JILS-20 FWD at 200-foot intervals and using a 9,000-pound loading. The JILS-20 FWD uses a 12-inch rigid steel loading plate; the deflection sensors are velocity transducers, and their response is single-integrated to determine the accompanying deflection. A unique feature of the JILS-20 FWD is its ability to report both the first and second peaks of each drop.

Data were collected from the right wheel path across both sections in both directions during data collection activities. The FWD deflection data were analyzed by individual section (i.e., the 2014 section (full FDR) and the 2015 section (FDR and conventional/control)). The back-calculated modulus of elasticity of the FDR materials averaged 845.11 KSI and 831.46 KSI for the 2014 and 2015 sections, respectively. The structural stiffness of the FDR sections proved greater than the conventionally rehabilitated sections by a factor of nearly two. Results of the FWD deflection analyses are presented in Appendix D.

d. Field Core Samples and Results

During field testing activities, core specimens were obtained for laboratory evaluations. Cores were extracted using a nominal six-inch diameter coring barrel, with water as a lubricant.

After extraction, the core specimens were measured in the field, placed in a plastic sample bag, and taped for transport to the laboratory. The field specimens were evaluated and measured in the laboratory. Cores were trimmed to form a nominal 6-inch by 12-inch cylinder, after which compressive strength testing was performed. A number of samples were evaluated for moisture content. Results of the laboratory evaluations are presented in Appendix E.

The compressive strength of the cores from the 2014 rehabilitation averaged 370 psi while the cores from the 2015 project averaged 336 psi. These values are representative of the typical compressive strength of soil-cement mixtures.

5. Specifications for Full Depth Reclamation

KYTC has heretofore utilized its Special Note for Cement Stabilized Roadbed for FDR. Two separate Draft Special Notes were developed during this study. The Draft Special Note for Full-Depth Reclamation (Cement) was developed using guidance from the National Concrete Pavement Technology Center's March 2017 publication (7) and the Portland Cement Association. A separate Draft Special Note for Full-Depth Reclamation (Emulsified Asphalt) was developed based on information gleaned from the Asphalt Recycling and Reclamation Association (3) and the states of Colorado and South Carolina (5, 13). The Draft Special Notes for FDR (cement) and FDR (asphalt emulsion) are contained in Appendices F and G, respectively.

6. Summary

This research study sought to assess the potential for implementing in-place asphalt pavement recycling and/or reclamation on low- to medium-volume roadways throughout Kentucky. In-place recycling and reclamation is a method whereby an existing deteriorated asphalt pavement is renewed using *in situ* materials in lieu of virgin paving mixtures and materials. In-place recycling and reclamation of asphalt pavements aids highway agencies in optimizing the value of in-place materials, minimizes construction time and traffic flow disruptions, and reduces the number of construction vehicles moving into and out of the construction area. However, in-place recycling and reclamation of asphalt pavements is rarely practiced in Kentucky, other than cold milling prior to placing a HMA overlay. Full-depth reclamation of asphaltic concrete pavements is a proven, cost-effective means of rehabilitating a deteriorated pavement structure; it is an easily implementable method for rehabilitating asphaltic concrete pavements. Therefore, the focus of this study skewed toward the design and construction of full-depth reclaimed HMA pavements.

Full-depth reclamation takes a degraded pavement and transforms it into a smooth and consistent structure that, when surfaced, supports the designed traffic requirements. Materials from the existing pavement structure are reused in the construction of the new subbase or base layer, which reduces the amount of material required and lowers overall construction costs. Pavement geometrics and layer thickness can be maintained during construction because the existing pavement materials are reused. Often, the impacts of FDR on the motoring public are less than what are experienced with other rehabilitation techniques. There are several advantages KYTC and the Commonwealth of Kentucky would realize from implementing FDR, including: environment benefits, as no millings are produced; cost savings due to less material hauling; deferral of maintenance activities; and lower overall traffic impacts.

KTC researchers reviewed literature focused on current design, construction, and QC/QA methods for HMA reclamation and in-place recycling. The review focused on the following questions:

- When is HMA reclamation and in-place recycling a viable option?
- What structural credit should be given to the stabilized layer?
- What is the optimal modulus/strength to require for the stabilized layer?

Reclamation of HMA pavements is a viable option when the following pavement conditions are present:

- Severe cracking or raveling;
- Potholes, high spots, or depressions due to base failures; and
- Rutting, shoving, and corrugations.

Published studies contain many structural layer coefficient values for the stabilized reclaimed layer. The general consensus is that structural layer coefficients of FDR stabilized with Portland cement range from 0.15 to 0.25 while values for FDR stabilized with bituminous materials range from 0.20 to 0.30. Structural layer coefficients for lime-stabilized FDR and mechanical-stabilized FDR were slightly lower. Strength characteristics of the stabilized FDR subbase and base materials were often limited to less than 500 psi. A stronger layer often results in reflective cracking in the layers above the FDR layer. However, as is often the case, the cement- and bituminous-stabilized materials will modestly increase in strength over time if properly cured. Drainage is also critical to achieving satisfactory performance of the FDR layer.

Preconstruction procedures often involve pavement distress surveys, materials testing, establishing the depth of reclamation based on the existing distresses, and the required structural capacity of the new pavement structure. Information on materials guides the selection of a proper stabilizing agent. Construction of FDR sections typically require pulverization, stabilization, shaping and compacting. After reviewing published specifications on FDR from many agencies and organizations, two separate Special Notes were drafted for implementation by KYTC.

Many highway agencies and private entities have found the use of FDR results in economic benefits, which accrue during both the initial construction phase and across a pavement's long-term service life. The life cycle cost analysis of two projects in Kentucky demonstrate that using FDR for pavement rehabilitation offers clear economic advantages over conventional rehabilitation techniques.

As part of this study, researchers forensically investigated two projects on which FDR techniques were applied to rehabilitate existing pavements — one project was constructed in 2014, the other in 2015. Both projects were constructed using guidance from the Kentucky Special Note for cement roadbed stabilization. Six percent Portland cement was used to stabilize the pulverized pavement materials. Deflection data were gathered and analyzed. The back-calculated modulus of elasticity of the FDR materials averaged 845.11 KSI and 831.46 KSI for the 2014 and 2015 sections, respectively. The structural stiffness of the FDR sections proved greater than the conventionally rehabilitated sections by a factor of nearly two. Core samples of the materials were obtained and evaluated. The compressive strength of the cores from the 2014 rehabilitation averaged 370 psi while the core from the 2015 project averaged 336 psi. Pavement performance data on rutting, cracking, and IRI were obtained. Cracking and rutting were minimal and the IRI values reasonable one year after rehabilitation.

Two separate Draft Special Notes were developed based on information gathered from several resources. One note concerns FDR-cement, and the other FDR-emulsified asphalt. Both notes are presented in the appendices.

7. Conclusions and Recommendations

Full-depth reclamation of old and worn asphalt pavements is a cost-effective means of rehabilitation. There have been some very successful projects constructed in Kentucky by the Kentucky Transportation Cabinet and other agencies over the years with minimal preconstruction and design activities. This report presents information on two KYTC projects that have performed well since their completion. It is recommended that these two projects be rolled in to the Long-Term Monitoring of Experimental Features and monitored for a sufficient period of time to document performance of the FDR layer and overlying pavement.

This report presents draft preliminary specifications for use in FDR construction. It is recommended that KYTC implement the draft specifications on new rehabilitation projects where the existing pavement exhibits severe base failures, cracking or raveling, rutting or shoving, and therefore needs rehabilitation. Potential projects should implement the guidelines and specifications for the use of the FDR in Kentucky developed as part of this study. The guidelines will be utilized to identify suitable projects for FDR and examine material sampling, testing, mixture design, structural design parameters, and selection requirements for FDR treatment established through preconstruction planning activities. Additionally, it is recommended that QC/QA and monitoring be performed to validate the performance of the designs. The results of this continuing research may be used to modify the Special Notes and fully develop specifications for FDR design and construction.

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Appendix A: Life Cycle Cost Analysis

Two contracts were let in Fleming County, Kentucky. Each contract included two pavement sections. One section was to be rehabilitated using conventional construction methods, and the other rehabilitated using FDR.

The first contract was identified by Contract ID No. 143223. The first section was to be rehabilitated by a conventional asphalt overlay with some leveling and wedging. This section was:

- *Cherry Grove Road (KY 597) from KY 3299 extending north to the Mason County line - a distance of 3.09 miles.*

The second section on Contract ID No. 143223 was slated for rehabilitation using FDR construction methods, and was identified as:

- Beechburg Road (KY 3301) from Colgon Road, extending south to 1.38 miles north of KY 559 – a distance of 3.09 miles.

Figures A1 and A2 are the typical sections for this contract.

