APPENDIX J

DEVELOPING STANDARDS AND SPECIFICATIONS FOR FULL DEPTH RECLAMATION: A BEST PRACTICES GUIDE

EXECUTIVE SUMMARY

This document represents the Best Practices identified and developed for the use of full-depth reclamation of flexible roads. Full Depth Reclamation (FDR) is among the most cost-effective and popular methods of reconstructing deteriorated flexible pavements and unpaved roads. The method is well-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 existing material is pulverized to a specific depth (typically 5 inches to 16 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 requiring mechanical or chemical stabilization of the reclaimed pavement before compaction. The reclaimed material serves as a strong base upon which a hot-mix asphalt overlay, or a surface treatment is applied.

J.1 INTRODUCTION

A. The Overall Process. The document provides guidelines for the individual activities that 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; and
- Final surfacing.

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

B. Overview of the Categories of FDR. FDR includes the following construction processes. The existing pavement layer materials are pulverized to a 2-inch-minus size by a road reclaimer. Moisture and/or specific stabilizing additives may be added, depending upon the category of FDR employed, to enhance the characteristics of the reclaimed materials, and compacted.

The general categories of FDR available are:

- Pulverization;
- Mechanical Stabilization;
- Asphalt Stabilization;
- Chemical Stabilization; and
- Other Stabilization Methods.

Each of these categories of FDR is discussed in greater detail in Section J.3, Design. The final product is a renewed stabilized pavement base layer with uniform characteristics.

J.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 requires conducting the following steps:

- Determination of traffic level;
- Survey of pavement condition;
- In-situ testing; and
- Sampling.

A. Traffic Level. Generally, traffic loading is a significant contributor to most pavement distress. Therefore, it is important to obtain a reliable estimate of traffic projected to use the road during the planned design life. 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 Publication 242, *Pavement Policy Manual*.

B. Pavement Condition Survey. Having a recent pavement condition survey is important. This is typically carried out by following the procedures provided in Publication 336, *Automated Pavement Condition Survey Field Manual* and in Publication 343, *Continuously Reinforced Concrete and Unpaved Roads Condition Survey Field Manual*. 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. Understanding the mechanisms responsible for existing pavement damage is useful for preventing the same damage mechanisms from causing failure of the rehabilitated pavement.

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

C. In-Situ Testing. Beyond visual survey of pavement condition, assessing the in-situ strength of the unbound material, specifically the subgrade upon which the rehabilitated pavement will be residing is important. Two tests are suitable 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 and uniformity.

1. Falling Weight Deflectometer. 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 of support, 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. 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-pound hammer is repeatedly raised and then dropped onto the coupling for a drop distance of 22.6 inches. As the 0.75-inch 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 (i.e., Penetration Rate) or the rate of penetration DCPI (inches per blow) are correlated with other strength parameters such as California Bearing Ratio (CBR) or resilient modulus.

3. Light Weight Deflectometer (LWD). The LWD is another simple tool for determining in-situ characteristics of the unbound material, specifically the subgrade soil. The 22-pound drop hammer delivers energy to deflect the subgrade under the load plate. Drop weight can be extended to 66 pounds and the drop height could be as high as 33.5 inches. The load plate is flat and circular and may have diameters of approximately 4 inches or approximately 12 inches. 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 (material stiffness for design purposes) of the in-situ material through a simple, fast test.

D. Sampling. Proper sampling plays a vital role in the 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; and
- Handling and evaluation.

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-foot intervals per lane but under no circumstances should fewer than three samples per lane be obtained for a project. For FDR projects extending longer than 1 mile, sampling could be reduced to one per mile if uniform conditions are observed.

It is best that the sampling locations be selected randomly and without bias, in order to achieve a representative composition of the road section under consideration. If a fixed interval sampling plan is proposed, the reasoning supporting that choice must be justified. An example of fixed interval sampling is establishing the first location, and from there sampling every 1000 feet, 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. Follow the guidance in PTM No. 1 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. 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.

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 or broken down using a laboratory jaw crusher. 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 feet by 3 feet - 3 feet by 5 feet being optimal - with the depth of excavation established as noted below in Section J.2.D.4. As material is 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.

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 estimated depth of pulverization. The actual depth of pulverization will likely not be known, so 1.5 times the estimated depth should assure excavation of the material needed for the sample. Several testing iterations may be necessary to determine the required sampling depth. It is best if the material from different layers is kept separate, with the expectation that they will be proportionally blended in the lab, especially if the depth of reclamation is not known.

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 8 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;
- Moisture content at the time of testing;
- Relative-density for coarse-grained soils;
- Characteristics of fine-grained soils (liquid limit, plastic limit, shrinkage limit);
- Other descriptive terms relative to identification of the soil and its composition; and
- AASHTO soil classification.

