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Best Practices for Full-Depth Reclamation Using Asphalt Emulsions

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16. Abstract

Full depth reclamation of asphalt pavements using asphalt emulsions (AEFDR) is a process that recycles and rejuvenates the existing asphalt pavement surface, base, and, sometimes, the subgrade, providing an improved underlying structure for the new asphalt pavement. This report provides design guidance, standardized plans and specifications, construction inspection best practices, materials testing procedures and frequencies, a performance evaluation process, and quality assurance and quality control protocols when constructing FDR projects.

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EXECUTIVE SUMMARY

As deterioration of our pavement network increases and funding to rehabilitate these pavements decreases, the search for more cost effective solutions to maintain a viable infrastructure will continue. One solution is reusing material in the existing pavement to form the new pavement. Various forms of in situ pavement recycling have been practiced for many years. The current ‘mill-and-fill’ technique of removing the top layer of deteriorated asphalt and replacing it with a new hot mix asphalt overlay has become standard practice. However, when the pavement structure is deteriorated to the point that deeper repairs are required, more comprehensive techniques are needed. One method of accomplishing this is full-depth reclamation. This process grinds up the asphalt pavement, aggregate base, and, sometimes, the upper layer of the subgrade to form a homogenous base course for the new wearing course. An improvement to this process stabilizes the pulverized asphalt pavement, base, and, sometimes, subgrade with asphalt emulsion.

This best practices manual describes the planning, design, construction, and performance evaluation processes for asphalt emulsion stabilized full-depth reclamation (AEFDR).

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INTRODUCTION

Full-depth reclamation (FDR) of asphalt pavements is a rehabilitation technique where the existing asphalt pavement some, or all, of the base course, and some of the subgrade are uniformly pulverized and blended to form a new, homogenous base course. After compaction, this new base course serves as the foundation for a new pavement surface. This process can be done using water, asphalt emulsions, lime, fly ash, portland cement, and calcium chloride as binding mediums. This best practices manual focuses on asphalt emulsions as the binder.

Major steps in the FDR process using asphalt emulsions (AEFDR) are pulverization of pavement, base course, and perhaps subgrade, adding additional virgin aggregates, if necessary, remixing with emulsified asphalt, shaping, compaction, and placement of new wearing course.

Pavements that are candidates for AEFDR include those with severe rutting, transverse thermal, longitudinal, alligator, or edge cracking, raveling, potholes, bleeding, bumps, oxidation, and polishing.

Numerous benefits are derived from the use of AEFDR for pavement rehabilitation. These include economical, sustainable outcomes that reduce demand on raw materials, energy consumption, and production of greenhouse gases, while maintaining functionality and performance. Specifically, the following benefits are known:

- Cost effective rehabilitation of underlying structural elements
- In situ materials are reconfigured to provide improved pavement structure
  - Reduces surface irregularities and distress type, severity, and extent
  - Addresses some existing material problems such as moisture damage
- Construction Advantages
  - Reduces traffic disruption
- Environmentally compatible and sustainable cold in situ processes
  - Conserves nonrenewable resources
  - Reduces emissions
  - Reduces fuel consumption
  - Reduces number of haul trucks
  - Eliminates materials generated for disposal
- Potentially useful for all traffic levels

This best practices manual provides design guidance, standardized plans and specifications, construction inspection best practices, materials testing procedures and frequencies, a performance evaluation process, and quality assurance and quality control protocols to use when considering rehabilitating asphalt pavements using the AEFDR process.

WHAT IS AEFDR?

