Guide to Full-Depth Reclamation (FDR) with Cement

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PCA
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Table of Contents

1 Introduction

When flexible pavements fail, determining the best rehabilitation procedure can be difficult. A simple asphalt overlay or a "mill and fill" approach can improve the appearance of the pavement surface, but may do little to correct the underlying problems that caused the failure in the first place. Within a short period of time the problems will likely reappear.

Long-term solutions to failed flexible pavements include a thick structural overlay or complete removal and replacement of the existing base and asphalt surface. Both methods can be very expensive and wasteful of virgin aggregates.

A third choice, recycling the failed flexible pavement through a process called "full-depth reclamation" (FDR) using portland cement, can provide the benefits of reconstruction without the substantial costs and environmental concerns. This procedure pulverizes the existing asphalt and blends it with underlying base, subbase, and/or subgrade materials,

Table 1 - Characteristics of Flexible Pavement Rehabilitation Strategies

Solution	Advantages	Disadvantages
Thick Structural Overlay	• Provides new pavement structure • Quick construction • Only moderate traffic disruption	• Elevation change can present problems for existing curb and gutter and overhead clearances • Large quantity of material must be imported • Old base/subgrade may still need improvement • High cost alternative
Removal and Replacement	• Provides new pavement structure • Failed base and subgrade are eliminated • Existing road profile/elevation can be maintained	• Long construction cycle requiring detours and inconvenience to local residents/businesses • Increased traffic congestion due to detours, construction traffic • Rain or snow can significantly postpone completion • Large quantity of material must be imported • Old materials must be dumped • Highest cost alternative
Recycling Surface, Base and Subgrade with Cement (Full-Depth Reclamation)	• Provides new pavement structure • Fast construction cycle • No detours • Minimal change in elevation, thus eliminating problems with curb and gutter, overhead clearances • Minimal material transported in or out • Conserves resources by recycling existing materials • Local traffic returns quickly • Rain does not affect construction schedules significantly • Provides moisture- and frost-resistant base • Least cost alternative	• May require additional effort to correct subgrade problems • Some shrinkage cracks may reflect through bituminous surface

Figure 1.1 Example of pavement distress indicating base problems.

which are mixed with cement and compacted to provide a new stabilized base. A new concrete or bituminous surface is then applied, which completes the FDR process, providing a new roadway structure using recycled materials from the failed pavement. Because of cement stabilization, the new base will be more uniform, stronger, and provide better long-term performance than the original pavement.

The cost advantages of recycling materials from the original pavement are obvious; however, there are other environmental advantages that are important to the FDR process:

- Conservation of new aggregates that must be quarried and transported to the site
- Conservation of land areas that would be used to dispose of the asphalt and base materials from the failed pavement
- Reduced air pollution, traffic congestion, and damage of nearby roadways resulting from hauling new materials to the site, and disposal of old materials

This document provides an overview of the FDR process using cement, making reference to additional documents in each section if more information is desired.

Determining When FDR Is Appropriate

FDR is most appropriate under the following conditions:

- The pavement is seriously damaged and cannot be rehabilitated with simple resurfacing.
- The existing pavement distress indicates that the problem likely exists in the base or subgrade.

Figure 1.2 Excessive patching is often more expensive than FDR.

- The existing pavement distress requires full-depth patching over more than 15 to 20 percent of the surface area.
- The pavement structure is inadequate for the current or future traffic.

Serious Damage or Base Failure

An engineer can evaluate the reasons for pavement failure by observing the types of distress that are visible. For example, alligator cracking, deep depressions, or soil stains on the surface are all signs of base or subgrade problems in the pavement structure (Figure 1.1).

Excessive Patching

Although patching is often necessary to keep a road serviceable, it can be expensive. In fact, once the area of full-depth patching exceeds 15 to 20 percent, simple math proves it less expensive to use FDR than to perform the patching. Of course, the final product achieved with FDR is far superior to a road that is severely patched. Figure 1.2 is an example of a heavily patched pavement that was selected for FDR.