The second contract in Fleming County was identified by Contract No. 153220. The two different design sections were:

- *Hilltop Road (KY 170) from end of bridge B00066N over Fleming Creek, extending east to KY 32 – a distance of 2.93 miles. This section was to have conventional rehabilitation.*

The second design section slated for FDR rehabilitation was:

- *Beechtree Pike (KY3301) from KY 57 extending north to Colgan Road – a distance of 3.43 miles.*

Figures A3 and A4, on the following pages, are typical sections for this contract.

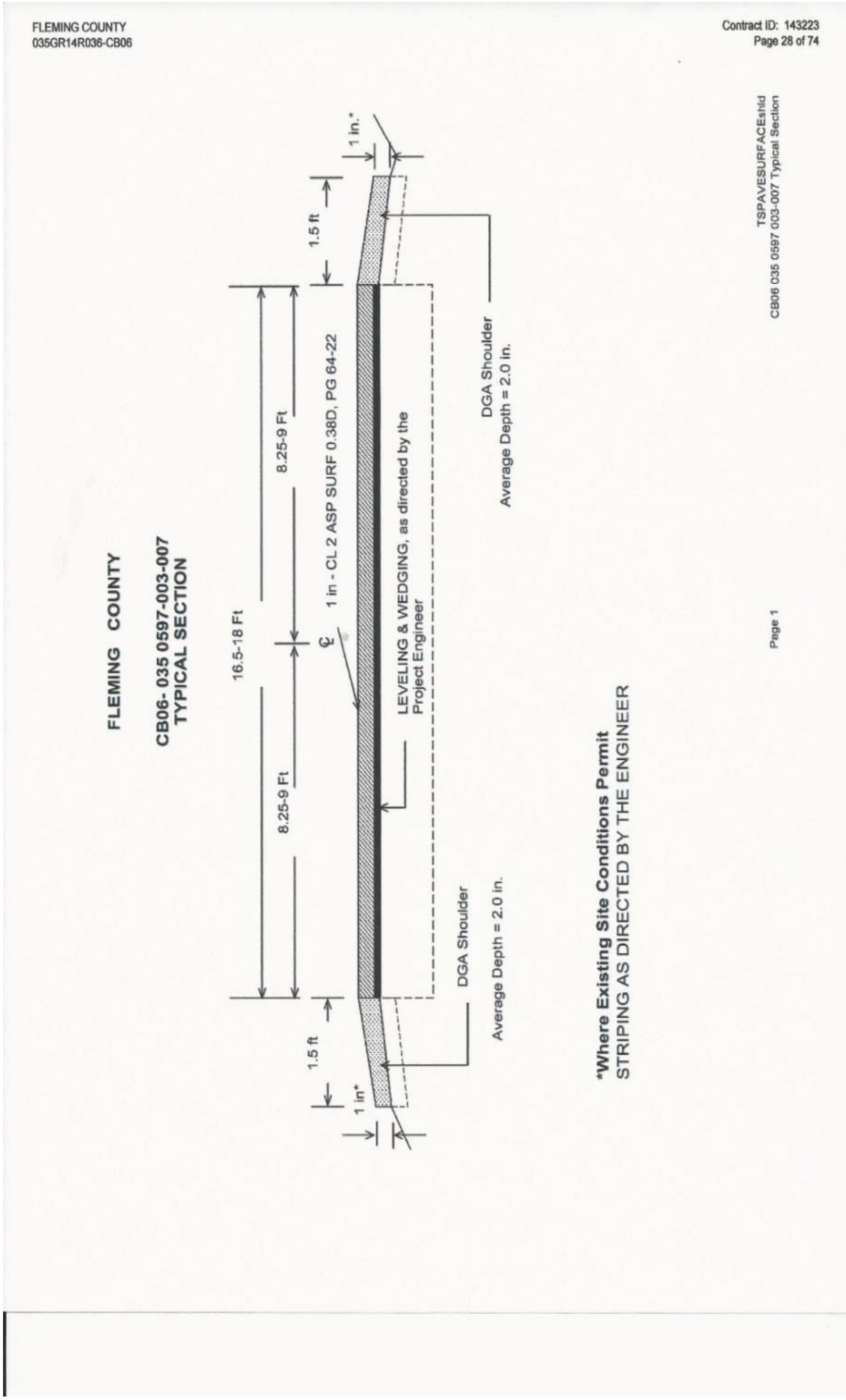

Figure A1. Typical Section for Conventional Rehabilitation.

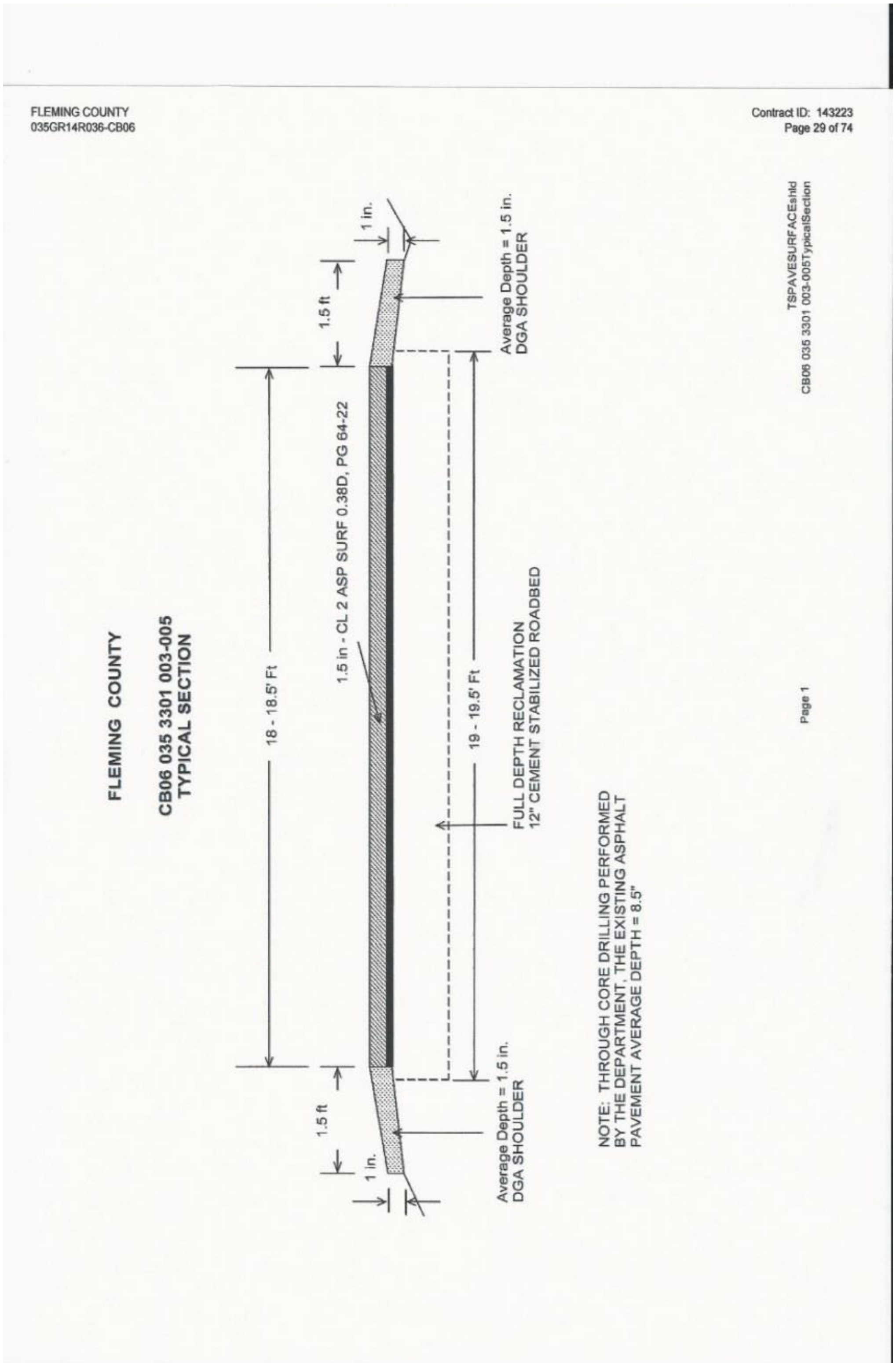

Figure A2. Typical Section for FDR Rehabilitation.