Asphalt emulsion full-depth reclamation (AEFDR) is a process that pulverizes an existing asphalt pavement, mineral aggregate base course, and, sometimes, the subgrade and mixes this resulting ground up granular material with a small quantity of emulsified asphalt. The emulsified asphalt acts as a binding medium together with the small quantity of water needed in the pulverization process. The resulting blend is a granular composition with more strength and reduced moisture sensitivity than occurs if water is the only binding medium. The emulsion content is usually less than 3 percent by weight of the combined pulverized layers and coats mostly the fine aggregate fraction of the mixture. The result is a new structural layer that resembles something between a water bound aggregate base course and cold mixed asphalt. Unlike hot-mix or cold-mix asphalt, AEFDR is not black in appearance nor sticky because the coarse aggregate particles are not well coated with asphalt. Instead, the asphalt coats only the finest aggregates, producing a mastic between the coarse particles and resulting in only a slight darkening in color of the material after treatment.

The compacted AEFDR has a void content similar to that of an aggregate layer, not an asphalt concrete. Therefore, AEFDR should be treated more like an aggregate base during construction.

The intent of AEFDR is to produce a new base layer for the wearing course placed on top. This wearing course is usually hot mixed asphalt, but could be any all-weather surface including seal coats.

HOW THIS MANUAL IS ORGANIZED

This manual has been organized into sections describing each phase of the AEFDR process. The basis for much of this description comes from the literature, so the first chapter in the report is background information discovered while putting the manual together. The background is followed by two chapters describing each step in the AEFDR process as outlined below.

- Preconstruction
    - Traffic
    - Existing Pavement Structure and Materials
    - Climate
    - Gradation of Materials After Pulverizing
    - Mixture Design for Asphalt Emulsion Content
    - Pavement Structural Design
    - Specifications
- Construction

  - Equipment and Operations
  - Planning Cuts for Longitudinal Joint Placement
  - Water and Emulsion Quantities
  - Pavement Gradient
  - Transverse Joints
  - Uniform Compaction
  - Quality Control and Quality Assurance
- Guide Specification

BACKGROUND

Much has been written regarding the rehabilitation of asphalt pavements using cold in situ recycling techniques (Epps, et al 1980, Scherocman 1983, Israel 1984, Epps 1990, Asphalt Recycling and Reclaiming Association 1992, Caterpillar 1995, Wirtgen 2004, Jones 2008, South Africa 2009). The benefits of this process (NCHRP 2011) have been identified by owner agencies and contractors to include (*a*) using fewer natural resources; (*b*) eliminates materials generated for disposal; (*c*) reduces fuel consumption; (*d*) reduces greenhouse gas emissions by between 50% and 85%; (*e*) minimizes lane closure times; (*f*) improves driver safety by improving friction, providing lane widening, and eliminating overlay edge drop-off; (*g*) maintains height clearances, which eliminates the need to adjust appurtenances; (*h*) addresses existing material deficiencies such as moisture damage; (*i*) reduces costs of preservation, maintenance, and rehabilitation; and (*j*) improves base support with a minimum of needed wearing course. And although FDR is a specific type of recycling and may not provide item (*g*) above, it certainly does qualify for the remaining nine advantages.

The FDR process has been used by 34 states and by at least 14 states for more than ten years. Twenty-two states use FDR on 50 lane-miles per year, six states for 50-100 lane miles and two states report usage at greater than 100 lane-miles annually (NCHRP 2011).

The most common wearing course placed on top of an FDR project is a new hot mix asphalt overlay. A few projects have been constructed with concrete over FDR. However, some states have reported using chip seals, slurry seals, open-graded friction courses, thin non-structural overlays, and even fog seals.