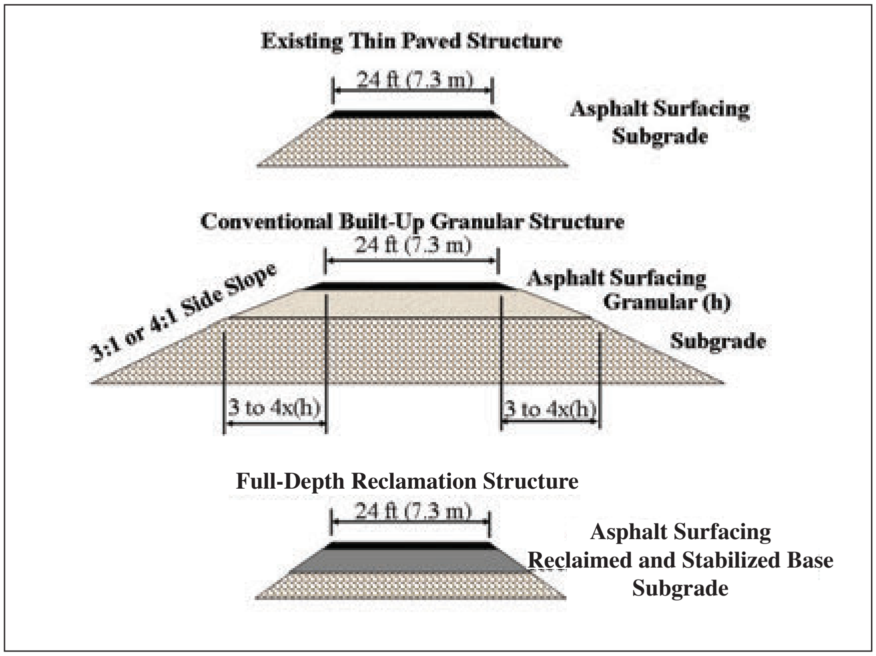

Figure 1.3 Using FDR to "build the pavement down."

Inadequate Pavement Structure

Often the traffic patterns on a road will change over the years. This sometimes results in roads that were originally constructed for light traffic but are now significantly under-designed for existing and future traffic loads. When this happens, often a road is "built-up" by increasing the thickness of the existing pavement structure. However, increasing the pavement thickness also requires building up and extending the shoulders, since a reasonable shoulder slope needs to be maintained for safety. This can require significantly more right-of-way. An alternative exists with FDR, where the pavement can be strengthened by "building the pavement down" (Figure 1.3). By reclaiming the existing pavement into a stabilized base, the road is strengthened without the requirement of more right-of-way.

Special Considerations When Using FDR

Because the pulverized asphalt from the existing pavement (called "reclaimed asphalt pavement," or RAP) is blended with the underlying roadway materials, the thickness of reclaimed asphalt cannot exceed the depth of reclamation for an extended length (short sections of full-depth asphalt, like a patch, are allowed). If a long section of thick asphalt is selected for reclamation, the asphalt layer can be partially milled and the RAP stockpiled for future use. The remaining asphalt in the old pavement is then reclaimed and blended with the underlying materials.

Another consideration when evaluating FDR is the existence of large rocks (larger than 4 inches (100 mm) in diameter) in the base or subgrade. If this material is within the depth of reclamation, the costs of reclaiming may be high because the contractor must take into consideration the slower and more difficult construction that is posed by the rocks.

2 Design

Performing the Initial Field Evaluation

After a road is selected as a candidate for FDR, a field evaluation should be performed to determine what materials make up the current pavement structure. The principal reason for the field evaluation is to determine: 1) the thickness of the pavement layers, and 2) the materials in each layer that will be blended for the reclaimed base.

In many cases, little will be known about the materials in the existing pavement and the thickness of the existing layers. The best way to determine these will be to sample the roadway. How frequently the samples should be taken depends on the variability of the existing pavement. Normally if a road is sampled every 1/4 mile (0.4 km) it will provide adequate information. Sampling can usually be accomplished using a coring rig or a jackhammer for the asphalt and an auger or post-hole digger for the base and subgrade.

At each location the thickness of the asphalt layer should be determined. If a core is taken it can be visually examined to see the condition of the asphalt and the size of the aggregate. Digging below the asphalt with an auger or post-hole digger will allow sampling of the base and subgrade materials. The thickness of the base layer and the type of aggregate should be noted. Also, the depth to subgrade and type of subgrade material should be recorded.

From a representative location, a sample of road materials should be taken back to the laboratory to perform a mix design. If the materials are relatively consistent along the project, only one location needs to be used to collect the laboratory sample. If a significant difference occurs in the materials along the project, then a second mix design may be necessary.

The easiest way to obtain a laboratory sample is to dig a small "test pit." For example, a 1 square foot (0.1 square meter) area, excavated to the depth of the proposed new base section, will normally provide the materials necessary for the mix design, and when exposed will provide a good "picture" of what the individual layers look like. Normally about 100 lbs. (45 kg) of material is sufficient (this can be carried in two 5-gallon (19-liter) buckets). It is advantageous if the asphalt, base, and subgrade materials can be kept separate, allowing for different blending ratios in the lab. For example, if the existing pavement is 3 inches (75 mm) of asphalt and 3 inches (75 mm) of base, in the laboratory it would be possible to make a 50:50 blend of asphalt and base (for a 6-inch (150 mm) stabilized base), or a 33:33:33 blend of asphalt, base, and subgrade (for a 9-inch (225 mm) stabilized base). This is discussed further in the section on Mix Design starting on page 5.