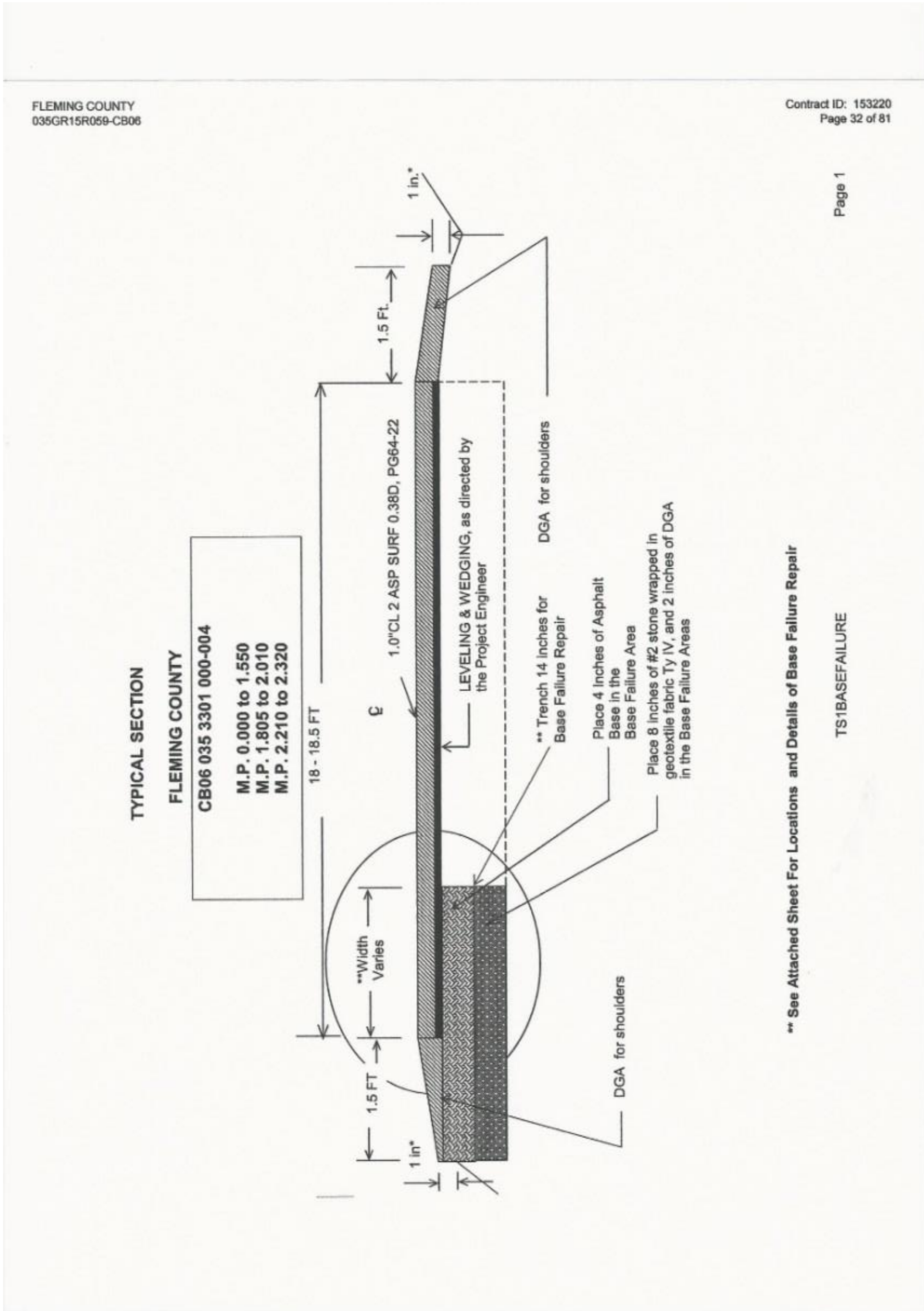

Figure A3. Typical Section for Conventional Rehabilitation.

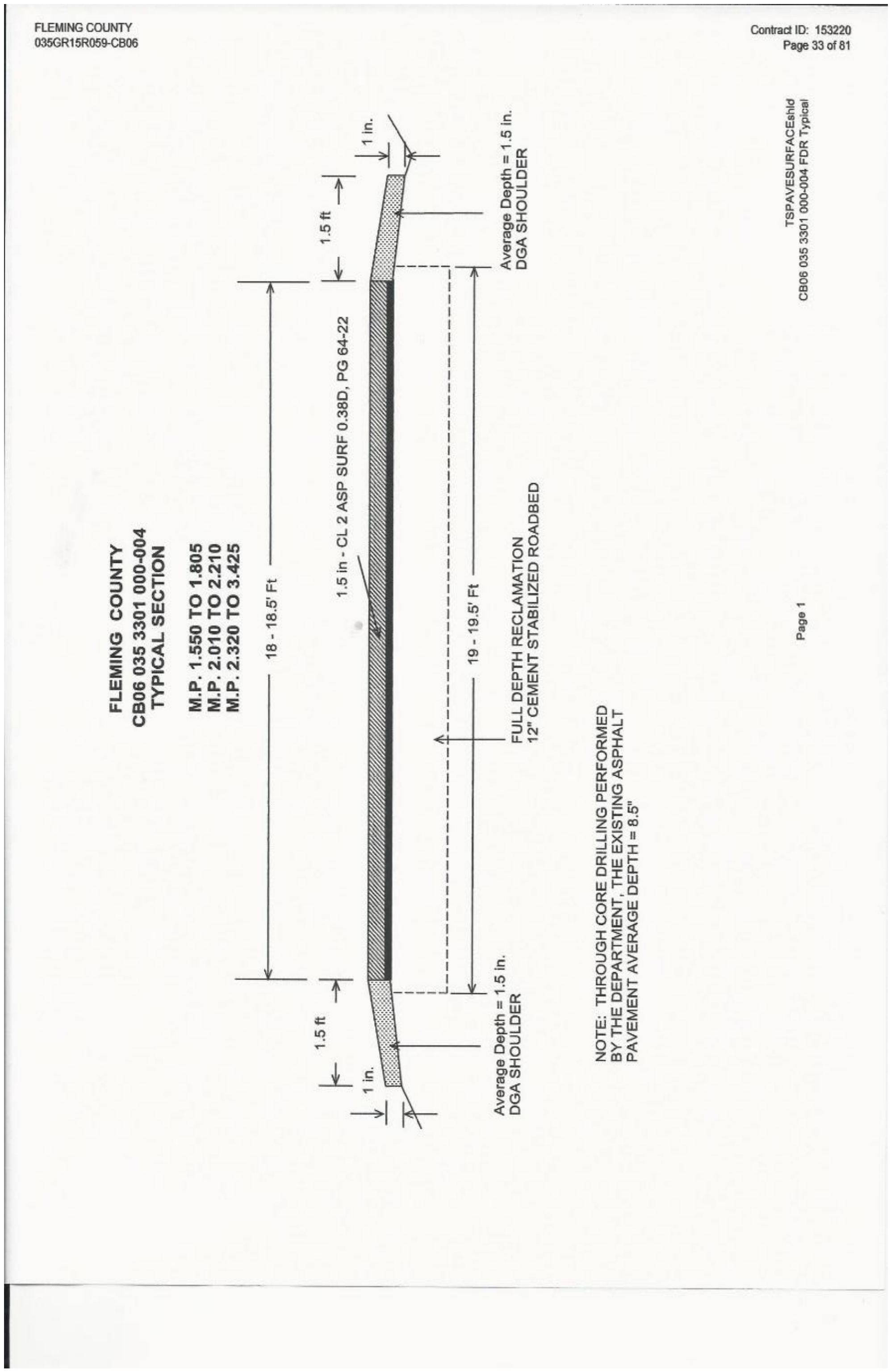

Figure A4. Typical Section for FDR Rehabilitation.

The LCCA method used in this analysis is similar to the one recommended by FHWA (20). One major difference is that *User Costs* were not analyzed for this study due to the lack of available current information. In addition, the analysis used only pavement-related items. Striping, signage, mobilization, and other incidental items were not included. Unit prices were based on the engineer's estimate. The following items and their estimated cost were used in the analysis.

• Cement stabilized Roadbed	\$3.80/sq. yd.,
• Class2 Asphalt Surface	\$58.50/ton,
• DGA Base	\$50.00/ton,
• Asphalt Curing Seal	\$600.00/ton,
• Sand	\$22.00/ton,
• Leveling and Wedging	\$58.50/ton, and
• Cement	\$120.00/ton.

For maintenance activities, these are the items used in the analysis:

• Crack Sealing	\$0.20/sq. yd.,
• 2" Milling and 2" Fill	\$8.62/sq. yd., and
• Patching	\$45.00/sq. yd.

All future maintenance costs have been discounted to net present value (NPV) using a discount rate of 4.0 percent. This method allows all future expenditures to be "brought back" to present day values. The LCCA analysis also assumed a 20-year design life.

The assumed costs listed above were all discounted in the outlying years by calculating the NPV. The equation used to discount the initial costs is as follows:

$$NPV = C_i * (1.0 + r)^{-n} \qquad (1)$$

Where:

NPV = Net Present Value,
C_i = Initial Cost,
r = Discount Rate, and
n = Years after Initial Construction.

The assumed maintenance schedules for each of the construction types and the assumed maintenance activity are shown in the table below. The proposed schedules and activities were obtained from published information and based on the authors' experience.

A life cycle cost analysis was performed using the above information. All costs for the outlying years were discounted using Equation 1. Results are given below, where costs are compared on *a per square yard basis*.

Table A1. Proposed Rehabilitation Schedules.

