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FULL-DEPTH RECLAMATION

A roadway rehabilitation technique using green technology

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While preparing your budget for next construction season, you conducted a roadway condition survey (an on-site evaluation of your road that takes into account the grade and slope, evidence of water damage and underlying cause, drainage, condition of shoulders, driving surface, average daily traffic (ADT), and current and future truck traffic) and observed a section of seriously damaged pavement. You determined that the pavement cannot be rehabilitated with a simple resurfacing because the distress likely exists in the base or subgrade. The road requires more than 15 to 25 percent base repair prior to resurfacing. You contact your PennDOT Municipal Services representative to discuss the poor condition of the municipal road.

More than likely, your Municipal Services representative is going to suggest that you consider full-depth reclamation, or FDR, as a way to rehabilitate your road. Full-depth reclamation takes the full flexible pavement section and a predetermined portion of the underlying material and uniformly crushes, pulverizes, and/or blends your road into a new subbase.

If you are considering FDR, you must conduct a thorough project evaluation to ensure the project's success. PennDOT Publication 447 contains guidelines for full-depth reclamation and is an essential document for you to follow when considering the various methods.

WHAT IS FULL-DEPTH RECLAMATION?

Full-depth reclamation is an in-place recycling process that reuses existing asphalt materials or gravel roads to produce a stabilized base course with improved structural characteristics. To this base, a final surface course or surface treatment is applied.

Full-depth reclamation has been proven to conserve energy and materials, eliminate reflective cracking, reduce or eliminate a loss of curb reveal, and restore proper crown and cross-slope. It is environmentally desirable and helps to reduce future maintenance costs. In addition, most FDR techniques reduce the inconvenience to the traveling public and local taxpayers when compared to other road rebuilding processes.

This road, a flexible pavement that is severely fatigued cracked, is a good candidate for full-depth reclamation. With high horsepower road reclaimers and state-of-the-art computerized additive systems, full-depth reclamation is able to cut through the asphalt road and underlying base layers to erase deep pavement crack patterns and eliminate the potential for reflective cracking. With today's equipment and stabilizing additives, FDR can be used to depths exceeding 12 inches, although it is usually performed at 6 to 9 inches.

A good road requires a suitable foundation, which in turn requires material stability. A material is stable if it has little or no volume changes and, either wet or dry, can resist deformation under repeated or sustained loads. Full-depth reclamation will create a uniform load-carrying capacity, a level surface, and a cross-slope on which to place a new bituminous surface.

Considering that soil types vary throughout Pennsylvania and may even vary within a section of roadway, we need to consider the following methods of FDR (Pub. 447):

- Pulverization (MS-0370-0005)
- Mechanical stabilization (MS-0370-0020)
- Calcium chloride stabilization (MS-0370-0030)
- Chemical stabilization (MS-0370-0035)
- Bituminous stabilization (MS-0370-0040)

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After full-depth reclamation has been chosen as the method to rehabilitate a road, a municipality must perform sampling and testing of asphalt materials, granular base, and subgrade soils to determine which, if any, stabilizing methods will be used. The sampling and testing methods can be performed by coring or excavating test pits. Several samples are necessary to account for changes in soil conditions that typically occur between different locations.

A qualified lab or technical representative performs the preliminary testing. Material composition, proposed pavement design, and the underlying base condition are used to determine the required tests. Samples must be taken from the road, and Table 2 (Pub. 447, Appendix A) is then used to determine which testing to conduct. After the preliminary testing is completed, the qualified entity will determine which stabilization method(s) to use based on the characteristics of the materials in Table 3 (Pub. 447, Appendix A). Then, further testing is performed and certified mix designs are developed to determine the quantities of the recommended additives as outlined in the specifications of the recommended stabilization method in Table 4 (Pub. 447, Appendix A).

