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DEPARTMENT OF TRANSPORTATION

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# **Developing Standards and Specifications for Full Depth Pavement Reclamation**

FINAL REPORT

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By Quality Engineering Solutions, Inc.

COMMONWEALTH OF PENNSYLVANIA  
DEPARTMENT OF TRANSPORTATION

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# **Developing Standards and Specifications for Full Depth Pavement Reclamation**

## **EXECUTIVE SUMMARY**

A detailed research study has been conducted to develop guidelines, and the necessary practice documentation for the Department to use full depth reclamation (FDR) as a standard pavement rehabilitation treatment. Several activities have been accomplished to fulfill this objective, including:

- Literature review of existing practices and specifications
- Update of related PennDOT documents
- Development of a Best Practices Document
- Participation in and documentation of two construction projects
- Preparation of Clearance Transmittal review of a construction specification
- Development of construction standards, design guidelines, material evaluation, and all other documents needed for implementation
- Development and delivery of a train the trainer course
- A project summary presented as the final report

The literature review focused on gathering information from several states with experience in the use and implementation of FDR strategies. Both chemical and bituminous stabilization were included. Related materials already in Publication 447 were also reviewed.

In particular, information was obtained from the states of Georgia, Maine, Texas, Virginia, Washington, Ohio, Illinois, and Ontario, Canada regarding their experience with FDR. Additionally, the review included guidance from the Asphalt Recycling and Reclaiming Association and a report on FDR mix design by the Worcester Polytechnic Institute. A review of numerous existing PennDOT publications was carried out to identify revisions or additions that will be needed to implement FDR. These included revisions to Publications 242 (Pavement Policy Manual), 27 (Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures), 23 (Maintenance Manual), 408 (Specifications), and 30 (Bulletin 5, Design Methods for Air-entrained Portland Cement Concrete and Ready-Mixed Portland Cement Concrete).

During the process of developing a Best Practices Manual for FDR, the research team assisted PennDOT with the construction of two separate FDR projects, one using chemical stabilization and the other emulsion stabilization. The effort included the development of a process for the identification of potential FDR projects and criteria for selecting which specific type of stabilizing material is best suited for an individual project. Project specific mix designs were developed for the two pilot projects, and general mix design procedures provided for future use. Assistance was also provided to the Department in planning and carrying out the construction of the two pilot projects. Onsite expertise was provided during construction, as well as quality control activities, and final testing for compliance with acceptance criteria. Procedures for the Best Practices document were refined following the completion of the two field projects.

Subsequently, a package containing all the documents developed was assembled for delivery to the Department. It contained the deliverables including the related Department documents, the constructions specifications, and Best Practices document.

The last activity before submission of the final report was the development and presentation of a train-the-trainer course. The course format includes an overview section of FDR at the management level, and more detailed discussion for those involved in conducting the work.

A final project report provides a summarization of work conducted and findings throughout the study. It discusses the conclusions from each task, and provides the final recommendations.

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## **I.0 INTRODUCTION**

### **I.1 Introduction to Full Depth Reclamation**

According to Asphalt Recycling & Reclaiming Association (ARRA), Full Depth Reclamation (FDR) is defined as:

“A pavement rehabilitation technique in which the full flexible pavement section and a pre-determined portion of the underlying materials are uniformly crushed, pulverized or blended, resulting in a stabilized base course.”

In general, it is preferred that the roads are maintained and preserved at reasonable intervals before they get distressed to the levels requiring major work. However, if preservation maintenance is not applied early enough or if there are base/subbase/subgrade problems, the road will probably be deteriorated to a level that needs major rehabilitation. FDR can be categorized as one of the major rehabilitation techniques.

#### ***I.1.1 FDR Methods and Materials***

In general, the type of FDR construction is selected based on the existing pavement condition and materials, availability of materials, traffic demand, and cost. In its simplest form, FDR consists of in-situ pulverization of existing pavement and underlying layers, uniform blending of pulverized material, grading, and compaction. The only additive in this case will be water to assist with blending and compaction. Water is the only additive common to all FDR techniques. Most often, additional materials are needed to improve the quality and capacity of the stabilized base through FDR. These materials include: emulsion or foamed asphalt for bituminous stabilization of the base, cement, or other cementing agents considered as chemical stabilizers, or simply aggregates to ensure proper material gradation to ensure durability and load carrying capacity. It is not uncommon to see a combination of these materials applied beneficial to the mix design.

#### ***I.1.2 FDR Application***

The road conditions suitable for the use of FDR include:

- Flexible pavements or unpaved roads
- Renewal of deteriorated roads by incorporating existing materials
- Severely raveled or cracked roads (block, alligator, longitudinal, thermal, reflective)
- Roads with high spots (heaves) or depressions if due to underlying layers
- Roads with heavy pothole patching
- Roads with severe plastic deformation (rutting, shoving, corrugation, etc) contributed to weak deficient base/subbase

FDR is primarily applied to low to medium volume roads and streets. However, there are many examples where it has been applied to parking lots, major roads, and interstate highways.

### ***1.1.3 FDR Benefits***

As FDR is categorized as a major rehabilitation technique, the FDR rehabilitated road could have improvements in all areas: increased capacity (through road widening), increased structural strength (through proper stabilization depth and structural overlay), and improved road condition and service life. This capability of FDR should be compared with typical preservation techniques where structural strength is not increased.

The benefits of FDR can be placed into three major categories: economical, technological, and environmental. The FDR process lends itself well to sustainable road concepts. First, all the existing road materials are recycled. Second, several potential stabilization materials, such as flyash and lime kiln dust, are also recycled products. Therefore, the opportunity exists to recycle multiple materials in the FDR process.

There are several road improvement objectives that can be addressed by FDR:

- Increase Capacity
- Increase Structural Strength and Stability
- Improve Pavement Condition
- Improve Serviceability
- Extend Service Life

To achieve the full benefit of FDR an engineering process must be followed. This process involves several important steps which are discussed in detail in subsequent chapters. It should be emphasized here that the quality of the final product depends on how well and accurately every step of the process is followed.

### ***1.1.4 FDR Construction***

The construction steps and activities carried out during FDR projects are summarized in this section. FDR consists of four steps:

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

Summaries of each of these steps are presented here.

**1.1.4.1 Pulverization.** Pulverization consists of grinding the road surface and base to be reclaimed. The cutting head (Figure 1) is similar to a very large rototiller with carbide teeth mounted on a cutting head that is typically between 8 and 14 feet wide and can cut to a depth of about 18 inches. Typical working depths are generally 6 to 10 inches. Experience has shown that the rotation of the cutting head is always in the ‘up’ direction as shown in the illustration on Figure 1.

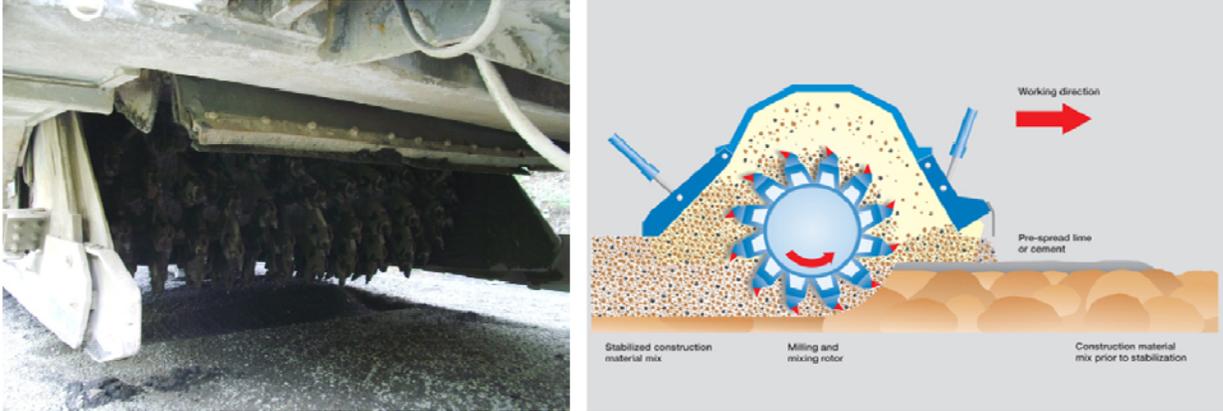


Figure 1. Cutting head of reclaimer

**I.1.4.2 Stabilization.** Stabilization consists of the addition of the selected additive onto the pulverized surface. Figure 2 shows an example of such application. In a second pass of the reclaimer, the stabilizing additive and water are integrated into the pulverized roadway as shown in Figure 3.

**I.1.4.3 Shaping.** Shaping consists of judicious grading to integrate into the base the surface profile that is desired in the final product. Figure 4 shows an example of shaping with a grader.

**I.1.4.4 Compaction.** Compaction techniques should be matched to the depth of the reclamation. To achieve the maximum benefits from this process the base needs to be at maximum density. Figure 5 shows compaction by a sheep's foot roller, which is necessary when the reclaimed depth exceed eight inches. A smooth drum, vibratory roller finishes the surface as shown in Figure 6.

## I.2 Problem Statement

The Pennsylvania Department of Transportation (PennDOT) had a need to organize and consolidate information about full depth pavement reclamation (FDR), with the objective of producing an implementable set of specifications, guidelines, and criteria. In the past, this pavement treatment strategy has encompassed a wide variety of equipment, materials, and processes. Research has been conducted involving some specific stabilization materials such as fly ash, while other materials have been used in the treatment of low volume roads. These include materials such as foamed asphalt, Portland cement, and lime kiln dust among others. A number of equipment companies provide suggested pulverizing, scarifying, and mixing equipment to achieve sometimes material specific and sometimes material neutral results. The necessary process is most often determined by the requirements for applying the stabilization material and the equipment selected for use. This matrix of variables results in many potential combinations, some of which are successful and others which may not provide suitable long term performance.

The focus of this project was to identify suitable materials and processes, develop guidelines for the use of FDR, and specifications and related criteria for the effective application of the process. The development of guidelines for the use of FDR, appropriate related standards and

specifications, with input from PennDOT and construction industry, and a summary of Best Practices were requested.



Figure 2. Application of stabilizing agent



Figure 3. Second pass of reclaimer



Figure 4. Shaping by a grader



Figure 5. Compaction by a sheep's foot roller



Figure 6. Final finishing by a smooth drum roller

### I.3 Project Objectives

The following elements were to be addressed during the project to achieve a complete and effective FDR specification and policy package:

- A decision tree approach for making a selection of the appropriate type (mechanical, chemical, bituminous, etc.) of FDR for a given project, based on road condition and in-situ materials.
- Guidance on appropriate roadway sampling.
- Guidance for characterization procedures that should be applied to the sampled roadway for all types of FDR.
- Guidance on FDR depth design.
- A menu of available potential additive products and a determination process of when and where to use each.
- Guidance for the development of a design method for both surfaced and unsurfaced gravel roads.
- A means to quantitatively measure the success of a completed project, including surface tolerance, and bearing capacity (CBR or resilient modulus).
- A means for evaluating a proposer's capability to satisfactorily perform the work.
- Consideration of a guarantee clause that would provide for the repair of defective FDR within one year.

## **I.4 Research Plan**

Each of the abovementioned items were to be woven into the development of policy, specifications, and Best Practices Manual. The exact determination of the content and form of each were decided in conjunction with the project panel before incorporation into the work.

In addition, the project team was to participate in and document two projects to be constructed by PennDOT to validate the Best Practices document. These projects were selected by the Department as the best opportunities to accomplish the necessary work.

The research team also planned to provide a train-the-trainer course to assist PennDOT with the implementation of the FDR Best Practices. The requested training aid materials were developed and provided to the Department, and two train-the-trainer courses were presented at the time and location requested by PennDOT.

The approach to the work was to generally follow the Task order as defined in the RFQ. These tasks are summarized below:

- Task 1 – Conducting the literature search and survey of other states.
- Task 2 – Updating the necessary PennDOT publications and other documents.
- Task 3 – Development of the FRD Best Practices document. Participating in the documentation and monitoring for two field construction projects.
- Task 4 – The Clearance Transmittal process for FDR documents.
- Task 5 – The Clearance Transmittal comment review process and finalization of FDR documents.
- Task 6 – Development of final standards, specification, and other internal PennDOT documents.
- Task 7 – Train-the-Trainer Course Development and presentation.
- Task 8 – Development of the draft final report.
- Task 9 – Revisions to the final report document.

These activities are summarized in the flowchart shown in Figure 7.

The project deliverables were identified in the RFQ by task. The deliverables for this project include:

- 1) A literature search and survey of Best Practices for Full Depth Reclamation presented in a summary report.
- 2) PennDOT standards, specifications, and appropriate language for all other required publications, manuals, bulletins, strike-off-letters, etc. that have been developed, revised, and updated.
- 3) Participate in, oversee and document two FDR projects and provide a report on the projects, including the research, process development, methods, etc. involved in finalizing the FDR “Best Practice.”

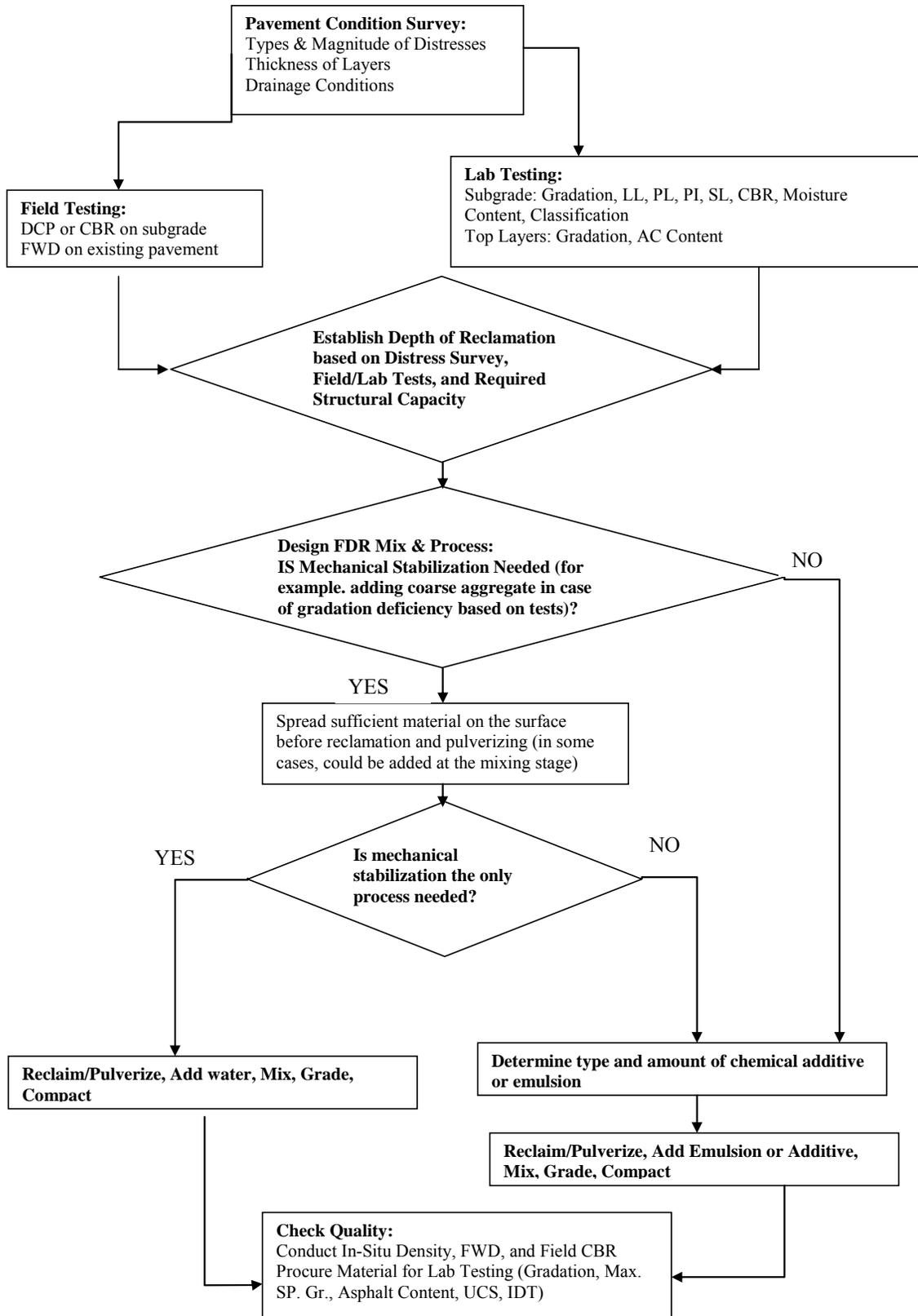


Figure 7. Conceptual flow chart demonstrating FDR design and construction process

- 4) Prepare all appropriate documentation for the updated, revised, etc. standards, specification, language, etc. for PennDOT publications, manuals, strike-off-letters, bulletins, etc. to be sent to appropriate PennDOT and customer groups via the Clearance Transmittal process for review and comment.
- 5) Provide PennDOT with all approved standards, specifications, language, etc. for inclusion in all appropriate manuals, publications, bulletins, etc. subsequent to any revisions resulting from the clearance transmittal process.
- 6) Present a Powerpoint Presentation with an overview of standards, specification and guideline modifications to PennDOT, in addition to providing a project highlight synopsis delivery.
- 7) Develop a Train-the-Trainer course and conduct two Train-the-Trainer courses for appropriate PennDOT personnel.
- 8) Meet in-person with the PennDOT project panel to review the Draft Final Report.
- 9) Provide a final report to PennDOT.
- 10) Submit all invoice and retainage documentation on time and in the correct format.

## **I.5 Report Organization**

A discussion of the review of relevant literature on design and construction of FDR projects is presented in Section II. This chapter also includes a survey of states in regard to FDR design and construction. Section III discusses the updates and additions to PennDOT publications and specifications. Development of the “Best Practices Guide” is described in Section IV which also includes a summary of construction activities for the two field FDR projects. Section V discusses this train-the-trainer course, and Section VI summarizes the findings and presents the concluding remarks followed by list of references and relevant appendices.

## II.0 LITERATURE REVIEW

### II.1 Introduction

Full depth reclamation (FDR) has received renewed interest as a pavement rehabilitation strategy in recent years. Several factors contribute to this interest including improved equipment, stabilization technology, sustainability, and costs relative to more conventional rehabilitation strategies.

FDR also presents highway agencies with an effective tool for achieving sustainability of their road system. Figure 8 provides an indication of benefits from FDR. These benefits can be realized in the form of both preservation of resources and reduction in roadway rehabilitation costs.[1]

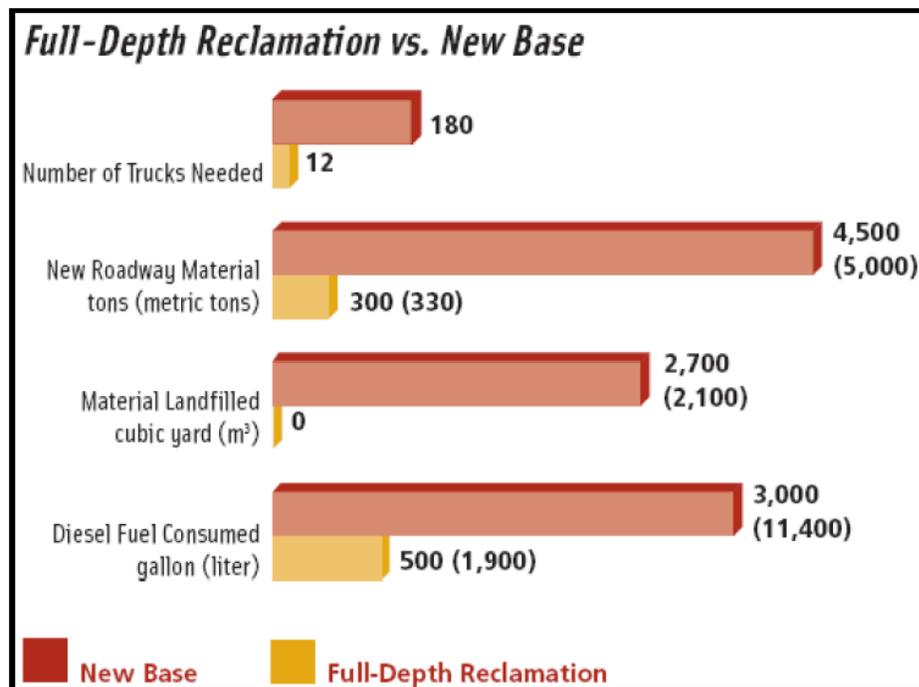


Figure 8. Energy use and materials for FDR and new base

The Pennsylvania Department of Transportation (PennDOT) had previously performed a limited number of FDR projects with positive results, but needed to organize and consolidate information about FDR, with the objective of producing an implementable set of guidelines, criteria, and specifications on the topic. This work incorporates a summary of related literature and agency practices which will serve as the base for the remainder of the project by identifying the information that currently exists with successful FDR programs.

### II.2 Objective

The focus of this PennDOT sponsored research project on FDR was to develop guidelines and best practices as well as identify suitable materials and processes, for the successful application

of FDR in Pennsylvania. It is necessary to develop guidelines for the selection and successful application of the FDR process. To do this, information must be gathered about the various FDR stabilization processes. The guidelines must provide procedures for:

- identifying suitable FDR candidates
- selecting an appropriate FDR treatment process
- developing the FDR mix design
- construction guidelines and specifications
- quality control/quality assurance procedure for FDR

### **II.3 Scope of the Chapter**

This chapter encompasses two specific activities:

1. Investigating past research on design and construction of FDR
2. Conducting a survey of states in regard to FDR design and construction

The first activity is based on the identification of prior research and related literature about the FDR process. The second presents a summary of information collected from selected states with experience in the use of FDR.

#### ***II.3.1 Investigating Past Research on FDR Design and Construction***

This research activity provided the basis for the development of “best practices” for FDR. The “best practices” document included a FDR selection guideline, a mix design protocol based upon the local geotechnical characteristics of the project site, and construction guidelines, including quality control/quality assurance procedures.

Items which were addressed in the “best practices” included as a minimum:

- Materials
- Equipment
- Weather limitations
- Design
- Processing steps
  - pulverization/shaping
  - additive application
- Stabilization/mixing
  - compaction
  - protection
  - surface tolerance
  - curing
- QA/QC

Therefore, it was appropriate to identify information related to all these issues during this task.

II.3.1.1 Treatment Overview. The first application of FDR dates to the 1910s. In this process, the recycled materials have been used for base course. Stabilization with bituminous materials is the most popular stabilization process. However, lime, portland cement, and calcium chloride have been researched as stabilizers for full-depth reclamation.[2,3,4] A report from 1977, “Hot Recycling of Yesterday ” indicates that pavement recycling existed as early as 1915.[5] The increased interest in recycling starting in 1975 was largely based on economics, with some interest in energy conservation. Many agencies, including the National Cooperative Highway Research Program (NCHRP), Federal Highway Administration (FHWA), Air Force Civil Engineer Corps, and U.S. Navy have sponsored recycling research and implementation studies.[6,7,8 and 2]

Guidelines for selecting the appropriate stabilizer type were published by Terrel in 1986.[9] The states that appear to have had the most experience with FDR techniques include California, Indiana, Kansas, Michigan, New Mexico, Oregon, Nevada, Pennsylvania, and Texas.

A nationwide survey was conducted by the Asphalt Recycling and Reclaiming Association (ARRA) in 1987.[10] In this study it was shown that FDR practice ranges from the bituminous stabilization process to a state-of-the-art multi-unit construction train. It shows wide diversity in use, design, construction, and testing. While the practices are variable, results have been reported as favorable

The project conducted by Mallick at Worcester Polytechnic Institute on Full Depth Reclamation provided a very important and useful source of information for this project, as that study included an extensive investigation of FDR in the Northeast [11]. The project, entitled “Development of a Rational and Practical Mix Design System for Full Depth Reclamation,” was conducted in the early 2000s and was sponsored by the FHWA and Maine DOT.

#### II.3.1.2 Process Related Studies.

##### ***Texas’ Practices in FDR Base Stabilization***

Garibay discusses seven steps in the construction of a stabilized base: 1) scarification and pulverization, 2) stabilizer spreading, 3) preliminary mixing and watering, 4) mellowing period (for lime), 5) final mixing, 6) compaction, and 7) final curing [12]. He provides guidance on selection of the type and determination of the percentage of additive depending on the soil classification and the desired degree of improvement. Generally, smaller amounts of additives are required to modify soil properties such as gradation, workability, and plasticity. Larger quantities of additives are used to significantly improve the strength, stiffness, and durability. Figure 9 shows the stabilization selection decision tree. The two main factors used are the percentage of material passing the No. 200 sieve and the Principal Investigator.

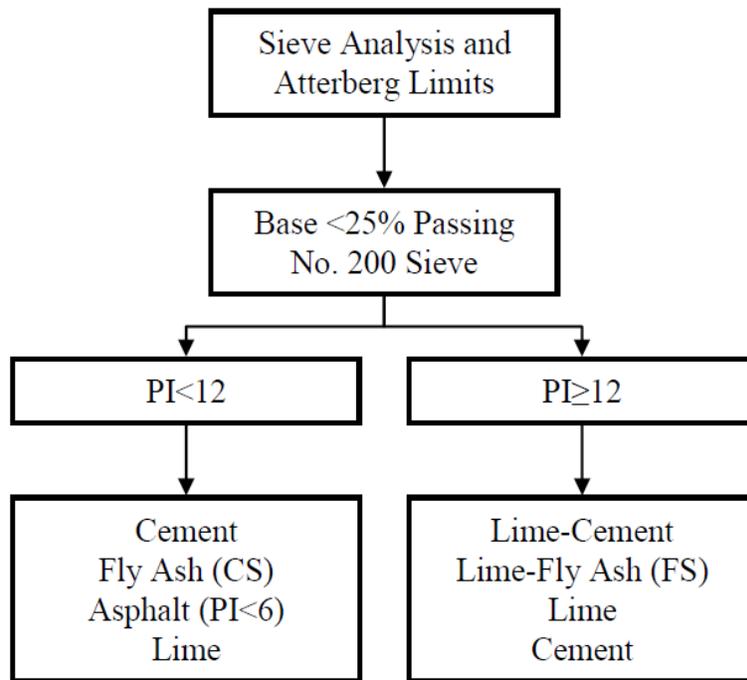


Figure 9. TxDOT stabilized selection decision tree

Garibay explains that one of the concerns with the pulverization activity is the possibility of the change in gradation during processing.[12] Current TxDOT specifications for new bases are shown in Table 1. TxDOT has specification Item 265 (Fly Ash or Lime-Fly Ash Treatment Road Mixed) and Item 275 (Cement Treatment Road Mixed) that require 100% of the pulverized material to pass a 2.5 in. sieve, as shown in Table 2.

Table 1. Specification Item 247: Base Material Requirements[13]

Property	Test Method	Grade 1	Grade 2	Grade 3	Grade 4
Master Gradation sieve size (% retained)	Tex-110-E				As shown on the plans
2½ in.		-	0	0	
1¾ in.		0	0-10	0-10	
7⁄8 in.		10-35	-	-	
3⁄8 in.		30-50	-	-	
No. 4		45-65	45-75	45-75	
No. 40	70-85	60-85	50-85		
Liquid limit, % max.	Tex-104-E	35	40	40	As shown on the plans
Plasticity index, max.	Tex-106-E	10	12	12	As shown on the plans
Plasticity index, min.		As shown on the plans			
Wet ball mill, % max	Tex-116-E	40	45	-	As shown on the plans
Wet ball max. Increase passing the No. 40 sieve		20	20	-	
Classification	Tex-117-E	1	1.1-2.3	-	As shown on the plans
Min. compressive Strength, psi		45	35	-	As shown on the plans
Lateral pressure 0 psi Lateral pressure 15 psi		175	175	-	

Table 2. TxDOT specifications for road mixed stabilized base[13]

Stabilizer	Gradation requirements		Gradation after Pulverization		Mellowing	Compaction	Curing
	Sieve Size, in.	Min. Percent Passing	Sieve Size, in.	Percent Passing			
Cement	1.75 0.75	100 85	2.5	100	None	Within 2 hours of cement application	3 days, by sprinkling or asphalt prime coat
Lime					1-4 days	After mellowing, mix until friable consistency, then compact	Up to 7 days
Fly ash					None	Within 6 hours of fly ash application	Allow 48 hours to dry before applying prime coat, then allow 24 hours before opening to traffic

For TxDOT construction procedures, cement, lime, or fly ash treated base must be compacted as stated in the given specification as shown in Table 3.