During the field evaluation is an excellent time to note drainage problems, locations where culverts or utility crossings are required, any recommendations to change grade or cross-slope, or locations where widening is desired. Since the roadway will be reconstructed from the base up, it is the best time to make desired permanent changes.

Pavement Design

The thickness design for a reclaimed pavement is similar to that for a new pavement structure, since the pavement is being rebuilt from the subgrade up. In most design procedures an engineer has the option of selecting a "cement-treated base" (CTB) for the pavement structure. A reclaimed pavement is designed the same way, characterizing the reclaimed base as CTB. The American Association of State Highway and Transportation Officials (AASHTO) procedure for pavement design, for example, uses a Structural Layer Coefficient to model base materials. AASHTO has also developed a mechanistic-empirical pavement design guide (MEPDG) which can be used for pavement design.

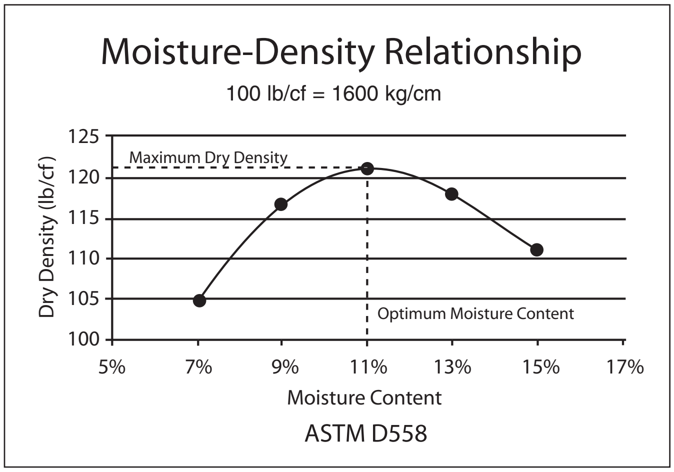

Figure 2.1 Determining the Maximum Dry Density and Optimum Moisture Content (ASTM D558).

The new cement-stabilized base from the FDR process will normally be between 6 inches (150 mm) and 12 inches (300 mm) in depth. Any depth of reclaimed base that is more than 12 inches (300 mm) will be difficult to compact in one lift and is not recommended.

The ability of a pavement base to carry loads depends on the strength of the base material and the depth of the base layer. A thin, but strong base can theoretically carry the same load as a thick, but weaker base. However, the thin, strong base should be avoided because it can become brittle and fracture, resulting in reflection cracks in the pavement surface (see page 11 under Reflective Cracking). When selecting thicknesses for reclaimed pavements, a thicker base with less strength should be preferred (see discussion of Balanced Design on page 6). Today's more powerful in-place pulverizing equipment has made the job of obtaining thicker mixed-in-place layers much easier and more reliable compared with equipment used years ago.

Mix Design

Designing the proper amount of water and cement for the stabilized base is not only important to obtain a good final product, it also provides important information for quality control during construction. The PCA publication *Soil-Cement Laboratory Handbook*, EB052, provides comprehensive information on testing procedures for determining the appropriate cement content, water content, and compaction requirements for cement-stabilized materials. Research has shown that cement-stabilized materials have better strength and performance when they are well compacted, so determining final compaction density is fundamental to the design procedure.

Compaction density is determined through the ASTM International (ASTM) *Standard Test Method for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures* (ASTM D558). The test procedure uses the standard compaction effort similar to ASTM D698 (*Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort [12,400 ft-lb/ft³ (600 kN-m/m³)])* for soils. The ASTM D558 test method is a common (as well as inexpensive) procedure for most construction testing labs. The test can be performed in either the laboratory or the field, and determines the maximum dry density (unit weight) for the FDR mix, and the influence of moisture content on obtaining that density. Figure 2.1 shows a typical compaction curve from the ASTM D558 test method. If the mix is too dry, there is not enough moisture available to lubricate the particles into a denser formation. If the mix is too wet, the excess moisture pushes the particles apart. The moisture content where maximum density is selected for mix design and field quality control is called the "optimum moisture content."

The amount of water in the mix is called the water content, and is defined as the weight of water in the mix (expressed as a percentage of the dry material).

$$\text{water content, } w\,(\%) = \frac{\text{weight of water in mix}}{\text{weight of oven-dry FDR material}} \times 100$$

The cement content by weight is based on the oven-dry weight of the soil/aggregate only (cement is not included) and is expressed as:

$$\text{cement content, } c\,(\%) = \frac{\text{weight of cement in mix}}{\text{weight of oven-dry soil/aggregate}} \times 100$$

The amount of water and cement required in the mix will depend upon the project specified strength and gradation of the final blend obtained from pulverizing the asphalt during construction and mixing it with the base material. Typical specifications for pulverizing call for 100 percent passing the 3-inch (75 mm) sieve, a minimum of 95 percent passing the 2-inch (50 mm) sieve, and a minimum of 55 percent passing the No. 4 (4.75 mm) sieve. If the blend contains more fine-grained soil, then more cement and water will be required because of the larger surface area of the finer particles.