E. Determine Layer Thicknesses and Drainage Conditions. The determination of layer thicknesses 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 traffic projected to use the road during the planned design life 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 upon the thickness of the existing pavement and the character and amount of subgrade material that 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: structural layer coefficient, resilient modulus, elastic modulus, and California Bearing Ratio (CBR).

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 should be corrected before reclaiming.

F. Evaluate Applicability of FDR. This section discusses the evaluation steps to determine the suitability of FDR for use on a road. Table J.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 improvement of the support layers is required. Other strategies are likely to be more effective for surface-related distresses.

TABLE J.1
SELECTION OF
FULL DEPTH RECLAMATION (FDR)

PAVEMENT DISTRESS	FDR
Surface Defects	
Raveling	
Flushing	
Low skid resistance	
Deformation	
Corrugations	
Ruts-shallow	
Rutting Deep[1]	X[2,3]
Cracking (Load Associated)	
Alligator	X
Longitudinal	
Wheel Path	X
Pavement Edge	X
Slippage	
Cracking (Non-Load Associated)	
Block (Shrinkage)	X
Longitudinal (Joint)	
Transverse (Thermal)	X
Reflection	X
Maintenance Patching	
Spray	X[4]
Skin	X[4]
Pothole	X
Deep Hot Mix	
Weak Base or Subgrade	X
Ride Quality/Roughness	
General Unevenness	
Depressions (Settlement)	X[5]
High Spots (Heaving)	X[6]

[1]Rutting originating from the lower portion of the pavement (below surface course and including base and subgrade).
[2]The addition of new aggregate may be required for unstable mixes.
[3]The chemical stabilization of the subgrade may be required if the soil is soft, or wet.
[4]In some instances, spray and skin patches may be removed by cold planing prior to these treatments (considered if very asphalt rich, bleeding).
[5]Used if depressions are due to a poor subgrade condition.
[6]Used if high spots caused by frost heave or swelling of an expansive subgrade soil exist.

1. Characterization of the Composition of the Roadway and Selection of the Stabilization Technique. Using the samples collected from the roadway prism; characterize the samples for the physical and mechanical characteristics referenced in Table J.2.

TABLE J.2
MINIMUM SOIL TESTING METHODS

Moisture Content	AASHTO T 265
Sieve Analysis	PTM No. 616
Mechanical and Hydrometer Particle Size Analysis of Soils	AASHTO T 88
Liquid Limit	AASHTO T 89
Plastic Limit	AASHTO T 90
Moisture-Density Relationship	PTM No. 106
Unconfined Compressive Strength	AASHTO T 208
Materials Finer Than No. 200 Sieve	PTM No. 100

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

TABLE J.3
CORRELATION OF STABILIZATION ADDITIVE AS A FUNCTION OF MATERIAL TYPE, PERCENT PASSING NO. 200 SIEVE, AND PLASTIC INDEX

Percent Passing No. 200	Plastic Index	Stabilizer	Soil Type												
			Granular Material								Silt-Clay Material				
											LL < 50			LL ≥ 50	
			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	CL	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-6	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 Portland cement with a fly ash material could result in a better material at a lower cost. If Portland cement content is too high, shrinkage cracking may develop. Partial Portland cement replacement with fly ash can mitigate this problem. If Class F fly ash is used, a small amount of activator, typically hydrated lime or calcium chloride, must be combined with the fly ash. Fluidized bed combustion fly ash not meeting AASHTO M 295 has been found to produce a useful blend with Portland cement.

Small contents of hydrated lime or Portland cement, typically 1.5% and 1.0% by weight, respectively, can produce higher early strength and resistance to moisture damage when added to asphalt 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. Laboratory Evaluation. Laboratory evaluation should be conducted by an AASHTO Materials Reference Laboratory (AMRL) or Cement and Concrete Reference Laboratory (CCRL) accredited laboratory, depending upon the material being tested and its intended usage. 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, dependent upon the stabilization process being considered.

3. Select Appropriate FDR Based on Findings. Based upon the results of work conducted in the previous sections, a determination of the specific FDR processes that may be suitable for the specific roadway should be made. 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.

J.3 DESIGN

A formal design protocol should be followed to optimize the performance of the pavement section. 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 asphalt stabilization. Strengths are typically measured following 7 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.

TEST DESIGNATION	TITLE
PTM No. 100	Standard Method of Test for Materials Finer than No. 200 Sieve in Mineral Aggregates by Washing
PTM No 616	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates
AASHTO T 176	Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
PTM No. 106 (AASHTO T 180)	The Moisture-Density Relations of Soils (using a 5.5-pound Rammer and a 12-inch Drop)

A. Pulverization Stabilization. Since only the in-place materials are being reclaimed, the mix design process should assess the strength potential of these materials when re-compacted at optimum moisture content.

The first step in the process is pulverization, which provides the basic operation for all FDR stabilization types. It consists of pulverizing the in-situ pavement layers and blending the predetermined level of underlying material. The layers and materials affected are determined as 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 1/2 inch of the lines and grades of the proposed roadway.