Table 3. TxDOT specifications for Stabilized Base Material[13]

Specification		Procedure
Item 260	Lime Treatment (Road Mixed)	Compaction of bottom course at least 95% of maximum dry density obtained from Tex-121-E, compact subsequent courses at least 98% of Tex-121-E
Item 265	Fly Ash or Lime-Fly Ash Treatment (Road Mixed)	Compaction of bottom course at least 95% of maximum dry density obtained from Tex-127-E, compact subsequent courses at least 98% of Tex-127-E
Item 275	Cement Treatment (Road Mixed)	Compact to at least 95% of maximum dry density obtained from Tex-120-E.

Based on testing El Paso limestone, Geiger, et al. proposed the test procedure summarized in Figure 10.[14] The first step, preliminary testing, consists of establishing the gradation, index properties and the hardness of the aggregates. The next step is to establish the moisture-density/moisture-modulus relationships for the raw materials as well as the blends with varying contents of stabilizers. Finally, the strength, stiffness and moisture susceptibility of the mixes are evaluated. Figure 11 contains a step-by-step procedure for this activity.

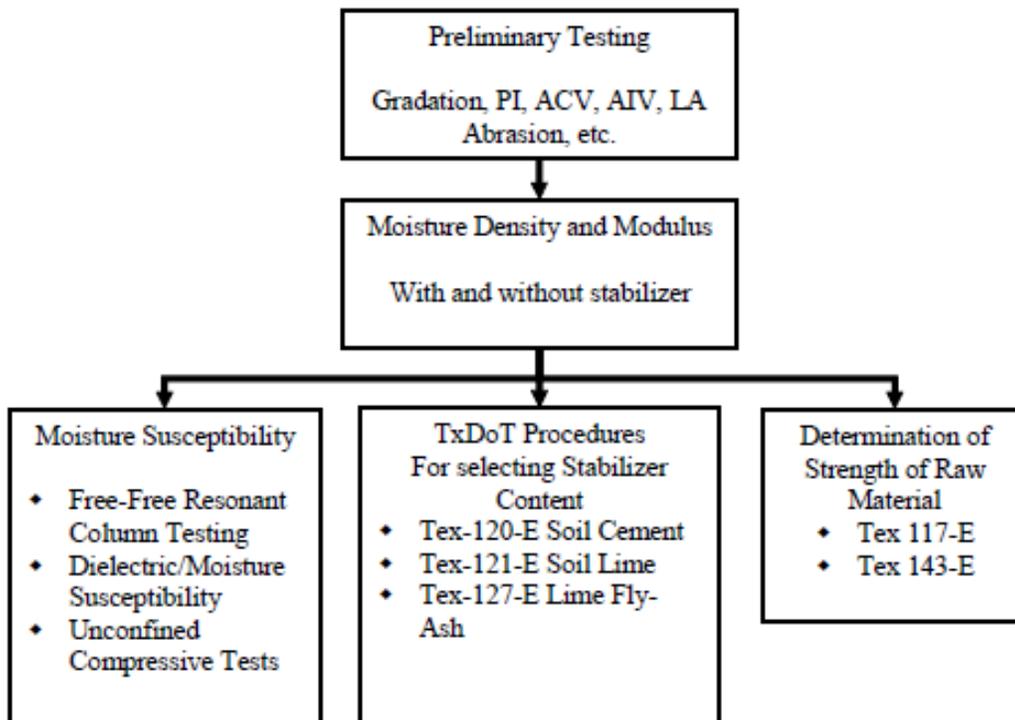


Figure 10. Testing procedure developed based on El Paso limestone

### II.3.1.3 Asphalt Stabilization.

#### ***Cold In-Place Recycling and Full-Depth Recycling with Asphalt Products***

***(CIR&FDRwAP)***[15] – The purpose of this project was to evaluate and contribute to the facilitation and implementation of currently available CIR&FDRwAP technology. An “information/data” survey was conducted, 10 selected CI&FDIRwAP projects were documented and evaluated, mixture properties (modulus, strength, fatigue) were established, thickness design options were evaluated, mixture design approaches were evaluated, and construction aspects considered. The mixture design procedures currently used by SemMaterials for Engineered Emulsions and the Wirtgen procedure (or procedures similar to the Wirtgen procedure) for foamed asphalt mixtures are recommended for interim use. Typical successfully used specifications (*FDR - engineered emulsion – SemMaterials specification; FDR - foamed asphalt – Project 1 – Champaign County; CIR – foamed asphalt – Livingston County*) for Full-Depth Recycling and Cold-in-Place-Recycling are presented.

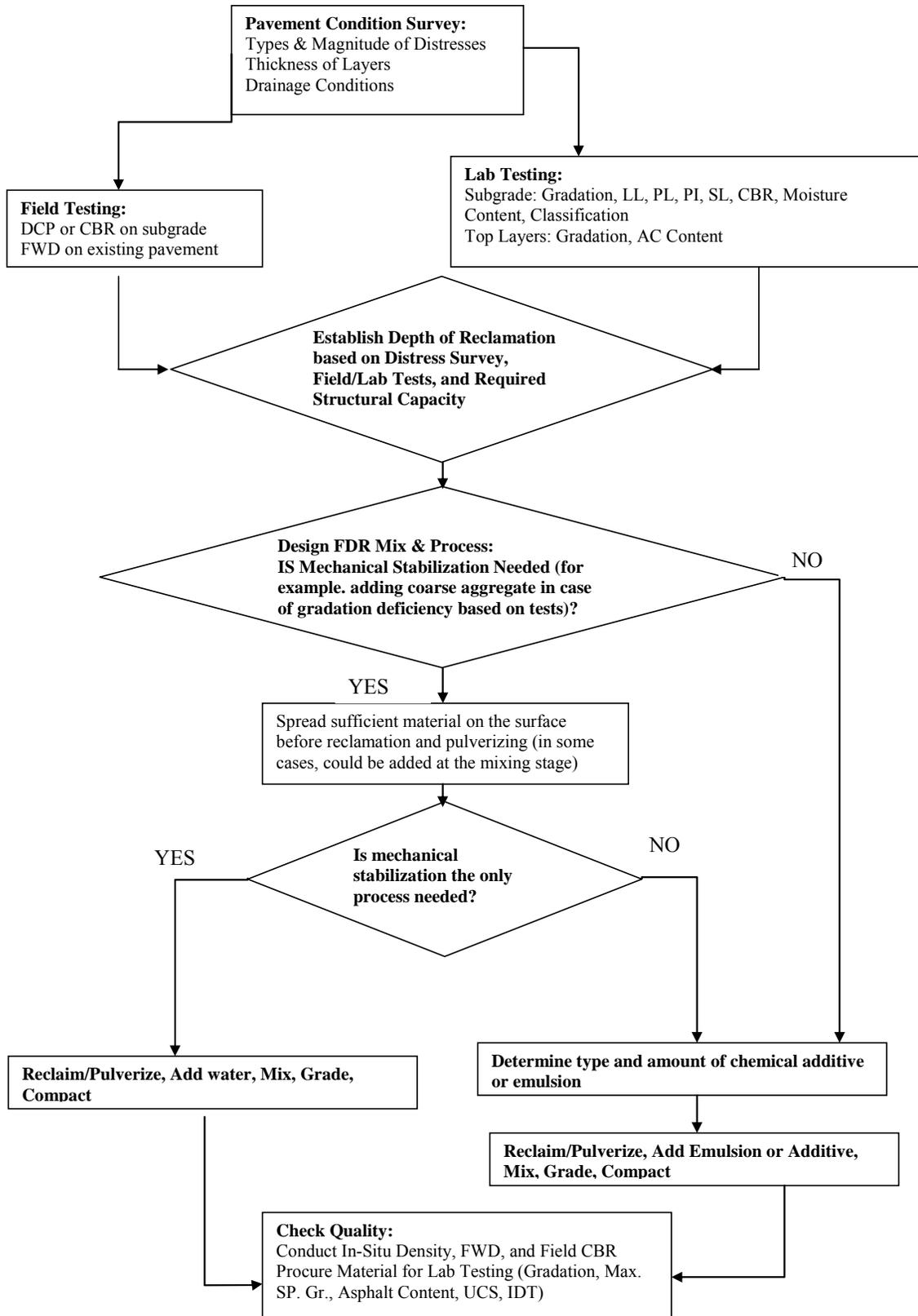


Figure 11. Flow chart for testing activities

***Evaluation of Full-Depth Reclamation (FDR) on the Strength and Durability of Pavements Base Layer***[16] –

The purpose of this research was to determine the effect of FDR on the strength and durability of aggregate base layers in a coordinated approach involving both field and laboratory testing. Field comparisons between the pre-reclamation neat base and post-reclamation blended base were supplemented with laboratory experiments conducted to determine the effects of reclaimed asphalt pavement (RAP) content, compaction effort, and heating on the strength and durability of roadways reconstructed using FDR with a portable asphalt recycling machine (PARM). Also, the effect of reclamation on the spatial uniformity of the pavement structures was explored by comparing variability in the pre- and post-reclamation material properties. Test sites in Orem, Utah; San Marcos, Texas; and South Jordan, Utah, were selected for this research.

The results of field testing indicate that the FDR process significantly increased the stiffness and/or strength of the base material at two of the test locations and did not significantly change the third base material. An evaluation of spatial variability indicated that the FDR process produced equivalent or lower spatial variability with respect to both base modulus and California bearing ratio (CBR) values at one site, while the other two sites exhibited equivalent or higher spatial variability after FDR.

The results of laboratory testing for all three locations indicate that specimens compacted using the modified Proctor method exhibit significantly higher CBR values and dry densities than specimens compacted using the standard Proctor method. Also, the CBR values for specimens tested in the dry condition were significantly higher than those obtained from specimens tested at optimum moisture content. These results demonstrate the value of achieving a high level of compaction during construction and preventing water ingress into the pavement over time. The blended material exhibited a significantly lower CBR value than that of the neat material at only one location; the addition of RAP to materials at the other locations did not significantly change the CBR values of those materials. In the tube suction test (TST), most of the specimens were classified as marginally or highly moisture-susceptible, and the effect of RAP on the dielectric value in the TST was of no practical importance. The use of PARMs in the FDR process is an acceptable, economical, and environmentally friendly approach to reconstruction of flexible pavements. To ensure satisfactory performance of FDR projects, engineers and managers should carefully follow recommended guidelines for project selection, pavement testing, material characterization, design, construction, and quality assurance testing.

In 1997, Kandhal from Auburn University published pavement recycling guidelines for state and local governments.[17] In this publication, full-depth, in-place recycling was included. Materials and mix design, construction methods and equipment, case histories and quality control/quality assurance have been discussed.

II.3.1.4 Cement Stabilization. A study by Demarre focused on a method known as the ARC 700 process for full-depth reclamation with portland cement.[18] ARC 700 uses two pieces of equipment: ARC dosage, a semi-trailer that stores cement and water, used for dosing and spreading cement on the old pavement; and ARC 700, which is composed of a powerful milling

cutter drum and a horizontal axis mixer. More than 4,000,000 m<sup>2</sup> of pavements have been recycled in Europe with this process.

***Long-Term Performance of Failed Flexible Pavements Stabilized with Cement***[19] – The projects evaluated and summarized in the report prepared for PCA on the long-term durability of FDR with cement pavements included those from six city agencies, three private developers, eight county agencies, and four districts within state departments of transportation. Along with the excellent durability noted in these pavements, one of the biggest advantages of FDR with cement is the versatility that it offers in terms of its use in various geographic and environmental conditions and loading applications. The PCA study investigated the performance of FDR with cement to rebuild distressed asphalt pavements. The project sections studied were between three and 26 years old with an average age of nine years. The FDR with cement process is popular with state and local agencies trying to maintain their highway network in the face of shrinking budgets. The economics of the FDR with cement process has helped the highway agencies reconstruct 50% to 100% more projects than the conventional construction process.

Lewis et al. report of the work by Georgia DOT using cement stabilizations.[20] The authors demonstrated a 42% cost saving when applying a cement stabilized reclaimed base of a sand-clay soil topped with a hot asphalt mix. Falling weight deflectometer (FWD) data collected after construction indicated that deflections were significantly lower in the FDR section than in the overlay only section. After nine months of heavy use, the 1.8 km FDR section is performing well, with minimal observed rutting, and levels of unconfined compressive strength averaging 25% greater than at the time of construction. A small amount of premature cracking in the FDR section may be indicative of excessive cement content.

***Full Depth Reclamation with Cement: Sample Collection and Preparation Procedures***[21] – The success of any FDR with cement project begins with the proper sampling and preparation of pavement, base and/or subgrade materials to be used in lab tests. Lab data from the sampled materials will ultimately provide the basis for an appropriate FDR mix design. If field samples are not obtained, and a mix design is not performed, it can lead to premature failure of the reclaimed layer and ultimately lead to costs that could have been avoided by following some simple procedures. Materials that will be used in the FDR process can be sampled in two ways:

1. Field pulverization (using a special drill bit) and collection of materials to the expected reclamation depths.
2. Collection of materials by auger or manual methods (i.e., shovel, post hole digger, pick, etc.). No field pulverization is performed.

***Method 1:***

Field pulverization and sample collection using a specialized drill bit mimics the pulverization done by reclaiming equipment used in FDR construction, and reduces lab preparation time. Samples should be collected to the expected reclamation depth (usually 6 to 12 inches). A minimum of 100 pounds of material is needed from each sample location to run the necessary lab tests needed for a mix design. (Note: one 5-gal bucket will hold about 50 lbs. of material.)

### *Method 2:*

If field pulverization methods are not used to obtain mix design samples, attention to sample collection is vital. Samples should be obtained from all layers expected to be reclaimed (asphalt, base, and possibly subgrade). The asphalt layer can be saw cut, or in most cases simply removed using hand tools such as picks and shovels. Underlying base and/or subgrade materials should be sampled to the expected reclamation depth. If the depth of reclamation is not known, the materials should be kept separate so that blending can be done in the lab. (For example, if it is not known if the subgrade will be included in the reclamation, it should be bagged separately so that the effect of including the subgrade material can be evaluated in the lab.) As with the field pulverization sampling technique, a minimum of 100 pounds of material is needed for the necessary lab tests. The asphalt sample obtained for lab testing is usually collected in large pieces. This material must be broken down to a size that is comparable to the pulverization that occurs during FDR construction. For instance, Summit Engineering (located in Charlotte, NC) places sampled asphalt in a drying oven and heats the material to approximately 110° F. By using just hand manipulation, the softened asphalt can be reduced to an appropriate size similar to that obtained during field pulverization. Once a lab has prepared the material, testing will proceed using ASTM D558, “Standard Test Methods for Moisture Density (Unit Weight) Relationships of Soil-Cement Mixtures” and if unconfined compressive strength data is desired, ASTM D1633, “Test Method for Compressive Strength of Molded Soil-Cement Cylinders” is recommended.

The road to success with FDR begins with proper sampling and preparation of materials for lab tests. With a few simple procedures in sampling and material preparation, an optimized mix design can be obtained that will contribute in part to the success of a FDR project.

II.3.1.5 Calcium Chloride Stabilization. At the 19th annual meeting of the Asphalt Recycling and Reclaiming Association in 1995, Brown presented a paper titled: “Full Depth Reclamation with Calcium Chloride – 50 Years of Use and Growing.”[22] This paper focused on FDR with calcium chloride and the technical data that have been amassed. This additive produced results that proved, without a doubt, its versatility and effectiveness in reducing frost heaves as well as aiding in compaction.

The use of calcium chloride as a stabilizing agent in FDR construction was investigated by Pickett.[23] Pickett reported that provided a workable, cost effective solution to road deterioration. This paper suggests a 50% cost savings when FDR of recycled asphalt roads is conducted with the addition of calcium chloride.

### II.3.1.6 Fly Ash Stabilization.

***Environmental Analysis of Full Depth Reclamation Using Coal Combustion By-Products***[24] – In order to investigate the environmental impact of using coal combustion by-products in FDR, Mackos conducted an environmental analysis of FDR using coal combustion by-products. They combined field monitoring and laboratory experiments to track the environmental impact of using coal combustion by-products (CCPs) in the FDR of damaged roads. The results of the environmental monitoring show that values for the pore water consistently result in lower concentrations than the U.S. EPA sets for drinking water maximum contaminant levels (MCLs).

The laboratory leaching tests result in concentrations of As, Ba, Cd, Cr, Hg, Pb, and Se that are far below the Ohio EPA non-toxic criteria.

In 1998, Bergeson published a report intended to provide pavement thickness design parameters and a design method for low-volume roads and streets utilizing Iowa reclaimed fly ashes.[25] Based on extensive laboratory testing, this paper presents layer coefficients for reclaimed hydrated class C fly ash bases for use in AASHTO thickness design for low-volume roads. This research project addresses roadway pavements to be reconstructed or rehabilitated by recycling multiple flexible pavement layers into new base or subbase courses prior to placement of the surface course. The study is restricted to cold processes of recycling.

The work by Beeghly correlates the use of a pozzolanic mixture of Class F fly ash when it is activated with lime that relies on the hydration of the glassy component of the fly ash to gain strength.[26] The author correlates the use of this selection of additives to low cohesive or silty soils. After discussing the mix design and testing protocol, examples (not case studies) in Pennsylvania, Ohio, Kentucky, and Indiana are presented.

A report by Wolfe et al. describes several FDR test sections constructed in Ohio.[27] Quarterly deflection test results for one year after construction, backcalculated modulus values and structure layer coefficients are reported. The report concludes that stabilization with lime kiln dust and Class F fly ash can provide stiffness similar to FDR stabilized with portland cement at significant reduction in costs.

***Full Depth Reclamation of Asphalt Pavements Using Lime-Activated Class F Fly Ash: Structural Monitoring Aspects***[27] – The service performance and structural behavior of FDR pavements constructed with Class F fly ash in combination with lime and lime kiln dust (LKD) were compared to other more traditional pavement rehabilitation techniques. Monitoring results of the FWD tests conducted up to two years after reclamation show that the sections utilizing fly ash (in combination with lime or LKD) outperformed the cement test section, while the emulsion sections were not as effective. The mill and fill test section indicated little or no increase in resilient modulus values as would be expected. The cement+emulsion and LKD+emulsion mixes were effective but their performance was much lower than the cement, fly ash+LKD, and fly ash+lime mixes. The cement+emulsion and LKD+emulsion resilient modulus values were lower than those typically obtained for soil cement (less than 500 ksi). The cement, fly ash+LKD, and fly ash+lime sections exhibited resilient modulus values comparable to open graded cement stabilized aggregates (more than 750 ksi). The cement treatment resulted in a significant increase in resilient modulus within three weeks of reconstruction, and beyond this curing time the stiffness increases were very low. On the other hand, the fly ash+LKD and fly ash+lime test sections indicated slower shorter-term increase in stiffness, but after about one year of monitoring, the fly ash+LKD and fly ash+lime sections had outperformed the cement test section. The fly ash+LKD section average resilient modulus value one year after construction was in excess of 1000 ksi.

**II.3.1.7 Class C Fly Ash.** Wolfe et al. used Class C fly ash, the residual waste utility power plant, to stabilize a sandy clay highway subgrade.[28] Testing to evaluate its performance was conducted with FWD, CBR, and unconfined compressive strengths. CBR values at 7 days

ranged between 46 and 150 versus 0 for the unstabilized soils. Resilient modulus  $M_r$  determined with FWD ranged between 11 and 28 MPa at 7 days and 17 to 68MPa at 28 days for the stabilized material. The modulus could not be measured for the unstabilized soils due extremely low strength. The unconfined compressive strength (UCS) of the stabilized soil at 7 days varied between 276 and 607 KPa at 7 days and 304 to 883 KPa at 28 days. UCS of unstabilized soil was less than 200KPa.

II.3.1.8 Lime Stabilized Subgrade. Yusuf et al. developed a mix design for lime treatment of subgrades that was demonstrated in Mississippi on four roads.[29] The completed projects were evaluated with FWD, ground penetration radar, and dynamic cone penetrometer logs. The lime-treated subgrades proved to be effective structural layers and the laboratory test specimen results agreed well with the field measurements.

#### II.3.1.9 Other Related Information.

##### *Enzymes*

There have been chemical additives developed by different manufacturers to address stabilization of mixes with high clay content. An example is Permazyme 11X, a proprietary mixed enzyme formula dispersed in water with fermented organic compounds.[30] It is reported to work best on soils with up to 30% of material passing #200 sieve. This product is applied at a rate of 1 liter per 30 cubic meters to bring the moisture content of the soils to ‘optimum moisture.’ Once the road surface is shaped, the subgrade is compacted to 95% of the modified Proctor density. Proper compaction is heavily stressed by the product manufacturer.

##### *Mixture of asphaltic emulsion and 2% lime*

A comprehensive study was conducted by Mallick et al. investigating design and construction of FDR using emulsions.[31] The objective of this study was to determine the suitable compactive effort for designing FDR mixes with different types of additives when applied to reclaiming an asphalt-bound road section and underlying base. It was concluded that samples should be compacted to 50 gyrations which compared well with a minimum of 98% of the modified Proctor density. Cost comparison showed that recycling with 3.4% emulsion and 2% lime was the most cost-effective option.

Another article published by Flynn in 1995 answered questions about the use of full-depth recycling on seriously deteriorating and aging roads, in terms of soil types, freeze-thaw cycles, and economics.[32] A project in Dublin, Ohio, is highlighted, demonstrating the usefulness of this technique.

In 1994, Ayers published a paper named “Recycling Methods Keep Pavement, Costs From Piling Up.”[33] In this paper, Ayers indicated that full-depth reclamation cost can be as little as \$1 per square yard (considering the construction cost around 1994). Studies showed that for streets with poor aggregate or excessive thickness due to repeated pavement overlays, this method is the most cost effective.

A number of projects conducted by PennDOT in the Harrisburg area in the 2002 and 2003 construction seasons have demonstrated that the strengthening of the subgrade can result in a general increase in the life of the pavement system, reduce the base layer thickness, and result in a general cost savings.[26] Beeghly also reports on substantial strength gains by the effective use of mixtures of lime, LKD, and Class F fly ash in these applications.[26] Mix designs for FDR typically call for 100 psi unconfined compressive strength in three days for the stabilized subgrade, which have been demonstrated to be readily achievable with Pennsylvania derived Class F/lime mixtures.

II.3.1.10 Summary of Literature Review. As presented above, there is a considerable amount of existing research related to the selection and use of FDR. A wide range of stabilization materials and combinations of materials have been studied with positive findings. In addition, the industry has developed general guidelines for performing this work. All of this information will be reviewed in the development of an FDR Best Practices Document.

### ***II.3.2 Survey of States Regarding FDR Design and Construction***

The approach taken by different states to conduct full depth reclamation projects varies within a wide range. The research included a survey of states which had done pioneering work on FDR construction. A questionnaire was developed to investigate application of FDR in different states and was sent to these states to collect required information. This was preceded by direct phone calls to states and interviewing materials or construction engineers or their assistants. The states included in the survey were Georgia, Maine, Texas, Virginia, Minnesota, Ohio, Virginia, Washington, and Illinois. The response of the surveyed states to the questionnaire is provided in Appendix A. The results are summarized below:

II.3.2.1 Georgia. Georgia Department of Transportation (GDOT) has extensive experience with soil-cement base stabilization. GDOT has also conducted many projects with lime stabilization. Their experience with asphalt emulsions is limited and not as successful as the usage of cement and lime perhaps because of applying emulsion to some specific areas within the state with very fine grained soil, not well suited for stabilization using emulsions.

GDOT has standards in the form of special provisions for application of cement and lime. There is a well established procedure for determination of optimum moisture content and optimum cement or lime content using standard test procedures. Desired cement content is determined based on unconfined compressive strength, with a minimum requirement of 300 psi.

Construction requires a test section in the range of 350 to 500 feet. There are time restrictions on construction and compaction of FDR. The time between adding cement and finishing the job should not exceed 4 hours and the time between water application and initiation of compaction is limited to 45 minutes. Compaction must be completed within two hours. No vibratory rollers are allowed on material after 90 minutes from the time cement is added.

The quality of construction is accepted through measurement of maximum dry density, in-place density, gradation, transverse profile, thickness, and unconfined compress strength of cores.

II.3.2.2 Maine. Maine Department of Transportation (MDOT) has been using foamed asphalt technology with FDR since early 2000. They have also used cement stabilization in cases of excessive fines in their gradation even though using asphalt foaming is the dominant approach and used as standard. Quality of production is controlled through density measurements, air and surface temperature measurements, and material yield. The quality of construction is decided based on nuclear density and material yield. Maine has established procedures and specifications for FDR.

II.3.2.3 Texas. Texas Department of Transportation (TxDOT) has been mostly using asphalt emulsions with FDR. Sometimes 1% cement is added to expedite the curing process. Overall, they have been satisfied with the process except some of the eastern areas of the state due to clayey subgrade. Required laboratory test properties for design include minimum of 50 psi for the indirect tensile strength, minimum 150 psi for unconfined compressive strength (UCS), and minimum required retained UCS of 80% after conditioning.

Quality of construction is controlled by determining moisture content before addition of emulsion, determination of emulsion content based on meter readings or truck weight ticket, and determination of density of laboratory compacted specimens from road samples before rolling.

II.3.2.4 Virginia. The Virginia Research Council returned the questionnaire indicating that they do use the FDR process. Virginia has experience with Portland cement, asphalt emulsion, and foamed asphalt as stabilizing materials. Pre-treatment investigation includes a combination of deflection testing, distress evaluation, and core sampling. The state is compiling a post construction deflection test database as part of an ongoing performance monitoring program. To date the treatment is performing well and no problems have been identified.

II.3.2.5 Washington. The Washington DOT responded that they do not use FDR. However, some of the municipalities within the state do use it. A specification for Spokane County was provided, although the county did not return the questionnaire. The County specifies a minimum four inch treatment depth. They also require the contractor to demonstrate the effectiveness of his cement application rate, and require a fog seal application for curing protection of the completed layer. The reclaimed layer is covered by either a chip seal or HMA surface.

II.3.2.6 Ohio. Ohio DOT responded that they do not use FDR. However, ODOT reported that the local municipal agencies in Ohio have used the technique. A report describing an extensive study under way by Ohio State is monitoring several projects evaluating the use of lime-kiln dust with class F fly ash in FDR. This study is part of an investigation into the use of coal combustion byproducts undertaken by the Ohio Department of Development.

II.3.2.7 Illinois. Illinois Department of Transportation (IDOT) has broad experience with bituminous stabilization FDR. Many Illinois local road agencies successfully used asphalt emulsions in their FDR mixture design procedures. They adopted some typical specifications that have been proved successfully by local road agencies. Table 4 shows a typical specification regarding the FDR asphalt emulsion mixture testing requirements.[34]

Table 4. Testing Requirements for FDR Asphalt Emulsion Mixture[34]

<i>FDR Type 1 – For mixtures containing <math>\geq 8\%</math> passing No. 200 or for all granular mixtures</i>	
<b>150</b> -mm diameter specimens shall be prepared in a Superpave™ gyratory compactor	
Property	Criteria
Superpave™ gyratory compaction, 1.25° angle, 600 kPa, gyrations	30
Short-term strength test, 1 hour – modified cohesiometer, ASTM D 1560-92 (Part 13), g/25mm of width (see Appendix 1 for modifications)	175 min.
Indirect tensile strength (ITS), ASTM D 4867 Part 8.11.1, 25°C, psi	40 min.
Conditioned ITS, ASTM D 4867 (see Note 1), psi	25 min.
Resilient modulus, ASTM D 4123, 25°C, psi x 1000	150 min.
Thermal cracking (IDT), AASHTO T-322 (Based on LTPPBind for climate)*	See note in appendix
<i>FDR Type 2 – For mixtures containing <math>\geq 8\%</math> passing No. 200 or for all granular mixtures</i>	
<b>150</b> -mm diameter specimens shall be prepared in a Superpave™ gyratory compactor	
Property	Criteria
Superpave™ gyratory compaction, 1.25° angle, 600 kPa, gyrations	30
Short-term strength test, 1 hour – modified cohesiometer, ASTM D 1560-92 (Part 13), g/25mm of width (see Appendix 1 for modifications)	150 min.
Indirect tensile strength (ITS), ASTM D 4867 Part 8.11.1, 25°C, psi	35 min.
Conditioned ITS, ASTM D 4867 (see Note 1), psi	25 min.
Resilient modulus, ASTM D 4123, 25°C, psi x 1000	150 min.
Thermal cracking (IDT), AASHTO T-322 (Based on LTPPBind for climate)*	See note in appendix

\* Optional if project is in -20°C or warmer climate (98% reliability)

They also state that construction of FDR work shall not proceed in the rain. The weather forecast shall not call for freezing temperatures for 7 days. The historical weather database shall not call for freezing temperatures within 7 days of the end of the project; this shall be based on 50% reliability. Any deviation from these requirements requires the written authorization of the Engineer.