The next step is to conduct a moisture-density test to determine the moisture content for molding the FDR

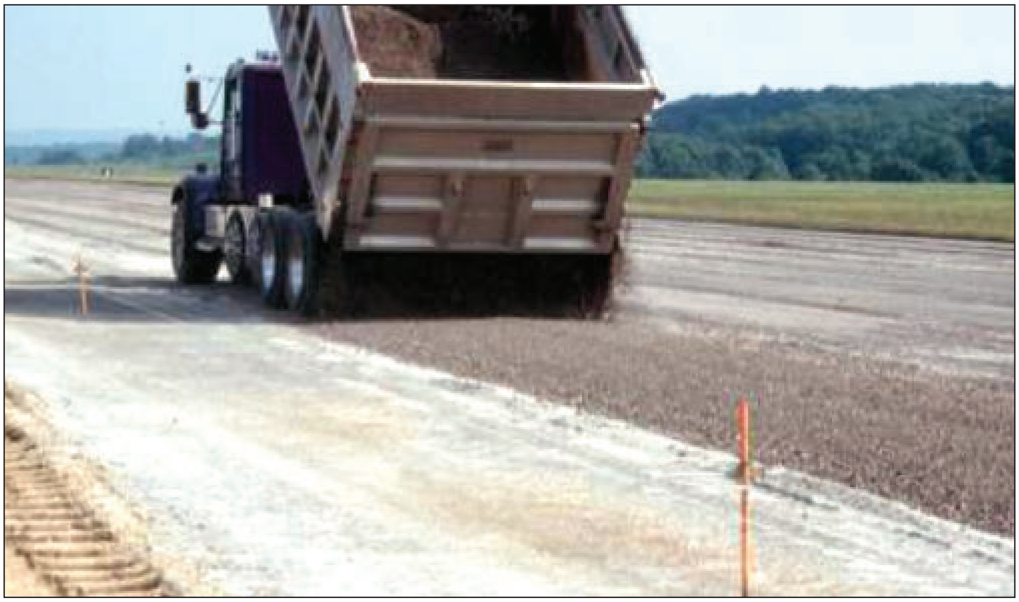

Figure 2.2 Placing additional aggregate for inclusion in the FDR process.

specimens for unconfined compressive strength (UCS) testing. Since the exact cement content is not known at this stage of the design, an assumed cement content can be chosen in conducting the test. Table 1 in PCA publication *Soil-Cement Laboratory Handbook*, may be used to estimate a cement content for the moisture-density test. Cement contents within a range of one or two percent will not significantly influence the results. However, once the exact cement content is established, a moisture-density test should be conducted with the established cement content in order to determine the control factors for field construction.

Using the optimum moisture content from the initial moisture-density test, a series of FDR specimens are prepared at different cement contents to determine UCS. Typically three cement contents are chosen (for example, 3, 5, and 7 percent). It is recommended that a minimum of two specimens be prepared for each cement content. These specimens are moist-cured for 7 days, and then tested for UCS according to ASTM D1633, *Standard Test Method for Compressive Strength of Molded Soil-Cement Cylinders*. This will give a range of strength results in which to determine the required cement content.

Balanced Design

The stabilized base must be strong enough to provide adequate pavement support for the current and future traffic loading conditions. In addition, the stabilized base needs to remain hard and durable and be able to resist the volume changes or hydraulic pressures caused by freezing-and-thawing and moisture changes that could gradually break down the cementitious bonds.

In general, a cement content that will provide a 7-day UCS between 300 and 400 psi (2.1 and 2.8 MPa) is satisfactory for most FDR applications. Higher strengths may be required if it is determined that the base materials are moisture sensitive, or that special conditions exist that warrant more strength. The main reason for limiting the strength is to keep the cement-stabilized base from becoming too brittle. Experience has shown that high strengths can cause additional cracks to reflect through the pavement surface. The objective is to have a "balanced design," where enough cement is used so that the resulting stabilized base is strong, durable, and relatively impermeable, but not so strong that it results in other types of distress in the pavement.

Aggregate Adjustment

In some cases FDR is the preferred solution, but the existing asphalt and base layers do not provide the desired amount of aggregate for the new base. This can happen when the original pavement structure was under-designed, or traffic conditions have changed over the years, and a substantially heavier pavement is required.

In this situation an "aggregate adjustment" can be made, where additional aggregate is placed on the pavement surface in a thin lift, and is then blended into the base during the reclamation process. A picture of this process is shown in Figure 2.2.