Because FDR includes both the existing pavement, base, and, sometimes, the subgrade, the structural section must be known before construction begins to be sure there is enough material available to provide an adequate section for the rehabilitated pavement, and to be sure the existing pavement will support the FDR train of equipment. The most common methods of assessment include coring of the pavement, auger and tube samples for base and soils classifications, dynamic cone penetrometer testing (DCP), California bearing ratio, resistance value (R-value), historical records, falling weight deflectometer (FWD) layer moduli, ground-penetrating radar (GPR), or local experience (Jahren et al. 1999; Loizos and Papavasiliou 2006; Loizos 2007; Malick et al. 2007). According to the recent NCHRP survey, states most frequently (more than 50% of the time) use coring and boring to determine thickness, and often (25 to 50 % of the time) use falling-weight deflectometer readings to determine structural integrity. Ground penetrating radar was reported to be rarely used for this purpose (NCHRP 2011). Wirtgen (2004) suggests cutting a test pit, coring, and dynamic cone penetration testing to determine materials characteristics prior to construction. Information obtained includes soils, base, and pavement properties needed to assess the existing structural capacity and compare this with the desired capacity to come up with the necessary overlay thickness to be applied, if any.

Mixture designs for FDR projects stabilized with emulsion are varied. Methods in use are Marshall, Superpave, Wirtgen (Wirtgen 2004), Proctor (AASHTO T99), modified Proctor (Kim and Labuz 2007), and unconfined compressive strengths.

Selection of the appropriate project on which to use FDR is judged one of the most important aspects of the process. Of the 34 states responding to the NCHRP survey that indicated they use FDR, 25 indicated they conduct a condition survey to identify candidate projects, and 10 use smoothness measurements to further refine the selection process. Pavement geometry plays a role in project selection, however, because the equipment utilized in FDR is relatively large. Therefore, tight turns with less than 40 ft. radiuses or switchbacks, when manholes or other castings in the pavement layer are frequent or when grades exceed 8 percent, FDR should be examined to determine if it is appropriate. However, FDR can be used where superelevation, cross-slope correction, or minor profile corrections are required, and in urban environments with curb and gutter profiles and where even minor widening needs are required.

Climate does not affect the use of FDR as it does other pavement recycling processes according a recent survey (NCHRP 2011) completed by both owner agencies and contractors. The survey ranked FDR as ‘very good’ as a construction process in the four climatic regions of hot-dry, hot-wet, cold-dry, and cold-wet.

The FDR construction process pulverizes the existing asphalt pavement, mixing this with the base, and, sometimes, the subgrade to form a new base course. When asphalt emulsion is mixed with the FDR pulverized asphalt, base, and subgrade, a new stabilized base with improved structural capacity somewhere between crushed stone base and hot mixed asphalt is created. Crushed stone base usually is assigned an AASHTO structural layer coefficient of 0.12 to 0.14. Hot mixed asphalt is often assigned a layer coefficient of 0.40 to 0.44. When the FDR base is stabilized with asphalt emulsion it seems reasonable the layer coefficient of this new material would be somewhere between 0.12 and 0.44 depending upon the quantity and quality of the combined, pulverized materials and the properties of the asphalt emulsion residue. Romanoschi et al. (2004) recommended a coefficient of 0.18 for foamed asphalt-stabilized FDR. The Ontario Ministry of Transport (MTO) uses 0.20 to 0.28 (estimated from gravel equivalent) for foamed FDR (Thompson et al. 2009). In addition, although foamed asphalt is somewhat different from emulsion, the results of the stabilization process for both systems are probably similar.

Although the asphalt emulsion FDR (AEFDR) process could be done with the asphalt emulsion added to the pulverizer during the first pass (Wirtgen 2004), most reports indicate that two steps are used to accomplish this task (FHWA 1997; Harris 2007). The first pass of the pulverizer grinds up the existing asphalt pavement, base course, and, sometimes, the subgrade to create a mixture that should all pass the 1-1/2-inch screen. This loosened layer is then compacted using a vibrating pad-foot or similar sheep’s-foot roller to approximately 1 percent less than the optimum moisture content determined by a standard Proctor (AASHTO T99) moisture density test. This is followed by a 20-ton pneumatic roller with the objective of locating weak areas. Weak areas identified by this pneumatic 'proof rolling' are then repaired to the full-depth of the pulverized layer with crushed stone base. After achieving 95 percent of the maximum dry density with the vibrating rollers the profile of the new untreated base course is established by fine grading with a conventional motor grader. A second pass of the pulverizer then occurs with the addition of asphalt emulsion. This second pass can occur immediately following grading of the first pass or can occur after opening the roadway to traffic for a period of time. The emulsion stabilized base course is then compacted using conventional double-drum, vibrating, steel-wheel rollers to achieve the appropriate density. Curing of the stabilized base must occur before placing the new wearing course. This curing is usually considered completed after 50 percent of the emulsion water has evaporated.