TABLE 2: General Materials Testing for FDR – Laboratory Testing

DESCRIPTION OF TEST METHOD	TEST METHOD
Asphalt Mixtures	
Quantitative Extraction of Bituminous Paving Mixtures	PTM #702, AASHTO T164 or ASTM D2172
Asphalt Content of Hot Mix Asphalt by Ignition Method	PTM #757, AASHTO T308 or ASTM D6307
Resistance to Plastic Flow of Bituminous Mixtures using Marshall Apparatus	PTM #705, or AASHTO T245 (Modified)
Bulk Specific Gravity of Compacted bituminous mixtures using Saturated Surface-Dry Specimens	PTM #715, or AASHTO T166
Sieve or Mechanical Analysis of Extracted Aggregates	PTM #739 (for use with PTM #702, Method D), AASHTO T30 or ASTM D5444
Granular Base and Soil Materials	
Determining the Plastic Limit and the Plasticity Index of Soils	AASHTO T90 or ASTM D4318
Plastic Fines in Graded Aggregates and Soils by use of Sand Equivalent Test	AASHTO T176 or ASTM the D2419
Sieve Analysis of Fine and Coarse Aggregates	PTM #616, AASHTO T27 or ASTM C136
Materials Finer than 75μm (No. 200) Sieve in Mineral Aggregates by washing	AASHTO T11 or ASTM C117
Particle size analysis of Soils	AASHTO T88

TABLE 4: Testing Methods for Evaluation of Stabilized Materials FDR – Laboratory Testing

TYPE OF STABILIZER	TESTING PROCEDURES APPLICABLE
Hydrated Lime (2 to 6% by weight) Lime-Pozzolan (6 to 8% by weight)	Liquid Limit, Plastic Limit and Plasticity Index of Soils, AASHTO T90 or ASTM D4318 Moisture Density Relations of Soils and Soil-Aggregate Mixtures, AASHTO T99 or ASTM D698 or D1557 Unconfined Compressive Strength of Compacted Lime Mixtures, ASTM D5102, Procedure B
Fly Ash (6 to 14% by weight) Cement (3 to 8% by weight)	Moisture-Density Relations of Soil-Cement mixtures. AASHTO T134 or ASTM D558, Method B Compressive Strength of Molded Soil-Cement Mixtures, ASTM D1633 Wetting and Drying Compacted Soil-Cement Mixtures, ASTM D559, Test Method B
Asphalt Emulsion (1.5 to 4.5% by weight typical)	Refer to Guidelines and design process for Full Depth Reclamation listed in Chapter 2, Section 7 of Bulletin 27 "Bituminous Concrete Mixtures, Design Procedures and Specifications for Special Bituminous Mixtures."
Calcium Chloride (Use a minimum of 35% solution at a rate of 0.45 to 0.68 l/m2 for every 25 mm of depth, (0.10 to 0.15 gallons/square yard for every inch of depth)).	Liquid Limit, Plastic Limit and Plasticity Index of Soils, AASHTO T90 or ASTM D4318 Moisture Density Relations of Soils and Soil-Aggregate Mixtures, AASHTO T99 or ASTM D698 or D1557

WHAT IS PULVERIZATION?

Pulverization is the most basic and economical FDR method available. Under this process, all the in-situ pavement layers are pulverized and blended with a predetermined amount of the underlying base material. A self-propelled rotary reclaimer, capable of cutting through existing roadway materials with one pass to a depth of 5 to 16 inches and a minimum width of 8 feet, is used. The operator of the reclaimer controls the sizing of the pulverized material by balancing the machine's forward working speed, cutting rotor speed, gradation control beam position, and mixing chamber front and rear door position. When the process is completed, 95 percent of the pulverized surface material must pass through a 2-inch sieve.

The machine is equipped with a computerized integral liquid proportioning system capable of regulating and monitoring the water application rate relative to depth and width of cut and speed. This ensures that the proper amount of moisture is added to the pulverized material to aid in compaction. Breakdown compaction takes place immediately behind the reclaimer to achieve a more consistent material density throughout the reclaimed mat prior to any shaping with the motor grader.

Compaction equipment consists of a vibratory pad-foot roller (52,000-pound centrifugal force) and/or pneumatic tire roller (25 tons) relative to the depth and characteristics of the pulverized layer.