The quality of construction is achieved through controlling the asphalt emulsion properties, moisture content before emulsion, maximum material size, emulsion content, compaction density, and reclaiming depth.

II.3.2.7 Ontario, Canada. The Ontario Ministry of Transportation (MTO) has been using FDR with expanded asphalt stabilization (EAS) since 2001. MTO has construction specification (OPSS 331)[35] for FDR with EAS. Basically, the process of FDR with EAS is carried as follows[36]: The reclaimed material is shaped, compacted and then stabilized in place by the addition of expanded asphalt. A small amount of cold water is injected into the hot asphalt cement in the expansion chamber of a reclaimer/stabilizer to expand the asphalt. As the cold water turns to steam, the asphalt cement expands and is dispersed through nozzles onto the reclaimed material. Expanding the asphalt cement reduces its viscosity and increases adhesion, facilitating mixing with the cold, damp, reclaimed material. The expanded asphalt mixes readily

with the fine aggregate particles, forming a mortar which bonds the coarse aggregate particles together. The stabilized material is then graded to the required profile and compacted. Following a minimum two-day curing period, the stabilized base is overlaid with HMA.

Based on OPSS 331, the percent by mass of new performance graded asphalt pavement added to the unstabilized material shall be a minimum of 2.5%. The compaction of EAM shall be carried out to be 97% of the target density. There are also some gradation requirements and tensile strength requirements for expanded asphalt mix (EAM).

II.3.2.8 Summary of Results from States' Surveys. Results from the review of agency practices has identified that several states have successfully developed procedures for, and do use FDR on a routine basis. The state survey found that different states may use different stabilization materials, largely based on the existing soil types, as well other conditions under which pavements must perform. For example, Texas and Maine previously used asphalt as a stabilization material. Maine specifically uses a foamed asphalt process. Georgia uses specifically portland cement or lime for stabilization. Virginia has used both asphalt and cement stabilization. All of these states have comprehensive FDR procedures in place, and have adopted it as a standard practice. Minnesota, on the other hand, is also in the process of evaluating FDR, and the various processes which are available. To date, they are achieving some well performing sections from their trial sections.

## **II.4 Summary**

The literature review identified the mix development and successful application of a wide variety of FDR stabilization materials. The state survey revealed several states which do successfully utilize FDR routinely. These states have procedures in place to select and construct successful FDR projects.

From this investigation, the research team has developed the conceptual flow diagram (Figure 12) for the selection of FDR projects. While very general at this point, this concept can serve as the basis for a more detailed process analysis as work on the project proceeds.

Specific conclusions have been reached about the needs of a Best Practice guide for FDR in Pennsylvania, to be developed as a subsequent activity. These are provided in the following.

There is sufficient information available to develop a FDR stabilization type selection procedure that should be followed for a given situation. While industry guidelines are typically general, several states have developed more detail procedures which they use in actual practice. These procedures include material sampling and testing guidelines to be used as the basis for process selection. It is important that a sufficient number of samples and an adequate amount of material be collected to adequately represent the materials that will be incorporated into the reclaimed layer. A firm procedure for sampling and testing is very important to assure the treatment undertaken is appropriate for the in place materials. The procedure must clearly present the reasoning for the mix design testing and associated sampling, explaining why tests are conducted and how they influence the resulting mix design.

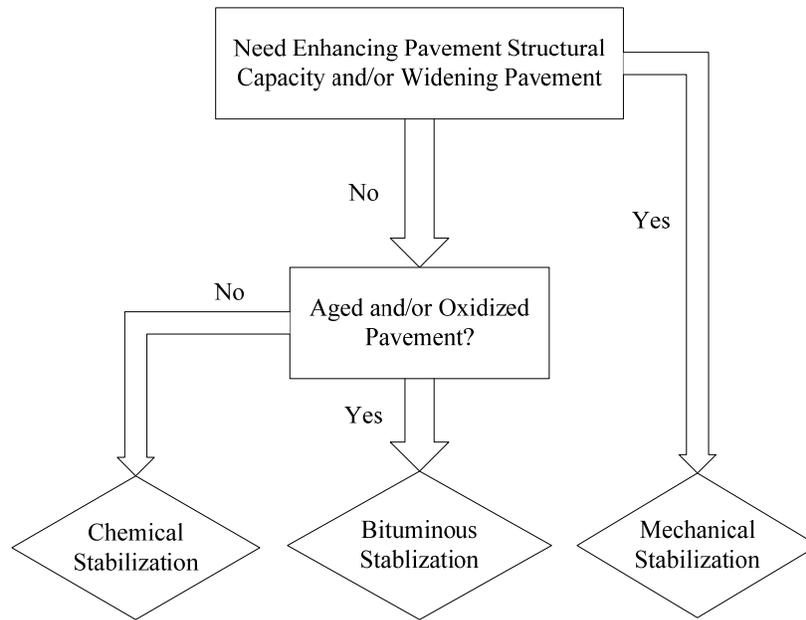


Figure 12. Conceptual flow diagram

In the case of each stabilizing material, functional ranges of stabilizer content have been identified, which provides a useful basis for the development of project specific mix designs. The process must be structured to prevent low bid contractor selection from diluting the sampling and testing process used to determine the appropriate stabilization material, and associated mix design process.

Adequate information is available about the construction of all the FDR stabilization processes identified as being in use. The general pulverization process is used in conjunction with all available stabilizing materials, the differences being in how the stabilizers are applied and blended, and how they improve the condition of the reclaimed materials. Quality control and acceptance tests must be consistent with the stabilizing material used. For example, the unconfined compressive strength test has been found to be suitable for cement and other chemical stabilizers. For asphalt stabilization, typical parameters must be achieved, such as moisture content and density of the stabilized mat.

As with any construction specification, it is important that specifications provide acceptance criteria for the FDR process. These acceptance criteria must be tied to the mix design, so that they provide verification that the work accomplished represents the mix design, and ultimately pavement section, conceived. The use of valid quality control/quality assurance and acceptance testing is an important part of this process.

In conclusion, the results of this investigation indicate that Full Depth Reclamation can be a cost effective tool to better highways. However, it is important that adequate control be practiced over the process to assure the expected benefit is realized from the roadway rehabilitation investment made. This conclusion was incorporated into the future work of developing a Full Depth Reclamation Best Practices document for Pennsylvania.

## **III. PENNDOT PUBLICATION UPDATES**

### **III.1 Introduction**

The necessary PennDOT publications and other documents were updated to include FDR as a rehabilitation strategy. The appropriate documents for inclusion in this task were determined by close coordinated with the PennDOT Project Technical Advisor. The updated publications are:

- Publication 408 (Section 344)
- Publication 242 (Sections 3.1.5 and 5.12; Table 9.3)
- Publication 27 (Chapter 1B and Chapter 2, Section 7.2)
- Publication 23 (Chapter 7, Section 7.4)
- Publication 30 (Bulletin 5)

### **III.2 Publication 408**

Section 300 of publication 408 (Highway Specifications) discusses “base courses”. Section 344, “full depth reclamation” was added to describe FDR, materials, construction, measurement and payment. Appendix B1 of this report includes this section.

### **III.3 Publication 242**

Several parts of publication 242 (Pavement Policy Manual) were updated to include FDR:

Chapter 3 discusses “project considerations.” Section 3.1.5 (Recycling Existing Pavement Materials) as updated to include FDR as an effective and sustainable way to recycle existing pavement.

Chapter 5 discusses “Bituminous Concrete Pavement Guidelines and Policies.” Section 5.12 (Full Depth Reclamation with Asphalt Emulsion) was added to this chapter in order to introduce FDR with asphalt emulsion and discuss selection of projects, determining layer thicknesses and drainage conditions, evaluating the applicability of FDR, material design, and quality control.

Chapter 9 discusses “full-depth flexible pavement design.” Table 9.3 in this chapter shows “Structural Coefficients for Materials in Flexible Pavements.” This table was modified to include structural coefficients for different types of FDR.

Appendix B2 of this report includes the above mentioned updates. A Best Practices Guide has been added to Publication 242 as Appendix L and its development will be discussed in Chapter IV. The Best Practices Guide is also included as Appendix C to this report.

### **III.4 Publication 27**

Publication 27 (Bul. 27) discusses “bituminous concrete mixtures, design procedures, and specifications for special bituminous mixtures.” There were two updates for this publication:

Chapter 1B (Department Criteria for Full Depth Reclamation Mix Design Procedure Using Asphalt Emulsion Stabilization) was added to this publication and the scope, referenced documents, apparatus, procedure, and report were discussed in this added chapter.

Chapter 2 of this document discusses “design and control of bituminous mixtures using a modified Marshall design procedure.” Section 7.2 (Guidelines for Selecting Asphalt Emulsions as Stabilizers for FDR) was updated to include the bituminous stabilization mix design process; scope, referenced documents, apparatus, procedure, and report in this section.

Appendix B3 of this report includes these updates.

### **III.5 Publication 23**

Section 7.4 (Bituminous Pavement Maintenance) of Publication 23 (Maintenance Manual) was updated to include FDR as a maintenance strategy. The update includes a description of the FDR process, and specific references to other publications for carrying out the process.

Appendix B4 of this report includes this update.

### **III.6 Publication 30 (Bulletin 5)**

Publication 30 or Bulletin 5 (Portland Cement Concrete) was updated to include “Mix Design Procedure for Chemical Stabilization as a Full Depth Reclamation (FDR) Method”. This section includes materials and mix design procedures for the chemical stabilization FDR process. The process includes a range of dry additive materials including, lime, flyash, lime kiln dust, Portland cement, and other potential materials.

Appendix B5 of this report includes this addition.

## **IV. DEVELOPMENT OF THE BEST PRACTICES GUIDE**

### **IV.1 Introduction**

The best practices document represents the “Best Practices” identified and developed for the use of full depth reclamation of flexible roads (FDR). It addresses a process for developing and constructing FDR projects. The document provides guidelines for the individual activities which must be accomplished including

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

The specific details to be followed for each of these steps are discussed so that PennDOT and other users can develop projects from the information provided.

The Best Practices Guide was added to Publication 242 as Appendix L and is presented in Appendix C of this report.

### **IV.2 Development of the Document**

Upon completion of a draft “best practice” document, PennDOT performed FDR projects in two of the engineering districts to test and prove the recommended approach. These projects were selected to cover different techniques and stabilizers identified under “best practices” to the extent possible. The research team provided technical guidance and oversight of these construction projects, and developed procedures for design, construction, and mix design development.

Both QES and PennDOT participated in the documentation and monitoring of two field construction projects. The construction projects were coordinated with PennDOT. Testing in the form of DCP, nuclear density testing, and coring along with other monitoring activities were carried out. Technical monitoring, development of criteria for stabilization additives, and developing the evaluation plan for all FDR sections were also carried out as part of this task.

Task 3 was conducted under the following subtasks:

#### ***IV.2.1 Selection of Projects for FDR***

During this subtask the research team cooperated with the Department with regards to the selection of projects to be rehabilitated using FDR within the construction season that followed the start of the project. The selection process was accomplished through the project coordinator and with the assistance of PennDOT personnel. While the reality of what was available and

feasible could dictate selection and construction of the projects, it was desirable to include a number of different methods of construction and different stabilizers, which were identified under “best practices,” in these projects. The projects provided the main foundation for comparing the performance of different sections under different conditions, and for validating the procedures in the Best Practices document. Once the projects had been selected, the research team reviewed the projects in the field and otherwise coordinated with PennDOT’s planning efforts for both projects. The team was on site for the startup of construction of each project to properly document the construction technique and to guide, observe, and document the construction procedure firsthand. This firsthand interaction also provided the opportunity to document any shortcomings or problems observed during construction.

Construction of pavement sections has always played an important role in a field evaluation program. This is true because the influencing factors can be better evaluated when test sections with various materials are built in a sequence on the same road. For example, at the same test site, different stabilizers and recycling materials could be utilized to compare their effect on performance. Since the test site remains the same, the effect of climatic and traffic conditions remains the same for all of the test sections at the site, yielding a more meaningful comparison between the materials in regard to performance. For this reason, projects selected for construction were to accommodate different test sections, and each long enough to provide for sufficient characterization of their performance. Different types and amounts of different stabilizers could be evaluated at these sites. While such a test site would provide valuable information, it required careful consideration in terms of number of test sections to ensure feasibility under time, resources, and budget constraints.

#### ***IV.2.2 Survey of Rehabilitation Sites before FDR Application***

Each construction site had been visited by the researchers before the milling and reclaiming operation was commenced so that the existing pavement condition was properly appraised and documented. During these preliminary visits to the site, information was collected regarding pavement condition and developed distresses. Information on influencing factors such as climate, loading, drainage, soils, and any variables affecting the pavement performance were gathered for each project site. Other factors that needed to be considered before actual construction included the following:

- The type and amount of stabilizer;
- The construction technique and details utilized for pavement recycling and placement;
- The overlay thickness; and
- The procedure, criteria, and tests used to determine the design process, and to determine the thickness of the hot mix asphalt overlay, or the suitability of the surface treatment.

The selected demonstration sites required a thorough characterization in order to ensure the development of a mix design that would address the unique properties of the site. This site characterization involved a two-fold evaluation: (1) a detailed examination of the distress associated with the site in order to evaluate the nature of the FDR that was to be applied and (2) a

detailed geotechnical evaluation of the soils and subgrade materials present for their gradation and mineralogical composition, so that the appropriate additives could be selected and the proportions determined that resulted in the target mechanical properties for the FDR. The latter task required a limited number of cores and test pits through the road surface to a depth of 1.5 times the anticipated FDR depth.

#### ***IV.2.3 FDR Process Design***

As previously discussed, the depth of FDR treatment must be selected as part of the total pavement structural design to support the anticipated traffic loading during the intended design period. To accomplish this, the FDR material must be appropriately characterized. Therefore, an interactive design process is necessary between the structural design of the pavement and the mix design process for the (Figure 13). The structural design must depend upon the structural characterization of the design of the FDR mixture. However, the FDR mixture design depends on the anticipated depth of reclamation, and must take into account all the existing pavement layers to be incorporated in the FDR, including subgrade.

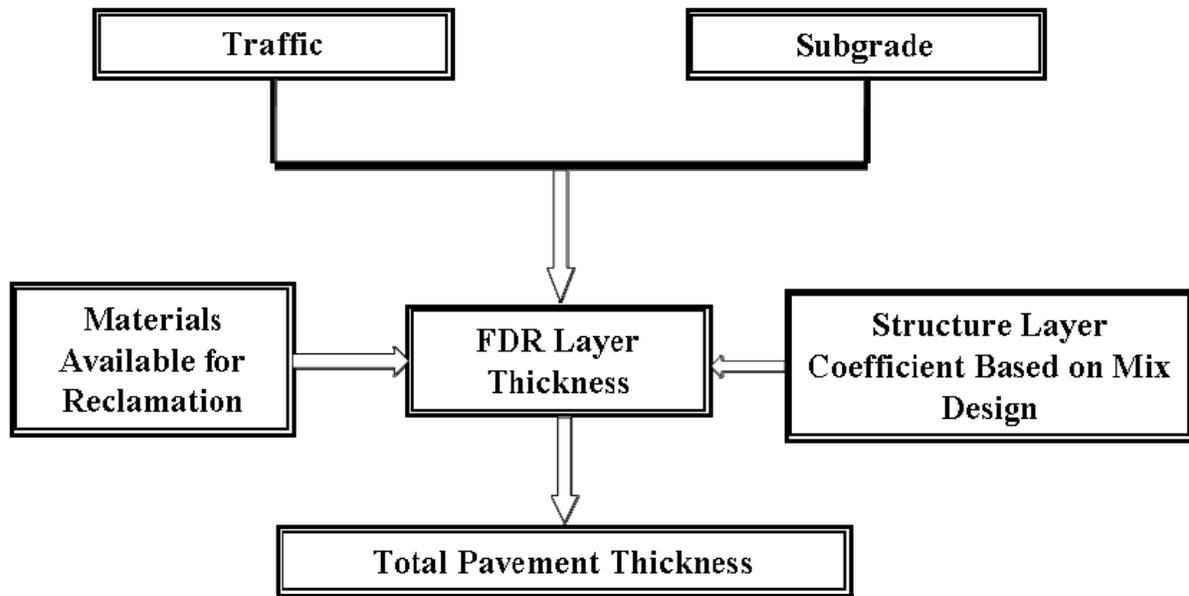


Figure 13. FDR Design Flow Chart

#### ***IV.2.4 Monitoring and Documentation of Project Construction***

Field quality control measures during construction included monitoring the depth of pulverization, the coating of the aggregate by the emulsion (in case of emulsion application), the proper curing of the emulsion, the proper application of chemical additives if any, the visual appearance and possible segregation of the recycled material, the compaction procedure, and appearance of the recycled pavement surface after compaction.

The reclaimed material had to be closely inspected to make sure that it was consistent in size and appearance. Achieving the proper compaction or densification of the reclaimed paving material was essential to proper performance. The in-place density of the recycled mix was monitored by using a nuclear density gauge in accordance with PennDOT PTM 402.

To establish a sound structural design approach and to determine the effectiveness of different techniques, it was proposed that a FWD be used at the following stages:

- On the existing pavement before FDR is initiated,
- After the recycled base is complete and before the HMA overlay is applied, and
- After the HMA overlay is applied.

The deflection response under FWD, when related to the applied loading, provides information about the strength and condition of the various elements of the test structure. In general, this deflection response can be used for evaluation of multi-layer pavement structure and backcalculation of the elastic moduli. Information about layer thicknesses and expected traffic load during the desired period combined with the FWD-generated data enables calculation of the elastic moduli of the pavement.

Pavement testing using the FWD was proposed to be performed at intervals of about 150 meters (500 feet) at two different loading magnitudes. This testing was to be coordinated with the Bureau of Materials and Operations. The final design element necessary for structural design of the pavement, characterization of the subgrade can also be accomplished using FWD testing. Alternatively, the subgrade material can be characterized using the dynamic cone penetrometer (DCP).

#### ***IV.2.5 Laboratory Study for Pilot FDR Projects***

The best practice was implemented for required sampling and laboratory testing. The best practice required the laboratory tests for this project to be conducted at two stages: (1) prior to FDR construction and (2) after FDR construction, as discussed below.

IV.2.4.1 Testing Prior to FDR Construction. Proper characterization of subgrade and final stabilized material was an essential and integral part of this project for complete evaluation of the constructed projects. For this reason, the “best practices” included proper material testing in the laboratory in addition to field evaluation. Selected “best practice” required following a laboratory procedure for designing FDR. Prior to FDR application, samples were obtained from the subgrade to determine the following characteristics:

- Liquid Limit, Plastic Limit, and Plasticity Index (PI)
- Gradation
- Unconfined Compressive Strength
- California Bearing Ratio

Samples were also obtained from the surface/base/subbase material to determine aggregate gradation. A detailed plan was developed by the research team to cover the magnitude of

sampling and the number of tests for each category. AASHTO classification of the material was established based on the results, and a determination was made whether reclamation should include a portion of the subgrade material or should have been limited to the depth of only base/subbase.

The laboratory work prior to construction also included the FDR mix design discussed above under section IV.2.2. Based on “best practices” the design determined whether mechanical stabilization (i.e., adding coarse aggregate) was needed in case of deficiency of coarse aggregate. The design also determined the type of base stabilization: chemical additives, emulsions, or a combination. Testing required by “best practices” was performed for individual FDR processes. This included, for example, optimum amount of additive, water, or emulsion. Based on the research on FDR mix design, Mallick suggests using the Superpave Gyratory Compactor to prepare specimens of the stabilized material and determine properties such as dry density and strength.[16]

IV.2.4.2 Testing After FDR Construction. Once construction of FDR was completed, to assure quality of construction, samples were obtained from the compacted mix and tested in the laboratory. “Best Practice” determined which tests were needed for this purpose. Examples include the following.

- Gradation
- Maximum Theoretical Density
- Moisture Content
- CBR
- Unconfined Compressive Strength
- Indirect Tensile Strength

The number of samples and magnitude of testing were decided once “best practices” had been established. Support laboratory tests such as those identified above were conducted at Penn State pavement materials and geotechnical laboratory.

### **IV.3 Bituminous FDR Project**

#### ***IV.3.1 Introduction***

The FDR using bituminous stabilization method was selected for a Pennsylvania state route (SR 1017, Honeymoon Trail Road) in Dauphin County. The project section was between west Main Street and 100 feet past the Coleman Church road intersection. The project began on 8/23/2010 and was completed in three days. The total length of the project was approximately 0.7 miles.

#### ***IV.3.2 Equipment***

The equipment used in this project is shown in Table 5.

Table 5. Equipment used in the project

Equipment	Model
Reclaimer	Wirtgen
Grader	John Deere 627 A
Roller	Dynapac CC 422VHF/055-3431

### *IV.3.3 Construction Activities*

FDR work began at the south end of the road and proceeded northward. Reclamation was accomplished in discrete section of the road. The first pulverization pass was made for a section of road that it was anticipated the reclamation could be processed in a reasonable time period of a few hours. Once the pulverization was complete, the reclaimer returned to the start point, connected to the emulsion and water supplies, and performed reclamation of the road segment. Verification of both the water and emulsion application rates is important to assure the appropriate amount of asphalt binder is mixed into the material, near the optimum moisture content.

The next step in the process was shaping of the material to the final geometric line and grade of the road. This was followed by the compaction operation. Subsequent passes of the roller were monitored by the nuclear density gage until the optimum density was achieved. Once the required density was achieved, a rolling pattern was established on the first day of construction for use throughout the remainder of the project.

This construction sequence then proceeded along the length of the road until the entire roadway had been reclaimed. Local traffic was permitted on the road at the end of each day, once the emulsion had broken.

The photographs in Figures 14 through 20 depict the various stages of the reclamation process.

Material samples to verify the acceptance strength were taken after seven days. Since the emulsion is not fully cured at this early age, it is necessary to use dry ice to facilitate the recovery of core samples. These samples were subsequently tested at the lab, to assure the desired strength and depth of reclamation material was achieved.

Finally, a bituminous surface treatment was applied to the reclaimed base, to complete the project.



Figure 14. Underneath of the reclaimer



Figure 15. Water truck hooked up to the reclaimer



Figure 16. Water Truck and reclaimer after 1<sup>st</sup> pass



Figure 17. Emulsion truck connected to the reclaimer



Figure 18. Taking moisture readings with nuclear gauge

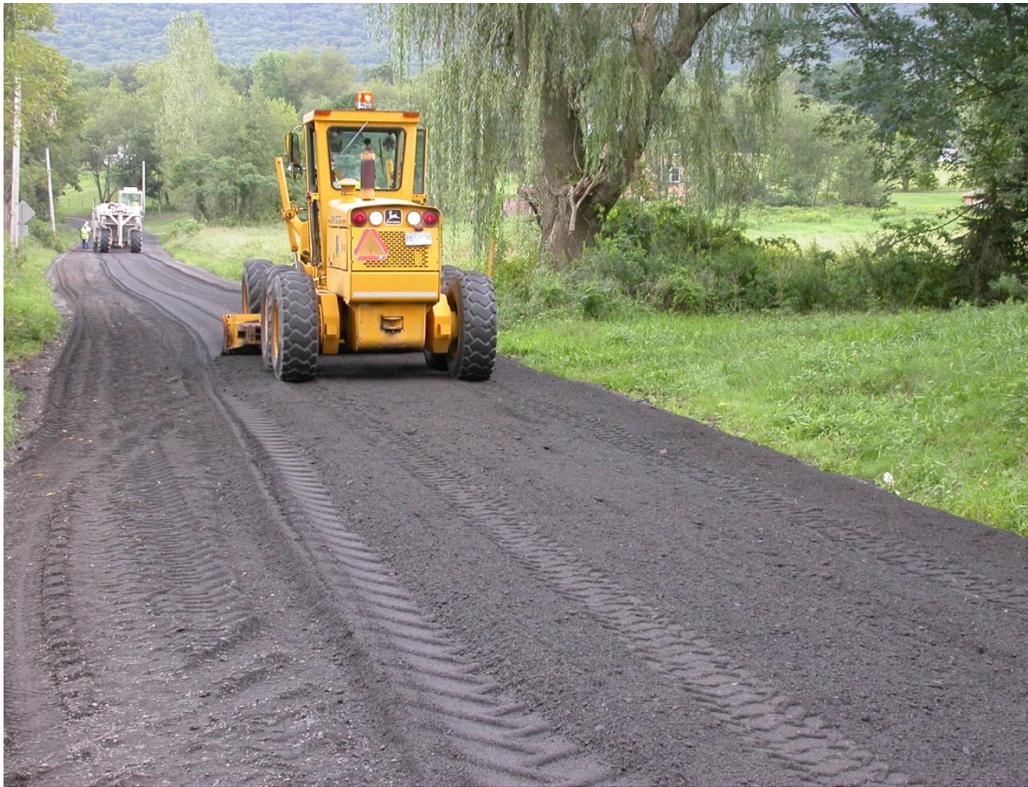


Figure 19. The grader



Figure 20. The roller

## IV.4 Chemical Stabilization FDR Project

### IV.4.1 Introduction

The FDR using chemical stabilization method was selected for a Pennsylvania state route (SR 3016, Plains Church Road) in Butler County (shown in Figure 21).



Figure 21. Approximate limits of the Butler County project

### IV.4.2 Equipment

The equipment used in this project is shown in Table 6.

Table 6. Equipment used in the project

Equipment	Model
Reclaimer	Wirtgen 2400 stabilizer/reclaimer
Cement applicator (Force)	Stoltzfus
Grader	Galion 850
Sheep's foot roller	15-ton Dynapac CA250 single drum vibratory roller
Steel Drum roller	10-ton Ingersoll-Rand DD-90 vibratory asphalt compactor
Rubber-tire roller	Rosco Tru-Pac 915 pneumatic roller

#### *IV.4.3 Construction Activities*

The construction sequence followed the one discussed earlier in Chapter I. One issue associated with the use of finely ground cement can be excessive dust generation as shown in Figure 22. The threat of dust is linked to the effectiveness of the applicator truck to limit dust, and to local wind speed. The use of slurries in place of dry powders is starting to gain acceptance because of the dust issue, but this process was not available for this project. Figure 23 shows a pass of reclaimer plus water truck.



Figure 22. Excessive dust created by cement application



Figure 23. Reclaimer and water truck

Shaping was accomplished by using two graders as shown in Figure 24.



Figure 24. Graders finishing the surface

Sheep's foot and smooth drum rollers were utilized for initial and final compaction respectively. Figure 25 shows a sheep's foot roller and Figure 26 shows a smooth drum roller. The sheep's foot roller is necessary when the depth of reclamation exceeds an eight inch depth.



Figure 25. Sheep's foot roller performs initial compaction



Figure 26. Smooth drum roller performs final compaction

The following is the summary of construction activities carried out during each construction day of the Plains Church Road.

**6-1-2011**

The FDR started by making 3 pulverization passes of the reclaimer (8-foot width) to achieve a total width of 22 feet, over a length of 320 feet. Graders were used for shaping followed by cement application and water application by a water truck.