3 Construction

The construction process for FDR is straightforward. It requires the following equipment:

- pulverizer/mixer
- grader
- cement spreader
- water truck
- roller

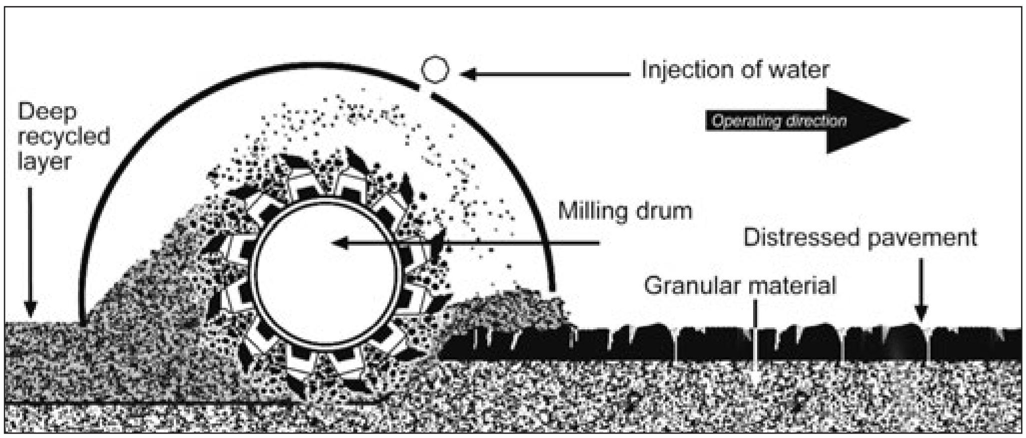

Figure 3.1 Inside a reclaimer.

Pulverizing

The process begins by pulverizing the existing asphalt pavement (Figures 3.1 and 3.2). As discussed earlier, the depth of pulverizing should be more than the thickness of the existing asphalt. The amount of RAP included in the total recycled layer depends predominantly on the pulverized material meeting the gradation requirement for FDR construction, but rarely exceeds 80 percent of the total. Additionally, contractors prefer to pulverize below the thickness of the failed asphalt layer as the unbound stone or soil beneath it helps to keep the cutting teeth of the reclaimer cooler, which ultimately increases production and reduces costs. Modern equipment can pulverize to depths exceeding 18 inches (450 mm), but the difficulty lies with getting compaction deeper than 12 inches (300 mm). If the depth of pulverization exceeds 12 inches (300 mm), then the material should be windrowed and compacted in two lifts after treatment.

Pulverization can occur safely in urban areas with curb and gutter, manholes, and valve covers. The manholes, valve covers, and other buried obstructions are removed below the depth of the pulverization. Wooden or steel plates are used to cover and protect the structures during the processing operation. In rare cases, more than one pass of the pulverizing equipment may be necessary to achieve the required gradation.

Grading, Shaping, and Widening

Once the existing roadway has been pulverized and blended together, the material is graded to the desired elevation and

Figure 3.2 Pulverizing a failed asphalt pavement.

Figure 3.3 Grading and shaping.

Figure 3.4 Placing cement dry.

shape (Figure 3.3). When working between curb and gutter, there may be a need to remove some of the pulverized material and haul it away in order to leave room for the pavement surface layer.

When the reclaimed road is being graded, it is an ideal time to make improvements to the road crown, grade, drainage, and superelevation, because after stabilization the improvements will be permanent. It is also an excellent time to perform road widening. Stabilizing the entire roadway creates uniformity of the pavement base that greatly reduces maintenance compared to roads that are widened without being reclaimed.

Often following grading and shaping, the pulverized material will be compacted to accommodate traffic during construction and improve uniformity for subsequent cement placement and mixing operations.

Cement Placement

Cement is usually spread in a controlled manner by spreader trucks that are designed for this operation. Placing the cement in an uncontrolled manner by blowing under pressure should be avoided.

Cement is most commonly applied dry (Figure 3.4), but can also be applied in a slurry form (Figure 3.5). Most specifications call for the application of cement in terms of weight per area (e.g., pounds of cement per square yard (kilograms of cement per square meter)). The most important time for dust control is when cement impacts the ground. Special enclosures can be used to minimize the amount of dust when cement is applied (Figure 3.6). Except for very windy days, dust should not be a problem once the cement is on the ground. With a slurry application, it is important that the slurry be dispersed uniformly over the placement area so that it will not pool or run off in any manner.

Figure 3.5 Placing cement in slurry form.

Figure 3.6 Enclosure for dry cement application.

Figure 3.7 Water being injected during mixing operation.