Year	Conventional Construction	FDR Construction
0	Initial construction	Initial construction
4	Crack Seal	-------------------
5	----------------	Crack Seal
7	Mill 2" – 2" Surface	-------------------
9	----------------	Mill 2" – 2" Surface
10	Crack Seal, 1% Patch	-------------------
13	----------------	Crack Seal
14	Mill 2" – 2" Surface	-------------------
16	----------------	Mill 2" – 2" Surface
17	Crack Seal, 2% Patch	-------------------

Table A2. Results of LCCA.

Year	Conventional Construction		FDR Construction	
	Maint. Activity	**$/Sq. Yd.**	**Maint. Activity**	**$/Sq. Yd.**
0	Level/Wedging, 1" Surface	$4.42	FDR Roadbed, 1.5" Surface	$6.34
4	Crack Seal	$0.17		
5			Crack Seal	$0.16
7	Mill 2", 2" Surface	$7.37		
9			Mill 2", 2" Surface	$6.82
10	Crack Seal, 1% Patch	$0.44		
13			Crack Seal	$0.12
14	Mill 2", 2" Surface	$5.60		
16			Mill 2", 2" Surface	$5.39
17	Crack Seal 2% Patch	$0.56		
20	Salvage	($0.24)	Salvage	($2.31)
	Twenty-Year Cost /sq. yd.	**$18.32**	**Twenty-Year Cost /sq. yd.**	**$16.52**

Assuming a 20-year design life, the data in Table A2 show the FDR construction method is more $1.80 less expensive per square yard than conventional construction techniques. If maintenance costs only are considered over the design life, FDR construction is still cheaper by $1.65 per square yard.

Accounting for salvage value, FDR construction is significantly more economical than conventional construction. Salvage value is defined as follows:

> *The number of years remaining in the design life (DL) / The expected service life of the last rehabilitation activity (SL) * The cost per square yard of the last rehabilitation activity (RC):*
>
> Salvage = (DL / SL) * RC.

For the two projects analyzed for this study, the salvage value was calculated as:

Conventional Construction Salvage:

SL = (17-10) =7 years between *Crack Seal and Patching*, which is the last rehab activity**,**
DL = (20-17) = 3 years remaining between the end of design life and date of last rehabilitation activity,
RC = $0.56 = cost of last rehabilitation activity at year 17, therefore,
*3 / 7 * 0.56 = $0.24 = equals salvage per square yard.*

FDR Construction Salvage:

SL = (16 – 9) = 7 years between *Mill 2", 2" Surface* which is the last rehabilitation activity,
DL = (20 -16) = 4 years remaining between the end of the design life and the date of the last rehabilitation activity,
RC = $5.39 = cost of the last rehabilitation activity at year 16, therefore,
*4 / 7 * 5.39 = $2.31 = equals salvage per square yard.*

Assuming a 20-year design life, the FDR option for pavement rehabilitation is the clear choice over conventional rehabilitation from an economic perspective.

Appendix B: KY 3301 Investigation — Soil Proctor Results

TABLE B1: Eaton Asphalt Paving / Contract ID 143223 / KY 3301 Mile Point 3.43 to 5.0				
Station	**Maximum Dry Density (pcf)**	**Optimum Moisture Content (%)**	**Sampled Depth (FT)**	**Sample Description**
2+80	131.7	7.2	0.0 - 1.0	Light brown and gray, slightly moist silty fine to coarse SAND and GRAVEL with asphalt fragments, little sandy silt and 6% cement.
12+95	132.7	6.7	0.0 - 1.0	Brown, gray and black slightly moist fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
22+95	128.8	7.4	0.0 - 1.0	Dark brown and black slightly moist fine to coarse SAND and GRAVEL with asphalt fragments, trace clay and 6% cement.
33+20	128.1	7.2	0.0 - 1.0	Dark gray and black, trace brown slightly moist fine to coarse SAND and GRAVEL with asphalt fragments, trace clay and 6% cement.
43+25	127.9	7.8	0.0 - 1.0	Gray and dark brown, trace black slightly moist fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
53+70	132.7	7.0	0.0 - 1.0	Gray and black, trace brown slightly moist fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
63+30	128.0	7.9	0.0 - 1.0	Gray and brown, slightly moist silty fine to coarse SAND and GRAVEL with asphalt fragments, trace silty clay and 6% cement.
73+45	135.7	6.0	0.0 - 1.0	Brown and gray, trace black slightly moist fine to coarse GRAVEL and SAND with asphalt fragments, trace silt and 6% cement.
83+40	129.2	7.6	0.0 - 1.0	Reddish brown, brown, gray, and black slightly moist fine to coarse SAND with asphalt fragments, little fine to coarse gravel, trace silty clay and 6% cement.
AVERAGE	130.5	7.2	0.0 - 1.0	

TABLE B2: Mount Carmel Stabilization Group / Contract ID 153220 / KY 3301 Mile Point 0.00 to 3.43				
Mile Point	**Maximum Dry Density (pcf)**	**Optimum Moisture Content (%)**	**Sampled Depth (FT)**	**Sample Description**
0.212 WB	128.3	7.6	0.0 - 1.0	Brown, gray, and black fine to coarse SAND and GRAVEL with asphalt fragments and gravel, trace brown silty clay and 6% cement.
1.616 EB	126.8	7.9	0.0 - 1.0	Gray and black fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
2.132 EB	125.8	7.8	0.0 - 1.0	Brown, gray, and black fine to coarse SAND and GRAVEL with asphalt fragments and gravel, trace brown silty clay and 6% cement.
2.370 EB	125.9	7.3	0.0 - 1.0	Gray and black, fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
2.422 WB	124.0	6.2	0.0 - 1.0	Brown, gray and black fine to coarse SAND and GRAVEL with asphalt fragments, gravel, trace brown silty clay and 6% cement.
2.773 EB	124.9	7.8	0.0 - 1.0	Gray and black fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
3.047 WB	127.5	8.0	0.0 - 1.0	Gray and black fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
3.074 EB	121.1	8.0	0.0 - 1.0	Brown, gray, and black fine to coarse SAND and GRAVEL with asphalt fragments and gravel, trace brown silty clay and 6% cement.
3.259 WB	127.6	6.7	0.0 - 1.0	Gray and black fine to coarse SAND and GRAVEL with asphalt fragments and 6% cement.
AVERAGE	125.8	7.5	0.0 - 1.0	

Appendix C: Field Results — Laser Crack Measurement System, KY 3301 in Fleming County

Table C1: LCMS Data: KY 3301, Mile Point 3.43 to 5.00

2014	Rutting (in.)	Total Cracking (%)	IRI	Lane Area (FT^2)
EB	0.23	27.9	327	88,209
WB	0.22	27.6	303	91,428
2016				
EB	0.06	0.9	136	94,492
WB	0.05	1.2	146	95,876

Table C2: LCMS Data: KY 3301, Mile Point 0.00 to 3.43

2014	Rutting (in.)	Total Cracking (%)	IRI	Lane Area (FT^2)
EB	0.17	38.1	174	160,788
WB	0.11	36.7	157	150,749
2016				
EB	0.06	2.0	111	154,761
WB	0.06	1.9	107	156,747

Appendix D: Field Results — Falling Weight Deflectometer, KY 3301 in Fleming County

Collecting Data with the Kentucky Transportation Center's Falling Weight Deflectometer.

Falling Weight Deflectometer (FWD) measurements were obtained at 200-foot intervals within the right wheel path in each direction of KY 3301 between Mile Point 0.0 and 5.0. Deflection testing and data collection were performed using a JILS-20 FWD and a 9,000 pound loading. The JILS-20 FWD uses a 12-inch rigid steel loading plate; the deflection sensors are velocity transducers and their response is single-integrated to determine the accompanying deflection. A unique feature of the JILS-20 FWD is its ability to report both the first and second peaks of each drop. The FWD data were post-processed to back calculate a layer moduli value for the FDR material. The FWD deflection data were used to determine the relative structural stiffness values for the FDR materials for each direction and each year.

Overall the FWD data suggest a range of elastic layer moduli for the FDR material (Table D1). The modulus values presented are widely scattered as evident by the large standard deviations. Because of the differences in the structure of the conventionally rehabilitated section and the FDR sections, the FWD data were analyzed for structural stiffness. The dynamic stiffness modulus is calculated as the ratio of the loading force and deflection in the load axis, expressed in units of kilo-pounds, or kips, per inch. The average stiffness of the 2015 FDR materials were slightly higher than that of the 2014 FDR materials. The average stiffness of the FDR materials in the 2014 section was 2,156.07 and 2,281.52 Kips/inch in the northbound and southbound directions, respectively. The average standard deviations for the 2014 section were 788.56 and 734.12 Kips/inch for the northbound and southbound directions, respectively. The average stiffness of the FDR materials in the 2015 section was 2,504.35 and 2,506.40 Kips/inch in the northbound and southbound directions, respectively. The average standard deviations for the 2015 section were 833.12 and 630.02 Kips/inch for the northbound and southbound directions, respectively. For comparative purposes, the stiffness of the conventionally rehabilitated sections was 1,217.86 and 1,056.29 Kips/inch for the northbound and southbound directions, respectively. The average standard deviations were 363.47 and 392.91 Kips/inch for the northbound and southbound directions, respectively. Figures D1 and D2 plot the stiffness for each direction.