The initial cement application was insufficient (1.22 and 1.25 lbs/ft<sup>2</sup> versus the target design rate of 7.22 lbs/ft<sup>2</sup>) and its distribution was non-uniform. The application of water was also insufficient and not evenly distributed. After graders shaped the pavement again, the adjusted rate of water was applied directly from the truck followed by cement application at an adjusted rate. The reclaimer then made mixing passes again, and graders subsequently reshaped the road. The pavement was rolled by the sheep’s foot roller, which was followed by a light grading to remove depressions from the roller. Finish rolling was accomplished using a steel-drum roller.

**6-2-2011**

Approximately 380 feet was reclaimed. The cement application rate was about 5.93 lbs/ft<sup>2</sup>, which was still less than the target rate of 7.22 lbs/ft<sup>2</sup>. The thickness of loose cement on the pulverized pavement was measured throughout section as shown below.

Cement Thickness (inch)	2.38	1.25	2.00	1.75	1.50	1.50	2.00	2.25
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**6-3-2011**

The construction began with application of cement to the first section that was pulverized and shaped the day before. The application rate test showed 2.76 lbs/ft<sup>2</sup> of applied cement. Then, the reclaimer (with a water truck attached to it) made passes to cover the section. After the graders shaped the section, 6 passes of sheep’s foot roller and 8 passes of steel-drum roller finished the construction of the first section.

Second section’s construction was started by pulverizing and shaping, other activities followed those of the first section. The application rate test showed 2.57 lbs/ft<sup>2</sup> of applied cement. Construction was finished by 4:35 p.m. Approximately 1035 feet was reclaimed.

**6-4-2011**

Approximately 104,000 lbs of cement was applied to the construction section of 13,194 ft<sup>2</sup>. The cement application rate was about 7.90 lbs/ft<sup>2</sup>, which was more than the target rate of 7.22 lbs/ft<sup>2</sup>. Again, in order to check the uniformity, the thickness of cement on the pulverized pavement was measured throughout section as shown below. Approximately 650 feet was reclaimed.

Cement Thickness (inch)	1.50	2.10	1.60	1.75	2.35	1.85	1.90	2.25
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**6-6-2011**

The construction began at 6:45 a.m. The same construction sequence used before was followed. The first and second sections used cement for stabilization. The cement application rate using the Mt. Carmel truck with 8-foot spreader was 7.27 lbs/ft<sup>2</sup>. The cement was applied by the Force company truck for the second section. The calibration test was not successful since the truck (skirt or pressure) folded the calibration cloth.

Fly ash and cement were applied respectively at half of the previous application rate for the third and fourth sections. Application rate tests for the third section showed 4.32 lbs/ft<sup>2</sup> for fly ash (versus 3.61 lbs/ft<sup>2</sup> target rate) and 6.18 lbs/ft<sup>2</sup> for fly ash plus cement.

The total length of construction for the day was 927 feet and the construction was concluded at 6:30 p.m.

**6-7-2011**

A mixture of fly ash and cement was applied to the construction sections. The fly ash was first applied to the pulverized pavement and the cement was then followed. The calibration showed that application rate for fly ash was 4.95 lbs/ft<sup>2</sup> and 7.10 lbs/ft<sup>2</sup> for the mixture of fly ash and cement. The thickness of fly ash and fly ash with cement on the pulverized pavement was measured throughout section as shown below. The total length of construction for the day was 900 feet.

Fly Ash Thickness (inch)	1.15	1.00	1.20	1.50	1.40	1.30	1.60
Fly Ash +Cement (inch)	1.75	2.06	2.38	1.86	2.25	1.95	2.10

**6-8-2011**

Following the same construction sequence used before, three 300-foot sections using fly ash and cement mixture were constructed. Application rate tests for the third section showed 4.75 lbs/ft<sup>2</sup> for fly ash and 5.68 lbs/ft<sup>2</sup> for fly ash plus cement. The other half of the width seemed to have more cement applied to it.

The last 57 feet of the project leading to the intersection of Plains Church Road and Franklin Road was constructed with only cement in the FDR process. The construction was finished at 4:20 p.m.

Cores were also taken from this project after a seven day wet cure period, for acceptance testing. The results met the requirement provided in the Best Practices documents.

Subsequently, a hot mix asphalt overlay was placed as the final wearing surface of the project.

## **V. TRAIN-THE-TRAINER COURSE**

### **V.1 Introduction**

A training package was developed to be used in a training course on FDR “best practices.” The training materials were formatted as a course for “train-the-trainer.” The course material included PowerPoint presentations, handouts, and quizzes. Pictures and videos were incorporated in the relevant modules. The course materials were submitted to the PennDOT project technical panel for review and approval and it was discussed with the project technical panel in a meeting prior to conducting the course.

### **V.2 Course Content**

The content of the course and the training materials depends on the type of audience receiving this training. Two sets of training modules were developed; an executive review module, and a series of six detailed modules on all the elements of an engineered FDR project. The executive review module included a summary of the detailed modules and was intended for management level personnel. The detailed modules were intended for all other personnel involving in the management, design, construction, and quality control of FDR projects. Summaries of module contents are presented here. A supplemental example of calibration calculations was also provided to participants.

#### ***V.2.1 Module 1: FDR Introduction and Overview***

This module included the following topics:

- What is FDR?
- Types of FDR
- Applications
- Benefits
- Steps involved in design and construction
- PennDOT specifications and standards

#### ***V.2.2 Module 2: Process Description***

Module 2 discussed the following topics:

- Process overview
- Pulverization
- Incorporation of water and additives
- Blending
- Grading and compaction

#### ***V.2.3 Module 3: Selection of Stabilization Approach***

This module discussed the following topics:

- Reasons to select stabilization approach
- Selection of stabilization approach
- Chemical stabilization
- Mechanical stabilization
- Bituminous stabilization

#### ***V.2.4 Module 4: Assessment and Sampling***

Module 4 included the following topics:

- FDR design considerations
- Project assessment
- Sampling procedures
- Characterization of subgrade
- Completion of pavement design

#### ***V.2.5 Module 5: Materials Testing and Mix Design***

This module discussed the following topics:

- General design considerations
- Steps in mix design
- Design procedures:
  - Mechanical stabilization
  - Chemical Stabilization
  - Emulsion/Foaming Stabilization

#### ***V.2.6 Module 6: Construction***

Module 6 included the following topics:

- FDR Equipment
- Construction process – Chemical
- Construction process – Bituminous
- Quality control/Quality assurance

### **V.3 Delivery of the Training Materials**

The training materials (executive review and detailed modules) were presented in two identical sessions held in PennDOT Riverfront Office Center in Harrisburg, PA on February 28, 2012, and in PennDOT District 9 office in Hollidaysburg, PA on March 1, 2012.

## **VI. SUMMARY AND CONCLUDING REMARKS**

FDR can be an effective major rehabilitation strategy. For it to be carried out successfully, thorough assessment including sampling and testing of the existing road must be conducted. The test results from the lab are important in selecting the appropriate type of stabilizer and developing an effective FDR mix design so the mix design and structural design must be performed together. A relatively standard construction process is used for all FDR stabilization techniques. However, the importance of good quality control and quality assurance testing to a successful project cannot be overemphasized.

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## **Appendix A – Response to Questionnaires**

## Full Depth Reclamation (FDR) Questionnaire

Contact Person: Rick Bradbury	Date: 02-17-2010
Position: Quality Assurance Engineer	Jurisdiction, State: Maine DOT

Please provide "Yes/No" answers to the questions below.	Yes	No
1. Is there an established practice for design and construction of FDR in your jurisdiction?	x	
2. Do you characterize subgrade soil before design and construction of FDR?	x	
3. Is any effort made to match the stabilizer to the soil type?	x	
4. Do you evaluate performance of FDR after construction?	x	
If desired, provide any further explanation regarding your preceding answers in this space:		

Please briefly respond to the questions below. Use back of the form if extra space is needed.
5. List any specific technique(s) is (are) used in regard to design and construction of FDR? See applicable special provisions and design procedures.
6. What criteria or tests are utilized to assess the quality of the existing pavement and to decide whether the pavement is a good candidate for recycling? FWD, borings, pavement thickness, soil type, existing profile/cross-slope.
7. What kind of stabilizer is commonly used and at what percentage? Foamed asphalt – typically 2.5 – 3.5 percent. Cement – typically 3 – 4 percent. Emulsified asphalt – typically 3 – 4 percent.
8. Could you list any specific types of tests performed to evaluate the quality of the recycled base after the job is complete? FWD testing, smoothness testing.
9. Could you list any specific types of criteria used to evaluate the quality of the recycled base after the job is complete?
10. How would you evaluate performance of FDR after construction (i.e. what criteria used for evaluation)? Resistance to cracking, rutting; smoothness.

## Full Depth Reclamation (FDR) Questionnaire

<b>Contact Person:</b> Dwane Lewis – Georgia Dept. of Transportation Office of Materials & Research	<b>Date:</b> Friday, February 12, 2010
<b>Position:</b> Branch Supervisor – Technical Services	<b>Jurisdiction, State:</b> Georgia

Please provide “Yes/No” answers to the questions below.	Yes	No
5. Is there an established practice for design and construction of FDR in your jurisdiction?	<b>X</b>	
6. Do you characterize subgrade soil before design and construction of FDR?	<b>X</b>	
7. Is any effort made to match the stabilizer to the soil type?	<b>X*</b>	
8. Do you evaluate performance of FDR after construction?	<b>X**</b>	
<p><b>If desired, provide any further explanation regarding your preceding answers in this space:</b></p> <p>*At this point we only use Type I Portland cement &amp; pelletized hydrated quicklime as stabilizers. There is an ongoing study with the possible use of Emulsion in FDR construction.</p> <p>**We do not evaluate performance on all FDR Projects but have a few that are checked yearly.</p>		

Please briefly respond to the questions below. Use back of the form if extra space is needed.
<p>5. List any specific technique(s) is (are) used in regard to design and construction of FDR?</p> <p>Mix design for cement FDR is a modified version of the GDOT soil-cement design process. Pills are created at different percentages of cement and the spread rate is determined by the unconfined compressive strengths (PSI). FDR is field tested for PSI, compaction, thickness, and grade.</p>
<p>6. What criteria or tests are utilized to assess the quality of the existing pavement and to decide whether the pavement is a good candidate for recycling?</p> <p>FDR is recommended when roads are beyond asphalt overlays and have base/subbase issues. Economics and Traffic Counts are also taken into the consideration.</p>
<p>7. What kind of stabilizer is commonly used and at what percentage?</p> <p>Georgia is divided into three geologic provinces. The Coastal Plain Province is general where cement is use 100%. Due to the abundance of aggregate quarries located within the Blue Ridge &amp; Piedmont Province, there is very little FDR construction. When it is used, typically pelletized hydrated quick lime is required because of the characteristics of the soil. (lime75% /cement 25%)</p>

**\*\*\*Note: A Georgia Geologic Provinces map is on the page following this survey.**

8. Could you list any specific types of tests performed to evaluate the quality of the recycled base after the job is complete?

Unconfined Compressive Strength (PSI)

9. Could you list any specific types of criteria used to evaluate the quality of the recycled base after the job is complete?

The development of ruts and cracking.

10. How would you evaluate performance of FDR after construction?

As I stated earlier, we follow up on a few specific projects for research purposes or by request from the Project Engineer. This includes a visual inspection and in some cases Falling Weigh Deflectometer Testing (FWD) and rut measurements.

## Full Depth Reclamation (FDR) Questionnaire

Contact Person: Brian Diefenderfer	Date: 2-26-2010
Position: Research Scientist	Jurisdiction, State: Virginia Transportation Research Council

Please provide "Yes/No" answers to the questions below.	Yes	No
9. Is there an established practice for design and construction of FDR in your jurisdiction?		x
10. Do you characterize subgrade soil before design and construction of FDR?		x
11. Is any effort made to match the stabilizer to the soil type?	x	
12. Do you evaluate performance of FDR after construction?	x	
<p>If desired, provide any further explanation regarding your preceding answers in this space:</p> <p>3 demonstration projects were constructed in 2008 with one more to be constructed in 2010. For all projects, the design and stabilizer materials were provided by the contractor. I am performing the agency follow-up FWD testing (to date, periodically over first 20 months).</p>		

Please briefly respond to the questions below. Use back of the form if extra space is needed.
5. List any specific technique(s) is (are) used in regard to design and construction of FDR?
Unable to comment on designs (performed by contractor). Construction details are similar to other FDR projects.
6. What criteria or tests are utilized to assess the quality of the existing pavement and to decide whether the pavement is a good candidate for recycling?
A combination of coring, FWD, and condition surveys.
7. What kind of stabilizer is commonly used and at what percentage?
All are project specific Portland cement, 5% Foamed asphalt, 2.7% Asphalt emulsion, 3.5%
8. Could you list any specific types of tests performed to evaluate the quality of the recycled base after the job is complete?
Agency relied on contractor test data. Field tests performed were field Marshalls and nuclear density gauges. The agency has been conducting on-going FWD analysis to gather data for future projects.
9. Could you list any specific types of criteria used to evaluate the quality of the recycled base

after the job is complete?

ITS and density values were tested versus the design criteria. The post-construction FWD testing has been compared to pre-construction testing.

10. How would you evaluate performance of FDR after construction?

So far, the process has been well received and there are no reported concerns.

## Full Depth Reclamation (FDR) Questionnaire

Contact Person: Jeff Uhlmeyer	Date: 2-26-2010
Position: State Pavement Engineer	Jurisdiction, State: Washington

<b>Please provide “Yes/No” answers to the questions below.</b>	Yes	No
13. Is there an established practice for design and construction of FDR in your jurisdiction?		X
14. Do you characterize subgrade soil before design and construction of FDR?		
15. Is any effort made to match the stabilizer to the soil type?		
16. Do you evaluate performance of FDR after construction?		
If desired, provide any further explanation regarding your preceding answers in this space:		

<b>Please briefly respond to the questions below. Use back of the form if extra space is needed.</b>
5. List any specific technique(s) is (are) used in regard to design and construction of FDR?
6. What criteria or tests are utilized to assess the quality of the existing pavement and to decide whether the pavement is a good candidate for recycling?
7. What kind of stabilizer is commonly used and at what percentage?
8. Could you list any specific types of tests performed to evaluate the quality of the recycled base after the job is complete?
9. Could you list any specific types of criteria used to evaluate the quality of the recycled base after the job is complete?
10. How would you evaluate performance of FDR after construction?

## Full Depth Reclamation (FDR) Questionnaire

Contact Person: Roger Green	Date: 2-10-2010
Position: Pavement Research Engineer	Jurisdiction, State: Ohio DOT

<b>Please provide “Yes/No” answers to the questions below.</b>	Yes	No
17. Is there an established practice for design and construction of FDR in your jurisdiction?		X
18. Do you characterize subgrade soil before design and construction of FDR?		
19. Is any effort made to match the stabilizer to the soil type?		
20. Do you evaluate performance of FDR after construction?		
If desired, provide any further explanation regarding your preceding answers in this space:		

<b>Please briefly respond to the questions below. Use back of the form if extra space is needed.</b>
5. List any specific technique(s) is (are) used in regard to design and construction of FDR?
6. What criteria or tests are utilized to assess the quality of the existing pavement and to decide whether the pavement is a good candidate for recycling?
7. What kind of stabilizer is commonly used and at what percentage?
8. Could you list any specific types of tests performed to evaluate the quality of the recycled base after the job is complete?
9. Could you list any specific types of criteria used to evaluate the quality of the recycled base after the job is complete?
10. How would you evaluate performance of FDR after construction?

## **Appendix B – PennDOT Updated Documents**

## **Appendix B1 – Publication 408**

## APPENDIX B1: PUBLICATION 408

### Publication 408

#### SECTION 344

#### FULL DEPTH RECLAMATION

**344.1 DESCRIPTION**—This work is full depth reclamation of an existing flexible pavement or unpaved road surface. The work includes pulverization of existing pavement layers, and incorporation of additional materials using reclamation techniques and compaction as specified, complete in place. Pulverize reclaimed material such that the maximum particle size does not exceed 2 inches in its greatest dimension.

#### 344.2 MATERIAL—

(a) Reclaimed aggregate material with 95% passing the 50 mm (2-inch) sieve. Incorporate reclaimed material into the stabilized base.

1. **RAM.** As specified in Section 703.1, Table A or 703.2 Table B. RAM may be used from the project, or from stockpiles off the project.

2. **RAP.** Section 702. Add reclaimed bituminous material according to the approved mix design.

(b) **Aggregate.** Section 703. Provide aggregates as specified, or as required to conform with the project mix design.

(c) **Bituminous Material.** Add bituminous material to the reclaimed material according to the approved mix design. Use one of the following bituminous materials, conforming to the applicable requirements of Bulletin 25.

Emulsified Asphalt CMS-2, SS-1h, CSS-1h, or polymer modified grades of these materials.

(d) **Cement.** Section 701.

(e) **Hydrated Lime.** Section 723.

(f) **Flyash.** Section 724.2.

(g) Other stabilization materials, such as calcium chloride, Section 721, lime pozzalon, Section 725, lime kiln dust, and pozzalons, Section 724, as approved in and required by the project mix design.

(h) **Water.** Section 720.2.

**344.3 CONSTRUCTION**—This work consists of pulverizing and mixing a combination of virgin aggregate, Reclaimed Asphalt Pavement, Reclaimed Aggregate Material, stabilization materials, and Subgrade Material to the specified length, width, and depth. Full depth reclamation (FDR) will consist of pulverization of the existing pavement layers to the specified depth, treatment with an approved stabilizing material and/or other approved materials, and compaction in place.

Comply with applicable environmental standards. Appropriate equipment and techniques should be used to adequately protect adjacent properties from fugitive dust or other material components of the FDR process.

Stabilization may be accomplished using bituminous material, cement or other chemical stabilization materials, or calcium chloride consistent with recommendations of the FDR Best Practices, and approved in the project mix design.

**(a) Equipment.** Provide the necessary equipment to pulverize, blend, shape, and compact the full depth reclamation materials.

**1. Reclaimer.** Provide a self-propelled, traveling rotary reclaimer or equivalent machine capable of cutting through existing roadway material to depths of up to 406 mm (16 inches) with one pass. The equipment will be capable of pulverizing “in-place” the existing pavement, base and subgrade at a minimum width of 2.44 m (8 feet), and mixing any added materials to the specified depth. The cutting drum must have the ability to operate at various speeds (rpm), independent of the machine’s forward speed, to control oversized material and gradation.

Use a machine equipped with a computerized integral liquid proportioning system capable of regulating and monitoring the water application rate relative to depth of cut, width of cut, and speed. Connect the water pump on the machine to the supply tanker or distributor by a hose, and mechanically or electronically interlock the flow of material with the forward ground speed of the machine. Mount the spray bar to allow the water to be injected directly into the cutting drum/mixing chamber. Provide equipment capable of mixing water, dry additives, emulsion, and the pulverized pavement materials into a homogenous mixture. Keep the cutting drum fully maintained and in good condition at all times throughout the project. Equipment such as road planers or cold-milling machines designed to mill or shred the existing roadway materials rather than crush or fracture it is not allowed.

**1.a** Use equipment capable of automatically metering liquids in the mixture to ensure thorough mixing of the reclaimed materials.

**1.b** Maintain equipment as specified in Section 108.05(c).

**2. Placement Equipment.** Motor Grader, or by another method approved by the Representative.

**3. Compaction Equipment.** Provide suitable compaction equipment as follows. For reclamation greater than 8-inch depth, use a vibratory pad-foot roller having 25 000 kg (25 ton) for breakdown compaction of the lower lift. For reclamation of 8-inch depth or less use a Pneumatic Tire Roller weighing 22 tonne (25 tons) for breakdown compaction, or following the

pad-foot roller when reclamation exceeds 8-inch depth. Perform finish rolling using a single or tandem steel drum static roller of 11 to 13 tonne (12 to 14 tons).

**(b) Reclamation.**

**1. Pulverization.** Before the application of any stabilizing additives pulverize the roadway materials to the depth specified by the project design.

**2. Mixing.** Combine the reclaimed material, aggregates (if necessary), stabilizing additive(s), and water according to the mix design and at the mix design recommended moisture content. Maintain adequate liquids in the mixture to ensure thorough mixing of the reclaimed material, aggregates, and stabilizing materials. If conditions change, make field adjustments to obtain a satisfactory FDR material.

If slurries are to be used, the distributor and tanker trucks will be equipped with a recirculating pump and/or agitation system to prevent settling of the materials before application.

**3. Finishing.** Shape the reclaimed material surface not to exceed 18 mm (¾-inch) irregularity of the lines, grades and/or cross-slope of the proposed roadway. Perform the shaping activity required to achieve specified grades in a timely manner so as to accomplish compaction as required in Section 344.4. Avoid excessively working the chemically stabilized material, which may detrimentally affect the ultimate strength of the stabilized layer.

**4. Compaction.** Compact the reclaimed material to a minimum density of at least 95% of the laboratory compacted maximum density at optimum moisture content. Verify achieving this density through the control strip as described in Section 344.3(b)4.a. Determine the in-place density according to PTM No. 402 for each 2 500 m<sup>2</sup> (3,000-square yard) area.

Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. Compact the entire reclaimed area using uniform passes of compaction equipment as determined from the control strip, ensuring that uniform density is achieved throughout. For FDR exceeding 8 inches of depth in a single lift, perform initial compaction using a vibratory pad-foot roller.

Complete compaction of chemically stabilized reclaimed material within two hours of the water/additive mixing operation.

**4.a Control Strip.** Determine the in-place density requirements by the construction of at least one 300-foot long control strip during initial reclamation. The control strip can be contained within the project startup test strip. Take a nuclear density reading according to PTM No. 402 after each pass of the compaction equipment. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of ten tests at random locations to determine the average in-place density of the control strip. Record and provide results to the Representative for use in Section 344.3(b)4.

If the density of an area is less than the minimum density, but the base course is uniform in texture, stable and otherwise acceptable, provide additional compaction. If additional compaction does not achieve the minimum density, complete an additional control strip to verify that proper density is being obtained. Take a minimum of ten tests at random locations to

determine the average in-place density of the new control strip. The minimum density for the new control strip is 98% of the average in-place density.

**4.b Moisture Content.** Verify the original moisture content of the road material to be reclaimed before beginning work. Make any appropriate adjustment between the moisture content determined at the time of mix design sampling and current moisture content by adjusting the design recommended water application rate.

The moisture content for compaction must achieve the optimum moisture content as determined from the project mix design, but cannot exceed optimum by more than 3%.

**5. Test Strip.** Before beginning full production work, construct a 300-foot test strip demonstrating the full reclamation process including final compaction and shaping. Verify application rates for all materials incorporated into the reclamation process including stabilization materials and water. Identify and correct any aspects of the work not conforming with the contract requirements before proceeding with full production work. If aspects of the work are not found to be adequately controlled to produce the desired reclaimed roadway, construct additional test sections until the necessary control is established.

**6. Cure.** All full depth reclamation using a stabilizing additive must be cured until the 7-day strength requirement is met. Do not allow heavy traffic on the reclaimed material during the 7-day cure period.

For chemical stabilization, maintain the reclaimed layer in a damp condition by the daily application of water to the surface, or the application of a bituminous emulsion cure material approved in Bulletin 27 at a rate between 0.05 to 0.1 gallons per square yard.

**7. Protection.** Protect completed portions of the reclaimed work from damage by construction equipment. Immediately correct any such damage to the satisfaction of the Representative.

**8. Surface Tolerance.** Test the completed stabilized base for smoothness and accuracy of grade, both transversely and longitudinally using suitable templates and straightedges. Satisfactorily correct any 2 500 m<sup>2</sup> (3,000-square yard) area where the average surface irregularity exceeds 13 mm (½ inch) under a 10-foot template or straightedge, based on a minimum of at least three measurements within the area.

Provide a minimum final surface cross slope of ½-inch per foot, or as otherwise required by the project design.

(c) **Mix design.** Provide a mix design according to:

1. The provisions of Chapter 2, Section 7 of Bulletin 27 for bituminous stabilization materials,
2. The provisions of the full depth chemical reclamation section of Bulletin 5, or

3. Procedures contained in PTM 106 to determine density and optimum moisture content for other FDR types. When used as the primary stabilizing material, calcium chloride should be applied as a minimum 35% solution at a rate between 0.45 and 0.68 L/m<sup>2</sup> (0.10 to 0.15 gallons per square yard) for each inch of depth reclaimed.

(d) **Maintenance of Traffic.** Control traffic, including construction traffic, to prevent damage to the completed reclamation work throughout the 7-day cure period.

(e) **Weather Limitations.** Do not place FDR materials when air temperature falls, or is anticipated to fall, below 4 °C (40F) within the subsequent required 7-day cure period. Do not perform reclamation in rain, or if rain is anticipated within two hours of completion of the work. This work can be conducted at night should project circumstances require, so long as the above temperature requirements can be achieved.

(f) **Quality Control.** Provide a quality control plan for the reclamation work a minimum of two weeks before beginning the work. The plan should identify the equipment, personnel, and processes to be used during the work. Ensure that all equipment is operational and functional before deployment to the job site. All equipment must be properly calibrated before application. This calibration should be verified through the control strip. The application rate of water and additives shall be properly maintained during the construction. Operators of water and additive applicators must keep proper records of the amount of material applied and the times of application.

(g) **Opening to Traffic.** Do not open the road to traffic until the specified 7-day strength has been achieved. Limited local light vehicular traffic may be permitted once the reclaimed material has obtained a stable condition. Repair any damage resulting from local traffic. Do not allow trucks to use the road until the above referenced 7-day strength has been achieved.

(h) **Acceptance.** Verify acceptance on the basis of each 2 500 m<sup>2</sup> (3,000-square yard) lot. All completed work must comply with requirements for surface tolerance (344.3.b.6), density (344.3.b.4), and strength as follows:

**1. Bituminous stabilized full depth reclamation.** Achieve a minimum indirect tensile strength of 50 psi when tested according to Section 7 of Bulletin 27.

**2. Stabilized full depth reclamation.** Achieve an unconfined compressive strength of 1 379 to 3 447 kPa (300 to 500 psi) in 7 days when tested as prescribed in Section 344.3.c.2 when the road will be surfaced with less than a 3-inch overlay, or bituminous surface treatment.

Achieve an unconfined compressive strength value of 2 068 to 3 447 kPa (200 to 500 psi) in 7 days for roads to be surfaced with a bituminous overlay of 3 inches, or greater.

Any lot failing to meet the acceptance criteria will be identified for rework. With the approval of the Representative, the contractor may take additional cores to determine the extent of the failing area, if he believes the entire lot is not affected. Once the failed area has been clearly identified, develop and obtain approval of a new mix design. The failed areas must be reclaimed again with the additional stabilizing material as necessary to achieve the required

acceptance criteria. Fill any core holes remaining outside the reworked area with an approved repair material listed in Bulletin 15.

#### **344.4 MEASUREMENT AND PAYMENT-**

Full depth reclamation of the type specified and meeting the acceptance criteria will be paid on the basis of square yards of road surface treated.

## **Appendix B2 – Publication 242**

## **APPENDIX B2: PUBLICATION 242**

### **PennDOT Pub 242 – Section 3.1.5 (Modified)**

#### **3.1.5 Recycling Existing Pavement Materials (Modification)**

Recycling of construction materials becomes an increasingly valuable strategy as the cost of these materials increases. Recycling also supports the sustainability of the highway system. The limited national supply of good quality aggregates in conjunction with the cost of liquid asphalt, and energy costs makes recycling more attractive than ever from resource, environmental, and cost perspectives. Currently, Recycled Asphalt Pavement (RAP) can only be used in Hot Mix Asphalt (HMA) and in Cold Recycled Base Course to conserve asphalt binder and aggregates. If RAP is carefully managed, it can also conserve high quality SRL aggregates for RAP use in high ADT Wearing Courses. Recycled Concrete aggregate can only be used for subbase (Pub 408 Section 703.2(a)7). It is likely that additional recycled pavement uses will be developed in the future. Activities recycling bituminous pavement materials are governed by Pennsylvania Department of Environmental Protection recycled asphalt products General Permit WMGR090.