Mixing

Mixing is performed by the reclaimer/mixer, either by injecting the proper amount of moisture into the mixing chamber (Figure 3.7), or by placing water on the ground with a water truck in a separate operation. In either case, obtaining the correct amount of moisture is very important in achieving the target compaction.

Figure 3.8 Compaction and final grading.

Compaction and Final Grading

After the materials are well mixed, it is time for compaction and final grading (Figure 3.8). Smooth-wheeled vibrating rollers, or tamping rollers can be used to provide initial compaction, with smooth-wheeled or pneumatic-tire rollers used to complete the operation. Once the cement is mixed with water and the pulverized base material, the maximum time allowed for compaction is 2 hours.

Curing

Proper curing is very important to the quality of the final product. If the base is allowed to dry, it will develop cracks, and the continued gain in strength over time will be compromised. The CTB must be kept moist a minimum of 7 days following compaction. Proper curing can be achieved by continuous water spraying or application of an approved sealing compound or membrane. If the road will have an asphalt surface, a bituminous prime-coat can be applied at any time, as this will act as a curing membrane.

Surfacing

The CTB that results from the FDR process can have any type of pavement surfacing (e.g., chip seal surface treatment, hot mixed asphalt, or concrete). The surfacing can be applied as soon as the CTB is stable (does not rut or shove) under construction traffic. The time required for this can range from 4 to 48 hours.

Traffic can be placed on the CTB in the same time frame, as long as repeated applications of heavy trucks are not involved. In many cases with low-volume roads, traffic is allowed to run on the compacted base until the project is ready for surfacing. For conditions where heavy truck traffic is involved, up to 7 days may be required to make sure the base has gained sufficient strength.

Field Quality Control

Field quality control procedures are similar to those used for standard CTB. A thorough discussion on field inspection and testing procedures can be found in PCA publication *Soil-Cement Inspectors Manual,* PA050.

Traffic Control

The FDR process can be performed under traffic (Figure 3.9 and Figure 3.10). With low-volume roads, traffic is usually allowed on one side of the road while construction occurs on the other. Traffic is controlled with flagging personnel. With some projects, vehicles are allowed on the finished CTB prior to surfacing. On other projects, traffic will not return to the lane until surfacing is finished.

For projects with higher traffic volumes, a surface treatment over the new CTB acts as an excellent curing membrane and allows traffic to travel easily until the roadway is ready for surfacing.

Figure 3.9 Traffic being allowed on completed FDR base prior to surfacing while processing operation proceeds in adjacent lane.

Figure 3.10 Traffic control in an urban area.

Reflective Cracking

Cement-treated materials will shrink naturally while curing. With properly designed pavements, and good construction procedures, the resulting cracks in the base will not significantly affect pavement performance. In some cases larger cracks in the base layer can result in stress concentrations, and the cracks may reflect from the base into the surface. This does not normally affect pavement roughness, but may influence the overall appearance of the pavement.

Usually proper construction procedures, crack minimization strategies, and maintenance sealing, if necessary, can eliminate requirements for significant maintenance due to reflective cracking. Newer techniques, such as microcracking or using a stress absorbing inter-layer, have been very successful. A well designed and properly maintained CTB will normally outlast several asphalt overlays, providing decades of low maintenance service.

More information on control of reflective cracking in CTB can be found in the following PCA documents:

Reflective Cracking in Cement-Stabilized Pavements, IS537

Minimizing Cracking in Cement-Treated Materials for Improved Performance, RD123.

4 Suggested Construction Specification for Full-Depth Reclamation

1. GENERAL

1.1 Description. Full-depth reclamation (FDR) with cement shall consist of pulverizing and mixing to a specified depth existing asphalt pavement and underlying materials with portland cement and water to produce a dense, hard, cement-treated base. It shall be proportioned, mixed, placed, compacted, and cured in accordance with these specifications, and shall conform to the lines, grades, thicknesses, and typical cross sections shown in the plans.

1.2 Caveat. These specifications are intended to serve as a guide to format and content for normal FDR construction. Most projects have features or requirements that should be incorporated in the project documents.

2. REFERENCED DOCUMENTS

ASTM International (ASTM) with corresponding American Association of State Highway and Transportation Officials (AASHTO) designations:

ASTM

C150 Specification for Portland Cement (AASHTO M 85)

C309 Specification for Liquid Membrane-Forming Compounds for Curing Concrete (AASHTO M 148)

C595 Specification for Blended Hydraulic Cements (AASHTO M 240)

C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete (AASHTO M 295)

C989 Specification for Ground Granulated Blast-Furnace Slag for Use in Concrete and Mortars (AASHTO M 302)

C1157 Performance Specification for Hydraulic Cement (AASHTO M 240)

C1240 Specification for Silica Fume Used in Cementitious Mixtures (AASHTO M 307)

D558 Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures (AASHTO T 134)

D977 Specification for Emulsified Asphalt (AASHTO M 140)

D1556 Density and Unit Weight of Soil in Place by the Sand-Cone Method (AASHTO T 191)

D2167 Density and Unit Weight of Soil in Place by the Rubber Balloon Method

D6938 In-Place Density and Water Content of Soil and Soil Aggregate by Nuclear Methods (AASHTO T 310)

3. SUBMITTALS

3.1 Submittal Requirements. The contractor shall submit the following to the engineer at least 30 days before start of any production of FDR:

3.1.1 Certifications. Certifications for portland cement and supplementary cementitious materials as required by the engineer.