TABLE D1: KY 3301 Structural Analysis

2014 Section MP 3.43 to 5.00	**NB Modulus (KSI)**	**SB Modulus (KSI)**
MAX Value	1000.00	1000.00
AVG Value	820.34	869.88
MIN Value	115.23	81.07
Standard Deviation	295.50	252.68
2015 Section MP 0.00 to 3.43		
MAX Value	1000.00	1000.00
AVG Value	833.10	829.83
MIN Value	142.80	114.73
Standard Deviation	292.93	317.40

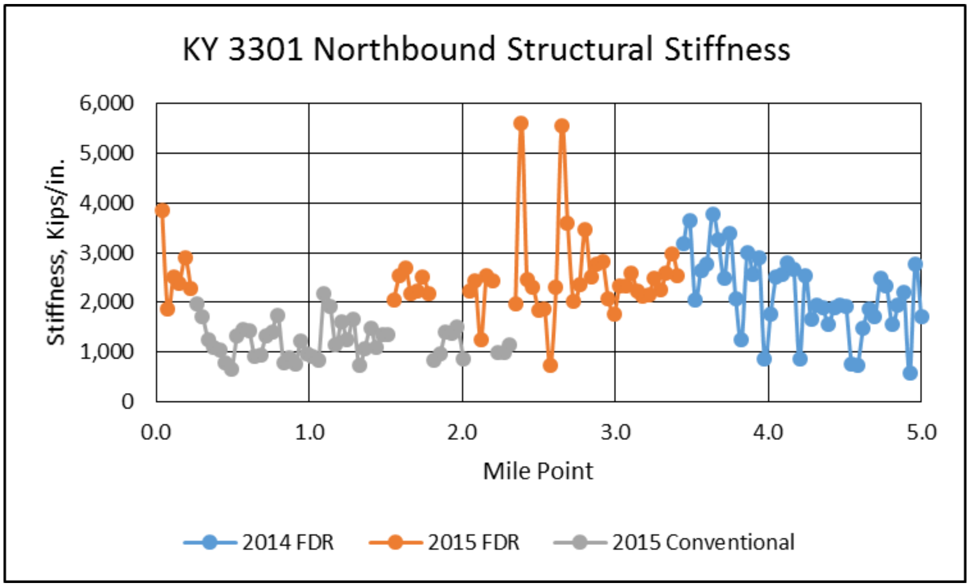

Figure D4. KY 3301 Northbound Structural Stiffness

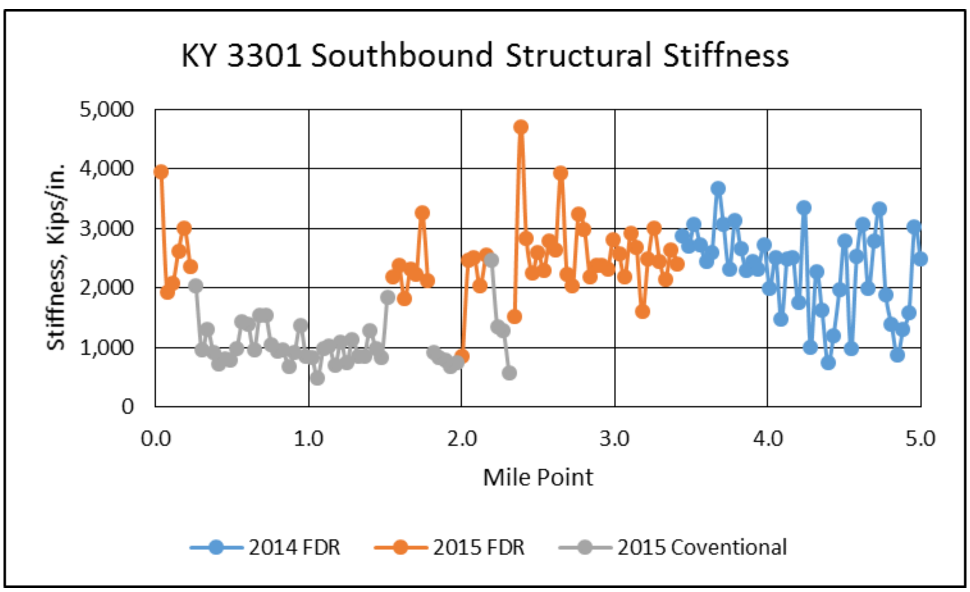

Figure D5. KY 3301 Southbound Structural Stiffness.

Appendix E: Field Results — Coring and Materials Sampling, KY 3301 in Fleming County

KTC Crew Coring Roadway for FDR Sample.

Coring and Materials Sampling

The FDR technique was used on two sections of KY 3301. The oldest section, constructed in 2014 extends from MP 3.43 to MP 5.0. This section was designed to utilize FDR throughout the entire width and length of the project. The second section constructed using FDR methods extends from MP 0.0 at KY 57 northward to MP 3.43. This section was not designed to utilize FDR throughout the entire width and length of the project. It contained areas where conventional methods were employed to remedy significant base failures.

Coring, materials sampling, and dynamic cone penetrometer tests were initially proposed to be performed over a two-day period. However, due to the nature of the roadway, the amount of traffic, and the traffic control provided by KYTC forces, both sections were cored and sampled on the same day. As a result, fewer cores were obtained in the older 2014 section. Coring and materials sampling were performed at locations randomly selected through visual survey. A dynamic cone penetrometer test of the FDR material was attempted initially but the FDR materials were much too hard to permit successful testing with the test device.

The field investigative work was conducted in early December 2016. Work began on the 2015 section and proceeded in the northbound direction. Core specimens were obtained from both the FDR sections and the conventionally repaired sections. Table D1 lists core sample information from the 2014 section while Table D2 contains sample information from the section constructed in 2015. The FDR material was trimmed from the field core specimens and unconfined compressive strength testing was performed. The compressive strength of the cores from the 2014 rehabilitation averaged 370 psi while the core from the 2015 project averaged 336 psi. The unconfined compressive strength values were within expectations for soil-cement mixtures.

Thicknesses of the field samples varied from 9-1/2 to nearly 18 inches. Once the cores were removed, it was determined that no coarse aggregate, such as dense-grade or crushed stone base, was below the core. The thickness of the FDR samples ranged from 11-1/2 to 13 inches. The thickness of the HMA surface above the FDR material ranged from 1/2 inch to 1-7/8 inches. The control section cores ranged in thickness from 9-1/2 to 13 inches.

Evidence found during the coring operations indicated that in some areas the thickness of the *in situ* pavement exceeded what had been measured through previous sampling by KYTC. Sampling prior to construction established an average HMA thickness of 8-1/2 inches. The total length of Core #13, obtained in the southbound lane and approximately 530 feet north of the intersection with KY 57, was 17-3/8 inches. The total thickness of the HMA surface and FDR was 14 inches. Therefore, there was 3-3/8 inches of HMA base material remaining below the FDR material. This indicated that there was no additional aggregate or soil combined with the HMA in this area, and the core was comprised entirely of HMA layers and 6% Portland cement. Figure E1 shows Core #13 photographed prior to trimming for compressive strength testing. This core achieved an unconfined compressive strength of 263 psi.

TABLE E1: KY 3301 Core Samples and Results - Contract ID 143223 / KY 3301 Mile Point 3.43 to 5.00						
Core No.	HMA / Surface Thickness (in.)	FDR Thickness (in.)	FDR Unit Weight (pcf)	FDR Compressive Strength (psi)	FDR Moisture Content (%)	Core Location
7[B]	1-3/8	14	132.4	370.0	7.0	MP 4.0 NB
8[B,C]	1-1/4	NA	NA	NA	NA	MP 4.4 SB
Average		**14**	**132.4**	**370.0**	**7.0**	
NOTES:	B = FDR Sample					
	C = Sample damaged during removal process					

TABLE E2: KY 3301 Core Samples and Results - Contract ID 153220 / KY 3301 Mile Point 0.00 to 3.43						
Core No.	HMA / Surface Thickness (in.)	FDR Thickness (in.)	FDR Unit Weight (pcf)	FDR Compressive Strength (psi)	FDR Moisture Content (%)	Core Location
1[A]	1-7/8	12	130.2	215.0	6.2	MP 0.15 NB
2*	13	NA	NA	NA	NA	MP 1.0 NB
3[A]	7/8	12-1/4	133.0	398.0	4.2	MP 1.75 NB
4*	9-1/2	NA	NA	NA	NA	MP 2.0 NB
5[A]	1/2	11-1/2	127.4	247.0	5.0	MP 2.15 NB
6[A]	1-1/2	12-1/2	131.3	245.0	--	MP 3.0 NB
9[A]	1-1/2	12-1/2	135.0	362.0	--	MP 2.75 SB
10[A]	1-1/4	11-7/8	132.0	580.0	3.3	MP 2.10 SB
11[A]	1	13	128.9	378.0	4.1	MP 1.69 SB
12*	12-1/2	NA	NA	NA	NA	MP 0.75 SB
13[A]	1-7/8	12-1/8	127.1	263.0	--	MP 0.1 SB
Average		**12-1/4**	**130.6**	**336.0**	**4.6**	
NOTES:	A= FDR Sample					
	* = Control section					