After the material is properly sized by pulverization and shaped, moisture may be 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 well distributed moisture content required to achieve proper compaction exists in the material.

Breakdown compaction takes place immediately behind the reclaimer to achieve a more consistent density throughout the mat. Requirements for 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 includes a 20-ton vibratory padfoot roller, a pneumatic 20-ton roller, and a padfoot roller for depths 8 inches or greater.

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 may be added in front of the roller, or by some other approved method. 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- to 14-ton single or tandem static drum roller.

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

B. Mechanical Stabilization. This process includes the integration of aggregate material, or RAP material, to improve the gradation of pulverized road materials. In this instance the mix design process will evaluate the incorporation of the appropriate amount and size of aggregate material to achieve the desired gradation and reclaimed strength.

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 asphalt 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, reclaimed asphalt pavement, or reclaimed 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 may be used alone or in combination with other asphalt or chemical stabilizing additives.

C. 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 (AASHTO M85) or blended cement (AASHTO M240), 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 may be applied in either dry or slurry form ahead of the reclaimer. The stabilizing additive may 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 dependent 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 the final product. If the reclaimed layer is too brittle, the fatigue life of the pavement will be reduced.

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

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 2 weeks before the planned start of work. Provide an approved mix design and work plan to the Department Representative 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 their responsibilities.

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. The Representative will oversee the analysis of the samples and the following information will be provided to the DME/DMM as part of the mix design.

3. Strength Requirements.

- Portland cement, Portland Cement Slurry, (AASHTO M85) or Blended cement (AASHTO M240), Admixtures (PennDOT Pub. 408, Section 711.3)
- Make, cure, and test three unconfined compressive strength specimens of FDR material and Portland 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.
    - The final mix design will use the amount of Portland cement that provides an unconfined compressive strength that meets these criteria: a minimum unconfined compressive strength value of 200 pounds per square inch in 7 days; and a maximum unconfined compressive strength value of 500 pounds per square inch in 7 days for roads that are designed with a minimum of 3-inch pavement overlay.
    - A minimum unconfined value of 300 pounds per square inch in 7 days and a maximum unconfined compressive strength value of 500 pounds per square inch in 7 days are required for roads that are to be surface treated or overlaid with less than 3 inches of pavement. The mix design chemical application rate may be determined by interpolation between compressive strength test results.
- 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 104°F before testing.

- For the final mix design, the required amount of L/FA or Lime Pozzolan will be that which provides an unconfined compressive strength that meets these criteria: a minimum unconfined compressive strength value of 200 pounds per square inch in 7 days; and a maximum unconfined compressive strength value of 500 pounds per square inch in 7 days for roads that are designed with a minimum of 3 inch pavement overlay.

- A minimum unconfined value of 300 pounds per square inch in 7 days and a maximum unconfined compressive strength value of 500 pounds per square inch in 7 days are required for roads that are to be surface treated or overlaid with less than 3 inches of pavement. The mix design chemical application rate may be determined by interpolation between compressive strength test results.

- 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 in-place materials are significantly wetter or drier than measured in the mix design, make field adjustments as recommended in the design under the guidance of the Representative and Qualified Technical Representative to obtain a satisfactory stabilized base course.

D. Stabilization Using Chlorides. Similar to pulverization or mechanical stabilization, this process includes evaluation of the addition of calcium or magnesium chloride to the material.

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: compactability and 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 0.1 to 0.15 gallon per square yard for each 1 inch of depth reclaimed followed by a fog seal at the rate of 0.25 gallon per square yard.

Magnesium chloride is available in a 30% concentration for FDR applications. The typical amount of magnesium chloride to be used for a 6-inch FDR application is 1.0 gallon per square yard, with the first application at 0.75 gallon per square yard and then a second application at the rate of 0.25 gallon per square yard, followed by a fog seal at the rate of 0.25 gallon per square yard. If a supplier is not listed in Publication 35, *Approved Construction Materials* (Bulletin 15), the use of magnesium chloride may be permissible on a project approval basis.

E. **Emulsified Asphalt Stabilization.** The addition of asphalt stabilizing additives to the FDR process is identified by the term asphalt stabilization. The addition of asphalt stabilizing materials to the pulverized layer can increase the stiffness of the layer and improve resistance to water-related damage. This product could, depending upon the design details, provide improved fatigue resistance to loading as compared with other stabilizing materials. These guidelines are also available in Publication 27, *Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures* (Bulletin 27).