The areas of concern to most agencies for process control and acceptance for FDR are shown below.

- Project Concerns
    - Treatment depth
    - Addition of additives (type and quantity)
    - Additives thoroughly mixed
    - Placement of recycled mix
    - Excess Moisture Removed
    - Compaction
    - Consistent Surface Appearance
    - Proper grade and cross slope
- Reclaimed Mix Properties of Concern
    - Gradation
    - Asphalt Content
    - Recovered binder Properties
    - In-place Density
    - Recycled Mixture Strength
    - Compaction Uniformity

Quality control activities include emulsion testing to determine the percentage of residue from distillation (Thompson et al. 2009). Field-testing recommendations include depth measurements, compaction monitoring with nuclear density gauge (direct transmission), and moisture content verification before overlay.

Suggested specification requirements have been summarized as follows:

- Compaction
    - 97% of laboratory density
    - 92% to 98% of theoretical maximum density (Thompson et al. (2009)
    - Maximum dry density and optimum moisture content (Franco et al. 2009)
- Dry Marshall stability, minimum, of
    - 1,250 lb. (Caltrans 2008),

- Indirect tensile strengths, minimum, of
  - 43 to 50 psi; dry and 22 to 25 psi; wet (Lane and Kazmierowski 2005a)
  - Tensile Strength Ratio
    - Greater than 70% (Caltrans 2008),
    - Greater than 50% (Lane and Kazmierowski 2005a)
- Resilient modulus of 120 to 150 ksi (SemMaterials)
- Moisture content of less than 2.0%, with no sub lot value above 3.0% (Lane and Kazmierowski 2005a)

The types of specifications used in FDR include method, end result, performance, and warranty. In a recent survey, 22 out of 34 states utilize method specifications; 7 out of 34 use end result; 3 out of 34 use performance; and 1 state uses a warranty specification (NCHRP 2004).

Although the FDR process provides an improved base course compared with a conventional water bound base, the amount of improvement with respect to structural capacity still requires study. However, some information on the improvement provided by asphalt emulsions in the FDR process was discovered based on experience in Georgia (Besseche et al. 2009). This project was to be reclaimed using full-depth reclamation with asphalt emulsion as a binder. The project was a one-mile-long, two-lane road, with widening, constructed in 2006. The hot-mix asphalt surface and base were pulverized to 9.5 inches, and an extra 1.5 inches of pre-pulverized base was added to the mixture. A second and third round of pulverization with asphalt emulsion was done to 8 inches depth to complete the base construction. This pulverized material was pulverized a second time to 8 inches with asphalt emulsion added. Motor graders were used to shape the surface to grade followed by rubber-tire and steel wheel rollers. A new 2.5-inch hot mix surface course was placed seven days later.

The original gravel aggregate base had a modulus of 9,000 psi; it increased to about 180,000 psi after FDR using emulsion stabilization. Dynamic cone penetration (DCP) data were used to determine base and subgrade consistency prior to construction to identify areas along the alignment that might need strengthening.

During construction, the moisture content was taken every 1,000 feet. Prior to adding the emulsion, the moisture content of the pulverized mixture was 1.7%. This increased to 3.2% to 3.5% after the emulsion was mixed into the pulverized materials. After curing for seven days the moisture content was again reduced to 1.7% and the new hot mixed asphalt overlay was placed.