There are many ways that existing pavement materials can be recycled back into the roadway. Full Depth Reclamation (FDR) is one effective and sustainable way to recycle existing pavement. FDR is a pavement rehabilitation technique in which the full flexible pavement section and a predetermined portion of the underlying materials are uniformly crushed, pulverized, or blended resulting in a stabilized base course. Additional stabilizing material may be added to further improve the integrity of the recycled product. FDR not only conserves the investment in in-situ materials, but also resolves the issues and minimizes the costs associated with their removal and disposal when following conventional pavement reconstruction practices.

The FDR process can include stabilization by mechanical, chemical, bituminous, or other processes. Detailed discussion of each is contained in the document (Appendix L) entitled “Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide.” There may be differences in the material structural capacity, and consequently the structure layer coefficient associated with different stabilization materials. Recommended structure layer coefficient values are provided in Table 9.3. In general the range of structure layer coefficients vary from values typical of subbase material to those representative of stabilized materials, depending upon the type of stabilization used. For example, basic pulverization will produce a product similar in support characteristics to a standard 2A subbase material. Stabilization with calcium chloride or similar additives will be slightly improved. Asphalt stabilized layers can generally be considered similar to existing layer coefficients for cold recycling. Chemical stabilization using cement, lime, and similar additives will provide support stiffness equivalent to or slightly better than those achieved from asphalt material stabilization. The values provided are based on available information from the literature, verified by Department research where possible. Values may be further refined as additional experience is gained with various types of stabilization.

## **PennDOT Pub 242 – Section 5.12 (New Section)**

### **5.12 FULL DEPTH RECLAMATION WITH ASPHALT EMULSION**

#### **5.12.1 Introduction**

Full Depth Reclamation (FDR) with asphalt emulsion is an effective method for rehabilitating distressed roads. A road reclaimer pulverizes the existing asphalt layer, incorporating underlying aggregate base and/or subgrade, adds asphalt emulsion, mixes the material, and places it back on the roadway grade. The reclaimed material is then shaped using motor graders, and compacted. The newly reclaimed can be trafficked in the same day. This process adds strength and flexibility to the existing pavement materials at the same time eliminating existing distresses to provide a renewed pavement base. FDR is an effective tool for highway agencies to reduce rehabilitation costs and achieve sustainability of their road system.

FDR is distinguished from other rehabilitation techniques like Cold In-Place Recycling or Hot In-Place Recycling by the fact that the pulverizing machine always penetrates completely through the asphalt layers into the underlying base layers, thereby eliminating the potential for reflective cracking or pavement failure resulting from a weak base layer. The following benefits can be achieved from the FDR process:

- Bases can be reclaimed for upgrading existing roads.
- The asphalt gives a flexible but strong base resistant to fatigue, cracking, and moisture damage.
- Pavements experiencing severe distresses can be reclaimed.
- Using materials in-place minimizes disposal and the use of virgin materials.
- Drainage and cross slopes can be re-established.
- The existing road material is completely recycled.
- The process builds structure down into the pavement cross section, minimizing the need for surface elevation adjustments.
- Reclamation can be used as a first step in stage construction, adding more structure as needed to meet increasing traffic demands over time.
- Full depth reclamation is a low cost process for improving road structure and widening roads.

#### **5.12.2 Selection of Projects**

##### **5.12.2.1 Evaluation and Assessment of the Roadway**

As with other pavement treatments, it is important that sufficient information about the existing pavement be gathered when attempting to determine if FDR is a suitable rehabilitation strategy, or to design a successful FDR project. The initial evaluation and assessment of the existing pavement will require the following information:

- Determination of Traffic level (ADT Count)
- Survey of the existing Pavement Condition
- In-Situ Testing
- Field Sampling

### ***Traffic Level***

Pavement damage resulting from traffic loading is the most prominent cause of pavement failure. Therefore, it is important to obtain a reliable estimate of future design traffic loading on the road before the road is constructed. While FDR may be applicable over a range of traffic levels, the overall pavement design must be consistent with standard pavement design traffic analysis procedures.

### ***Survey Pavement Condition Regarding Distresses***

It is important to have a recent pavement condition survey. For PennDOT projects this is typically performed in accordance with the criteria provided in PennDOT Pub 336, Automated Pavement Condition Survey Field Manual or PennDOT Pub 343, Continuously Reinforced Concrete and Unpaved Roads Condition Survey Field Manual, depending on existing road surface type. Alternatively, other distress procedures such as those defined in MicroPaver™ or a similar distress evaluation procedure may be used for municipal projects.

The distress survey not only provides information about the condition of the pavement at the time of survey, but also provides insight into the causes of the visible distresses. It is always important to understand the mechanisms responsible for existing pavement damage, in order to prevent the same damage mechanisms from causing failure of the rehabilitated pavement.

Upon completion of the distress survey, a summary report should be provided to document the level of distresses and corresponding observations. The severity of rutting, cracking, raveling, pot holes, and drainage issues should be specifically considered in the rehabilitation strategy performed to assure each is appropriately addressed.

### ***In-Situ Testing***

Beyond a visual survey of the pavement condition, it is important to assess the in-situ strength of the subgrade material which will support the rehabilitated pavement structure. Falling weight deflectometer (FWD) testing before rehabilitation provides valuable information about the stiffness of the existing pavement materials. Testing after construction is useful for determining the stiffness of the new pavement.

### ***Sampling***

Proper sampling plays a vital role in the successful design and construction of FDR. The following criteria must be considered when obtaining samples from the FDR candidate roadway.

- Number and locations of samples
- Quantity of material to be obtained at each sample location
- Techniques for obtaining samples
- The appropriate depth of sampling, and the accurate identification of layer thicknesses
- Handling and evaluation of sampled materials

#### **5.12.2.2 Determine Layer Thicknesses and Drainage Conditions**

The determination of an appropriate layer thickness is critical to the success of FDR, as with any other well designed pavement alternative. There are two considerations in selecting a FDR layer thickness. One is the composition of the existing pavement and subgrade materials which could

be incorporated into the reclaimed layer. The second is the structural requirement for the pavement based on the anticipated traffic and environmental conditions, and the role of the reclaimed layer within the total required pavement structure. The practicality of using FDR is to some degree determined from the thickness of the existing pavement and the type and amount of subgrade material which will be incorporated into the reclaimed layer.

The construction of a well drained pavement system is vital to the successful performance of all pavements. The presence of excess water within a pavement structure, including the subgrade, is detrimental to any pavement. Excess moisture can result in several accelerated damage mechanisms which result in the loss of pavement material integrity and weakening of the pavement structural capacity. Therefore, it is important that any existing drainage problems be identified and corrected prior to constructing the reclaimed pavement layer. Wet subgrade locations should be identified and effective drainage installed before FDR is undertaken. Other water related damage within the existing pavement layers should be evaluated to determine the source of water, and a solution for correcting the problem before reclamation.

### 5.12.2.3 Evaluate the Applicability of FDR

The following table provides an indication of when FDR is a suitable rehabilitation strategy, based on pavement surface distresses present. This procedure is the first step in the FDR decision making process. In general, FDR is indicated for use in situations where the problem is not limited to the immediate surface layer. Other strategies are likely to be more effective in that case.

Table --. Selection of FDR

<b>Pavement Distress</b>	<b>FDR</b>
<b>Surface Defects</b> <ul style="list-style-type: none"> <li>• Raveling</li> <li>• Flushing</li> <li>• Slipperiness</li> </ul>	
<b>Deformation</b> <ul style="list-style-type: none"> <li>• Corrugations</li> <li>• Ruts-shallow</li> <li>• Rutting Deep1</li> </ul>	X <sup>2,3</sup>
<b>Cracking (Load Associated)</b> <ul style="list-style-type: none"> <li>• Alligator</li> <li>• Longitudinal</li> <li>• Wheel Path</li> <li>• Pavement Edge</li> <li>• Slippage</li> </ul>	X  X X
<b>Cracking (Non-Load Associated)</b> <ul style="list-style-type: none"> <li>• Block (Shrinkage)</li> <li>• Longitudinal (Joint)</li> <li>• Transverse (Thermal)</li> <li>• Reflection</li> </ul>	X  X X
<b>Maintenance Patching</b> <ul style="list-style-type: none"> <li>• Spray</li> </ul>	X <sup>4</sup>

<ul style="list-style-type: none"> <li>• Skin</li> <li>• Pothole</li> <li>• Deep Hot Mix</li> </ul>	X <sup>4</sup> X X
<b>Week Base or Subgrade</b>	X
<b>Ride Quality/Roughness</b>	
<ul style="list-style-type: none"> <li>• General Unevenness</li> <li>• Depressions (Settlement)</li> <li>• High Spots (Heaving)</li> </ul>	 X <sup>5</sup> X <sup>6</sup>

<sup>1</sup> Rutting originating from the lower portion of the pavement (below surface course and includes base and subgrade).

<sup>2</sup> The addition of new aggregate may be required for unstable mixes.

<sup>3</sup> The chemical stabilization of the subgrade may be required if the soil is soft, or wet.

<sup>4</sup> In some instances, spray and skin patches may be removed by cold planning prior to these treatments (considered if very asphalt rich, bleeding).

<sup>5</sup> Used if depressions are due to a poor subgrade condition.

<sup>6</sup> Used if high spots caused by frost heave or swelling of an expansive subgrade soil exist.

### 5.12.3 Material Design and Quality Control

FDR can be performed using one of several stabilization mechanisms including mechanical, chemical, and bituminous.

Mechanical stabilization is accomplished by pulverization of the existing pavement, reshaping, and re-compacting the reclaimed material. It may be necessary to make appropriate adjustment of the moisture content during the reclamation process to achieve good compaction.

The quality of the reclaimed material can generally be improved by the introduction of a stabilizing material. Typical stabilization materials are chemical, bituminous, or some others such as calcium chloride. Chemical stabilization involves mixing and reacting some stabilization material or materials such as cement, fly ash, or lime kiln dust.

Bituminous stabilization typically includes an asphalt emulsion, but may also include the foamed asphalt process. The selection of an appropriate amount and type of stabilizing material is part of the mix design process. The mix design process for FDR is outlined in Chapter Two of Bulletin 27 (Bituminous Concrete Mixtures, Design Procedures and Specifications for Special Bituminous Mixtures). The design method lists applicable test procedures and the types of emulsified asphalts for use on PennDOT system FDR projects. The design procedure and quality control listed in Bulletin 27 must be utilized for PennDOT FDR projects.

## Publication 242

**Table 9.3**  
**Structural Coefficients for Materials in Flexible Pavements**

Pavement Component	Structural Coefficient
<b>Surface Course; New Construction, Reconstruction, or Overlay:</b>	
Superpave 9.5 mm, 12.5 mm, 19 mm, 25 mm (Wearing and Binder Courses)	0.44
FB-1, FB-2 (Wearing and Binder Courses)	0.20
FJ-1, FJ-1C, FJ-4 (Wearing Courses)	0.35
<b>Base Course; New Construction, or Reconstruction:</b>	
Plain Cement Concrete (PCBC)	0.50
Lean Cement Concrete (LCBC)	0.40
Superpave 25 mm Base Course	0.40
Superpave 37.5 mm Base Course	0.40
Crushed Aggregate (CABC)	0.14
Crushed Aggregate, Type DG (CABCDG)	0.18
Aggregate – Bituminous (ABBC)	0.30
Aggregate – Cement (ACBC)	0.40
Aggregate – Lime – Pozzolan (ALPBC)	0.40
<b>Existing Materials to be Overlaid</b>	
Cement Concrete (Good condition, < 5% patching)	0.40
Cement Concrete (Fair condition, < 10% patching)	0.30
Cement Concrete (Failed – no patching or > 10% patching)	0.25
Cracked and Seated Cement Concrete	0.25
Bituminous Concrete	0.30
Cold Recycled Bituminous Concrete	0.30
Full Depth Reclamation	
Pulverization	0.11
Calcium Chloride and similar additives	0.14
Bituminous Stabilization	0.25 – 0.3
Chemical Stabilization	0.3 – 0.37
Scarified Bituminous Concrete	0.14
Brick with Rigid Base	0.40
Brick with Flexible Base	0.20
Crushed Aggregate Base Course	0.14
Crushed Aggregate Base Course, Type DG	0.18
Miscellaneous Existing Materials (CP-2, AT-1, HEs, Oil Bond Stone, Bit. Road Mixes)	0.20
<b>Subbase; New Construction, Reconstruction, or Existing to be Overlaid*:</b>	
Open Graded Subbase	0.11
No. 2A Subbase	0.11
Asphalt Treated Permeable Base Course (ATPBC)	0.20
Cement Treated Permeable Base Course (CTPBC)	0.20
Rubblized Cement Concrete	0.21

\* See Section 10.1 for guidance regarding subbase inclusion in overlay designs

## **Appendix B3 – Publication 27**

## APPENDIX B3: PUBLICATION 27

### Publication 27

#### Chapter 1B

#### Department Criteria for Full Depth Reclamation Mix Design Procedure Using Asphalt Emulsion Stabilization

#### 1. Scope

1.1 This procedure provides instructions for preparing a Job Mix Formula (JMF) for a stabilized base using reclaimed asphalt material with emulsified asphalt binder, water, and other additives.

#### 2. Referenced Documents

2.1 AASHTO Standards, Test Methods and Protocols, ASTM Standards, and Pennsylvania Test Methods.

#### 3. Apparatus

3.1 Calibrated gyratory compactor, indirect tensile tester, balance, oven, and other equipment.

#### 4. Procedure

4.1 **Check Suitability of FDR Design Using Emulsion.** Design using emulsion is applicable for cases where reclaimed material is not excessively fine grained. Specifically, the amount of material passing No. 200 sieve must not exceed 20 percent and plasticity index must not exceed 10. Design suitability should be checked based on the guide provided in Table 1 below.

**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	Stabilizer	Soil Type												
			Granular Material						Silt-Clay Material						
			Well-graded gravel	Poody 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-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													

**4.2 Asphalt Emulsion Selection.** Select a PennDOT approved asphalt emulsion with minimum residue of 63 percent when tested according to AASHTO T59. The residue should meet AASHTO M320 requirements for PG 58-22 or PG 58-28. The emulsion should be of either the slow or medium set type. The slow setting emulsion type is typically preferred to facilitate curing when the final reclaimed mix is dense or fine graded. Typical emulsions for full depth reclamation include CMS-2, CSS-1h, and MS-2.

**4.3 Requirements on the Reclaimed Material.** The existing pavement or any recycled asphalt pavement (RAP) material shall be crushed to meet the maximum size requirement. All materials larger than 2 inches in size shall be removed before further processing. The materials will be blended in the proportions that are representative of the project depth and cross section. The gradation of the composite (blended) reclaimed material shall be determined in accordance with AASHTO T11 and T27. If the gradation is deficient or there is a not sufficient amount of coarse aggregate in the gradation, mechanical stabilization should be applied before emulsion application. Mechanical stabilization includes incorporation of virgin aggregate to the extent needed to satisfy gradation requirements. The final gradation shall meet the gradation criteria presented in Table 2.

**TABLE 2 Gradation Requirements**

Sieve Size	Percent Passing
2 inches	100
1.75 inches	95-100
#200	0-20

The sand equivalent (SE) test shall be performed and reported in accordance with AASHTO T176. SE value is from the combined materials. SE should not be less than 30 percent.

**4.4 Selection of Water Content for Design.** A modified Proctor compaction shall be conducted in accordance with PTM 106 (AASHTO T-180, ASTM D558) to determine the optimum moisture content (OMC) at peak dry density. Material containing 20 percent or more passing No. 200 shall be mixed with target moisture, sealed, and set aside a minimum of 12 hours. All other material shall be set aside a minimum of 3 hours. If a material contains a significant amount of RAP or coarse material and does not produce a well defined moisture-density curve, then the moisture content shall be fixed at 3 percent.

If a material contains less than 4 percent passing No. 200 or if no peak develops with the OMC curve, then fix the moisture content between 2 and 3 percent.

**4.5 Preparation of Test Specimens.** Sufficient samples shall be taken before the addition of water and emulsion to produce at least  $50 \pm 5$  mm height and 150 mm diameter compacted specimens.

Specimens shall be mixed with the required amount of water for 60 seconds before addition of the asphalt emulsion. These specimens shall be allowed to sit sealed as specified in Section xxx.

Four emulsion contents shall be selected. Note: Four emulsion contents of 3 percent, 4 percent, 5 percent, and 6 percent by weight of total mix are typically used, but other ranges or narrower bands (0.5 percent) can be selected.

Number of specimens shall be produced for each test method in the laboratory at each emulsion content according to Table 3.

**TABLE 3 Required Number of Laboratory Prepared Specimens**

Test	# of Specimens Per Emulsion Content	Specimen Status
Max. Theoretical Sp. Gr.	2	Loose
Indirect Tensile Strength, AASHTO T 283	6	Compacted

**4.5.1 Mixing.** Aggregate material and emulsion shall be mixed in a mechanical mixer at a temperature of 20°C to 26°C for 60 seconds.

**4.5.2 Curing.** Specimens after mixing shall be cured individually at 40° C for 27 to 33 minutes.

**4.5.3 Other Additives.** If other materials are added, such as lime or cement, then they shall be introduced in a similar manner as they will be on the project. For example, if lime is incorporated a day or more before emulsion addition, then it shall be added to the wet aggregate a day or more before mixing with emulsion. If lime is incorporated as a slurry, then it shall be incorporated as a slurry in the laboratory.

Note: In some cases, adding one percent lime or cement would be desirable before adding emulsion. Whether lime or cement should be added depends on plasticity index and percent material passing No. 200 sieve.

**4.6 Compaction.** Specimens shall be compacted in a gyratory compactor satisfying requirements outlined in PennDOT Bulletin 27. Thirty gyrations shall be applied at a temperature of 20°C to 26°C. After the last gyration, 600 kPa pressure shall be applied for 10 seconds. The mold shall not be heated.

**4.6.1 Curing.** Specimens shall be cured for 24 hours at 40°C temperature, and 48 hours at room temperature.

#### **4.7 Volumetric Measurements**

**4.7.1 Gmm.** Determine the Maximum Specific Gravity at each emulsion content in accordance with AASHTO T209 and modified requirements outlined in PennDOT Bulletin 27.

**4.7.2 Gmb.** Determine the Bulk Specific Gravity of all compacted specimens at each emulsion content using AASHTO T166.

**4.8 Indirect Tensile Strength and Moisture Susceptibility.** The six prepared specimens at each emulsion content shall be tested according to AASHTO T 283.

**4.9 Selection of Emulsion Content.** A design emulsion content shall be selected to produce a FDR mixture that meets the design criteria in Table 4. If more than one emulsion content produces mixtures which meet the criteria, then select the emulsion content that produces a mixture with the highest indirect tensile strength.

**TABLE 4 Design Criteria**

<b>Properties</b>	<b>Criteria</b>
Air Voids	6-8%
Indirect Tensile Strength of Control Specimens, min.	50 psi
Indirect Tensile Strength Ratio, min.	0.7

## **5. Report**

**5.1** The report for the JMF shall be as follows: Physical address of the road and project information. Performance Grade of the emulsion residue used in the mix design. General description of the materials received, their locations, and sampling procedure. Average thickness of hot mix asphalt. Thickness of different layers to be reclaimed. Density and optimum moisture content from Proctor compaction. Moisture content used in mix design. Indirect tensile strength. Level of saturation and conditioned indirect tensile strength

## **PennDOT Pub 27 – Chapter 2, Section 7 (Update)**

### **7. FULL DEPTH RECLAMATION (USING BITUMINOUS STABILIZATION PROCESS)**

#### **7.1 General**

Full depth reclamation (FDR) is a method by which asphalt layers and underlying base, subbase, and subgrade layers may be treated to produce a stabilized base course. FDR is suitable for pavements where inadequate asphalt pavement depth precludes the use of cold recycling. Unlike cold recycling, FDR may incorporate suitable subgrade soil, making it ideal for lower type roads, including roads with poor base conditions, ‘pie-crust’ roads consisting of multiple thin layers and surface treatments, or even unpaved roads.

Different types of additives may be used to treat reclaimed materials. This section provides mix design guidelines for FDR with asphalt emulsion stabilizers. *Guidelines for FDR using pulverized stabilization, mechanical stabilization, chemical stabilization and calcium chloride stabilization are provided in PennDOT FDR Best Practice Manual 090107 dated* (to be determined). *Non-bituminous methods should be considered if the preliminary analysis of in-situ materials determines asphalt emulsions are unsuitable for this process (See the following*

## *Guidelines for Selecting Asphalt Emulsions for FDR)*

### **7.2 Guidelines for Selecting Asphalt Emulsions as Stabilizers for FDR**

**SCOPE:** This procedure provides instructions for preparing a Job Mix Formula (JMF) for a stabilized base using an emulsified asphalt binder, water, and other additives.

#### **REFERENCED DOCUMENTS: AASHTO Standards**

AASHTO T11  
AASHTO T27  
AASHTO T49  
AASHTO T59  
AASHTO T84  
AASHTO T85  
AASHTO T100  
AASHTO T166  
AASHTO T176  
AASHTO T180  
AASHTO T209  
AASHTO T245  
AASHTO T255  
AASHTO T283  
AASHTO T315

**APPARATUS:** Calibrated gyratory compactor, indirect tension tester, balance, oven, and other equipment.

#### **PROCEDURE:**

**Check Suitability of FDR Design Using Emulsion.** Design using emulsion is applicable for cases where reclaimed material is not excessively fine grained. Specifically, the amount of material passing #200 sieve must not exceed 20 percent and the plasticity index must not exceed 10. Design suitability should be checked based on the guide provided in the Best Practice Manual.

**Asphalt Emulsion Selection.** Select a PennDOT approved asphalt emulsion with minimum residual asphalt of 63 percent when tested according to AASHTO T59. The residue should meet AASHTO M320 requirements for PG 58-22 or PG 58-28.

**Requirements on the Reclaimed Material.** The existing pavement or any added recycled asphalt pavement (RAP) material shall be crushed to meet the maximum size requirement. All materials larger than 2" in size shall be removed before further processing. The materials will be blended in proportions that are representative of the project depth and cross section. The gradation of the composite (blended) reclaimed material shall be determined in accordance with AASHTO T11 and T27. If the gradation is deficient, mechanical stabilization should be applied before emulsion application. Mechanical stabilization includes the incorporation of virgin aggregate needed to satisfy gradation requirements. The final gradation shall meet the gradation criteria presented in Table 1.

**Table 1. Gradation Requirements**

Sieve Size	Percent Passing
2 inches	100
1.75 inches	95-100
0.75 inches	80-90
#200	0-20

The sand equivalent (SE) test shall be performed and reported in accordance with AASHTO T176. Sand equivalent value (SE) is from the combined materials. SE should not be less than 30 percent.

**Selection of Water Content for Design.** A modified Proctor compaction shall be conducted in accordance with PTM 106 (AASHTO T-180, ASTM D558) to determine the optimum moisture content (OMC) at peak dry density. Material containing 20% or more passing the No. 200 sieve shall be mixed to the target moisture, sealed, and set aside a minimum of 12 hours. All other material shall be set aside a minimum of 3 hours. If a material contains a significant amount of RAP or coarse material and does not produce a well defined moisture-density curve, then the moisture content shall be fixed at 3%. If a material contains less than 4 percent passing the No. 200 sieve, or if no peak develops with the OMC (optimum moisture curve), then fix the moisture content between 2 and 3 percent.

**Preparation of Test Specimens.** Sufficient samples shall be taken before the addition of water and emulsion to produce at least  $95 \pm 5$  mm height and 150 mm diameter compacted specimens. Specimens shall be mixed with the required amount of water for 60 seconds before the addition of the asphalt emulsion. These specimens shall be allowed to cure.

Four emulsion contents shall be selected. Note: Four emulsion contents of 3%, 4%, 5%, and 6% by weight of total mix are typically used, but other ranges or narrower bands with 0.5% increments can be selected. The required number of specimens shall be produced for each test method in the laboratory at each emulsion content as identified in Table 2.

**Table 2. Required Number of Laboratory Prepared Specimens**

Test	# of Specimens Per Emulsion Content	Specimen Status
Max. Theoretical Sp. Gr.	2	Loose
Indirect Tensile Strength, AASHTO T 283	3	Compacted

**Mixing.** Reclaimed material and emulsion shall be mixed in a mechanical mixer at a temperature of 20C to 26C for 60 seconds.

**Curing.** Specimens are to be cured individually at 40° C for 27 to 33 minutes after mixing.

**Other Additives.** If other materials are added, such as lime or cement, then they shall be introduced in a similar manner to that anticipated for use on the project. For example, if lime is to be incorporated a day or more before the addition of the emulsion, then it shall be added to the wet aggregate a day or more before mixing with emulsion. If lime is incorporated as a slurry, it should be incorporated as a slurry in the laboratory procedure.

Note: In some cases, adding one percent lime or cement would be desirable before adding emulsion. Whether lime or cement should be added depends on plasticity index and percent material passing #200 sieve.

**Compaction.** Specimens shall be compacted in a gyratory compactor satisfying requirements outlined in PennDOT Bulletin 27. Thirty gyrations shall be applied at a temperature of 20°C to 26°C. After the last gyration, 600 kPa pressure shall be applied for 10 seconds. The mold shall not be heated.

Curing. Specimens shall be cured for 48 hours at room temperature.

**Volumetric Measurements.**

Gmm. Determine the Maximum Specific Gravity at each emulsion content in accordance with AASHTO T209 and modified requirements outlined in PennDOT Bulletin 27.

Gmb. Determine the Bulk Specific Gravity of all compacted specimens at each emulsion content using AASHTO T166.

**Determination of Indirect Tensile Strength and Moisture Susceptibility.** The three prepared specimens at each emulsion content shall be tested according to Section 11 of AASHTO T 283.

**Selection of Emulsion Content.** A design emulsion content shall be selected to produce a FDR mixture that meets the design criteria in Table 3. If more than one emulsion content produces mixtures which meet the criteria, then select the emulsion content that produces a mixture with the highest indirect tensile strength.

**Table 3. Design Criteria**

Properties	Criteria
Air Voids	6-8%
Indirect Tensile Strength of Control Specimens, min.	50 psi

**Investigation of Moisture Susceptibility.** Once design emulsion content is selected, specimens should be prepared and tested according to AASHTO T 283. The indirect tensile strength ratio (TSR) shall exceed 0.7.

**REPORT.** The report for the JMF shall be as follows:

- Physical address of the road and project information
- Grade of the emulsion residue used in the mix design; general description of the materials received, their locations, and sampling procedure
- Average thickness of hot mix asphalt
- Thickness of the several layers to be reclaimed
- Density and optimum moisture content from the modified Proctor
- The moisture content used in the mix design
- Indirect tensile strength
- Level of saturation, conditioned indirect tensile strength, and TSR

## **Appendix B4 – Publication 23**

## APPENDIX B4: PUBLICATION 23

### **PennDOT Pub 23 – Chapter 7, Section 7.4 (Addition following “MILLING, RECYCLING, LEVELING, AND RESURFACING”)**

#### **FULL DEPTH RECLAMATION**

Full depth reclamation (FDR) is a pavement rehabilitation technique in which the full flexible pavement section and predetermined portion of the underlying materials are uniformly crushed, pulverized or blended, resulting in a stabilized base course; further stabilization may be obtained through the use of available stabilizers such as bituminous, cement, fly ash and lime. The selection of FDR stabilizers should be based on the soil type, percent passing No. 200 sieve, and plasticity index. FDR not only conserves the investment in in-situ materials, but also resolves the issues and minimizes the costs of material disposal normally associated with conventional pavement reconstruction practices. FDR provides an effective and sustainable way to recycle the existing pavement.