Two separate processes can be classified as asphalt stabilization: conventional stabilization using emulsified asphalt material, and foamed asphalt processes. More study is required before foamed asphalt processes are implemented, so the focus here is conventional stabilization using emulsified asphalt material. In the conventional FDR with emulsified asphalt process, the asphalt additives can be blended into the reclaimed material through the liquid additive injection system. The asphalt 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. This is followed by intermediate shaping, and then a pass for blending the stabilizing additives into the pulverized mat. The multiple-step process is useful for achieving 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 57% to 65% residual asphalt. Publication 27, *Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special*

Bituminous Mixtures (Bulletin 27) specifies several different emulsions approved for reclamation. Publication 37, *Specifications for Bituminous Materials* (Bulletin 25) specifies the percentage of asphalt residue for those particular emulsions. When the water dissipates the emulsified asphalt is said to have broken, at which point the residual asphalt particles revert to a continuous film that coats the reclaimed material particles. The time required for the emulsified asphalt to break is influenced by the following factors:

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

Asphalt-stabilized FDR works well with other additives, including granular material and/or Portland cement or lime. The mix design process should evaluate whether the moisture from slurry is feasible for construction. Any water content which part of a slurry medium must be considered as a part of the total water in the mixtures. In keeping with this concept, it may be necessary to make a field adjustment to the amount of water added in the field if the in- situ moisture condition of the materials to be reclaimed is significantly different from that used during the mix design process. If more or less water is present at the time of reclaiming, the water added during the process should be adjusted to account for this change from the original mix design.

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 emulsified asphalt onto the pulverized material surface and blend it with the reclaimer. Once the liquid emulsified asphalt breaks, breakdown compaction should occur using a padfoot roller, for depths greater than 8 inches, or pneumatic roller, 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.

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

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 the mix design to the District Materials Engineer/District Materials Manager (DME/DMM) for approval 3 weeks before the planned start of work. Provide an approved mix design and work plan to the Department Representative 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 histheir responsibilities.

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 required by the appropriate documents listed in Section J.3.E.3, below, as part of the mix design to the DME/DMM.

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3. Referenced Documents.

TEST DESIGNATION	TITLE
AASHTO T 59	Standard Method of Test for Emulsified Asphalts
AASHTO M 320	Standard Specification for Performance-Graded Asphalt Binder
PTM No. 100	Standard Method of Test for Materials Finer than No. 200 Sieve in Mineral Aggregates by Washing
PTM No. 616	Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates
AASHTO T 176	Standard Method of Test for Plastic Fines in Graded Aggregates and Soils by Use of the Sand Equivalent Test
AASHTO T 209	Standard Method of Test for Theoretical Maximum Specific Gravity and Density of Hot-Mix Asphalt (HMA)
AASHTO T 166	Standard Method of Test for Bulk Specific Gravity of Compacted Hot-Mix Asphalt (HMA) Using Saturated Surface - Dry Specimens
AASHTO T 283	Standard Method of Test for Resistance of Compacted Hot-Mix Asphalt (HMA) to Moisture-Induced Damage
PTM No. 106	The Moisture-Density Relations of Soils (using a 5.5-pound Rammer and a 12-inch Drop)
ASTM D558-04	Standard Test Methods for Moisture-Density (Unit Weight) Relations of Soil-Cement Mixtures
ASTM D698	Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lb/ft^3)

4. Apparatus. In the design process, use a calibrated gyratory compactor, indirect tensile testing device, balance, oven, and other equipment.

5. Procedure.

a. Check Suitability of FDR Design Using Emulsified Asphalt. Design using emulsified asphalt is applicable for cases where reclaimed material is not excessively fine-grained. Specifically, the amount of material passing the No. 200 sieve <u>must not</u> exceed 25% and plasticity index <u>must not</u> exceed 6. Design suitability should be checked based on the guidance provided in Table J.3.

b. Emulsified Asphalt Selection. Select emulsified asphalt as approved in Publication 27, *Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures* (Bulletin 27). Publication 37, *Specifications for Bituminous Materials* (Bulletin 25) specifies the percentage of asphalt residue for those particular emulsions. These emulsions are specified with a minimum residue of between 57% and 65% when tested according to AASHTO T 59. The residue should meet AASHTO M 320 requirements for PG 58-22 or PG 58-28, and PG 64-22 or PG 64-28.

c. Requirements of the Reclaimed Material. The existing pavement or any reclaimed 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 shall 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 T 11 and T 27. If the gradation is deficient, mechanical stabilization should be applied before emulsified asphalt application. Mechanical stabilization includes the incorporation of virgin aggregate to the extent needed to satisfy gradation requirements. The final gradation shall meet the gradation criteria presented in Table J.4.