3.1.2 Specifications. Manufacturers' data and specifications for equipment including capacities to be used in mixing and compacting FDR.

3.1.3 Proposed FDR Mix Design. If the proposed mix design is developed by the contractor or there is a suggested change to the mix design, it must be submitted to the engineer for approval at least two weeks prior to FDR construction. This mix design shall include details on soil/aggregate gradation, cementitious materials, compressive strengths, and required moisture and density to be achieved during compaction.

4. MATERIALS

4.1 Recycled Asphalt Pavement, Base, and Subgrade Material. Shall consist of the existing asphalt pavement, existing base course material, and/or subgrade material. The base course and subgrade material shall not contain roots, topsoil, or any material deleterious to its reaction with cement. The particle distribution of the processed material shall be such that 100% passes a 3-inch (75 mm) sieve, at least 95% passes a 2-inch (50 mm) sieve, and at least 55% passes a No. 4 (4.75 mm) sieve.

4.2 Portland Cement. Shall comply with the latest specifications for portland cement (ASTM C150 or AASHTO M 85) or blended hydraulic cements (ASTM C595, ASTM C1157, or AASHTO M 240).

4.3 Water. Shall be free from substances deleterious to the hardening of the cement-treated material.

4.4 Pozzolans. If used, pozzolans including fly ash, slag, and silica fume shall comply with the appropriate specifications (ASTM C618, AASHTO M 295 for fly ash; ASTM C989, AASHTO M 302 for slag; and ASTM C1240, AASHTO M 307 for silica fume).

4.5 Curing Compounds. Curing compounds shall comply with the latest specifications for emulsified asphalt (ASTM D977, AASHTO M 140) or liquid membrane-forming compounds for curing concrete (ASTM C309, AASHTO M 148).

4.6 Sand Blotter. Sand used for the prevention of pickup of curing materials shall be clean, dry, and non-plastic.

5. EQUIPMENT

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

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

5.3 Cement Proportioning. The cement spreader for in-place mixing shall be capable of uniformly distributing the cement at the specified rate. Cement may be added in a dry or slurry form. If applied in slurry form, the slurry mixer and spreading equipment shall be capable of completely dispersing the cement and water and maintaining uniform, consistent slurry without separation throughout the slurry placement.

5.4 Application of Water. Water may be applied through the mixer or with water trucks equipped with pressure-spray bars.

5.5 Compaction. The processed material shall be compacted with one or a combination of the following: tamping or grid roller, pneumatic-tire roller, steel-wheel roller, vibratory roller, or vibrating-plate compactor.

6. CONSTRUCTION REQUIREMENTS

6.1 General

6.1.1 Preparation of Subgrade. Before FDR processing begins, the area to be processed shall be graded and shaped to lines and grades as shown in the plans or as directed by the engineer. During this process, any unsuitable soil/aggregate or material shall be removed and replaced with acceptable material. Any manholes, valve covers, or other buried structures shall be protected from damage prior to processing. The subgrade shall be firm and able to support, without yielding or subsequent settlement, the construction equipment and the compaction of the FDR material. Soft or yielding subgrade shall be corrected and made stable before construction proceeds.

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

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

6.2 Pulverization/Mixing

6.2.1 Preparation. The surface of the pavement prior to mixing shall be at an elevation so that, when mixed with cement and water and re-compacted to the required density, the final elevation will be as shown in the plans or as directed by the engineer. The material in place and surface conditions shall be approved by the engineer before the next phase of construction is begun.

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

1) When the processed material is more than 3% above or below optimum moisture content. When the material is below optimum moisture content, water shall be added. The pre-pulverized material shall be sealed and properly drained at the end of the day or if rain is expected.

2) For slurry application of cement, initial pulverization shall be performed to provide a method to uniformly distribute the slurry over the processed material without excessive runoff or ponding.

6.2.3 Application of Cement. The specified quantity of cement shall be applied uniformly in a manner that minimizes dust and is satisfactory to the engineer. If cement is applied as slurry, unless an approved retarding admixture is used, the time from first contact of cement with water to application on the soil/aggregate shall not exceed 60 minutes. The time from cement placement on the soil/aggregate to start of mixing shall not exceed 30 minutes.