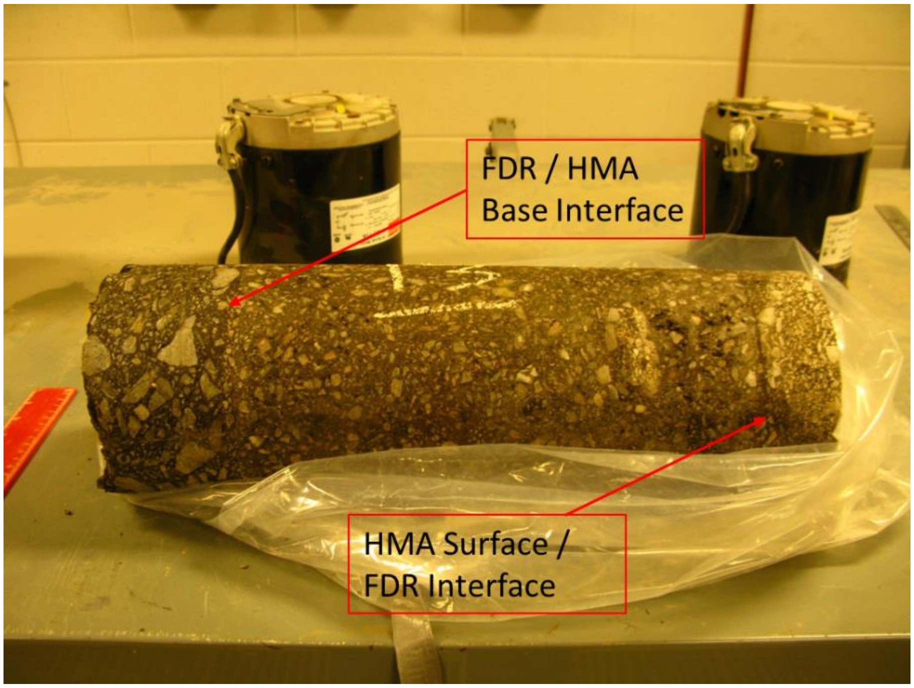

Figure E1. Full Depth Reclamation sample # 13 prior to trimming for compressive strength testing shows unreclaimed HMA material below the reclaimed materials.

Appendix F: Special Note for Full-Depth Reclamation of HMA with Cement

SPECIAL NOTE FOR FULL DEPTH RECLAMATION OF HMA WITH CEMENT

1. **GENERAL**

   1.1. **Description.** Full-depth reclamation (FDR) with cement, shall consist of pulverizing and mixing existing asphalt pavement and base course material with Portland cement, soil, and water to produce a dense, hard, cement-treated base. It shall be proportioned, mixed, placed, compacted, and cured in accordance with this specification, and shall conform to the lines and grades shown in the plan.

2. **MATERIALS**

   2.1. **Recycled Asphalt Pavement (RAP) and Base Material.** Shall consist of the existing asphalt pavement, existing base course material, and/or subgrade material. The base course and subgrade material shall not contain roots, topsoil, or any material deleterious to its reaction with cement. The particle distribution of the processed material shall be such that 100% passes a 3-inch sieve, at least 95% passes a 2-inch sieve, at least 55% passes a No. 4 sieve, and maximum 20% passes a 200 sieve.

   2.1.1. **Mix Design.** Remove samples of RAP and base material to the specified depth and perform appropriate testing to establish mix design. Submit mix design to the Engineer for approval one week before the planned start of work. Approval of the mix design by the Engineer is solely for monitoring quality control and in no way releases the Contractor from their responsibilities.

   2.1.2. **Mix Design Development.** Mix Design Development — Samples must be obtained inclusive of the depth to be recycled. Use a 1x1x1 foot excavation to closely simulate field conditions. A Qualified Technical Representative will analyze the samples and provide the following information as part of the mix design to the Engineer:

   - Location of core samples.
   - Thickness and description of existing pavement and aggregate layers to be reclaimed.
   - A selected matrix of soils testing standards (performed on mixed sample, except T208.)
     - Moisture Content AASHTO T265 — Mechanical and Hydrometer
     - Particle Size Analysis of Soils AASHTO T88
     - Liquid Limit AASHTO T89
     - Moisture Density AASHTO T99 (KM 64-511)
     - Unconfined Compression AASHTO T208 (KM 64-522) — To be performed on subgrade soil only if more than 20% of the underlying subgrade is to be included in the Portland cement stabilized layer.

   2.2. **Cement.** Shall comply with Section 801 of the KYTC Standard Specifications for Road and Bridge Construction, current edition.

   2.3. **Water.** Shall be free from substances detrimental to the curing of the cement-treated material.

EQUIPMENT

2.4. **Description.** FDR may be constructed with any machine or combination of machines that will produce a satisfactory product meeting the requirements for depth of pulverization, cement and water application, mixing, compacting, finishing, and curing, as provided in this specification.

2.5. **Mixing Methods.** Mixing shall be accomplished in place, using single-shaft or multiple-shaft mixers. Agricultural disks or motor graders are not acceptable mixing equipment.

2.6. **Cement Proportioning.** Spreading of the cement shall be done with a spreader truck designed to spread dry particulate such as cement to insure a uniform distribution. Spreaders or distributors used shall be able to demonstrate a consistent and accurate application rate, as well as dust control during application. The mechanical cement spreader shall be capable of dispensing a measured quantity of cement +/- 3 pounds per square yard in advance of the pulverizer just prior to each pass of the stabilizing operation. The pulverizer shall abut or slightly overlap (3") the previous pass to ensure a continuous homogeneous mass of granular material and cement. Cement spreader does not have to abut or overlap the previous pass as long as the calculated quantity of cement is dispersed in front of the pulverizer.

2.7. **Application of Water.** Water may be applied through the mixer or with water trucks equipped with pressure-spray bars. If using the spray bar system, road base shall be pre-wetted to obtain optimum moisture content prior to the dispensing of cement. Do not apply water directly to the roadway before or after cement placement without first pulverizing the roadbed.

2.8. **Compaction.** Compact the FDR base uniformly to a minimum of 95% of maximum dry density in accordance with KM 64-511 based on a moving average of five consecutive tests with no individual test below 94%. Establish a compaction pattern that will achieve the required density without over compaction.

3. CONSTRUCTION REQUIREMENTS

3.1. General

3.1.1. **Preparation.** Methods, equipment, tools, and any machinery to be used during construction shall be approved by the Engineer prior to the start of the project. Prior to the actual reclaiming of the roadway, drop inlets or catch basins that might be affected shall be sufficiently barricaded to prevent reclaimed subbase material, silt or runoff from plugging the drainage system.

Sufficient surface drainage must be provided for each stage of construction so that ponding does not occur on the reclaimed sub-base course prior to the placement of bituminous concrete.

Reclamation shall be accomplished by means of a self-propelled, traveling rotary reclaimer or equivalent machine capable of cutting through existing bituminous concrete pavement to depths of up to 15 inches with one pass. The machine shall be equipped with an adjustable grading blade, leaving its path generally smooth for initial compaction. Equipment such as road planers or cold milling machines designed to mill or shred the existing bituminous concrete, rather than crush or fracture it, shall not be allowed.

Existing bituminous concrete pavement and any underlying granular material must be pulverized and mixed so as to form a homogenous mass of reclaimed sub-base material which will bond together when compacted.

In areas where the vertical or horizontal geometry of the proposed roadway is different than that of the existing roadway, the roadway shall be reclaimed in-place and the reclaimed material sub-base placed in windrows or stockpiled while any filling or excavation is performed. When the proposed sub-grade elevation is achieved, the reclaimed sub-base material will be placed back onto the roadway in lifts no greater than five (5) inches in depth before being compacted.

Reshaping using the reclaimed sub-base material should be minimized in order to ensure that the roadway has a uniform thickness of reclaimed sub-base material throughout. Unless otherwise specified, when reshaping of the roadway is required, it should be performed utilizing additional sub-base or processed aggregate base.

The reclaimed sub-base material shall be compacted prior to the placement of any additional granular material (sub-base or processed aggregate base). Subsequent to the compaction of the reclaimed sub-base material, any reshaped material or additional material placed on the roadway should not exceed five (5) inches in depth before being compacted.

A motor grader shall be used for shaping, fine grading, and finishing the surface of the reclaimed material or any other granular materials placed to form the surface prior to paving.

Any surface irregularities which develop during or after the above-described work shall be corrected until it is brought to a firm and uniform surface satisfactory to the Engineer.