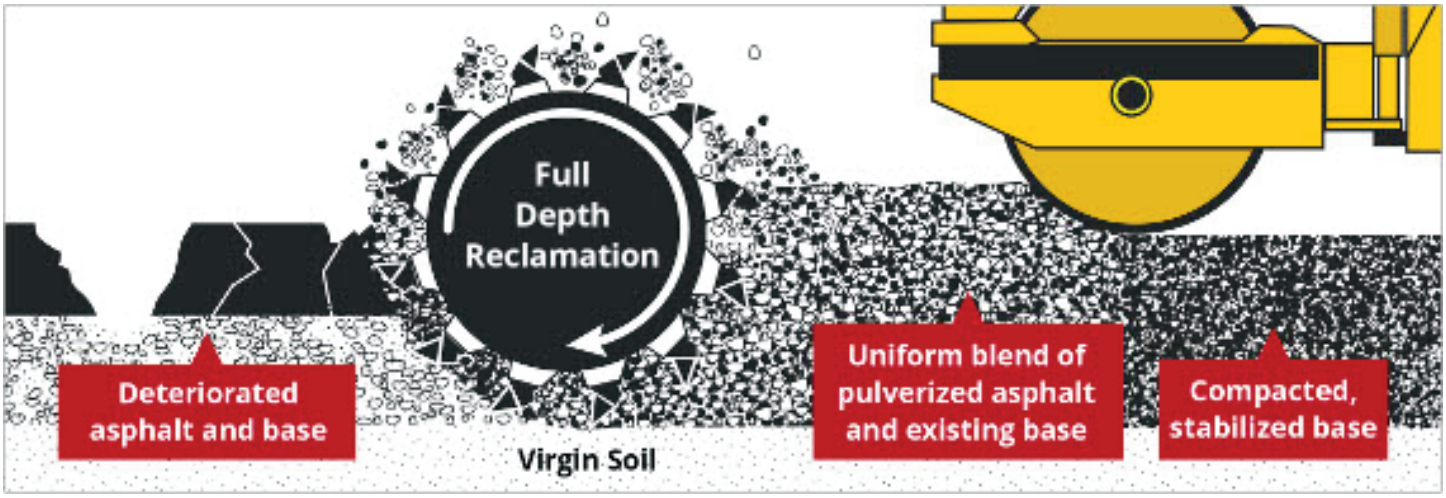
TABLE 3: General Guidelines for Selecting Stabilizers for FDR – Laboratory Testing

CHARACTERISTICS OF RECLAIMED PAVEMENT MATERIALS	TYPE AND TYPICAL TRIAL PERCENTS OF STABILIZER
Reclaimed asphalt pavement (RAP) having some amount of silty-clay soil from subgrade with a plasticity index (P.I.) greater than 10.	Lime-pozzolan (6-8% by weight) Hydrated Lime (2-6% by weight)[1]
Materials consisting of 100% RAP or blends of RAP and underlying granular base or soil. The soil fraction can have plasticity or be similar to soils acceptable for lime treatment.	Fly Ash (6-14% by weight)[1]
Materials consisting of 100% RAP or blends of RAP and underlying granular base or non-plastic or low plasticity soils. There should be sufficient fines to produce an acceptable aggregate matrix for the cement treated base (CTB) produced (not less than 45% passing the 4.75 mm or No. 4 sieve preferred).	Cement (3-8% by weight)
Materials consisting of 100% of RAP and underlying granular base or non-plastic or low plasticity soils. The maximum percent passing the 75μm (No. 200) sieve should be less than 25%, the plasticity index less than 6 or the sand equivalent 30 or greater, or the product of multiplying the P.I. and the percent passing the 75μm (No. 200) sieve being less than 72.	Emulsified Asphalt (1.5-4.5% by weight)[2] Determine the optimum emulsion content based on the averages for maximum stability and maximum density for the mixture specimen.
Materials consisting of a blend of RAP and non-plastic base soils with 8-12% minus 75 micron material. Small amounts of clay 3-5% are also beneficial.	Calcium Chloride (35% minimum solution at a rate of 0.45 to 0.68 l/m2 for every 25 mm of depth, (0.10 to 0.15 gallons/square yard for every inch of depth)).

[1]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 will be referred to as Lime/Fly Ash (L/FA).

[2]Small amounts of hydrated lime or cement, typically 1.5 and 1.0 percent respectively by weight, are being added with asphalt emulsion to produce reclaimed mixtures with higher early strength and greater resistance to water damage.

To select the proper stabilizing agent, the qualified lab or technical representative must have an understanding of both the soil and additive to be used. The additive must be of the correct type and quantity to produce a stable base to apply the final proposed surface.



A single reclamation pass is typical only with pulverization. No other stabilizers are added, and no major geometric corrections are neccesary. This process is commonly used with thin (<6-inch) asphalt pavement thicknesses.

After breakdown compaction, a motor grader provides shaping to establish proper grade and cross-slope. During the intermediate rolling, loose aggregate generated by the motor grader is then either kneaded by a pneumatic roller or seated by a heavy smooth drum vibratory compactor.