Compaction was evaluated at 500-foot intervals in each lane using AASHTO T180, nuclear density gauge, and AASHTO T191 sand cone testing.

The resilient modulus of the AEFDR one year later ranged from 214 ksi to 474 ksi, with an average value of 349 ksi. This equals a structural coefficient of 0.24, compared with the original coefficient of 0.07 for the gravel aggregate base. The structural coefficient from laboratory test results of the cores was calculated as 0.31.

PRECONSTRUCTION

Traffic

The traffic volume and type affects the structural section of the completed pavement and is a consideration when deciding to use asphalt emulsion as a binding medium. The additional cost associated with using asphalt emulsion may not be justified on low volume roadways where improved water resistance and strength may not be cost effective. Therefore, some average annual daily traffic (AADT) traffic volume and truck percentage thresholds should be established when asphalt emulsions are considered. The literature was not specific regarding this threshold since each agency must determine the traffic level above which asphalt emulsion is cost effective. However, at least one agency (South Africa 2009) subdivides roadways into three classifications when determining design criteria, which may be useful. These classifications are less than 3 million ESALS, 3 to 6 million ESALS and greater than 6 million ESALS.

Existing Pavement Structure and Materials

The materials present in the pavement to be treated by AEFDR must be known. This includes identifying the existing structural section and the properties of the materials in each pavement layer including the subgrade soil. This information is needed to determine how uniform the materials and pavement section are throughout the project, whether the section will support the construction equipment, and whether additional materials will be needed to make the pavement capable of supporting the anticipated traffic.

A number of approaches have been used to define the existing section geometry and layer stiffnesses. The most common methods of assessment include test pits, coring, boring logs for base and subgrade, dynamic cone penetrometer testing (DCP), California Bearing Ratio (CBR), or resistance value (R-value), falling weight deflectometer data (FWD) for layer moduli, ground-penetrating radar (GPR), or local experience (Jahren et al. 1999; Loizos and Papavasiliou 2006; Loizos 2007; Malick et al. 2007).

An example of the sampling program suggested by Wirtgen is shown in Figure 1 below:

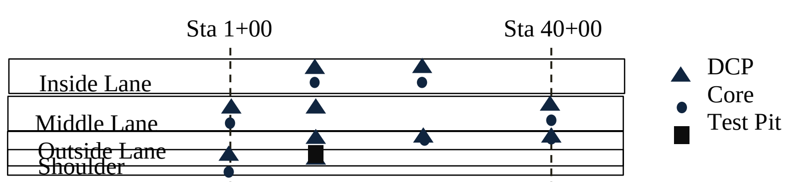


Figure 1. Example Preconstruction Sampling and Testing Program

Results of the sampling and testing program are then compiled and summarized as shown in Table 1 to determine the composition and capabilities of the materials along the alignment. Table 1 is a sample of just some of the results that might be obtained from the in situ and laboratory tests conducted as an example. Table 2 is a more complete list of tests used by South Africa to classify candidate AEFDR pavement materials.

Table 1. Example of Results from Preconstruction Sampling and Testing Along Alignment

Material	Thickness, in		FWD Modulii, MPa		R-Value	
	Range	95%tile	Range	95%tile	Range	95%tile
HMA	4 – 6	5	2500-4000	3300		
ABC	8 – 12	11	275-425	350	55-80	75
A-5	Subgrade		55-105	85	12-20	18

Table 2. Materials Requirements for Candidate AEFDR Projects[1]