The Department has experience with FDR dating back many years. However, a research project was initiated in 2010 to comprehensively investigate the subject, and develop detailed processes and procedures for use by the Department. The resulting details of the processes and procedures for conducting FDR projects are contained in Publication 242, “Pavement Policy Manual,” and construction requirements are contained in Publication 408, Section 344. Appendix L of Publication 242 is the document “Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide,” which discusses the various options for full depth reclamation, project selection guidelines, mix design methods, and construction procedures. Maintenance forces are required to follow the guidelines and criteria provided in these reference documents. The FDR process is illustrated below. Specific references for carrying out the steps outlined in the process flowchart are:

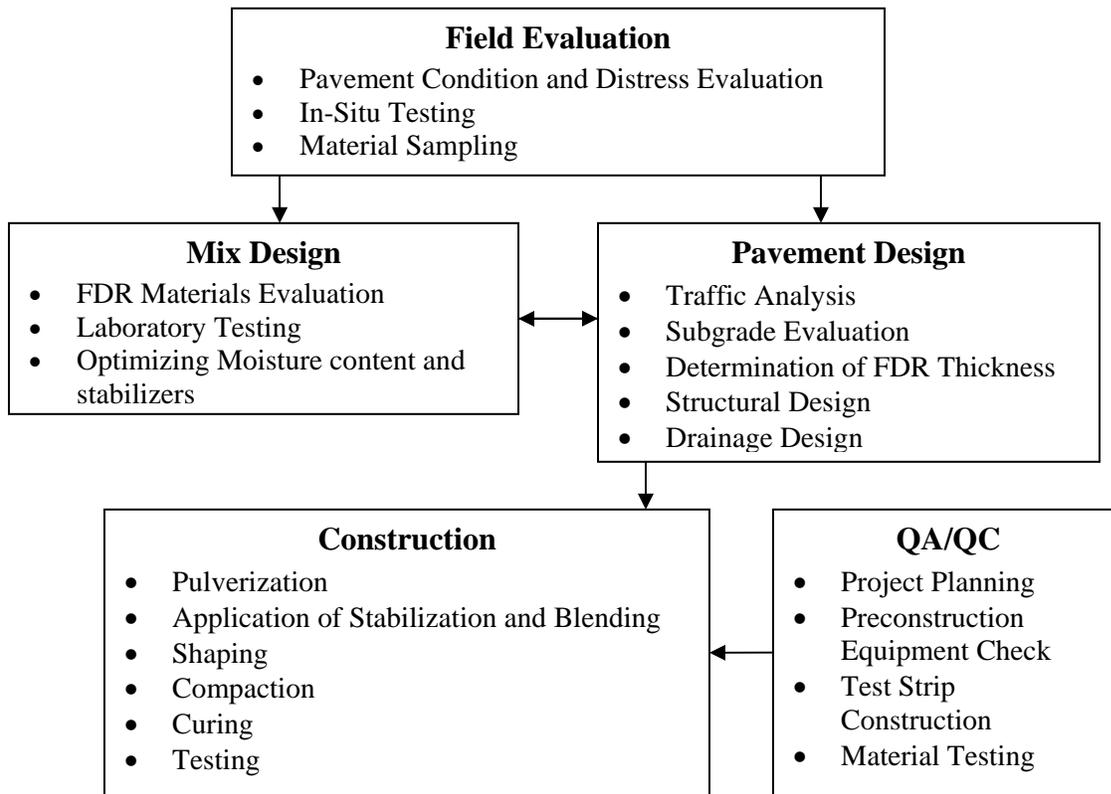
Project Selection – Appendix L of Publication 242, “**Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide,**” Chapter 2.

Mix Design – Appendix L of Publication 242, “**Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide,**” Chapter 3. For bituminous stabilization design also refer to Publication 27, Chapter 2 section 7, and for chemical stabilization design also refer to Bulletin 5.

Pavement Design – Publication 242, Section 3.1.5, 5.12 and Appendix L “**Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide,**” Chapters 2.5 and 6.

Construction – Appendix L of Publication 242, Chapter 4, and 408, Section 344.

QC/QA – Appendix L of Publication 242, “**Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide,**” Chapter 5.



## **Appendix B5 – Publication 30 (Bulletin 5)**

## **APPENDIX B5: PUBLICATION 30 (BULLETIN 5)**

### **Mix Design Procedure for Chemical Stabilization as a Full Depth Reclamation (FDR) Method**

In this section, the mix design procedure for the chemical stabilization method of full depth reclamation (FDR) rehabilitation strategy is presented. Chemical stabilization is the addition of wet or dry chemical additives (and virgin aggregate or recycled asphalt pavement (RAP) from a different source if needed) to the reclaimed materials in order to stabilize the course. The stabilizing agents discussed here are cement, lime/Fly ash (L/FA), lime pozzolan, and blends of these materials. Other examples of stabilizing agents include calcium chloride, magnesium chloride, enzymes, and other material combinations providing suitable mix properties.

There are four major parts to laboratory mix design for full depth reclamation when using chemical stabilization, 1) characterization of reclaimed materials, 2) establishing the type of chemical stabilizer, 3) determination of optimum moisture content, and 4) determination of amount of stabilizer.

The materials used in the mix design and the mix design procedure are discussed below.

#### **1. Materials**

The materials and their typical application rates used in the mix design are as follows:

##### **1.1 Reclaimed Materials**

Characterization of reclaimed material: The gradation of reclaimed materials should be conducted separately for the reclaimed asphalt, unbound base/subbase, and subgrade. The greatest challenge will be in the determination of the gradation of the recovered asphalt layer. It is best if the asphalt in the laboratory is crushed using a suitable crusher to deliver a gradation close to what is expected during the field pulverizing process. If the gradation of the laboratory asphalt mix is significantly different from what is expected from the field pulverization process, the mix design properties may not be representative of the field properties to the level expected. The consistency characteristics of the subgrade soil in terms of liquid limit, plastic limit, and shrinkage limit must be determined and the soil must be classified according to AASHTO Specification M 145. This classification is needed for selection of the chemical stabilizer. The sealed samples obtained from different layers should be processed to determine the moisture content for each layer. The details of this testing are provided in Section 2 of this document. One hundred percent of the pulverized surface material is required to pass through a 50 mm (2 inch) sieve. Incorporate all reclaimed material into the stabilized base. These materials consist of:

- Reclaimed Aggregate Material (RAM): In-situ aggregate material which is incorporated in the stabilization.
- Reclaimed Asphalt Pavement (RAP): Processed paving material containing asphalt cement and aggregates.

## 1.2 Stabilizing Agents

Establishing the type of chemical stabilizer:

Select the type of stabilizer based on the gradation and soil characteristics such as plasticity index. Refer to Table 2 for this selection.

Stabilizing agent can be the following materials or combinations of these materials:

- Cement: Publication 408, Section 701. (3 to 8% by weight).
- Hydrated Lime: Publication 408, Section 723. (2 to 6% by weight).
- Fly Ash: Publication 408, Section 724.2(a). (6 to 14% by weight).
- Lime Pozzolan: Publication 408, Section 725. (6 to 8% by weight).
- Quicklime
- Class C Fly Ash
- Fluidized bed combustion flyash

Class C fly ash can be used without any other agents, but Class F fly ash needs to be used with a cementitious agent such as cement or hydrated lime. The latter combination is referred to as Lime/Fly Ash (L/FA). Fluidized bed combustion flyash has been used as a partial cement replacement with success.

Environmental issues represent an additional consideration in the selection of stabilization materials for a project. Environmental concerns such as the potential for fugitive dust or contamination of runoff during construction activities may influence the selection of stabilization material, or the application process used.

## 1.3 Aggregates

Additional non-reclaimed aggregates are added to the mix according to the required gradation and quantities. Publication 408, Section 703.2 (Type A), No. 8, 10, 57, and 67.

## 1.4 Recycled Asphalt Pavement (RAP)

Add reclaimed bituminous material (complying with Section 702) according to the approved mix design.

## 2. Mix Design Procedures

Develop a chemically stabilized mix design using approved material. Make, cure, and test three unconfined compressive strength specimens of FDR material and cement in accordance with AASHTO T 220 (ASTM 1633, method A). Wrap the specimens in plastic wrap, seal in an airtight, moisture proof bag and cure the test specimens for a period of 7 days. For the final mix design, the required amount of cement will be that which provides an average unconfined compressive strength of the three specimens not less than 2068 kPa (300 psi) in 7 days. Hydrated Lime or Fly Ash (including fluidized bed combustion fly ash) can be used in place of cement as long as the desired strength can be met. They will not be used as a singular additive

but will be used as a combination of the two. The mix design for this option will need to be approved by the Engineer.

The mix design process involves five or six steps:

1. Evaluation of the reclaimed materials
2. Determining the materials to be used in the mix and their proportions
3. Testing of the laboratory samples
4. Selecting the final quantity of the stabilizing agent(s)
5. Field adjustments
6. Additional testing (if required)

Details of the above mentioned steps follow.

## **2.1 Evaluation of the Reclaimed Materials**

The first step in the mix design is evaluation of the reclaimed materials. This evaluation will determine the suitability of the materials and their physical properties such as gradation and plasticity index. This evaluation is done by proper sampling and testing of the in-situ materials to be used in the reclamation process.

### **2.1.1 Sampling**

Proper sampling plays a vital role in the design and construction of FDR. The samples will be investigated and used for material selection and the mix design procedure. The following criteria must be considered when obtaining samples from the FDR candidate roadway.

- Number of samples and locations of sampling
- Amount of material to be sampled at each location
- Techniques of sampling
- Depth of sampling and identification of layer thicknesses
- Handling and evaluation

Details about the above considerations are presented in the FDR Best Practices Manual.

Samples of RAM and RAP should be removed to the specified depth and appropriate testing to establish a mix design should be performed.

### **2.1.2 Testing of the Field Samples**

The individual layers consist of bituminous materials (HMA, chip seal, etc.), base, subbase, and if applicable, subgrade and virgin aggregate. The material test results define the pavement composition and are used in the mix design process.

The evaluation of the existing road materials must also include the combined gradation of the material planned for inclusion in the reclaimed layer. Sampled materials must be properly processed and prepared to closely simulate field conditions.

The samples should be characterized for the physical characteristics referenced in Table 1. It should be mentioned that some of the tests in this table are conducted at subsequent steps of the mix design process (namely the moisture-density relationship and unconfined strength tests).

**Table 1. Minimum soil testing methods**

Test	Designation
Moisture content	AASHTO T265
Sieve analysis	PTM 616
Mechanical and hydrometer particle size analysis of soils	AASHTO T88
Liquid limit, plastic limit	AASHTO T89, T90
Moisture-density relationship	PTM 106
Unconfined compressive strength	AASHTO T220
Materials finer than No. 200 sieve	PTM 100

## 2.2 Determining the Materials to be used in the Mix and their Proportions

The results of the aforementioned tests should be used in conjunction with Table 2 to select the appropriate stabilization approach based on soil classification type, and also based on the percent of material passing the No. 200 sieve, plasticity index, and liquid limit.

**Table 2. Correlation of stabilization additive as a function of soil type, percent passing No. 200 sieve, and plastic index**

Percent Passing No.200	Plastic Index	Stabilizer	Soil Type											
			Granular Material							Silt-Clay Material				
			Well-graded gravel	Poody graded gravel	Silty gravel	Clayey gravel	Well-graded sand	Poorly graded sand	Silty sand	Clayey sand	LL<50		LL≥50	
			GW	GP	GM	GC	SW	SP	SM	SC	Silt, Silt with sand	Lean clay	Organic silt/Organic lean clay	Elastic silt
			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												

For the chemical stabilization option, the materials i.e. stabilizing agent(s) and virgin aggregate (if needed) and their proportions in the mix should be specified in this step. For the stabilizing agents, the proportions are selected based on experience or trial and error.

Different percentages of the stabilizing agent(s) are selected for further testing. The percentage increment is usually at least 1%. Samples made according to these quantities should be tested in the next step for the optimum moisture content (OMC) and the maximum dry density (MDD) at each quantity level.

## **2.3 Testing of the Laboratory Samples**

For each application level of the stabilizing agent(s), the following tests should be performed on the samples.

OMC and MDD should be measured. The samples should also be tested for unconfined compressive strength. The results will be used in the selection of the final quantity of the agent(s).

### **2.3.1 Testing for Moisture-Density Relations**

Determination of Optimum Moisture Content: Once the depth of reclamation is determined based on structural design procedures contained in Publication 242, materials from different layers are blended in the laboratory proportionally. Determination of optimum moisture content should be based on AASHTO T-134. The first set of specimens for determination of moisture content will be prepared based on a trial content of the chemical stabilizer. For example, specimens could be prepared at 4 percent cement.

OMC and MDD should be measured for each application level of the stabilizing agent(s). Refer to Table 1 for the test designation.

### **2.3.2 Testing for Strength**

Unconfined compressive strength testing for cement, L/FA, lime pozzolan and their combinations are presented here.

#### 2.3.2.1 Cement

Make, cure, and test three unconfined compressive strength specimens of FDR material and Cement in accordance with AASHTO T 220 (ASTM 1633, method A). Wrap the specimens in plastic wrap, seal in an airtight, moisture proof bag and cure the test specimens for a period of 7 days.

#### 2.3.2.2 L/FA, Lime Pozzolan and their combinations

Make, cure, and test three unconfined compressive strength specimens of FDR material and L/FA or Lime Pozzolan in accordance with ASTM 5203, procedure B. Wrap the specimens in plastic wrap, seal in an airtight, moisture proof bag and cure the test specimens for a period of 7 days at 40°C (104°F) before testing.

### **2.3.3 Strength Requirements**

Examples of the strength requirements for cement, L/FA, lime pozzolan, and combination mixtures are followed.

### 2.3.3.1 Cement

Determination of Design Cement Content: Once optimum moisture content is determined, design cement content will be selected based on unconfined compressive strength. If 70 percent or more of the material is passing the 3/4-in sieve, use 4-inch diameter mold and a 6 inch specimen height. If less than 70 percent of the material passes the 3/4-inch sieve, use a 6-inch diameter mold with a height of 9 inches. In either case, the height to diameter ratio should be maintained at 1.5. Under no circumstances should molds smaller than 4 inches in diameter be used. Prepare 12 specimens. Compaction of specimens should be conducted according to AASHTO T 134. Each set of 3 specimens will have a different cement content and different water content as given below:

Cement Content, % by weight of Asphalt- Soil Mix	Water Content, % of total mix
Trial Level - 2	Optimum -0.5
Trial Level	Optimum
Trial Level + 2	Optimum+0.5
Trial Level + 4	Optimum+1.0

Place the compacted wet specimen in the 23 to 25C moist room (with minimum 95% humidity) for 7 days. Protect specimens from dripping water in the moist room.

After 7-day curing, softly dry the surface of the specimen, so that it is not wet at the surface, and measure the weight. Measure the unconfined compressive strength (UCS) of the specimens according to ASTM D 1633. Use the cement content giving an average minimum UCS strength of 300 psi but not exceeding 500 psi.

For the final mix design, the required amount of cement will be that which provides an average unconfined compressive strength of the three specimens as follows:

A minimum unconfined compression value of 1,379 kPa (300 psi) in 7 days and a maximum unconfined compression value of 3447 kPa (500 psi) in 7 days for roads that are designed with a minimum of 75 mm (3 inch) pavement overlay.

A minimum unconfined value of 2068 kPa (300 psi) in 7 days and a maximum unconfined compression value of 3447 kPa (500 psi) in 7 days is required for roads that are to be Surface Treated or overlaid with less than 75 mm (3 inch) of pavement.

### 2.3.3.2 L/FA, Lime Pozzolan and their combinations

For the final mix design, the required amount of L/FA or Lime Pozzolan will be that which provides an average unconfined compressive strength of the three specimens of at least 1,379 kPa (200 psi).

## **2.4 Selecting the Final Quantity of the Stabilizing Agent(s)**

For each stabilizing agent, the application quantity that results in strengths in excess of the minimum required strength is acceptable and can be selected as the final quantity.

## **2.5 Field Adjustments**

The final mix design may need to be adjusted based on the Quality Control/Quality Assurance (QC/QA) test results and mix workability in the field. The intention is to tweak the mix to account for differences between the laboratory and field produced mixes. The original objectives of the mix design should not change; strength requirements for the project as discussed in Section 2.3.3.1 of this document. Additionally, the acceptance requirements of Publication 408, Section 344.3(b) must still be achieved for final acceptance, unless otherwise waived by the Department's representative.

## **2.6. Additional Testing (if directed)**

Additional tests including those for durability, moisture sensitivity, etc. may be conducted on the mix, if directed by the owner agency.

**Appendix C – Standards and Specifications for Full  
Depth Pavement Reclamation: A Best Practices Guide  
(Publication 242, Appendix L)**

# **Developing Standards and Specifications for Full Depth Pavement Reclamation: A Best Practices Guide**

## **FDR Best Practices Manual**

PennDOT 090107

Draft

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## **EXECUTIVE SUMMARY**

This document represents the Best Practices identified and developed for the use of full depth reclamation of flexible roads (FDR). It addresses a process for developing and constructing FDR projects. The document provides guidelines for the individual activities which must be accomplished including

Determination of the suitability of a road as an FDR candidate  
Sampling and testing  
Determination of appropriate FDR techniques and materials  
FDR mix design development  
Project planning  
Project construction and quality control measures  
Final surfacing

The specific details to be followed for each of these steps are discussed so that PennDOT and other users can develop projects from the information provided.

## **1. INTRODUCTION**

Full Depth Reclamation (FDR) is among the most cost effective and popular methods of rehabilitating deteriorating flexible pavements and unpaved roads. The method is best suited for low volume roads and the best results are obtained if a sound engineering approach is utilized in designing and constructing FDR projects. FDR refers to a specific type of construction in which the existing material is pulverized to a specific depth (typically 8 to 12 inches), followed by grading and compacting the material to provide a smooth strong base. Most often the reclaimed material includes base, subbase, or subgrade material with a need for mechanical or chemical stabilization of the reclaimed pavement before compaction. Sometimes the rebuilt pavement is left without any overlay, but often times it serves as a strong base on which hot mix asphalt overlay or a surface treatment is applied.

These materials are pulverized to a two inch minus size by a road reclaimer. Specific stabilizing additives are added to enhance the characteristics of the reclaimed materials, and compacted.

The general categories of FDR available are;

- \*Pulverization
- \*Mechanical Stabilization
- \*Bituminous Stabilization
- \*Chemical Stabilization
- \*Calcium or Magnesium Chloride Stabilization

Each of these is discussed in greater detail in the subsequent section. The final product is a renewed stabilized pavement base layer with uniform characteristics.

## **1.1 Pulverization**

The first step in the process is pulverization, which provides the basic operation for all FDR stabilization types. It consists of pulverization of the in-situ pavement layers and blending of the predetermined level of underlying material. The layers and materials affected are determined as a part of the structure and mix design processes. A specific gradation of the materials being pulverized is accomplished by the reclaimer by controlling the combination of cutting rotor speed, forward machine travel, gradation control beam position, and mixing chamber front and rear door positions. After initial pulverization, the pulverized material is shaped and graded to within ½ inch of irregularity to the lines and grades of the proposed roadway.

After the material is properly sized by pulverization and shaped, moisture is added to enable the material to be properly compacted. This is best accomplished by adding a predetermined amount of water through the machine's fluid injection system during the blending process. Alternatively, moisture can be applied to the surface at a calibrated rate prior to the first stage of pulverization, but this relies on the pulverization process to uniformly blend the moisture throughout the pulverized material. The use of the fluid injection method provides much better assurance that the proper moisture content required to achieve compaction exists in the material.

Breakdown compaction takes place immediately behind the reclaimer to achieve a more consistent density throughout the mat. Requirements for the compaction equipment may vary with the depth of pulverized material and other characteristics of the pulverized layer because it must provide sufficient energy to achieve compaction. Typical compaction equipment might be a 25 ton vibratory padfoot roller or a pneumatic 25 ton roller.

Subsequent to the breakdown compaction, a motor grader is used to establish the final and proper roadway grade and cross slope. The grading process may result in loss of moisture from drying, so water is typically added to the surface prior to intermediate rolling. This rolling stage is typically performed using a pneumatic or heavy smooth drum vibratory compactor which can reseat aggregates loosened during grading. Finish rolling follows using a 12-14 ton single or tandem static drum roller.

Once compaction has been completed, a fog seal of asphalt emulsion or other sealer is applied to bond particles to the surface and protect the reclaimed layer from traffic and adverse climatic conditions until a new wearing surface is applied.

## **1.2 Mechanical Stabilization**

Mechanical stabilization incorporates imported granular materials into the recomposed FDR base layer during the pulverization process. The need for granular material is determined from a gradation analysis of the combined materials of the existing layers. The process can improve the structural integrity of the existing materials by improving the total grading, or can be used to improve the structural stability of in place material with excess bitumen content.

The introduction of additional granular material during mechanical stabilization can also be used to improve vertical curves, raise the pavement surface elevation, or accomplish widening without reducing layer thickness. Several materials can be used for mechanical stabilization such as

crushed aggregate, recycled asphalt pavement, or recycled concrete pavement. These materials may be introduced into the reclaimed layer by spreading ahead of the pulverization process, or as a blending pass after initial pulverization and shaping. The stabilization material can be uniformly spread by a motor grader or more consistently by mechanical spreaders or paving equipment.

Mechanical stabilization can be used alone or in combination with other bituminous or chemical stabilizing additives.

### **1.3 Bituminous Stabilization**

The addition of bituminous stabilizing additives to the FDR process is identified by the term bituminous stabilization. The addition of bituminous stabilizing materials to the pulverized layer can increase the stiffness of the layer, and improve resistance to water related damage. Since bituminous stabilized FDR is more flexible than other forms of FDR, this product could, depending upon the design details, provide improved fatigue resistance to loading as compared with others.

Two separate processes can be classified as bituminous stabilization; conventional stabilization using emulsified asphalt material, or a foamed asphalt process. In the conventional FDR with emulsion process the bituminous additives can be blended into the reclaimed material through the liquid additive injection system. The bituminous material can be added either in a single pass during the pulverization process, or in a multiple pass operation which is more suitable for projects where grade and cross slope adjustments are needed. In the multiple pass operation the initial pulverization pass is made at slightly less depth than the design depth. This is followed by intermediate shaping, and then a pass for blending the stabilizing additives into the pulverized mat. The multiple step process can achieve a more uniform final reclaimed layer.

Over the years several methods have been developed for disbursing the emulsified asphalt stabilizing material into a moist reclaimed material layer. Most emulsified asphalt used in stabilization consists of approximately 60% to 65% residual bitumen. When the water dissipates the emulsion is said to have broken, at which point the residual asphalt particles revert to a continuous film which coats the reclaimed material particles. The time required for the emulsion to break is influenced by the following factors:

- Climatic conditions
- The internal chemical composition and characteristics of the emulsion
- Water dissipation by evaporation or absorption by the reclaimed material
- External pressures from the mixing and compaction processes
- The addition of chemical catalyst such as cement or lime can accelerate the breaking process

Bituminous stabilized FDR works well with other additives including granular material and/or cement or lime. Cement or lime is usually applied in a slurry state for this type of combined product.

Either bulk tankers or distributor trucks containing emulsified asphalt material can be coupled to the reclaimer using an interlocking push bar and liquid delivery hose connected to the integrated liquid injection system. The pulverizing machine must be equipped with a computerized integral liquid proportioning system capable of regulating and monitoring the liquid application rate relative to depth of cut, width of injection, advance speed, and material density. A less effective alternative is to uniformly spray the emulsion onto the pulverized material surface and blend it with the reclaimer. Once the liquid emulsion breaks, breakdown compaction should occur using a padfoot roller or pneumatic roller depending on depth, followed by shaping with a motor grader. Intermediate rolling with a pneumatic roller is then carried out. If surface drying is evident, additional surface moisture may be needed during this step. This could be achieved with rollers equipped with a wetting device or by the direct application of water. Finish rolling should be accomplished using a single or double-drum vibratory steel wheel roller to eliminate pneumatic tire marks.

Another technique available for homogeneously incorporating bituminous material into the reclaimed layer is known as foamed or expanded asphalt. In this process a small amount of water is injected into hot asphalt creating small bubbles which carry a thin film of asphalt. The considerable volume expansion of foamed asphalt reduces its viscosity and makes it easily workable. The result should be proper coating of reclaimed material. As a general rule, the amount of water needed is approximately 2% of the mass of asphalt to foam a typical performance grade asphalt material. This small amount of water is to expand the asphalt volume and facilitate particle coating. This water evaporates quickly and, therefore does not replace the moisture needed to achieve density in the field, which should be determined based on the moisture-density relationship of the mix. For the foaming process to work effectively, the reclaimed material must have a minimum of 5% of the material passing the 200 sieve. If sufficient fine material is not present the addition of an appropriate fine aggregate could be useful in making this treatment process effective. Small amounts of Portland cement or lime can be added to increase the minus 200 sieve content.

A major advantage of the foamed asphalt process is that there are no manufacturing costs after acquisition of the foaming apparatus. Foamed FDR can be compacted, shaped, and opened to traffic immediately. Alternatively, the treated reclaimed material can be stored in stockpiles, requiring only moisture conditioning to complete the construction process.

Other additives can be used with bituminous stabilization process to modify existing reclaimed material to make bituminous stabilization a suitable option. The addition of lime or cement can also be used to decrease the cure time, mitigate stripping damage, and improve the retained strength characteristics of the reclaimed material.

#### **1.4 Chemical Stabilization**

This type of FDR addresses the addition of wet or dry chemical additives to stabilize the reclaimed material. The predominant chemical stabilizing additives used for FDR include Portland cement, lime, and fly ash, as well as blends of these materials. Lime kiln dust and other available reactive materials such as fly ash material from the fluidized bed combustion process have been used on a limited basis and are potentially available for use as FDR stabilizing materials. Chemical stabilizing additives can be applied in either dry or slurry form ahead of the

reclaimer. The stabilizing additive can also be introduced into the mixing chamber of the reclaimer through a spray bar, when applied in a slurry form.

The strength gain resulting from the addition of chemical additives is largely dependant upon the type of reclaimed material and the type and amount of stabilizers used. The stabilizer type and content should be determined through laboratory testing. In general, an increase in the amount of chemical stabilizer increases strength. However, an excessive amount of stabilizer could result in brittleness and crack susceptibility of final product. If the reclaimed layer is too stiff, the fatigue life of the pavement will be reduced

### **1.5 Other Stabilization Methods**

Additional stabilizing additives include calcium chloride and magnesium chloride, resulting in some strength gain from particle cementing. The introduction of calcium or magnesium chloride has the effect of lowering the freezing temperature of the reclaimed material, helping to reduce the damaging effects of cyclic freeze-thaw. Stabilization using calcium chloride has two advantages over pulverization; improved compactability and improved resistance to frost damage are improved. Both of these materials use the same construction techniques previously described.

Calcium chloride should generally be applied using a minimum 35% solution at a rate of 0.45-0.68 l/m<sup>2</sup> (0.1-0.15 gallons/ square yard) for each 25 mm of depth reclaimed.

## **2. EVALUATION AND ASSESSMENT OF THE ROADWAY**

As with other pavement treatments, it is important that sufficient information about the existing road or pavement materials be in hand when attempting to determine if FDR is a suitable rehabilitation strategy and/or to design a successful FDR project. Initial evaluation and assessment of the existing pavement condition will require conducting the following steps:

- Determination of traffic level (ADT Count)
- Survey of pavement condition
- In-situ testing
- Sampling

### **2.1 Traffic Level**

Traffic loading in general is the primary mechanism of pavement failure. Therefore, it is important to obtain a reliable estimate of future traffic on the road after FDR is carried out and the road has been constructed. FDR may be applicable for a variety of traffic levels. However, the overall pavement design, including FDR, must be consistent with standard pavement design traffic analysis procedures as described in PennDOT Publication 242.

## **2.2 Survey Pavement Condition Regarding Distresses**

It is important to have a recent pavement condition survey. This is typically carried out by following the criteria provided in PennDOT Publication 336. Alternatively, other distress procedures such as those defined in MicroPaver™ or a similar distress evaluation procedure may be used for municipal projects.

The distress survey provides not only information about the present condition of the pavement at the time of survey, but also insight into the causes of visible distresses. It is always important to understand the mechanisms responsible for existing pavement damage, in order to prevent the same damage mechanisms from causing failure of the rehabilitated pavement.

Upon completion of the distress survey, a summary report should be provided to document the level of distresses and corresponding observations. The severity of rutting, cracking, raveling, pot holes, and drainage issues should be specifically noted.

## **2.3 In-Situ Testing**

Beyond visual survey of pavement condition, it is important to assess the in-situ strength of the unbound material, specifically the subgrade on which the rehabilitated pavement will be residing. Two tests are proposed for this purpose: the dynamic cone penetrometer (DCP) and the light weight deflectometer (LWD). In addition, a falling weight deflectometer (FWD) could be used before and after construction to determine pavement strength.