Final or finish rolling is completed with a single or tandem steel-drum (static) roller (12 to 14 tons). Occasionally, water is added to the surface material to counteract any drying that occurs from motor grader material manipulation. Compaction is necessary until the pulverized material does not deform or rut under a loaded tri-axle (75,000 pounds). All portions of pulverization should be completed during daylight hours. To prevent marring, distortion, or damage of any kind, the finished portion of the pulverized material must be protected from construction equipment.

HOW IS MECHANICAL STABILIZATION DIFFERENT THAN PULVERIZATION?

Unlike the basic FDR method of pulverization, mechanical stabilization involves the incorporation of imported granular materials during the pulverization or mixing pass. Some of the more common imported granular materials are recycled asphalt pavement (RAP), crushed aggregates, and crushed recycled concrete. These stabilizers can be spread either ahead of the pulverization pass or incorporated into a blending pass after prepulverization and shaping. The granular material can be tailgated with dump trucks and spread to a uniform thickness with a motor grader. To achieve a higher level of consisitency, the material can be placed with a conventional paver. Mechanical stabilization is used for the following reasons:

- To improve the grading of the reclaimed material and thus increase its structural integrity.
- To decrease the in-place bitumen content and increase the mixture's structural stability. Incorporating virgin aggregates (lean in-situ materials that contain high concentrations of bitumen) ensures the excess bitumen has more surface area in which to coat.
- To establish projected increased pavement elevations and improve vertical curves by importing virgin or recycled granular materials prior to the FDR process.
- To more easily provide widening without sacrificing section thickness.

Mechanical stabilization is a cost-effective FDR process that can be used either alone or in combination with stabilizing additives in the chemical families and/or bituminous products based upon soil characteristics encountered within the project area.

As with pulverization, after the reclaimer completes the mechanical stabilization method, compaction of the homogenous mixture must achieve a target density of at least 98 percent of the density requirements of the control strip.

WHY DOES CALCIUM CHLORIDE STABILIZATION WORK IN FULL-DEPTH RECLAMATION?

Calcium chloride is a hydroscopic chemical, meaning it absorbs moisture. This extra moisture facilitates compaction and then imparts strength from properly graded quality aggregates. Calcium chloride is used to expedite the compaction process by slowing the rate of evaporation of moisture from the mixture during compaction and to aid in the retention of moisture during the service life of the soil-aggregate mixture.

Calcium chloride is generally the least expensive of the stabilizers used with full-depth reclamation and has been shown to reduce frost heaving. If the fines content of the mixture is higher than recommended, cement is sometimes used in small percentages with calcium chloride.

A nurse trailer containing calcium chloride is pulled behind a reclaimer on a pulverization FDR project in York County. The use of calcium chloride helped to provide dust control between the time the FDR was completed and a week later when the hot-mix asphalt paving on this industrial road was started. The calcium chloride stabilized base must cure for at least five days after final compaction.

WHAT CHEMICALS DO WE NEED TO STABILIZE A ROAD WITH FULL-DEPTH RECLAMATION?

As indicated earlier, the municipality must do preliminary sampling, and a geotechnical consultant or soil scientist experienced in performing the proper tests must complete analysis of asphalt materials, granular base, and subgrade soils to determine which chemicals are needed based on roadway materials and anticipated traffic type and volume. Full-depth reclamation may be stabilized with wet or dry chemical additives, such as cement, hydrated lime, fly ash, lime pozzolan, and various blends thereof, which for the most part are used as cementitious or pozzalonic additives.