Test	Material	Material/Traffic Class			Not Suitable	CF
		High	Med	Low		
Soaked CBR, %	CS[2]	> 80	25-80	10-25	< 10	0.4
	NG[3]		> 25	10-25	< 10	
P 200, %	CS	4-15			> 15	0.35
	NG		5-25	25-40	> 40	
	GS[4]		5-20	15-30	> 30	
	SSSC[5]			0-20	> 20	
AASHTO T180, %	All	> 98	95-98	93-95	< 93	0.1
DCP[6], in/blow	All	< 0.15	0.15-0.36	0.36-0.75	>0.75	0.1
FWD Stiffness, ksi	All	>43.5	22-43.5	10-22	<10	0.1
Plasticity Index	CS	< 10	>10			0.25
	NG	< 6	6-12	>12		
	GS		> 11	11-15	> 15	
	SSSC			< 15	> 14	
Relative Moisture, %	CS	< 90	> 90			0.1
	NG	< 70	70-100	< 80		
	GS		> 100	80-100	< 100	
	SSSC			> 100	> 100	
Grading Modulus	NG	2.0-3.0	1.2-2.7	0.15-1.2	0.15	0.2

[1] South Africa Technical Guideline TG-2, May 2009

[2] Crushed Stone

[3] Natural Gravel

[4] Gravel Soil

[5] Sand, Silty Sand, Silt, Clay

[6] Dynamic Cone Penetration

	GS		1.2-2.5	0.75-2.7	< 0.75	
Cohesion (psi)	All	> 36	15-36	8-15	< 8	0.45
Friction Angle, □	All	> 40	30-40	< 30		0.4
Tangent Modulus, ksi	All	>22	7-22	< 7		0.1
ITS Dry, psi	All, 4-inch	> 33	25-33	18-25	< 18	0.1
ITS Wet, psi	All, 4-inch	>15	11-15	8-11	< 8	0.1
UCS, psi	All	174-508	102-174	65-102	< 65	0.1
Retained cohesion after MIST, %	All	> 75	60-75	50-60	< 50	0.45
Rating	All	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	NA
Sand Equivalent[7]	All				< 30	

Three pieces of information are obtained from the results of the sampling and testing program. First, the uniformity of materials along the proposed alignment is defined. This establishes locations where repairs to localized weak areas may be needed and the extent of these areas. Second, it provides properties of the in situ materials useful in establishing the new structural section. Third, the quality of the in situ materials is identified that establishes how much of the existing structure should be reclaimed and what process should accomplish it. When the pulverized materials do not meet the requirements shown in Table 2, virgin aggregates should be added to the blend so the requirements are met. Essentially, the preconstruction sampling and testing program provides the information needed to determine how much pavement can be reclaimed, what the properties of the completed base course will be and what construction processes will be required to accomplish the task.

Climate

The climate in Colorado is favorable to AEFDR projects. However, as with any construction process utilizing asphalt emulsions, certain precautions should be taken during construction. When mixing the pulverized pavement with asphalt emulsion the moisture content of the pulverized pavement must be known. Therefore, rain must not be expected before the emulsion is added to the pulverized pavement. Since the AEFDR must be cured prior to placement of the final surface course, rain must not be expected during this curing period.