TABLE J.4
GRADATION REQUIREMENTS

SIEVE SIZE	PERCENT PASSING
2 inches	95
1 3/4 inches	90-95
3/4 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 T 176. SE is from the combined materials. SE should not be less than 30%.

d. Selection of Water Content for Design. A modified Proctor compaction shall be conducted in accordance with PTM No. 106 (AASHTO T 180, ASTM D558) to determine the optimum moisture content (OMC) at peak dry density. MatseeerialMaterials containing 20% or more passing the No. 200 sieve 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%. If a material contains less than 4% passing the No. 200 sieve or if no peak develops with the OMC curve, then fix the moisture content between 2% and 3%.

e. Preparation of Test Specimens. Sufficient samples shall be taken before the addition of water and emulsified asphalt to produce at least 95 ± 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 emulsified asphalt. These specimens shall be allowed to sit sealed as specified in Section J.3.E.5.d. Four emulsified asphalt contents shall be selected. Note: Four emulsified asphalt 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 emulsified asphalt content according to Table J.5.

TABLE J.5
REQUIRED NUMBER OF LABORATORY PREPARED SPECIMENS

TEST	NO. OF SPECIMENS PER EMULSIFIED ASPHALT CONTENT	SPECIMEN STATUS
Maximum Theoretical Specific Gravity	2	Loose
Indirect Tensile Strength, AASHTO T 283	6	Compacted

- Mixing - Aggregate material and emulsified asphalt shall be mixed in a mechanical mixer at a temperature of 68°F to 79°F for 60 seconds.
- Curing - Specimens after mixing shall be cured individually at 104°F for 27 to 33 minutes.
- Other Additives - If other materials are added, such as lime or Portland 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 emulsified asphalt addition, then it shall be added to the wet aggregate a day or more before mixing with emulsified asphalt. If lime is incorporated as slurry, then it shall be incorporated as slurry in the laboratory.

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

f. Compaction. Specimens shall be compacted in a gyratory compactor satisfying requirements outlined in Publication 27, *Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures* (Bulletin 27), Chapter 2, Section 7. Fifty gyrations shall be applied at a temperature of 68°F to 79°F. After the last gyration, 600 kPa pressure shall be applied for 10 seconds. The mold shall not be heated. After compaction, allow 5 minutes for the compacted mix to stabilize before removing from the mold.

- Curing - Specimens shall be cured at 104°F for 72 hours.

g. Volumetric Measurements.

- Gmm - Determine the Maximum Specific Gravity at each emulsified asphalt content in accordance with AASHTO T 209 and modified requirements outlined in Publication 27, *Bituminous Concrete Mixtures, Design Procedures, and Specifications for Special Bituminous Mixtures* (Bulletin 27).

- Gmb - Determine the Bulk Specific Gravity of all compacted specimens at each emulsified asphalt content using AASHTO T 166.

h. Indirect Tensile Strength and Moisture Susceptibility. The six prepared specimens at each emulsified asphalt content shall be tested according to AASHTO T 283, Section 11.

i. Selection of Emulsified Asphalt Content. A design emulsified asphalt content shall be selected to produce a FDR mixture that meets the design criteria in Table J.6. If more than one emulsified asphalt content produces mixtures which meet the criteria, then select the emulsified asphalt content that produces a mixture with the highest indirect tensile strength. The moisture damage resistance of the selected mix must be checked using AASHTO T 283.

TABLE J.6
DESIGN CRITERIA

PROPERTIES	CRITERIA
Indirect Tensile Strength of Control Specimens, min.	45-50 psi at 50 gyrations
Indirect Tensile Strength Ratio, min.	0.7

6. Report. The report for the Job Mix Formula (JMF) shall provide the following information:

- Physical address of the road and project information;
- Performance Grade of the emulsified asphalt 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; and
- Level of saturation and conditioned indirect tensile strength.

F. Foamed Asphalt Stabilization. A future research project will be performed to develop use guidelines.

J.4 CONSTRUCTION

The general construction sequence for FDR is similar for all processes. The generic description of 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.

A. Pulverization Stabilization.

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.

2. Material.

a. Reclaimed Material. 95% of the pulverized surface material is required to pass through a 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.

b. 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 3 weeks before commencement of work on the project. Provide the work plan to the Department Representative 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 their responsibilities.

3. Construction. Use equipment that produces the completed reclaimed base as follows:

a. Equipment.

- Maintain all equipment in a satisfactory operating condition as specified in Publication 408, *Specifications*, 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 16 inches, or as required by the design, with one pass. Provide equipment capable of pulverizing the existing pavement, base, and subgrade at a minimum width of 8 feet. 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 them is not permitted.

- Placement Equipment - Motor grader or by another method approved by the Representative.
- Compaction Equipment - Vibratory padfoot roller 40,000-pounds centrifugal force, particularly for depths 8 inches or greater, or Pneumatic Tire Roller 20 ton for breakdown compaction. Single or Tandem steel drum (static) roller 12-14 ton for finish rolling.

b. Weather Limitations.

Do not place paving mixtures from November 1 to March 31 unless approved in writing by the District Executive. Do not place mixtures when surfaces are wet or when the air or surface temperature fall or is anticipated to fall below 40°F within the subsequent required 7-day cure period. Cement Slurry with accelerating admixtures can be used in periods of cooler temperatures with the written approval of the DME/DMM. Do not place cement slurry mixtures with accelerating admixtures when the air temperature is anticipated to fall below 35º F within the first 24 hours following placement. Do not perform reclamation in rain, or if rain is anticipated within 2 hours of completion of the work.