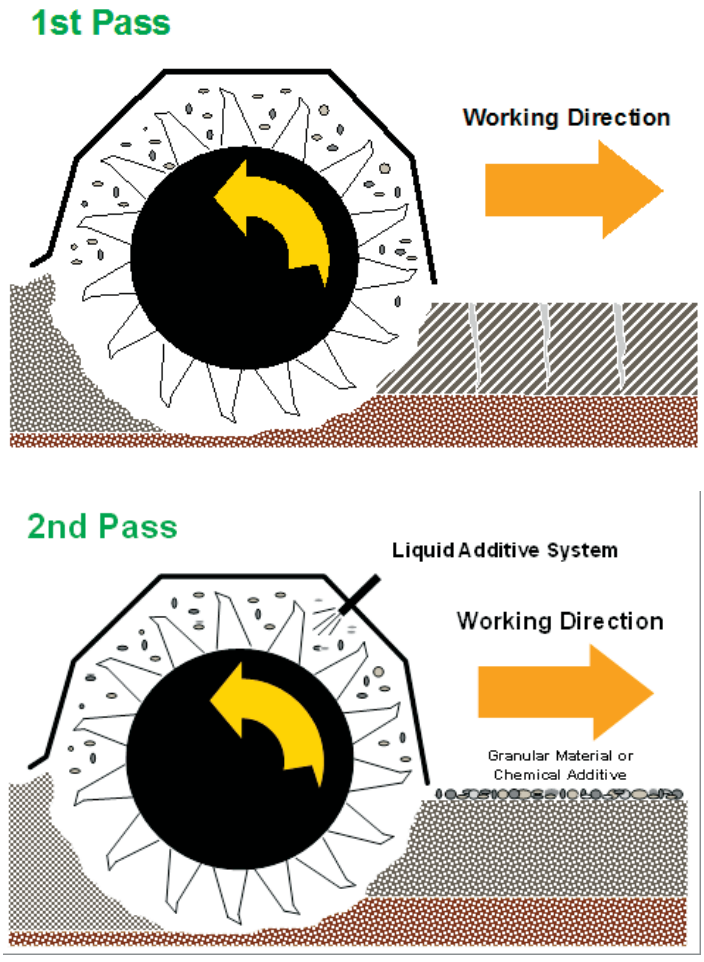
Strength is gained through the cementing together of material particles and aggregates in the reclaimed layer. The strength gain is governed by the type of reclaimed material being stabilized, along with the type and amount of stabilizers as determined through laboratory testing.

Cement stabilization can be used with most soils, although silts and heavy clays will require large percentages of cement for successful stabilization. Three control factors determine if soil–cement mixtures are successful: proper moisture content, adequate compaction, and proper cement content. That is why it is important to perform the necessary testing, monitoring, and proper mix design when considering cement stabilization. Cement is easy to apply dry or as a slurry and can be less expensive. Dry applications, however, can cause unacceptable dust problems in developed areas.

Lime stabilization involves the use of hydrated lime to improve plastic clay soils. The lime reacts with the clay and forms complex silicates or cementing materials. Applications of lime as slurry make handling and dust control much easier.

Fly ash stabilization can be used with cement to decrease shrinkage cracking or in combination with lime to increase the amount of silicates in silicate-deficient highly silted materials.

Lime pozzolan stabilization is necessary for soils with low amounts of clay to react and form a strong cementitious mixture.



The "first pass" is considered the pulverization pass, while the "second pass" is the mixing pass. Both first and second passes are required when performing FDR with chloride, chemical, or bituminous stabilization. The second pass is sometimes necessary with the mechanical stabilization process. The stabilizers are added dry or wet to the road after the pulverization pass and are then mixed uniformly and blended with the existing roadway surface material and underlying granular material to create a homogeneous mixture of reclaimed base material. Liquid additives can also be placed into the mixing chamber during the second pass.

WHEN DO WE ADD BITUMINOUS STABILIZERS TO A PROJECT?

Bituminous stabilization is a cost-effective way of improving the strength of a reclaimed material and reducing the effects of water. Bituminous stabilizers also work well in combination with virgin aggregates, such as AASHTO #8, 57 and/or 67. As with the other stabilizing additives, the addition of bituminous stabilizers, hydrated lime, or cement is based upon the mix design that is prepared by the qualified entity. The bituminous stabilizer is easy to apply and is dust-free. It is sprayed into the reclaimer's cutting head where it is mixed with the recycled materials. An emulsion-stabilized base is flexible, fatigue resistant, and not prone to cracking.

Lime/fly ash is mixed after the pulverization pass is completed on this FDR project near the Mason-Dixon Line.

(left) During bituminous stabilization FDR, such as on this road in Robesonia borough, the breakdown compaction takes place immediately after the emulsion break and can be followed with motor grader shaping. (right) A vibratory pad-foot roller compacts the FDR mixture.

HOW DO WE SELECT A QUALIFIED LAB OR TECHNICAL REPRESENTATIVE?

The selection of a qualified lab or technical representative can be done with help from your municipal engineer or Municipal Services representative or by searching the Internet or telephone directory for geotechnical consultants or soil scientists in your area. At a minimum, it is important that the municipality have a mix design prepared prior to bidding any FDR work using additives.