### ***2.3.1 Falling Weight Deflectometer (FWD)***

Pavement deflection testing provides additional insight into the load carrying response of a pavement layer system. First, the magnitude of deflection responses provides a relative indication of the strength of the total pavement system. In addition, FWD testing is a quick way to obtain useful information about the uniformity, or lack thereof, along the length or across the cross section of a roadway. An understanding of the uniformity of the existing pavement is vital to successfully designing a FDR project.

The pavement deflection response data also provides a useful means of determining in-situ material properties of the various layers within the pavement system. This information is important for design, particularly when mechanistic design methods are used.

One significant benefit of FWD testing is the portability and speed of testing. While some form of traffic control is usually needed when testing an active roadway, the operation can usually be set up as a moving one, minimizing the impact on the traveling public.

### ***2.3.2 Dynamic Cone Penetrometer (DCP)***

The DCP is a simple device for rapid measurement of the in-situ strength of unbound materials. The reference mark is first established once the cone is set to rest on the level flat soil. The DCP is held vertically at the test point and the 17.6 lb (8 Kg) hammer is repeatedly raised and

dropped onto the coupling for a drop distance of 22.6 inches (575 mm). As the 20-mm wide 60° angled cone penetrates into the soil, the number of blows and the penetration depth are recorded. The number of DCP blows per inch or per mm (i.e., Penetration Rate) or the rate of penetration DCPI (inches/blow or mm/blow) are correlated with other strength parameters such as California Bearing Ratio (CBR) or resilient modulus.

### ***2.3.3 Light Weight Deflectometer (LWD)***

The LWD is another simple tool to determine in-situ characteristics of the unbound material, specifically the subgrade soil. The 22 lb (10 kg) drop hammer delivers energy to deflect the subgrade under the load plate. Drop weight can be extended to 66 pounds (30 Kg) and the drop height could be as high as 33.5 inches (850 mm). The load plate is flat and circular with a diameter of 100-mm or 300-mm. The induced deflection is used by the built-in software to determine the material stiffness or modulus. The resulting modulus is correlated with other strength parameters such as CBR or DCP. The unique advantage of LWD is that it provides an engineering characteristic (modulus) of the in-situ material through a simple fast approach.

## **2.4 Sampling**

Proper sampling plays a vital role in design and construction of FDR. The following criteria must be considered when obtaining samples from the FDR candidate roadway.

- Number of samples and locations of sampling
- Amount of material to be sampled at each location
- Techniques of sampling
- Depth of sampling and identification of layer thicknesses
- Handling and evaluation

### ***2.4.1 Number of Samples and Locations of Sampling***

The number of samples to be obtained for the project depends on the project size (the project length and the number of lanes in the road section to be reconstructed), the level of subgrade/subbase non-uniformity, and the amount of material needed for laboratory testing. Longer project lengths, and high within project variability, require a larger number of road samples. In general, samples should be obtained at 500-ft intervals per lane but under no circumstances fewer than three samples per lane should be obtained for a project. For FDR projects extending longer than one mile, if uniform conditions are observed, sampling could be reduced to one per mile.

It is best that the sampling locations be selected randomly and without bias to achieve a representative composition of the road section under consideration. If a fixed interval sampling plan is proposed, the reasoning must be explained and be justified. An example of fixed interval sampling is establishing the first location and from there sampling every 1000 ft, or divide the total length by the number of samples and fix the distance between sampling locations. Samples from highly distressed localized areas may not be representative of the whole road section and should be kept separate from other samples. PTM Number 1 should be followed to determine

random sample locations. The location of samples needs to be carefully recorded. Specifically, it should be noted whether the samples are from wheelpath or from non-wheelpath areas.

#### ***2.4.2 Material Sample Size***

Sufficient material must be obtained to conduct the necessary laboratory tests. The amount of material needed must be estimated based on the testing required for initial laboratory work, as well as the follow-up mix design stage. Typically, a test pit provides a large portion of the material needed, but caution should be taken to ensure this material properly represents the job site material. It is desirable to obtain a minimum of 100 pounds of material from each sample location to conduct the lab tests needed for evaluation and design.

#### ***2.4.3 Sampling Techniques***

The objective of the sampling plan is to ensure that the sampled materials are as nearly as possible representative of the material which will be later pulverized during construction. Hence, the reclaimed material should be pulverized in the laboratory to get as close as possible to what will be produced through the reclamation process.

If sampling through field pulverization is not possible, standard borings and test pits should be utilized. The asphalt layer can be cored, saw cut, or removed using hand tools such as picks and shovels. This material is later broken down to finer sizes through laboratory oven heating and hand manipulation. The subbase/subgrade material can be sampled through a 4-inch auger drill.

At least one sample should be taken from a test pit. The test pit could be excavated at the shoulder or on the road. The pit should be at least 3 ft by 5 ft, with the depth of excavation being 1.5 times the depth of pulverization. As the material gets excavated, it should be maintained in an orderly fashion to facilitate logging of the material. Photographs of test pits can also be very helpful to document findings, and should be used as necessary.

All borings and test pit excavations shall be properly backfilled upon completion.

#### ***2.4.4 Depth of Sampling and Identification of Layers***

Samples should be obtained from all layers expected to be reclaimed (asphalt, base, and possibly subgrade). The depth of sampling for both standard borings and test pits should be 1.5 times the depth of pulverization. It is best if the material from different layers is kept separate, with the goal of having them blended in the lab, especially if the depth of reclamation is not known.

#### ***2.4.5 Handling and Evaluation***

Each sample shall be identified with a tag showing: 1) project name, 2) project number, 3) sample type and number, 4) the location or boring from which the sample was obtained, and 5) the depth interval of the sample.

Moisture content samples shall be a minimum of eight ounces, and shall be stored in airtight containers made of either glass or plastic. Each sample shall be identified with a tag stating: 1) project name, 2) project number, 3) sample type and number, 4) the location or boring from which the sample was obtained, and 5) the depth of the sample. These samples are to be subjected to classification and moisture-density determination.

Description of soil shall include the following as a minimum:

- Textural classification (such as clayey sand, lean clay, silt, etc.)
- Color
- Natural moisture content
- Relative-density for coarse-grained soils
- Consistency for fine-grained soils (liquid limit, plastic limit, shrinkage limit)
- Other descriptive terms relative to identification of the soil and its composition
- AASHTO soil classification

## **2.5 Determine Layer Thicknesses and Drainage Conditions**

The determination of layer thickness and needed drainage improvements are critical to the success of FDR, as with any other well designed pavement alternative. There are three considerations in selecting a FDR layer thickness. One is the composition of the existing pavement and subgrade materials which could be incorporated into the reclaimed layer. The second is the structural requirement for the pavement based on the anticipated traffic and environmental conditions, and the role of the reclaimed layer within the total required pavement cross section. The practicality of using FDR is to some degree determined based on the thickness of the existing pavement and the character and amount of subgrade material which will be incorporated into the reclaimed layer. The third factor is the structural contribution of the reclaimed layer to the new pavement structure. This can be significantly influenced by the type of FDR process, and the resulting material stiffness achieved. The stiffness contribution of the FDR layer can be characterized for design purposes in several forms including structure layer coefficient, resilient modulus, elastic modulus, and California Bearing Ratio.

The construction of a well drained pavement system is vital to the successful performance of all pavements. The presence of excess water within a pavement structure, including the subgrade material, is one of the most damaging conditions for any pavement. Excess moisture can result in several accelerated damage mechanisms which result in the loss of pavement material integrity and weakening of the pavement structural capacity. Therefore, it is important that any existing drainage problems be identified and corrected prior to constructing the reclaimed pavement layer. Wet subgrade locations should be identified and effective drainage installed before FDR is undertaken. Other water related damage within the existing pavement layers should be evaluated to determine the source of water, and the problem corrected before reclaiming.

## 2.6 Evaluate Applicability of FDR

This section discusses the evaluation steps to determine the suitability of FDR for use on a road. Table 1 provides an indication of when FDR is a suitable rehabilitation strategy, based on pavement surface distresses present. This procedure is the first step in the FDR decision making process. In general, FDR is indicated for use in situations where the problem is not limited to the immediate surface layer. Other strategies are likely to be more effective in that case.

Table 1. Selection of FDR

<b>Pavement Distress</b>	<b>FDR</b>
<b>Surface Defects</b> <ul style="list-style-type: none"> <li>• Raveling</li> <li>• Flushing</li> <li>• Slipperiness</li> </ul>	
<b>Deformation</b> <ul style="list-style-type: none"> <li>• Corrugations</li> <li>• Ruts-shallow</li> <li>• Rutting Deep<sup>1</sup></li> </ul>	X <sup>2,3</sup>
<b>Cracking (Load Associated)</b> <ul style="list-style-type: none"> <li>• Alligator</li> <li>• Longitudinal</li> <li>• Wheel Path</li> <li>• Pavement Edge</li> <li>• Slippage</li> </ul>	X X X
<b>Cracking (Non-Load Associated)</b> <ul style="list-style-type: none"> <li>• Block (Shrinkage)</li> <li>• Longitudinal (Joint)</li> <li>• Transverse (Thermal)</li> <li>• Reflection</li> </ul>	X X X
<b>Maintenance Patching</b> <ul style="list-style-type: none"> <li>• Spray</li> <li>• Skin</li> <li>• Pothole</li> <li>• Deep Hot Mix</li> </ul>	X <sup>4</sup> X <sup>4</sup> X X
<b>Weak Base or Subgrade</b>	X
<b>Ride Quality/Roughness</b> <ul style="list-style-type: none"> <li>• General Unevenness</li> <li>• Depressions (Settlement)</li> <li>• High Spots (Heaving)</li> </ul>	X <sup>5</sup> X <sup>6</sup>
<sup>1</sup> Rutting originating from the lower portion of the pavement (below surface course and includes base and subgrade). <sup>2</sup> The addition of new aggregate may be required for unstable mixes. <sup>3</sup> The chemical stabilization of the subgrade may be required if the soil is soft, wet. <sup>4</sup> In some instances, spray and skin patches may be removed by cold planning prior to these treatments (considered if very asphalt rich, bleeding). <sup>5</sup> Used if depressions due to a poor subgrade condition. <sup>6</sup> Used if high spots caused by frost heave or swelling of an expansive subgrade soil.	

### 2.6.1 Characterization of the composition of the roadway and selection of the stabilization technique

Using the samples collected from the roadway prism, they should be characterized for the physical and mechanical characteristics referenced in Table 2.

Table 2. Minimum Soil Testing Methods

Moisture Content	AASHTO T265
Sieve Analysis	PTM 616
Mechanical and Hydrometer Particle Size Analysis of Soils	AASHTO T88
Liquid Limit, Plastic Limit	AASHTO T89
Moisture Density Relationship	PTM 106
Unconfined Compressive Strength	AASHTO T208
Materials Finer Than No. 200 Sieve	PTM 100

The results of these characterization methods should be used in conjunction with Table 3 to select the appropriate stabilization approach based on soil classification type, and also based on the percent of material passing the No. 200 sieve, plasticity index, and liquid limit.

Table 3. Correlation of stabilization additive as a function of soil type, percent passing No. 200 sieve, and plastic index

Percent Passing No.200	Plastic Index	Stabilizer	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
<12	<6	Calcium Chloride													
<25	<6	Bituminous													
	<10	Cement													
	>10	Lime													
>25	<10	Cement													
	10-30	Lime													
	>30	Lime+cement													

Combinations of stabilization additives may also be cost effective under some circumstances. For example, partial replacement of cement with a flyash material could result in a better material at a lower cost. If cement content is too high, shrinkage cracking may develop. Partial cement replacement with flyash can eliminate this problem. If Class F flyash is used, a small amount of activator, typically hydrated lime or calcium chloride, must be combined with the flyash. Fluidized bed combustion flyash, not meeting AASHTO M295 has been found to produce a useful blend with cement.

Small contents of hydrated lime or cement, typically 1.5 and 1.0 percent by weight respectively can produce higher early strength and resistance to moisture damage when added to bituminous stabilization.

Hydrated lime or quicklime can be slaked by spreading the material and spraying it with water prior to mixing, or special mixing trucks can be used to prepare a hydrated lime slurry for use in reclamation.

The use of calcium chloride as the stabilizing additive can facilitate compaction and improve strength relative to untreated aggregate.

### ***2.6.2 Lab Evaluation***

The laboratory evaluation of the existing road materials must include the combined gradation of the material planned for inclusion in the reclaimed layer. During the mix design development, trial configurations of the combined FDR materials will be reviewed for further mix testing. Specific trial batch testing of the proposed FDR materials is to some degree dependant upon the stabilization process being considered.

### ***2.6.3 Select Appropriate FDR Based on Findings***

Based on the results of work conducted in the previous sections, a determination should be made of the specific FDR process that is suitable for the specific roadway. If more than one possible solution is available, other factors such as the desirability of individual processes for the project and potential cost/benefit of the entire roadway treatment including surfacing should be considered.

## **3. DESIGN**

The design requirements for FDR are somewhat unique to the stabilization process selected for use. Therefore, each is discussed below with attention to specific related details. The general procedure for all types of FDR involves a determination of the strength potential of the reclaimed material. This is typically measured using unconfined compressive strength, or indirect tensile strength in the case of bituminous stabilization. Strengths are typically measured following seven days of curing. For all types of reclamation except pulverization stabilization, the gradation of the combined materials of the final mix must be evaluated, as well as the additive types and contents at the optimum moisture content to achieve the required strength. Specific procedures and strength requirements for the various reclamation types are discussed in the following sections. The following standard test procedures apply to this general procedure.

AASHTO T011-05	Standard Method of Test for Materials Finer than 75- $\mu$ m (No. 200) Sieve in Mineral Aggregates by Washing
AASHTO T027-06	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates
AASHTO T176-08	Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
PTM 106 (AASHTO T180-10)	The Moisture-Density Relations of Soils (using a 2.5 kg (5.5 lb) Rammer and a 305 mm (12 in.) Drop)

### **3.1 Pulverization Stabilization**

Since only the in-place materials are being reclaimed, if only pulverization, shaping, and compaction are to be performed, the mix design process should assess the strength potential of these materials when re-compacted at optimum moisture content.

### **3.2 Mechanical Stabilization**

This process entails the incorporation of aggregate material to improve the gradation of the pulverized road materials. In this case, the mix design will evaluate the incorporation of the appropriate amount and size of aggregate material to achieve the desired gradation and reclaimed strength.

### **3.3 Chemical Stabilization**

Develop appropriate trial mix designs incorporating the in-situ materials, any aggregate for gradation adjustment, and appropriate chemical stabilization materials.

#### ***3.3.1 Mix Design***

Remove samples of RAP and RAM to the specified depth and perform appropriate testing to establish mix design. Submit mix design and work plan to the District Materials Engineer/District Materials Manager (DME/DMM) for approval one week before the planned start of work. Provide an approved mix design and work plan to the Municipality five (5) working days before the planned start of work. Approval of the mix design by the DME/DMM is solely for monitoring quality control and in no way releases the Contractor from his responsibilities.

#### ***3.3.2 Mix Design Development***

Samples must be obtained inclusive of the depth to be recycled. Sampled materials must be properly processed and prepared 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 DME/DMM.

### **3.3.3 Strength Requirements**

- Cement – Make, cure, and test three unconfined compressive strength specimens of FDR material and cement in accordance with ASTM 1633, method A. Wrap the specimens in plastic wrap, seal in an airtight, moisture proof bag and cure the test specimens for a period of 7 days. For the final mix design, the required amount of cement will be that which provides an average unconfined compressive strength of the three specimens of: A minimum unconfined compression value of 1,379 kPa (200 psi) in 7 days and a maximum unconfined compression value of 3447 kPa (500 psi) in 7 days for roads that are designed with a minimum of 75 mm (3 inch) pavement overlay. A minimum unconfined value of 2068 kPa (300 psi) in 7 days and a maximum unconfined compression value of 3447 kPa (500 psi) in 7 days is required for roads that are to be surface treated or overlaid with less than 75 mm (3 inches) of pavement.
- Lime/Fly Ash (L/FA), Lime Pozzolan and combinations thereof – Make, cure, and test three unconfined compressive strength specimens of FDR material and L/FA or Lime Pozzolan in accordance with ASTM 5203, procedure B. Wrap the specimens in plastic wrap, seal in an airtight, moisture proof bag and cure the test specimens for a period of 7 days at 40°C (104°F) before testing. For the final mix design, the required amount of L/FA or Lime Pozzolan will be that which provides an average unconfined compressive strength of the three specimens of at least 1,379 kPa (200 psi).
- Mixture – Combine the reclaimed material, aggregates (if necessary), stabilizing additive(s), and water according to the mix design and at the mix design recommended moisture content. If conditions change make field adjustments as recommended in the design under the guidance of the Inspector and Qualified Technical Representative to obtain a satisfactory stabilized base bourse.

### **3.4 Calcium Chloride Stabilization**

Similar to pulverization or mechanical stabilization, this process includes evaluation of the addition of calcium chloride to the material.

### **3.5 Asphalt Emulsion Stabilization**

#### **3.5.1 Mix Design**

Remove samples of RAP and RAM to the specified depth and perform appropriate testing to establish mix design. To determine the appropriate or Optimum Moisture Content (OMC) and corresponding Maximum Dry Density (MDD) use ASTM D698. Submit mix design to the District Materials Engineer/District Materials Manager (DME/DMM) for approval two weeks before the planned start of work. Provide an approved mix design and work plan to the Municipality five (5) working days before the planned start of work. Approval of the mix design

by the DME/DMM is solely for monitoring quality control and in no way releases the Contractor from his responsibilities.

### **3.5.2 Mix Design Development**

Core samples will be obtained inclusive of the depth to be recycled. Sampled materials must be properly processed and prepared to closely simulate field conditions. A Qualified Technical Representative shall analyze the samples and provide the following information as part of the mix design to the DME/DMM.

### **3.5.3 Referenced Documents**

Test Designation	Title
AASHTO T059-09	Standard Method of Test for Emulsified Asphalts
AASHTO M320-10	Standard Specification for Performance-Graded Asphalt Binder
AASHTO T011-05	Standard Method of Test for Materials Finer than 75- $\mu\text{m}$ (No. 200) Sieve in Mineral Aggregates by Washing
AASHTO T027-06	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates
AASHTO T176-08	Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
AASHTO T209-10	Standard Method of Test for Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt (HMA)
AASHTO T166-10	Standard Method of Test for Bulk Specific Gravity of Compacted Hot Mix Asphalt (HMA) Using Saturated Surface-Dry Specimens
AASHTO T283-07	Standard Method of Test for Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage
PTM 106 (AASHTO T180-10)	The Moisture-Density Relations of Soils (using a 2.5 kg (5.5 lb) Rammer and a 305 mm (12 in.) Drop)
ASTM D558-04	Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures

### **3.5.4 Apparatus**

In the design process, use a calibrated gyratory compactor, indirect tensile tester, balance, oven, and other equipment.

### **3.5.5 Procedure**

**3.5.5.1 Check Suitability of FDR Design Using Emulsion.** Design using emulsion is applicable for cases where reclaimed material is not excessively fine grained. Specifically, the amount of material passing the No. 200 sieve must not exceed 20% and plasticity index must not exceed 10. Design suitability should be checked based on the guide provided in Table 2.2.

3.5.5.2 Asphalt Emulsion Selection. Select a PennDOT approved asphalt emulsion with minimum residue of 63% when tested according to AASHTO T59. The residue should meet AASHTO M320 requirements for PG 58-22 or PG 58-28.

3.5.5.3 Requirements of the Reclaimed Material. The existing pavement or any recycled asphalt pavement (RAP) material shall be crushed to meet the maximum size requirement. All materials larger than 2 inches in size shall be removed before further processing. The materials will be blended in the proportions that are representative of the project depth and cross section. The gradation of the composite (blended) reclaimed material shall be determined in accordance with AASHTO T11 and T27. If the gradation is deficient, mechanical stabilization should be applied before emulsion application. Mechanical stabilization includes incorporation of virgin aggregate to the extent needed to satisfy gradation requirements. The final gradation shall meet the gradation criteria presented in Table 4.

Table 4. Gradation Requirements

<b>Sieve Size</b>	<b>Percent Passing</b>
2 inches	100
1.75 inches	95-100
0.75 inches	80-90
No. 4	30-60
No. 200	0-20

The sand equivalent (SE) test shall be performed and reported in accordance with AASHTO T176. SE is from the combined materials. SE should not be less than 30%.

3.5.5.4 Selection of Water Content for Design. A modified Proctor compaction shall be conducted in accordance with PTM 106 (AASHTO T-180, ASTM D558) to determine the optimum moisture content (OMC) at peak dry density. Material containing 20% or more passing No. 200 shall be mixed with target moisture, sealed, and set aside a minimum of 12 hours. All other material shall be set aside a minimum of three hours. If a material contains a significant amount of RAP or coarse material and does not produce a well defined moisture-density curve, then the moisture content shall be fixed at 3%. If a material contains less than 4% passing No. 200 or if no peak develops with the OMC curve, then fix the moisture content between 2% and 3%.

3.5.5.5 Preparation of Test Specimens. Sufficient samples shall be taken before the addition of water and emulsion to produce at least  $95 \pm 5$  mm height and 150 mm diameter compacted specimens. Specimens shall be mixed with the required amount of water for 60 seconds before addition of the asphalt emulsion. These specimens shall be allowed to sit sealed as specified in Section 3.5.5.4. Four emulsion contents shall be selected. Note: Four emulsion contents of 3%, 4%, 5% and 6% by weight of total mix are typically used, but other ranges or narrower bands (0.5%) can be selected. Number of specimens shall be produced for each test method in the laboratory at each emulsion content according to Table 5.

Table 5. Required Number of Laboratory Prepared Specimens

Test	No. of Specimens Per Emulsion Content	Specimen Status
Max. Theoretical Sp. Gr.	2	Loose
Indirect Tensile Strength, AASHTO T 283	6	Compacted

- Mixing – Aggregate material and emulsion shall be mixed in a mechanical mixer at a temperature of 20°C to 26°C for 60 seconds.
- Curing – Specimens after mixing shall be cured individually at 40° C for 27 to 33 minutes.
- Other Additives – If other materials are added, such as lime or cement, then they shall be introduced in a similar manner as they will be on the project. For example, if lime is incorporated a day or more before emulsion addition, then it shall be added to the wet aggregate a day or more before mixing with emulsion. If lime is incorporated as a slurry, then it shall be incorporated as a slurry in the laboratory.

Note: In some cases, adding 1% lime or cement would be desirable before adding emulsion. Whether lime or cement should be added depends on plasticity index and percent material passing No. 200 sieve.

3.5.5.6 Compaction. Specimens shall be compacted in a gyratory compactor satisfying requirements outlined in PennDOT Bulletin 27. Thirty gyrations shall be applied at a temperature of 20°C to 26°C. After the last gyration, 600 kPa pressure shall be applied for 10 seconds. The mold shall not be heated.

- Curing – Specimens shall be cured for 48 hours at room temperature.

3.5.5.7 Volumetric Measurements.

- Gmm – Determine the Maximum Specific Gravity at each emulsion content in accordance with AASHTO T209 and modified requirements outlined in PennDOT Bulletin 27.
- Gmb – Determine the Bulk Specific Gravity of all compacted specimens at each emulsion content using AASHTO T166.

3.5.5.8 Indirect Tensile Strength and Moisture Susceptibility. The six prepared specimens at each emulsion content shall be tested according to AASHTO T 283.

3.5.5.9 Selection of Emulsion Content. A design emulsion content shall be selected to produce a FDR mixture that meets the design criteria in Table 6. If more than one emulsion content produces mixtures which meet the criteria, then select the emulsion content that produces a mixture with the highest indirect tensile strength.

Table 6. Design Criteria

Properties	Criteria
Air Voids	6-8%
Indirect Tensile Strength of Control Specimens, min.	50 psi
Indirect Tensile Strength Ratio, min.	0.7

### 3.5.6 Report

The report for the JMF shall provide the following information:

Physical address of the road and project information.

Performance Grade of the emulsion residue used in the mix design.

General description of the materials received, their locations, and sampling procedure.

Average thickness of hot mix asphalt.

Thickness of different layers to be reclaimed.

Density and optimum moisture content from Proctor compaction.

Moisture content used in mix design.

Indirect tensile strength.

Level of saturation and conditioned indirect tensile strength.

### 3.6 Foamed Asphalt Stabilization

The mix design development process for the foamed asphalt process is somewhat similar to that described above for the emulsion stabilized material. The most significant difference is the use of foamed asphalt in lieu of the emulsified asphalt. The mix design process is generally described below.

- Select an asphalt binder for use in the project such as PG 64-22, PG 58-22, or PG 58-28.
- Prepare the existing roadbed material, and other materials to be incorporated (i.e., aggregates, RAP, etc).
- Determine the gradation of the reclaimed material, approximating field processing as nearly as possible.
- Determine optimum water content for foaming. This is achieved through foaming at moisture contents between 1 and 3 percent at 0.5% increments. For each water content, expansion ratio i.e. ratio of maximum expanded volume to the original asphalt volume, is determined. This could be achieved by the aid of a graduated dipstick. Similarly, the half-life is determined. Half life is defined as the time it takes for the volume to decrease from the maximum to half of the maximum. The intersection of lines for expansion ratio and half life on the x-y axes provides the optimum foaming water content.
- Determine the optimum moisture content using the standard Proctor method (AASHTO T99) or modified Proctor method (AASHTO T 180).
- Blend the RAP, cement (typically 1 to 1.5%), and water (85% of optimum moisture content) and mix uniformly.

- Add foamed asphalt to the mix and develop trial mixes at a range of asphalt contents, typically 2-3.5% in 0.5% increments. Develop no less than four trial batches at different binder contents.
- Compact the trial batches into 4 or 6 inch specimens using a gyratory compactor.
- Cure the specimens for three days at 40C.
- Let the specimens cool and measure bulk specific gravity.
- Measure indirect tensile strength using ASTM D 6931.
- Report results indicating asphalt content, air voids, and IDT values.

## **4. CONSTRUCTION**

The overall construction sequence for FDR is the same for all processes. The generic description of the work is included under the Pulverization Stabilization category. It is not repeated for each individual process. However, details specific to each individual process are included in the section addressing that specific process.

### **4.1 Pulverization Stabilization**

#### ***4.1.1 Description***

This work consists of the in-place pulverization and uniform blending of existing roadway surface materials and a predetermined thickness of underlying material creating a homogenous mixture of reclaimed base material. The work also consists of shaping, finishing, fine grading, and compaction of the reclaimed base material.

#### ***4.1.2 Material***

**4.1.2.1 Reclaimed Material.** 95% of the pulverized surface material is required to pass through a 50 mm (2 inch) sieve. Incorporate all reclaimed material into the base.

- Reclaimed Aggregate Material (RAM) – In-situ aggregate material which is incorporated in the base.
- Reclaimed Asphalt Pavement (RAP) – Processed paving material containing asphalt cement and aggregates.

**4.1.2.2 Composition of Mixture.** Remove samples of RAP and RAM to the specified depth and perform the appropriate testing to determine the appropriate or Optimum Moisture Content (OMC) and corresponding Maximum Dry Density (MDD) according to ASTM D698. Submit the results to the District Materials Engineer/District Materials Manager (DME/DMM) for approval at least two weeks before commencement of work on the project. Provide the work plan to the Municipality five (5) working days before the start of work. Approval of the results by the DME/DMM is solely for monitoring and quality control and in no way releases the Contractor from his responsibilities.