TYPE OF STABILIZER	CLIMATIC LIMITATION FOR CONSTRUCTION
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 40ºF and rising. Complete stabilization at least one month before the first forecast temperature drop below freezing. Two weeks minimum of warm to hot weather is desirable after completing the stabilization work.
Portland Cement, Portland Cement Slurry, or Portland Cement with Fly Ash	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 40ºF and rising. Complete stabilization should be at least one month before the first forecast temperature drop below freezing. Cement Slurry with accelerating admixtures can be used in periods of cooler temperatures with the written approval of the DME/DMM. Cement Slurry with accelerating admixtures can be used in periods of cooler temperatures with the written approval of the DME/DMM. Do not place cement slurry mixtures with accelerating admixtures when the air temperature is anticipated to fall below 35º F within the first 24 hours following placement.
Calcium Chloride	Do not perform work when reclaimed material could be frozen. Air temperature in shade should be no less than 40ºF and rising. Complete stabilization should be at least one month before the first forecast temperature drop below freezing.

Emulsified Asphalt	Do not perform work when reclaimed material could be frozen. Air temperature in the shade should be no less than 59ºF and rising. The curing process for emulsified asphalt stabilization can be affected by very high humidity. Defer work when rain is imminent or when humidity is greater than 80%. Warm to hot, dry weather is preferred for all types of asphalt stabilization involving cold mixtures because of improved binder dispersion and curing.

c. General. FDR consists of a series of steps of reclaiming which includes subgrade material, with typical depths ranging from 5 inches to 16 inches in depth, or as required by the design, with the aggregate base. The motor grader is used to move and place the reclaimed material to the desired longitudinal grade and cross-slope.

d. 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 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 3/4¾-inch sieve and less than 35% passing the No. 200 sieve, or more than 30% retained on the 3/4¾- inch sieve) to use these methods, compaction shall be determined based upon non-movement of material under compaction equipment specified in Publication 408, *Specifications*, Section 210.3(a). Compact until pulverized material does not rut under a loaded tri-axle (GVW 75,000 pounds).

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

f. 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.

g. Surface Tolerance. When directed by the Representative, test the completed base for smoothness and accuracy of grade, both transversely and longitudinally, using suitable templates and straightedges. Satisfactorily correct any 3000-square yard area where the average surface irregularity exceeds 0.5 inch under a template or straightedge, based on a minimum of at least three measurements.

B. Mechanical Stabilization.

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.

2. Material.

a. Aggregate. Publication 408, *Specifications*, Section 703.2 (Type A, B, or C). Add the gradation and quantity to the mix as required to achieve a dense gradation as characterized by the Fuller Power Curve. If required, add Type A or Type B aggregate, based upon Publication 408, *Specifications*, Section 703, to the mix to meet the target gradation.

3. Construction.

a. General. FDR consists of a series of steps that include pulverization and mixing of the existing roadway surface between 5 inches and 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.

b. 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 ±3% of the optimum moisture content at the time of compaction. Commence rolling at the low side of the course. Leave 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 ten tests at random locations to determine the average in-place density of the control strip. Record and provide the results to the Department Representative.

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 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.

C. Chemical Stabilization.

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.

2. Material.

a. Stabilizing Agent.

- Portland Cement - Publication 408, *Specifications*, Section 701 (3 to 8% by weight)
- Portland Cement Slurry – Publication 408, *Specifications,* Section 701 (3 to 8% weight of cement). Portland Cement Slurry must be produced at a concrete plant listed in Bulletin 42 and supplied in Ready Mix Concrete Trucks approved by the DME/DMM. Other slurries must be provided in distributor and tanker trucks equipped with a recirculating pump and/or agitation system to prevent settling of the materials before application.
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b. Admixtures (PennDOT Pub. 408, Section 711.3)

- Hydrated Lime* - Publication 408, *Specifications*, Section 723 (2 to 6% by weight)
- Fly Ash* - Publication 408, *Specifications*, Section 724.2(a) (6 to 14% by weight)
- Lime Pozzolan - Publication 408, *Specifications*, 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). There are extensive safety concerns about quicklime. Its use may be approved on a project basis, so long as appropriate safety measures are in place.