3.1.2. **Mixing and Placing.** FDR processing shall not commence when the soil aggregate or sub-grade is frozen, or when the air temperature is below 40°F (4°C). Moisture in the base course material at the time of cement application shall not exceed the quantity that will permit a uniform and intimate mixture of the pulverized asphalt, base material and cement during mixing operations, and shall be within +/-2% of the optimum moisture content for the processed material at start of compaction.

3.1.3. The operation of cement application, mixing, spreading, compacting, and finishing shall be continuous and completed within 2 hours from the start of mixing. Any processed material that has not been compacted and finished shall not be left undisturbed for longer than 30 minutes.

3.1.4. Scarifying. Before cement is applied, initial pulverization or scarification may be required to the full depth of mixing. Scarification or pre-pulverization is a requirement for the following conditions:

- When the processed material is more than 3% above or below optimum moisture content. When the material is below optimum moisture content, water shall be added. The pre-pulverized material shall be sealed and properly drained at the end of the day or if rain is expected.
- For slurry application of cement, initial scarification shall be done to provide a method to uniformly distribute the slurry over the processed material without excessive runoff or ponding

3.2. Application of Cement. The specified quantity of cement shall be applied uniformly in a manner that minimizes dust and is satisfactory to the Engineer. If cement is applied as a slurry, the time from first contact of cement with water to application on the soil shall not exceed 60 minutes. The time from cement placement on the soil to start of mixing shall not exceed 30 minutes.

3.3. Mixing. Mixing shall begin as soon as possible after the cement has been spread and shall continue until a uniform mixture is produced. The mixed material shall meet the following gradation conditions:

3.3.1. The final mixture (bituminous surface, granular base, and sub-grade soil) shall be pulverized such that 100% passes the 3-inch sieve, at least 95% passes the 2-in. sieve, and at least 55% passes the No. 4 sieve. Additional material can be added to the top or from the sub-grade to improve the mixture gradation, as long as this material was included in the mixture design.

3.3.2. The final pulverization test shall be made at the conclusion of mixing operations. Mixing shall be continued until the product is uniform in color, meets gradation requirements, and is at the required moisture content throughout. The entire operation of cement spreading, water application, and mixing shall result in a uniform pulverized asphalt, soil, cement, and water mixture for the full design depth and width.

3.4. Compaction. The processed material shall be uniformly compacted to a minimum of 95% of maximum density based on a moving average of five consecutive tests with no individual test below 94%. Field density of compacted material can be determined according to the KYTC standard specifications. Optimum moisture and maximum density shall be determined prior to start of construction and also in the field during construction by a moisture-density test approved by the Engineer.

At the start of compaction, the moisture content shall be within +/-2% (see 4.1.2) of the specified optimum moisture. No section shall be left undisturbed for longer than 30 minutes during compaction operations. All compaction operations shall be completed within 2 hours from start of mixing.

3.5. Finishing. As compaction nears completion, the surface of the FDR material shall be shaped to the specified lines, grades, and cross sections. If necessary or as required by the engineer, the surface shall be lightly scarified or broom-dragged to remove imprints left by equipment or to prevent compaction planes. Compaction shall then be continued until uniform and adequate density is obtained.

During the finishing process the surface shall be kept moist by means of water spray devices that will not erode the surface. Compaction and finishing shall be done in such a manner as to produce a dense surface free of compaction planes, cracks, ridges, or loose material. All finishing operations shall be completed within 4 hours from start of mixing.

3.6. Curing. Finished portions of the FDR base that are traveled on by equipment used in constructing an adjoining section shall be protected in such a manner as to prevent equipment from marring or damaging completed work.

After completion of final finishing, the surface shall be cured by application of a bituminous or other approved sealing membrane, or by being kept continuously moist for a period of 7 days with a water spray that will not erode the surface of the FDR base. If curing material is used, it shall be applied as soon as possible, but not later than 24 hours after completing finishing operations. The surface shall be kept continuously moist prior to application of curing material. For bituminous curing material, the FDR base surface shall be dense, free of all loose and extraneous materials, and contain sufficient moisture to prevent excessive penetration of the bituminous material. The bituminous material shall be uniformly applied to the surface of the completed cement-treated material. The exact rate and temperature of application for complete coverage, without undue runoff, shall be specified by the engineer.

Should it be necessary for construction equipment or other traffic to use the bituminous-covered surface before the bituminous material has dried sufficiently to prevent pickup, sufficient sand cover shall be applied before such use.

3.7. Traffic. Completed portions of FDR base can be opened immediately to low-speed local traffic and to construction equipment if a curing seal is used and provided the curing material is not impaired, and provided the FDR base is sufficiently stable to withstand marring or permanent deformation. The section can be opened up to all traffic after the FDR base has received a curing compound or subsequent surface and is sufficiently stable to withstand marring or permanent deformation. If continuous moist curing is employed in lieu of a curing compound or subsequent surfacing within 7 days, the FDR base can be opened to all traffic after the 7-day moist curing period, provided the FDR base has hardened sufficiently to prevent marring or permanent deformation.

3.8. Surfacing. In most cases, allow the FDR to cure for a minimum of two days (48 hours after completing finishing operations) before applying a surface course in order to determine if any isolated soft spots exist. If the Engineer deems the situation warrants faster construction, the surfacing can be placed any time after finishing, as long as the FDR base is sufficiently stable to support the required construction equipment without marring or permanent distortion of the surface.

3.9. Maintenance. The contractor shall maintain the cement-treated material in good condition until all work is completed and accepted. Maintenance shall include immediate repairs of any defects that may occur. If it is necessary to replace any processed material, the replacement shall be for the full depth, with vertical cuts, using either cement-treated material or concrete. No skin patches will be permitted. Such maintenance shall be done by the contractor at their own expense.

4. INSPECTION AND TESTING

4.1. Description. The contractor shall make such inspections and tests as deemed necessary to ensure the conformance of the work to the contract documents. These inspections and tests may include, but shall not be limited to:

Recycling operations including recycling speed, yield monitoring, monitoring treatment depth, procedures for avoiding recycling and curing in inclement weather, methods to ensure that segregation is minimized, procedures for mix design modification, grading and compacting operations, and cement application procedure.

Density testing of the recycled material will be performed using the nuclear method. When the quantity of +4 material prevents nuclear testing, proof rolling by a fully loaded tri axle dump truck (approximately 80,000, pounds total) may be used at the approval of the Engineer.

Only those materials, machines, and methods meeting the requirements of the contract documents shall be used unless otherwise approved by the Engineer.

All testing of processed material or its individual components, unless otherwise provided specifically in the contract documents, shall be in accordance with the latest applicable ASTM or AASHTO specifications in effect as of the date of advertisement for bids on the project.

5. MEASUREMENT AND PAYMENT

5.1. Measurement.

5.1.1. Full-Depth Reclamation. This Department will measure the quantity in square yards of completed and accepted full-depth reclamation. The Department will not measure corrective or reconstructed work for payment. The Department will not measure water for payment and will consider it incidental to this item of work.

5.1.2. Asphalt Curing Seal. The Department will not measure curing seal for payment and will consider it incidental to this work.

Payment. This Department will make payment for the completed and accepted quantities under the following:

Code	Pay Item	Pay Unit
24936EC	Full Depth Reclamation with Cement	Square Yard
02542	Cement	Ton
02702	Sand for Blotter	Ton

Appendix G: Special Note for Full-Depth Reclamation of HMA with Asphalt Emulsion

SPECIAL NOTE FOR FULL DEPTH RECLAMATION OF HMA WITH ASPHALT EMULSION

1. **GENERAL**

1.1. DESCRIPTION. This work consists of pulverizing the existing asphalt surfacing, aggregate base course and subgrade to the depth shown on the plans, mixing with water, spreading and compacting the mixed material, then pulverizing to the depth shown on the plans, mixing with asphalt emulsion, spreading, and compacting the mixed material.

2. **MATERIALS.**

2.1 Recycled Asphalt Pavement (RAP) and Base Material. Shall consist of the existing asphalt pavement, existing base course material and/or subgrade material. The base course and subgrade material shall not contain roots, topsoil, or any deleterious material. The pulverized material shall meet the following gradation requirements:

Sieve Size	Size, mm	Passing, %	
		Min	Max
2"	50	100	100
1-1/2"	37.5	87	100
1"	25	77	100
3/4"	19	67	99
1/2"	12.5	59	87
3/8"	9.5	49	74
4	4.75	35	56
8	2.36	25	42
16	1.18	18	33
30	0.6	12	27
50	0.3	8	24
100	0.15	3	16
200	0.075	2	9

2.1.1 **Mix Design.** Remove samples of RAP and base material to the specified depth and perform appropriate testing to establish mix design. Submit mix design to the Engineer for approval one week before the planned start of work. Approval of the mix design by the Engineer is solely for monitoring quality control and in no way releases the Contractor from their responsibilities.