[7] South Carolina DOT SC-T-99

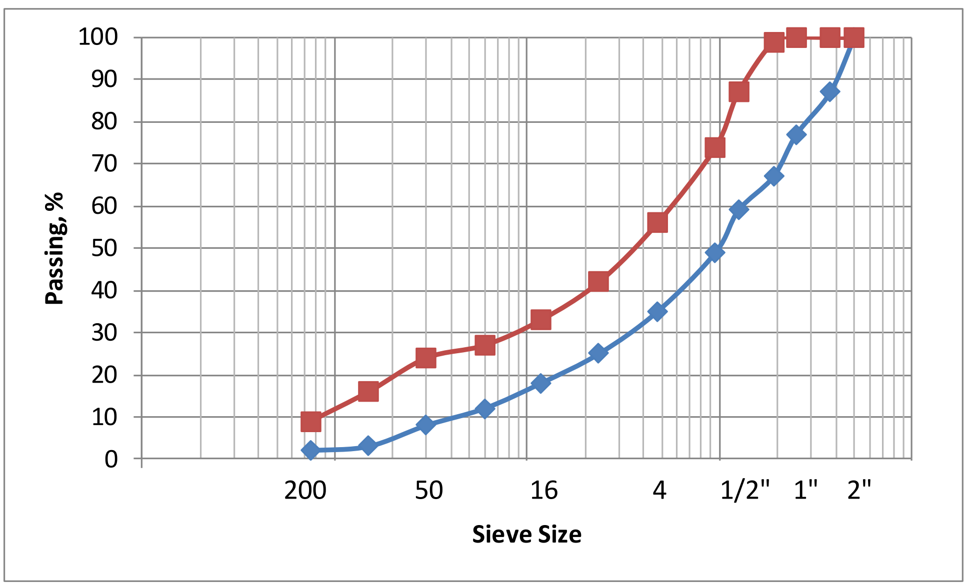
Gradation after Pulverizing

The gradation of the pulverized pavement, base, and, sometimes, subgrade must meet the requirements shown in Table 3 and Figure 2 to provide an adequate structure to support the new wearing course. When the pulverized materials do not meet this requirement virgin aggregates must be added to the blend so the resulting gradation conforms to this requirement.

Table 3. Gradation Limits after Pavement Pulverization

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

Figure 2. Gradation Limits after Pavement Pulverization



Mixture Design for Asphalt Emulsion Content

The emulsion content of the pulverized pavement, base and sometimes subgrade is determined in the laboratory using the general process shown in Figure 3. Several different approaches have been used around the world to accomplish this. This ranges from using no formal mixture design procedure at all to variations of Marshall and Superpave methods.