3. Construction.

a. 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 ±2% by weight of liquids. Calibrate before use.
- Portland Cement Slurry must be produced at a concrete plant listed in Bulletin 42 and supplied in Ready Mix Concrete Trucks currently approved by the DME/DMM. Other slurries must be provided in distributor and tanker trucks equipped with a recirculating pump and/or agitation system to prevent settling of the materials before application.

c.b. Pulverization / Shaping. Before the application of any stabilizing additives, pulverize the roadway materials to the depth specified by the project mix design. Adjacent passes of the reclaimer shall overlap by a minimum of 1 foot to ensure that there are no areas of untreated material left in place. Also, adjacent passes of the reclaimer shall occur within 4 hours so that the longitudinal joint does not adjoin material that has set. Follow up with good compaction. Shape to within 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 may be added to the pulverized material to adjust the moisture content to at least Optimum Moisture Content (OMC), but no more than +3% over OMC. Addition of this water can be done through the machine's 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:

- Portland 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/DMM 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 canvas, 4 square feet or greater as approved for the specific project, 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 Representative, 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. For heavy applications of Portland cement, such as when the design requires more than 90 pounds per square yard, a two- lift system of application may be applied with PennDOT approval on a project basis. If a two- lift system is used, the applications should be equally divided. Such an approach may give more control over fugitive dust.
- Lime or Portland 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, or a .Ready Mix Concrete Trucks currently approved by the DME/DMM.
- Portland Cement Slurry delivered in Ready Mix Concrete Trucks - Verify “cement” application rate by calculating the weight of cement contained in the mixer truck and the area covered by the slurry after discharge by the Ready Mix Truck. The cement slurry producer shall supply a written record of the amount of cement, water, and admixture with each load of cement slurry. Evenly

and uniformly distribute the cement slurry, over the area of the prepared subgrade, calculated to provide the required application rate.. Accelerating or retarding admixtures maybe added to the cement slurry with the written approval of the DME/DMM.

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- 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 emulsion to break, based upon field observation, before rolling. The emulsion will likely break during a time window of 30 minutes minimum and 90 minutes maximum. Also, the color may change from brown to black. The condition necessary for rolling may be compared to the initial set of a concrete mixture; it will be influenced by field and ambient conditions and assessed on site. Obvious damage to the FDR material will be observed if a roller is placed on it prematurely. Commence rolling at the low side of the course. Leave 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 Department Representative. 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 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 Representative 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. Final compaction must be completed within 4 hours or less of exposure of cement to water.

- Protection of Surface - Protect the surface from drying and apply an asphalt 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 0.4 gallon per square yard. Use emulsified asphalt meeting the requirements of Publication 408, *Specifications*, Section 461.2(a). If using CSS-1H, apply at between 0.06 gallon per square yard and 0.09 gallon per square yard. Where the surface is utilized for maintaining traffic the application of the asphalt material shall be immediately followed by the application of an approved cover aggregate. Moist curing using suitable equipment is also acceptable. Documentation of the work should be maintained.

- Curing - Allow the chemically stabilized base to cure for at least 5 days after final compaction has been completed.

D. Stabilization Using Chlorides.

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.

2. Material.

a. Stabilizing Additive. Calcium Chloride - Publication 408, *Specifications*, Section 721. Use a minimum of 35% solution at a rate of 0.10 to 0.15 gallon per square yard for every inch of depth.

b. Aggregate. Publication 408, *Specifications*, Section 703.2 (Type A), No. 8, 10, 57, and 67 - Add the gradation and quantity to the mix as required. If required, add Type A or Type B aggregate, based upon Publication 408, *Specifications*, Section 703, to the mix to meet the target gradation.

c. 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 Representative or Qualified Technical Representative to obtain a satisfactory stabilized base course.

3. Construction.

a. Pulverization/Stabilization/Mixing. Pulverize and mix the roadway material to the design specified treatment depth. 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. Rough grade to desired cross slope and profile. Apply the designed quantity of calcium chloride and liquid to assure proper compaction.

b. 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 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 gauge 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 the results to the Department Representative. 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 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 Representative 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.

c. Curing. Allow the calcium chloride stabilized base to cure for at least 5 days after final compaction has been completed. Only light, local vehicular traffic should be permitted during the curing period. Protect the surface from drying. The selection of the most appropriate approach is site specific, depending upon traffic and the planned surface material applications. Options for consideration include the application of a curing membrane, which in the case of an anticipated overlay would be an emulsion, which can include a fog seal, or the daily distribution of water to the surface during the curing period, although the application of water during high humidity may be unnecessary. If water is applied to the surface, be sure to control the runoff of that water.

E. Emulsified Asphalt 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.

1. Description. Stabilization may be accomplished using a mixture of emulsified asphalt, imported mineral aggregate, and existing roadway material, mixed and proportioned 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.

- Reclaimer - Provide a self-propelled, traveling rotary reclaimer or equivalent machine capable of cutting through existing roadway material to depths of up to 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 8 feet and mixing any added materials to the specified depth. The cutting drum must have the ability to operate at various speeds (revolutions per minute), 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, emulsified asphalt, 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.
  - Use equipment capable of automatically metering liquids in the mixture to ensure thorough mixing of the reclaimed materials.
  - Maintain all equipment as specified in Publication 408, *Specifications*, Section 108.05(c).
- Placement Equipment - Motor Grader or by another method approved by the Engineer.
- Compaction Equipment – Vibratory pad-foot roller 40,000-pounds centrifugal force or Pneumatic Tire Roller 20 ton for breakdown compaction. Use single or tandem steel drum (static) roller 12-14 ton for finish rolling.

b. Reclamation.