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

1) The final mixture (bituminous surface, granular base, and subgrade soil) shall be pulverized such that 100% passes the 3-inch (75 mm) sieve, at least 95% passes the 2-in. (50 mm) sieve, and at least 55% passes the No. 4 (4.75 mm) sieve. Additional material can be added to the top or from the subgrade to improve the mixture gradation, as long as this material was included in the mixture design.

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

6.3 Compaction. The processed material shall be uniformly compacted to a minimum of 98% of maximum dry density based on a moving average of five consecutive tests with no individual test below 96%. Field density of compacted FDR material can be determined by the 1) nuclear method in the direct transmission mode (ASTM D6938, AASHTO T 310); 2) sand cone method (ASTM D1556, AASHTO T 191); or 3) rubber balloon method (ASTM D2167). Optimum moisture and maximum dry density shall be determined prior to start of construction and also in the field prior to and during construction by a moisture-density test (ASTM D558 or AASHTO T 134).

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

6.4 Finishing. As compaction nears completion, the surface of the FDR material shall be shaped to the specified lines, grades, and cross sections. If necessary or as required by the engineer, the surface shall be lightly scarified or broom-dragged to remove imprints left by equipment or to prevent compaction planes. Compaction shall then be continued until uniform and adequate density is obtained. During the finishing process the surface shall be kept moist by means of water spray devices that will not erode the surface. Compaction and finishing shall be done in such a manner as to produce a dense surface free of compaction planes, cracks, ridges, or loose material. All finishing operations shall be completed within 4 hours from start of mixing.

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

After completion of final finishing, the surface shall be cured by application of a bituminous or other approved sealing membrane, or by being kept continuously moist for a period of 7 days with a water spray that will not erode the surface of the FDR base. If curing material is used, it shall be applied as soon as possible, but not later than 24 hours after completing finishing operations. The surface shall be kept continuously moist prior to application of curing material.

For bituminous curing material, the FDR base surface shall be dense, free of all loose and extraneous materials, and shall contain sufficient moisture to prevent excessive penetration of the bituminous material. The bituminous material shall be uniformly applied to the surface of the completed FDR base. The exact rate and temperature of application for complete coverage, without undue runoff, shall be specified by the engineer.

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

Sufficient protection from freezing shall be given the FDR base for at least 7 days after its construction or as approved by the engineer.

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

6.7 Surfacing. Subsequent pavement layers (asphalt concrete, bituminous surface treatment, or portland cement concrete) can be placed any time after finishing, as long as the FDR base is sufficiently stable to support the required construction equipment without marring or permanent distortion of the surface.

6.8 Maintenance. The contractor shall maintain the FDR base in good condition until all work is completed and accepted. Such maintenance shall be done by the contractor at his own expense.

Maintenance shall include immediate repairs of any defects that may occur. If it is necessary to replace any processed material, the replacement shall be for the full depth, with vertical cuts, using either fresh cement-treated material or concrete. No skin patches will be permitted.

7. INSPECTION AND TESTING

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

1) Obtaining test samples of the FDR base and its individual components at all stages of processing and after completion.

2) Observing the operation of all equipment used on the work. Only those materials, machines, and methods meeting the requirements of the contract documents shall be used unless otherwise approved by the engineer.

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

8. MEASUREMENT AND PAYMENT

8.1 Measurement. This work will be measured:

1) In square yards (meters) of completed and accepted FDR base course as determined by the specified lines, grades, and cross sections shown on the plans.

2) In tons (tonnes) or cwt of cement incorporated into the FDR base course in accordance with the instructions of the engineer.

8.2 Payment. This work will be paid for at the contract unit price per square yard (meter) of FDR base course and at the contract unit price per ton (tonne) or cwt of cement furnished, multiplied by the quantities obtained in accordance with Section 8.1. Such payment shall constitute full reimbursement for all work necessary to complete the FDR base course, including watering, curing, inspection and testing assistance, and all other incidental operations.

Abstract: Full-depth reclamation (FDR) is a roadway rehabilitation process that recycles the materials from deteriorated asphalt pavement, and, with the addition of portland cement, creates a new stabilized base. This guide to FDR discusses its applications, benefits, design, construction, and testing.

Keywords: Full-depth reclamation, FDR, flexible pavement, base failure, pavement structure, pavement design, field evaluation, moisture-density relationship, mix design, Tube Suction Test, construction process, reflective cracking, soil-cement, cement-treated base, CTB, cement-treated soil.

Reference: Luhr, David, R.; Adaska, Wayne, S.; Halsted, Gregory, E., Guide to Full-Depth Reclamation (FDR) with Cement, EB234 Portland Cement Association, Skokie, Illinois, USA, 2008, 15 pages.

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