#### ***4.1.3 Construction***

Use equipment that produces the completed reclaimed base as follows:

4.1.3.1 Equipment.

- Maintain all equipment in a satisfactory operating condition as specified in Publication 408, Section 108.05(c).
- Reclaimer – Use a self-propelled rotary reclaimer or equivalent machine capable of cutting through existing roadway materials to depths of up to 406 mm (16 inches) with one pass. Provide equipment capable of pulverizing the existing pavement, base, and subgrade at a minimum width of 2.44 m (8 ft). The cutting drum must have the ability to operate at various speeds (rpm), independent of the machine’s forward travel speed, in order to control oversized material and gradation. Use a machine equipped with a computerized integral liquid proportioning system capable of regulating and monitoring the water application rate relative to the depth of cut, width of cut, and travel speed. Have the water pump on the machine connected by a hose to the supply tanker/distributor, and mechanically or electronically interlocked with the forward movement/ground speed of the machine. Mount the spray bar to allow the water to be injected directly into the cutting drum/mixing chamber. Provide equipment capable of mixing water and the pulverized pavement materials into a homogenous mixture. Keep the cutting drum fully maintained and in good condition at all times throughout the project. Equipment such as road planers or cold-milling machines designed to mill or shred the existing roadway materials rather than crush or fracture it is not allowed.
- Placement Equipment – Motor grader or by another method approved by the Inspector.
- Compaction Equipment – Vibratory padfoot roller 23,500 Kg centrifugal force (52,000-pounds centrifugal force) or Pneumatic Tire Roller 22 Tonne (25 Ton) for breakdown compaction. Single or Tandem steel drum (static) roller 11-13 Tonne (12-14 Ton) for finish rolling.

4.1.3.2 Weather Limitations. Do not place paving mixtures from November 1 to March 31 unless allowed in writing by the District Executive. Do not place mixtures when surfaces are wet or when the air or surface temperature is 4°C (40°F) or lower.

<b>Type of Stabilizer</b>	<b>Climatic Limitation for Construction</b>
Lime, Fly Ash or Lime-Fly Ash	Do not perform work when reclaimed material could be frozen. Air temperature in the shade should be no less than 4°C (39°F) and rising. Complete stabilization at least one month before the first hard freeze. Two weeks minimum of warm to hot weather is desirable after completing the stabilization work.
Cement or Cement Fly-Ash	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 4°C (39°F) and rising. Complete stabilization should be at least one

	month before the first hard freeze.
Asphalt Emulsion	Do not perform work when reclaimed material could be frozen. Air temperature in the shade should be no less than 15°C (59°F) and rising. Asphalt emulsion stabilization should not be performed if foggy or when other high humidity conditions (humidity >80%). Warm to hot dry weather is preferred for all types of asphalt stabilization involving cold mixtures because of improved binder dispersion and curing.
Calcium Chloride	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 4°C (39°F) and rising. Complete stabilization should be at least one month before the first hard freeze.

4.1.3.3 General. FDR consists of a series of steps that include pulverization and mixing of the existing roadway surface between 125 and 406 mm (5 - 16 inches) in depth with the aggregate base. The motor grader is used to move and place the reclaimed material to the desired longitudinal grade and cross-slope.

4.1.3.4 Compaction. Shape, grade, and compact to the lines, grades, and depth shown on the plans and cross sections. Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. When material is too coarse (more than 20% retained on the 19 mm (¾ inch) sieve and less than 35% passing the 75µm (Number 200) sieve, or more than 30% retained on the 19 mm (¾ inch) sieve) to use these methods, compaction will be determined on non-movement of material under compaction equipment specified in Publication 408, Section 210.3(a). Compact until pulverized material does not rut under a loaded tri-axle (GVW 34 tonne (75,000 pounds)).

4.1.3.5 Finishing. Complete all portions of the pulverization during daylight hours, unless otherwise allowed.

4.1.3.6 Protection. Protect any finished portion of the reclaimed base upon which any construction equipment is required to travel to prevent marring, distortion, or damage of any kind. Immediately and satisfactorily correct any such damage.

4.1.3.7 Surface Tolerance. When directed by the Inspector, test the completed base for smoothness and accuracy of grade, both transversely and longitudinally, using suitable templates and straightedges. Satisfactorily correct any 2500 m<sup>2</sup> (3000 square yard) area where the average surface irregularity exceeds 13 mm (½ inch) under a template or straightedge, based on a minimum of at least three measurements.

## **4.2 Mechanical Stabilization**

### ***4.2.1 Description***

This work consists of the incorporation of imported granular materials during the pulverization or mixing pass of a FDR project. Provide reclaimed base course manufactured by in-place pulverizing and uniform blending of the existing roadway surface material and any underlying granular material, thus creating a homogenous mixture of reclaimed base material. The work also consists of shaping, finishing, fine grading, and compaction of the reclaimed base material.

### ***4.2.2 Material***

4.2.2.1 Aggregate. Publication 408, Section 703.2. (Type A), No. 8, 10, 57, and 67. Add the gradation and quantity to the mix as required to achieve a dense gradation as characterized by the Fuller Power Curve.

### ***4.2.3 Construction***

4.2.3.1 General. FDR consists of a series of steps that include pulverization and mixing of the existing roadway surface between 125 and 406 mm (5-16 inches) in depth with the aggregate base. Mechanical stabilizers can be spread either ahead of the pulverization pass or incorporated into a blending pass after pre-pulverization and shaping. The motor grader is used to move and place the reclaimed material to the desired longitudinal grade and cross-slope.

4.2.3.2 Compaction. Shape, grade, and compact to the lines, grades, and depth shown on the plans and cross sections after the material has been processed. Maintain material to within  $\pm 3\%$  of the optimum moisture content at the time of compaction. Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. Determine in-place density requirements by the construction of at least one control strip under the guidance of a nuclear gauge operator. After each pass of the compaction equipment take a nuclear density reading in accordance with PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of 10 tests at random locations to determine the average in-place density of the control strip. Record and provide the results to the Municipality. Compact the mechanically stabilized base to a target density of at least 98% of the density requirements of the control strip. Determine the in-place density in accordance with PTM No. 402 for each 2500 m<sup>2</sup> (3000 square yard) area. If the density of an area is less than the minimum density, but the base course is uniform in texture, stable and otherwise acceptable, try additional compaction. If additional compaction does not achieve the minimum density, complete an additional control strip in order to verify that proper density is being obtained. Take a minimum of five tests at random locations to determine the average in-place density of the control strip. The new minimum density is 98% of the average in-place density from the control strip.

## **4.3 Chemical Stabilization**

### **4.3.1 Description**

This work consists of pulverizing and mixing a combination of virgin aggregate (if/where specified), reclaimed asphalt pavement, reclaimed aggregate material, and subgrade material to the specified length, width, and depth. Once pulverized, add the chemical stabilizing additives as per Project Mix Design, and mix the materials together to create a chemically stabilized base course. This work also consists of shaping, finishing, fine grading, and compaction of the reclaimed base material.

### **4.3.2 Material**

#### **4.3.2.1 Stabilizing Agent.**

- Cement – Publication 408, Section 701 (3 to 8% by weight)
- \*Hydrated Lime – Publication 408, Section 723 (2 to 6% by weight)
- \*Fly Ash – Publication 408, Section 724.2(a) (6 to 14% by weight)
- Lime pozzolan – Publication 408, Section 725 (6 to 8% by weight)

\* Hydrated Lime or Fly Ash will not be used as a singular additive but will be used as a combination of the two. This combination shall be referred to as Lime/Fly Ash (L/FA).

### **4.3.3 Construction**

**4.3.3.1 Equipment.** Use equipment that will produce the completed chemical stabilized base as follows:

- Use equipment capable of automatically metering liquids with a variation of not more than  $\pm 2\%$  by mass (weight) of liquids. Calibrate before use.

**4.3.3.2 Pulverization/Shaping.** Before the application of any stabilizing additives, pulverize the roadway materials to the depth specified by the project mix design. Shape to within 18mm (3/4 inch) of irregularity to the lines, grades, and/or cross-slope of the proposed roadway and compact until no further densification is achieved. Water will be added to the pulverized material to adjust the moisture content to at least Optimum Moisture Content (OMC), but no more than  $\pm 3\%$  over OMC. Addition of this water can be done through the machines liquid additive system and/or through top watering. After acceptance by the DME/DMM the additive spreading and mixing will be done as described below.

#### *Additive Application*

- Cement, Lime/Fly Ash (L/FA), Lime Pozzolan and combinations thereof – Upon completion of the pulverization pass the stabilizing additives previously outlined will be applied at the rate established by the DME/SMM approved project mix design. The additive will be accurately and uniformly spread on the pulverized pavement by using an adjustable rate auger/vane type dry additive distributor. The contractor will provide a 0.37m<sup>2</sup> (2 square foot) of canvas and scale to check the application rate of the spreader. Control the

application of dry materials to the roadway to prevent an objectionable level of fugitive dust. Dry additive will not be applied when the wind conditions, in the opinion of the site Inspector, are such that blowing additives become objectionable to traffic or adjacent property owners. Manual and/or gravity (tail gate) spreading of the additives is unacceptable.

- Lime or Cement Slurry – If slurries are to be used, the distributor and tanker trucks will be equipped with a recirculating pump and/or agitation system to prevent settling of the materials before application.
- Compaction – Shape, grade, and compact to the lines, grades, and depth shown on the plans and cross sections after the material has been processed. The moisture content before compaction must be at or no more than 3% over OMC. Allow the mixture to cure as necessary before rolling. Commence rolling at the low side of the course. Leave 80 to 150mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. Determine the in-place density requirements by the construction of at least one control strip under the guidance of a nuclear gauge operator. After each pass of the compaction equipment take a nuclear density reading in accordance with PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of 10 tests at random locations to determine the average in-place density of the control strip. Record and provide results to the Municipality. Compact the chemically stabilized base to a target density of at least 98% of the average in-place density of the control strip. Determine the in-place density in accordance with PTM No. 402 for each 2500 m<sup>2</sup> (3000-square yard) area. If the density of an area is less than the minimum density, complete an additional control strip in order to verify that proper density is being obtained. Take a minimum of five tests at random locations to determine the average in-place density of the control strip. The new minimum density is 98% of the average in-place density. If it is determined that the contractor is achieving the minimum density with minimum compactive effort, the Inspector may require a new control strip to verify or establish a new minimum density. If the completed chemically stabilized base is unacceptable for any reason do not continue construction until the cause of the deficiency(ies) is determined and corrected.
- Curing – Allow the chemically stabilized base to cure for at least five days after final compaction has been completed. Protect the surface from drying and apply a bituminous prime coat, or DME/DMM approved equivalent over the entire surface within 24 hours of final compaction of stabilized base. Apply at a rate of 1.9 L/m<sup>2</sup> (0.5 gallon/square yard). Use emulsified asphalt meeting the requirements of Publication 408, Section 461.2(a). Where the surface is utilized for maintaining traffic the application of the bituminous material shall be immediately followed by the application of an approved cover aggregate.

## **4.4 Calcium Chloride Stabilization**

### ***4.4.1 Description***

This work consists of the pulverizing and mixing of a combination of virgin aggregate (if/where specified), reclaimed asphalt pavement, reclaimed aggregate material, and calcium chloride to the specified length, width, and depth. This work also consists of shaping, finishing, fine grading, and compaction of the stabilized base material.

### ***4.4.2 Material***

4.4.2.1 Stabilizing Additive. Calcium Chloride – Publication 408, Section 721. Use a minimum of 35% solution at a rate of 0.45 to 0.68 l/m<sup>2</sup> for every 25 mm of depth, (0.10 to 0.15 gallons/square yard for every inch of depth).

4.4.2.2 Aggregate. Publication 408, Section 703.2 (Type A), No. 8, 10, 57, and 67 – Add the gradation and quantity to the mix as required.

4.4.2.3 Mixture. Combine the reclaimed material, aggregates (if necessary), and calcium chloride, and water according to the mix design and at the mix design recommended moisture content. If conditions change, make field adjustments as recommended in the mix design under the guidance of the Inspector or Qualified Technical Representative to obtain a satisfactory stabilized base course.

### ***4.4.3 Construction***

4.4.3.1 Pulverization/Stabilization/Mixing. Pulverize and mix the roadway material to a minimum depth of 125 mm (5 inches). Thoroughly mix the existing roadway materials together at the design specified treatment depth while surface adding or injecting the design specified amount of calcium chloride to create a homogenous stabilized mixture. Roughly grade to desired cross slope and profile. Apply the designed quantity of calcium chloride and liquid to assure proper compaction.

4.4.3.2 Compaction. Shape, grade, and compact to the lines, grades, and depth shown on the plans and cross sections after the material has been processed. The moisture content before compaction should be not less than the OMC and no more than +3% over Optimum Moisture Content (OMC). Allow the mixture to cure as necessary before rolling. Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. Determine the in-place density requirements by the construction of at least one control strip under the guidance of a nuclear gauge operator. After each pass of the compaction equipment take a nuclear density reading in accordance with PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of 10 tests at random locations to determine the average in-place density of the control strip. Record and provide the results to the Municipality. Compact the calcium chloride stabilized

base to a target density of at least 98% of the average in-place density of the control strip. Determine the in-place density in accordance with PTM No. 402 for each 2,500 m<sup>2</sup> (3,000 square yard) area. If the density of an area is less than the minimum density but the base course is uniform in texture, stable, and otherwise acceptable, try additional compaction. If additional compaction does not achieve the minimum density complete an additional control strip in order to verify that proper density is being obtained. Take a minimum of five tests at random locations to determine the average in-place density of the control strip. The new minimum density is 98 % of the average in-place density. If it is determined that the contractor is achieving the minimum density with minimum compactive effort, the Inspector may require a new control strip to verify or establish a new minimum density. If the completed calcium chloride stabilized base is unacceptable for any reason do not continue construction until the cause of the deficiency (ies) is determined and corrected.

4.4.3.3 Curing. Allow the calcium chloride stabilized base to cure for at least five days after final compaction has been completed. Protect the surface from drying.

## **4.5 Asphalt Emulsion Stabilization**

This work consists of pulverizing and mixing a combination of virgin aggregate (if/where specified), Reclaimed Asphalt Pavement, Reclaimed Aggregate Material, and Subgrade Material to the specified length, width, and depth. Full depth reclamation will consist of pulverization of the existing pavement layers to the specified depth, treatment with an approved stabilizing material and/or approved other materials, and compaction.

### **4.5.1 Description**

Stabilization may be accomplished by bituminous material, cement or other chemical stabilization material, or calcium chloride consistent with recommendations of the FDR Best Practices, and approved in the project mix design.

4.5.1.1 Equipment. Provide the necessary equipment to pulverize, blend, shape, and compact the full depth reclamation materials.

- Reclaimer – Provide a self-propelled, traveling rotary reclaimer or equivalent machine capable of cutting through existing roadway material to depths of up to 406 mm (16 inches) with one pass. The equipment will be capable of pulverizing “In-place” the existing pavement, base and subgrade at a minimum width of 2.44 meters (8 feet), and mixing any added materials to the specified depth. The cutting drum must have the ability to operate at various speeds (rpm), independent of the machines forward speed, in order to control oversized material and gradation.

Use a machine equipped with a computerized integral liquid proportioning system capable of regulating and monitoring the water application rate relative to depth of cut, width of cut, and speed. Have the water pump on the machine connected by a hose to the supply tanker/distributor, and mechanically or electronically interlocked with the forward movement/ground speed of the machine. Mount the spray bar to

allow the water to be injected directly into the cutting drum/mixing chamber. Provide equipment capable of mixing water, dry additives, emulsion, and the pulverized pavement materials into a homogenous mixture. Keep the cutting drum fully maintained and in good condition at all time throughout the project. Equipment such as road planers or cold-milling machines designed to mill or shred the existing roadway materials rather than crush or fracture it is not allowed

- Use equipment capable of automatically metering liquids in the mixture to ensure thorough mixing of the reclaimed materials.
- Maintain all equipment as specified in Section 108.05(c).
- Placement Equipment – Motor Grader or by another method approved by the Engineer.
- Compaction Equipment – Vibratory pad-foot roller 23 (52,000-pounds centrifugal force) or Pneumatic Tire Roller 22 tonne (25 ton) for breakdown compaction. Single or tandem steel drum (static) roller 11-13 tonne (12-14 ton) for finish rolling.

#### 4.5.1.2 Reclamation.

- Pulverization – Before the application of any stabilizing additives pulverize the roadway materials to the depth specified by the project mix design.
- Mixing – Combine the reclaimed material, aggregates (if necessary), stabilizing additive(s), and water according to the mix design and at the mix design recommended moisture content. Maintain adequate liquids in the mixture to ensure thorough mixing of the reclaimed material, aggregates, and stabilizing materials. If conditions change, make field adjustments to obtain a satisfactory FDR material.

If slurries are to be used, the distributor and tanker trucks will be equipped with a recirculating pump and/or agitation system to prevent settling of the materials before application.

- Finishing – Shape the reclaimed material surface to within 18mm ( $\frac{3}{4}$  inch) of irregularity to the lines, grades and/or cross-slope of the proposed roadway.
- Compaction – The moisture content before compaction must be at or no more than 3% over OMC. Allow the mixture to cure as necessary before rolling. Commence rolling at the low side of the course. Leave 80 to 150 mm (3 to 6 inches) from any unsupported edge(s) unrolled initially to prevent distortion. **Determine the in-place density requirements by the construction of at least one control strip under the guidance of a nuclear gauge operator.** After each pass of the compaction equipment take a nuclear density reading in accordance with PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, make a minimum of

ten tests at random locations to determine the average in-place density of the control strip. Record and provide results to the District.

Compact the reclaimed material to a target density of at least 95% of the average in-place density of the control strip. Determine the in-place density in accordance with PTM No. 402 for each 2500 m<sup>2</sup> (3000-square yard) area. If the density of an area is less than the minimum density, but the base course is uniform in texture, stable and otherwise acceptable, try additional compaction. If additional compaction does not achieve the minimum density, complete an additional control strip in order to verify that proper density is being obtained. Take a minimum of ten tests at random locations to determine the average in-place density of the control strip. The new minimum density is 98% of the average in-place density.

- Curing – The emulsion stabilized base must undergo curing before application of the chip seal or overlay. The risk of rutting or moisture damage is increased in case the overlay is applied prematurely and before curing of the base is complete as the moisture is retained for a prolonged time and the rate of strength gain is reduced drastically. The rate of curing depends on many factors. In favorable weather conditions (no rain, sunshine, low humidity, high temperature) curing can take place at a considerably faster rate. Sufficient curing and strength gain could take from two or three days to at least two weeks depending on the type and amount of materials used and the climatic conditions.

The overlay or chip seal should be placed no earlier than 10 days from the date of construction. After 10 days, moisture content of the base must be checked with a nuclear gauge. The measured moisture content should not exceed 1.5% for emulsion stabilized base. Alternatively, if after ten days cores could be taken intact, the base is ready to be overlaid or chip sealed.

- Protection – Protect completed portions of the reclaimed work from damage by construction equipment. Immediately correct any such damage to the satisfaction of the Engineer.
- Surface Tolerance – When directed by the Inspector, test the completed chemical stabilized base for smoothness and accuracy of grade, both transversely and longitudinally using suitable templates and straightedges. Satisfactorily correct any 2500 m<sup>2</sup> (3000 square yard) area where the average surface irregularity exceeds 13 mm (½ inch) under a template or straightedge, based on a minimum of at least three measurements. Provide a minimum surface cross slope of ½ inch per foot, or as required by the design.
- Opening to Traffic – In general, the constructed base could be opened to light traffic (vehicles under 5 tons) 24 hours after completion of the base construction. Appropriate traffic signs must be posted to prevent heavy traffic on the constructed base until completion of base curing and application of the overlay, as described above in the discussion of curing.

## 4.6 Foamed Asphalt Stabilization

Construct foamed asphalt using a process similar to that described for asphalt emulsion stabilization modified as described below.

- Spread millings, crushed dust, or any other material needed on the surface to provide a thicker uniform base structure and to eliminate any material deficiencies.
- Conduct in-place pulverization of the millings and existing roadway surface to the established design depth.
- Grade and blade for profile, smoothness, and additional mixing action.
- Spray entire roadway surface with water to aid compaction. Rate of water application should be sufficient to deliver 85% of optimum moisture content.
- Add and mix in the expanded asphalt to the established design depth. The train consisted of an asphalt tanker connected to the reclaiming machine that includes a series of expansion chambers for the asphalt, followed by the water truck that is also connected to the milling machine. The hot asphalt rapidly expands several folds of its original volume in the chambers and is then metered and mixed into the roadway surface.
- Grade and blade thoroughly for profile, smoothness, and additional mixing action, check with straightedge and adjust as needed prior to compaction.
- Conduct breakdown rolling with a pad-foot roller if the reclaimed depth exceed 8 inches. Otherwise use a pneumatic-tired roller.
- Finish compaction with steel drum roller. Initial passes should be in vibratory mode and final pass should be in static mode.
- Monitor density using nuclear density gauge after each coverage.
- Curing the emulsion stabilized base prior to application of the chip seal or overlay. The risk of rutting or moisture damage is increased in case the overlay is applied prematurely and before curing of the base is complete as the moisture is retained for a prolonged time and the rate of strength gain is reduced drastically. The rate of curing depends on many factors. In favorable weather conditions (no rain, sunshine, low humidity, and high temperature) curing can take place at a considerably faster rate. Sufficient curing and strength gain could take from two or three days to at least two weeks depending on the type and amount of materials used and the climatic conditions.

The overlay or chip seal should be placed no earlier than 10 days from the date of construction. After 10 days, moisture content of the base must be checked with a nuclear gauge. The measured moisture content should not exceed 2.0% for foamed asphalt stabilized base. Alternatively, if after ten days cores could be taken intact, the base is ready to be overlaid or chip sealed.

## 5. QUALITY ASSURANCE / PERFORMANCE MEASUREMENT

Quality assurance and acceptance testing should be included in any controlled pavement rehabilitation process. Thorough documentation of all construction activities, application rates,

and work progress are important to verifying control of the reclamation process. Documentation should include test strip as well as final project work. Specific quality assurance and acceptance guidelines to be used in conjunction with FDR pavement rehabilitation are discussed in this section.

## **5.1 Preliminary Activities**

### ***5.1.1 Preconstruction Meeting***

A preconstruction meeting should be required for every FDR project undertaken. Participation by everyone involved in the project is important to insure that all activities are identified and responsibilities clearly defined for each.

### ***5.1.2 Preconstruction Equipment Check***

Prior to starting actual construction work it is important to conduct a shakedown of all equipment to be used on the project, to insure everything is in proper working order. Most importantly the calibration of the equipment to be used for distribution of the stabilizer material and water to be mixed in during the reclaiming process must be verified.

### ***5.1.3 Test Strip Construction***

The construction of a preliminary test strip having a minimum length of 300 ft is recommended. The test strip may be part of the final project, or at an alternative site designated beforehand. This test strip construction should be used to perform the following activities:

- Verify application rates for both the stabilization material and water. Use a 2 ft sq tarp to check the application rate of the stabilization material by spreading in the ground before application and weighing the material collected on the tarp after application.
- Establish a rolling pattern for compaction of the FDR material.
- Verify the density achieved using a nuclear density gage (PTM 402).
- Verify the in-situ moisture content of the reclaimed material using the nuclear gage (PTM 402) and by drying field samples with a portable burner and weighing on a portable scale. In-situ moisture of the pulverized material should be checked prior to reclamation to determine any deviation of the moisture content from the mix design condition. The water added during reclamation must be adjusted accordingly.

### ***5.1.4 Typical Testing of FDR Materials***

A sample construction plan for Plains Church Road, State Route 3016 in Butler County, PA, is enclosed as Appendix A. This plan contains the elements considered important for construction planning, and provides a sample for use on future projects.

### **5.1.5 Quality Control Measures**

- Sampling to ensure proper cement content
- Sampling to ensure proper moisture content
- Measure thickness of pulverization
- Sample pulverized material right before compaction
- Check adequate density is achieved through Nuclear Gauge
- Check adequate curing is achieved
- Coring – Unconfined Compressive Strength

### **5.2 Acceptance Criteria**

Full depth reclamation work will be accepted on the basis of roadway width, depth, smoothness, and 7 day unconfined compressive strength for chemical reclamation according to Method B of ASTM D 1633, except the aspect ratio being 1.5 (specimen with diameter of 4 inches and height of 6 inches). For chemical stabilization processes the minimum acceptance strength varies from 200-500 psi as specified by the project mix design. Consideration of specimen aspect ratio is very important in determining compliance with these criteria. The recommended aspect ratio (height to diameter) is 1:1.5. If a different aspect ratio is used results must be adjusted to reflect consistent strength values. For a test at the aspect ratio of 2, the strength could be increased by 5% and for a test at aspect ratio of 1 or 1.15, strength should be decreased by 5%.

For bituminous stabilization for acceptance the specimen must achieve a minimum indirect tensile test strength of 50 psi for a 4" diameter specimen.

The average surface tolerance must be ½" or less when measured at a minimum of three locations using a ten foot straightedge. Surface cross slope must comply with the design requirement, or ½" per foot at a minimum.

Measurement and Payment:

Once the project meets the acceptance criteria, payment may be made on the basis specified below.

- Chemical Stabilized Base – Square Meter (Square Yard)
- Aggregate – Tonne (Ton)
- Calcium Chloride – Liter (Gallon)
- Pulverized Base – Square Meter (Square Yard)
- Stabilized Base – Square Meter (Square Yard)
- Stabilizing Additives
  - Cement – Tonne (Ton)
  - Hydrated Lime – Tonne (Ton)
  - Fly Ash – Tonne (Ton)
  - Lime Pozzolan – Tonne (Ton)
- Bituminous Prime Coat – Square Meter (Square Yard) or Liter (Gallon)

## 6. SURFACING

Full depth reclamation results in the development of a renewed base course layer. The need for additional pavement structure can be determined from the procedures for structural design analysis provided in Publication 242. Within the PennDOT pavement surface strategies the surfaces most likely to be used following FDR are hot mix asphalt or seal coat. The latter could also be a bituminous surface treatment. Factors which should be considered in selecting a surface type following FDR include,

- Character of the road and surrounding development
- Traffic volume
- Heavy traffic use
- Anticipated design life of the road and the surface prior to the next surfacing
- Additional structural requirements

In general, surface treatments or seal coats are used for lower volume roads. However, in certain situations it is desirable to have a hot mix paved road surface. Either of these can be used following FDR reclamation. It is recommended that for a hot mix surface that a polymer modified asphalt binder material be applied to the FDR surface prior to paving. This will improve the flexibility of the bond response to climatic and traffic loads. For seal coats and surface treatments it is important to determine the absorption characteristics of the FDR surface when designing the emulsion application rate. If potential surface absorption is not considered it could result in insufficient binder thickness, and consequently inadequate aggregate adhesion. This situation would result in the loss of surface aggregate under traffic. It is also important to determine the absorption level of the aggregate used in seal coat or chip seal application. The emulsion application rate should take aggregate absorption level into consideration to ensure sufficient coating will be present. These recommendations are intended to result in satisfactory performance of the final road renewal project.

## 7. CONCLUSIONS AND RECOMMENDATIONS

Work accomplished during this project has demonstrated that the FDR process can successfully produce a sound pavement base layer from existing materials. The pilot projects demonstrated both bituminous and chemically stabilized FDR processes. The work completed during this project is documented for use by the Department in the form of both construction specifications and a best practices document. The construction specifications provide criteria for the successful construction of FDR work. The Best Practices document provides complete information about the process extending from the identification of candidate projects, determination of an appropriate stabilization medium, mix design procedures, and construction guidance. Construction guidance addresses equipment selection, calibration, quality control testing, and documentation of the work. Structural design using FDR is addressed in revisions to Publication 242, Pavement Policy Manual.

The project successfully demonstrated all these steps in an FDR project using both chemical and bituminous stabilization techniques. In addition to the conventional use of cement in the

chemical stabilization process, a blend of cement and fluidized bed combustor fly ash was also successfully constructed. While not every potential stabilization material was used in the pilot projects, other processes are discussed, and guidance provided for their use. It is also worthwhile to comment that it is possible to use still other stabilization materials. In some cases such work has been performed in other states, but additional potential materials may be identified in the future. These materials should be considered using a similar process to that followed in the pilot projects.

- Project identification
- Material sampling and testing
- Mix design
- Structural design

- Preconstruction planning
- Construction
- Follow-up evaluation

FDR promises to provide a cost effective pavement restoration strategy for use in the future. It has several advantages including,

- Low cost
- Can be used with broad range of existing road materials
- Relatively short construction time
- Design life can be determined during the mix and structural design processes

As with other pavement processes, achieving a consistent uniform reclaimed material is ultimately of great importance to the success of each project. Additional improvements in process design and construction techniques may result in improvement in the final reclaimed material. However, the processes outlined in this document are still expected to provide valid general guidance.

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