- Pulverization - Before the application of any stabilizing additives pulverize the roadway materials to the depth specified by the project mix design. Adding Calcium Chloride during pulverization is acceptable.
- 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 calcium chloride is used as an additive, the chemical may be applied during pulverization.

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 3/4 inch of irregularity to the lines, grades and/or cross-slope of the proposed roadway. Avoid excessively working the chemically stabilized FDR material, which may detrimentally affect the ultimate strength of the stabilized layer.

- 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 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 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 emulsified asphalt stabilized base must undergo curing before application of the chip seal or overlay. The risk of rutting or moisture damage is increased if the overlay is applied prematurely; curing of the base must be complete. If the overlay is applied prematurely, moisture is retained in the base for a prolonged time and the rate of strength gain is reduced. 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 2 or 3 days to at least 2 weeks depending on the type and amount of materials used and the climatic conditions. Verify by coring or test pit that curing has occurred throughout the full depth of the FDR before the application of an overlay or wearing course.

- FDR should be proof rolled with a vehicle similar to the heaviest vehicle expected in traffic, or base opening on a strength measurement of the FDR, prior to opening to traffic. Same day return to traffic at posted safe speeds is possible. Roadway should be at 50% of the design optimum moisture content or 3% total moisture content, whichever is reached first, prior to overlay. No damage should be apparent at slow speed, less than 10 miles per hour. Otherwise verify strength by testing.

- 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 Representative, test the stabilized base for smoothness and accuracy of grade, both transversely and longitudinally using suitable templates and straightedges. Satisfactorily correct any 3000 square yard area where the average surface irregularity exceeds 0.5 inch under a template or straightedge, based on a minimum of at least three measurements. Provide a minimum surface cross slope of 0.5 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) 2 hours after completion of the base construction, with proof rolling. Limit heavy load traffic to 7 days later. 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.

F. Foamed Asphalt Stabilization. A future research project will be performed to develop use guidelines.

J.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.

A. Preliminary Activities.

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

2. Preconstruction Equipment Check. Prior to starting actual construction work it is important to conduct an operational examination 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.

3. Test Strip Construction. The construction of a preliminary test strip having a minimum length of 300 feet 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 4 square foot tarp or greater, as approved, to check the application rate of the stabilization material by spreading on the ground before application and weighing the material collected on the tarp after application. For cement slurry, verify “cement” application rate by calculating the weight of cement contained in the mixer truck and the area covered by the slurry after discharge by the Ready Mix Truck.

- Establish a rolling pattern for compaction of the FDR material.

- Verify the density achieved using a nuclear density gage (PTM No. 402).

- Verify the in-situ moisture content of the reclaimed material using the nuclear gage (PTM No. 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.

4. Quality Control Measures. Develop a testing plan that includes coring locations and the number of cores needed for testing. Select at least three cores for every 500 feet of application. The testing plan should include the following measures:

- Calibration of stabilizer metering equipment and spreading units
- Verification of stabilizer application rates
- Sampling to ensure proper Portland 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

If test results fall outside limits, the District Executive may accept the product to accommodate project conditions.

B. Acceptance Criteria. Full-depth reclamation work will be accepted on the basis of roadway width, depth, smoothness, and seven-day unconfined compressive strength for chemical reclamation according to Method B of ASTM D 1633, except using a recommended aspect ratio being 1:1.5 (specimen with diameter of 6 inches and height of 9 inches). For chemical stabilization processes the minimum acceptance strength varies from 200- 500 pounds per square inch as specified by the project mix design. Consideration of specimen aspect ratio is very important in determining compliance with these criteria. 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 asphalt stabilization the specimen must achieve minimum indirect tensile test strength of 50 pounds per square inch for acceptance.

The average surface tolerance must be 1/2 inch or less when measured at a minimum of three locations using a 10-foot straightedge. Surface cross slope must comply with the design requirement, or 0.5 inch per foot at a minimum.

Measurement and Payment:

Once the project meets the acceptance criteria, payment may be made on the area, in square yards, of the whole.

J.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, *Pavement Policy Manual*. Within the PennDOT pavement surface strategies the surfaces most likely to be used following FDR are primarily hot-mix asphalt or seal coat in cases of low truck traffic. The latter could also be an asphalt 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 truck traffic distribution
- 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. Either of these can be used following FDR reclamation. It is recommended that for a hot-mix surface a polymer-modified asphalt binder material is applied to the FDR surface prior to paving but is not required. 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 emulsified asphalt 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 emulsified asphalt 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.

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