2.1.2 **Mix Design Development.** Mix Design Development — Samples must be obtained inclusive of the depth to be recycled. Use a 1x1x1 foot excavation to closely simulate field conditions. A Qualified Technical Representative will analyze the samples and provide the following information as part of the mix design to the Engineer:

- Location of core samples.
- Thickness and description of existing pavement and aggregate layers to be reclaimed.
- A selected matrix of soils testing standards (performed on

mixed sample, except T208).

- Moisture Content AASHTO T265 — Mechanical and Hydrometer
- Particle Size Analysis of Soils AASHTO T88
- Liquid Limit AASHTO T89
- Moisture Density AASHTO T99 (KM 64-511)
- Unconfined Compression AASHTO T208 (KM 64-522) — To be performed on subgrade soil only if more than 20% of the underlying subgrade is to be included in the asphalt emulsion stabilized layer.

2.2 Asphalt Emulsion. The asphalt emulsion shall be meet the requirements of subsection 806.04.

2.3 Water. Shall be reasonably clean and free from oil, salt, acid, alkali, sugar, vegetable, or other substances injurious to the finished product. Provide water that when tested in accordance with KM 64-226 meets the requirements provided in Section 803.02 of the current edition of the Kentucky Transportation Cabinet's Standard Specifications for Road and Bridge Construction.

3. CONSTRUCTION REQUIREMENTS

3.1 Weather Limitations. Daily recycling operations shall not begin until the atmospheric temperature is 55 ºF and rising. Recycling operations shall be discontinued when the temperature is 60 ºF and falling. Recycling operations shall not be performed when the weather is foggy or rainy, or when weather conditions are such that the proper mixing, spreading, compacting, and curing of the recycled material cannot be accomplished. Cold recycled pavement damaged by precipitation shall be reprocessed or repaired by methods approved by the Engineer, at the Contractor's expense. The construction of base layer using full depth reclamation with asphalt emulsion will not be allowed from September 16 through May 14 unless otherwise approved. The Contractor's Progress Schedule shall show the methods to be used to comply with this requirement.

3.2 Pulverizing-First Pass. The existing asphalt surfacing, base course and, if shown on the plans, subgrade, and any added virgin aggregates shall be pulverized. Adjacent recycling passes shall overlap at the longitudinal joint a minimum of 6 inches. The beginning of each day's recycling operation shall overlap the end of the preceding recycling operation a minimum of 100 feet unless otherwise directed. Any fillet of fine, pulverized material that forms adjacent to a vertical face shall be removed prior to spreading the mixed material, except that such fillet adjacent to existing pavement that will be removed by a subsequent overlapping milling operation need not be removed. Vertical cuts in the roadway shall not be left overnight.

The Contractor may add water to the materials during the first pass of the pulverizer to facilitate compaction and achieve the moisture content established during the mixture design. An allowable tolerance of plus or minus 0.2 percent of the initial design rate or directed rate of application shall be maintained at all times. The exact application rate of water may be varied as required by existing pavement conditions.

3.3 Grading-First Pass. The Contractor may be required to use a motor grader to bring the pulverized materials into conformance with elevations shown on the plans prior to the second pass of the pulverizer. If segregation occurs behind the paver, the Contractor shall make changes in equipment, operations, or both to eliminate the segregation.

3.4 Compacting-First Pass. After the recycled material has been graded to conform to planned elevations, initial compaction of the pulverized layer shall be by vibratory pad foot roller. The roller shall be operated at maximum amplitude and shall continue until the density of the pulverized layer is not less than 95 percent of the maximum density achieved by KM 64-511-08. Moisture content shall be the amount determined during mixture design prior to the addition of the asphalt emulsion. If the area tested fails to meet the required density, the area shall be reworked until it attains 95 percent compaction. The frequency of density testing for project acceptance will be one per 5000 square yards. The Engineer will perform one KM 64-511-08 for calculation of the percent relative compaction with each field density taken.

3.5 Pulverizing-Second Pass. Asphalt emulsion shall be added to the graded and compacted layer during the second pass of the pulverizer. An allowable tolerance of plus or minus 0.2 percent of the initial design rate or directed rate of application shall be maintained at all times. The exact application rate of the asphalt emulsion will be determined during production and may be varied as required by existing pavement conditions. A representative of the asphalt emulsion supplier shall be present on the project during recycling operations until an acceptable production sequence is established as determined by the Engineer.

3.6 Grading-Second Pass. The Contractor may be required to use a motor grader to bring the pulverized materials into conformance with elevations shown on the plans prior to placing the hot mix asphalt wearing surface. If segregation occurs behind the paver, the Contractor shall make changes in equipment, operations, or both to eliminate the segregation.

3.7 Compacting and Finishing-Second Pass. After the recycled material has been graded, traffic, including the Contractor's equipment, shall not be allowed on the recycled material until it starts its initial break as determined by the Engineer. However, if precipitation is imminent, compaction may proceed to seal the surface from additional moisture. Initial rolling shall be performed with one or more steel-wheeled vibratory rollers operated at the lowest amplitude setting. Intermediate pneumatic tire rollers shall be used to knead the surface closed prior to finish rolling. Final rolling to eliminate pneumatic tire marks and achieve the required density shall be done by steel wheel rollers in static mode. The use of vibratory rollers shall be approved by the Engineer. If rollers are used in the vibratory mode, vibration shall be at low amplitudes to prevent transverse cracks. The recycled material shall be compacted to 92 to 96 percent of the maximum theoretical density of laboratory specimens compacted from project materials.

If the area tested fails to meet the required density, the area shall be reworked until it attains the required compaction. The frequency of density testing for project acceptance will be one per 5000 square yards. The Engineer will perform one maximum theoretical density for calculation of the percent relative compaction with each field density taken.

Rollers shall not be started or stopped on un-compacted recycled material. Rolling shall be accomplished so that starting and stopping will be on previously compacted pulverized pavement or existing pavement. Any type of rolling that results in cracking, movement, or other types of pavement distress shall be discontinued until the problem is resolved.

After the recycled material has been compacted, traffic, including the contractor's equipment, shall not be permitted on the pulverized pavement for at least two hours unless otherwise approved. Before placing the hot mix asphalt overlay, the pulverized pavement shall be allowed to cure until the free moisture is reduced to 1 percent free moisture or less, by total weight of mix. Free moisture will be measured in substantial accordance with KM 64-434. After the free moisture content of the pulverized pavement has reached the acceptable level, the hot mix asphalt overlay shall be placed. However, unless otherwise approved by the Engineer, the pulverized pavement shall be covered with a minimum thickness of 2 inches of hot mix asphalt within ten calendar days after it is mixed and compacted.

Damage caused by the Contractor to the pulverized pavement shall be repaired at Contractor's expense, as directed, prior to placing any hot asphalt surfacing. Soft areas that are not caused by the Contractor or weather shall also be repaired prior to placing the hot mix asphalt.

3.8 Recycling Train. The Contractor shall furnish a self-propelled machine capable of pulverizing the existing asphalt surfacing to the depth shown on the plans, in one pass. The machine shall have a minimum rotor cutting width of 8 feet. The rotor cutting width selected for the project shall allow for the longitudinal joint to be offset from the longitudinal joint of the layer placed above by at least 6 inches. The longitudinal joint shall not fall in the wheel paths. The machine shall have standard automatic depth controls, and maintain a constant cutting depth. The machine shall also have screening capabilities to reduce or remove oversize particles prior to mixing with water and asphalt emulsion. Oversize particles shall be removed. The machine shall perform continuous weight measurement of the pulverized material interlocked with the asphalt emulsion metering device so the required asphalt emulsion content will be maintained. Positive means shall be provided for calibrating the weight measurement device and the asphalt emulsion metering device.

A positive displacement pump, capable of accurately metering the required quantity of asphalt emulsion at rates as low as 4 gallons per minute, shall be used to apply the asphalt emulsion. The interlock system shall allow addition the of the asphalt emulsion only when pulverized material is present in the mixing chamber.

Each mixing machine shall be equipped with a meter capable of registering the rate of flow and the total amount of asphalt emulsion introduced into the mixed material. The asphalt emulsion shall be applied through a separate mixing machine capable of mixing the pulverized material and the asphalt emulsion into a homogeneous mixture, and placing the mixture behind the pulverizer.

3.9 Compactors. Rollers shall be pad-foot, club-foot, taper-foot, steel-wheel, pneumatic tire, vibratory, or combinations of these types. The number and weight of rollers shall be sufficient to obtain the required compaction while the pulverized material is in a workable condition, except that each pneumatic tire roller shall be 20 tons minimum weight.

4.0 MEASUREMENT AND PAYMENT

4.1 Measurement.

4.1.1 Full Depth Reclamation. The Department will measure the quantity in square yards of completed and accepted full depth reclamation. The Department will not measure corrective or reconstructed work for payment. The Department will not measure water for payment and will consider it incidental to this item of work.

4.1.2 Payment. This Department will make payment for the completed and accepted quantities under the following:

Code	Pay Item	Pay Unit
TBD	Full Depth Reclamation with Asphalt	Square Yard
TBD	Asphalt Emulsion	Ton