IS IT NECESSARY TO APPLY A BITUMINOUS PRIME COAT?

When using chemical FDR, it is important to protect the surface from drying and to apply a bituminous prime coat over the entire surface during the minimum five-day curing period. When the FDR surface is to be used for maintaining traffic, the application of bituminous material should be immediately followed by an application of an approved cover aggregate.

When an FDR surface is stabilized with bituminous material and excessive raveling is present, a bituminous prime coat should be applied over the affected area.

WHAT OTHER ITEMS SHOULD WE BE AWARE OF?

PennDOT Publication 447 provides a great deal of information, including descriptions of materials, construction specifications that describe the proper equipment, weather limitations, compaction and density requirements, protection of the FDR surface until a final surface coating is applied, surface tolerances, and how to measure and pay a reclamation contractor. Publication 447 also contains a detailed use and design guide for evaluating FDR stabilization that municipalities can follow for the process description, laboratory testing, and additive selection.

If you are performing FDR using mechanical, calcium, chemical, or bituminous stabilization, you are required to submit the results of the composition of mixture and/or mix design to the PennDOT district materials engineer or manager for approval three weeks before the start of the work.

Mandatory pre-bid and preconstruction meetings are recommended to cover the project details. Your bid documents should also include the requirement that the responsible contractor with the lowest bid submit a quality control plan to define how

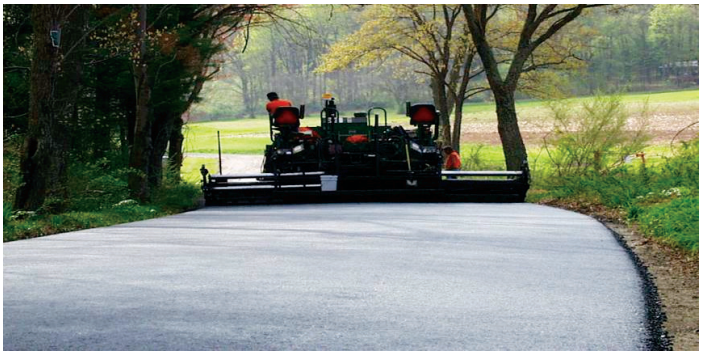
Schoonover Road in Graham Township, Clearfield County, before and after its calcium chloride stabilization FDR project.

the contractor will monitor the FDR construction and address any problems that may arise during construction due to an excess or lack of moisture throughout the FDR project.

A loaded wheel test of the finished FDR road (prior to surface placement) with a loaded tri-axle is an inexpensive method to proof roll the compacted surface. This type of proof rolling can uncover weak areas or a soft base within the project limits. The soft areas will need to be repaired prior to the surface application.

Full-depth reclamation is distinguished from other rehabilitation techniques, such as cold in-place recycling, by the fact that the rotor or cutting head in FDR always penetrates completely through the asphalt section and into the underlying base layers to erase deep pavement crack patterns and eliminate the potential of reflective cracking. In contrast, cold in-place recycling is a pavement-only recycling process that typically has a treatment depth of 3 to 5 inches, which is later capped with a scratch or leveling course and a 1½-inch asphalt overlay. PennDOT Publication 408, Section 341, provides more information on cold recycling of your bituminous base course.

Full-depth reclamation is a proven process that is environmentally sound, gives enhanced performance, and saves money.



Palestine Road in Wayne Township, Schuylkill County, receives final paving. Since 3 inches of 19-mm SUPERPAVE were placed over top of the FDR at this location in 2009, the road has not needed any maintenance.

Want More Assistance?

For more assistance on what is involved with full-depth reclamation, you might want to consider attending the LTAP Roads Scholar course on Full-Depth Recycling or request a technical assistance on-site visit to your municipality from LTAP.

You could also search any of the following websites for more information:

- PennDOT Municipal Services:
  www.dot.state.pa.us/Internet/Bureaus/pdBMS.nsf/BMSHomePage?OpenFrameset
- PennDOT Publication 447, Approved Products for Lower Volume Local Roads:
  ftp://ftp.dot.state.pa.us/public/PubsForms/Publications/PUB%20447.pdf
- FHWA - Distress Identification Guide:
  www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/03031.pdf
- Asphalt Recycling & Reclaiming Association:
  www.arra.org/presentations/full-depth_reclamation.pdf
- Pennsylvania Association of Asphalt Material Applicators:
  www.paama.org/index.html