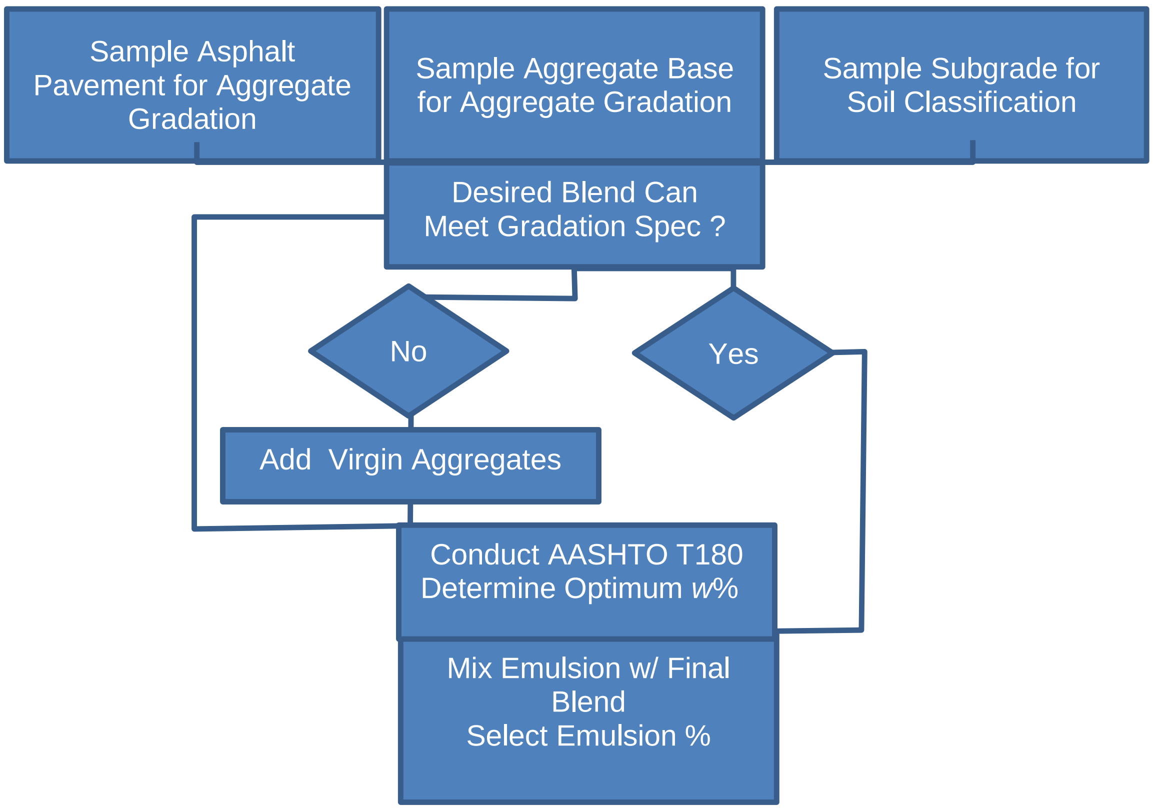


Figure 3. General Mixture Design Process

Wirtgen recommends indirect tensile strength before and after soaking to determine optimum emulsion content. A South African process includes three procedures depending on traffic level:

- Traffic below 3 million ESALS utilizes soaked and dry indirect tensile strength and TSR (tensile strength ratio), and the mixture has to meet a minimum wet IDT strength.
- Traffic between 3 and 6 million ESALS is the same but with 6-inch test specimens instead of 4 inch. And the equilibrium moisture content is used to determine IDT strength. According to the South African literature the 6-inch specimens and tests at equilibrium moisture provide higher confidence in the results.

- Traffic over 6 million ESALS requires a triaxial test to determine if minimum Mohr-Coulomb c and ϕ criteria are met after conducting the MIST (moisture induced sensitivity test) test.

The AASHTO AGC ARTBA Joint Task Force 38 adapted Marshall (50 blow) and Hveem mix designs (ARRA 2001) for use with recycled mixes. However, several disadvantages have been identified with this early work (Salomon and Newcomb 2000; Lee et al. 2002) as shown below:

- The mix design process required 8 days.
- Aggregate grading bands were missing.
- Sample preparation did not consider emulsion break period.
- Heating time for emulsion was not specified.
- Temperature differences for different emulsions were not addressed.
- High air voids mixtures were not addressed in bulk specific gravity testing.
- A process for determining optimum moisture and emulsion content was not defined.

Disadvantages associated with Marshall mix design (no agencies use Hveem) and the advent of the Superpave gyratory compactor indicate that gyratory compaction is useful for preparing samples for AEFDR. The gyratory compactor seems to provide compaction closer to actual in situ densities than other methods. Mallick et al. (2002) and Kim and Labuz (2007) found 50 gyrations produced laboratory compacted samples with densities similar to those found in the field. Other researchers investigated using 30 gyrations for preparing FDR samples (Cross 2002; Lee and Kim 2007b; Thompson et al. 2009). However, drainage for water pressed out of FDR mixes (Mallick et al. 2007) using a slotted gyratory mold was effective for developing higher levels of compaction.

NCHRP Synthesis 421 indicates that states evaluating rutting potential with the Asphalt Pavement Analyzer or Hamburg Rut Tester for hot-mix asphalt also use these tests to evaluate recycled mixes.

FDR produces a stabilized base. Therefore, soils tests are commonly used by agencies to measure compacted properties. These include using AASHTO T99 and T180 to determine optimum moisture content and maximum dry density. Strength testing is conducted using unconfined compressive strength, California Bearing Ratio, or resistance value (R-value) tests. Franco et al. (2009) recommended including Atterberg limits in the mix design methods for FDR.

Since the asphalt emulsions used for AEFDR have a viscosity similar to water before breaking, determining the maximum dry density at the optimum fluid content is recommended by Wirtgen as illustrated in Figure 4. When the Optimum Fluid Content shown in Figure 4 is exceeded, the mixture approaches saturation at the zero air void condition and cannot be compacted. For example in Figure 4, the in situ moisture content of the pulverized pavement and base is 2.5 percent. Then, 3.5 percent emulsion and 1 percent additional water is added bringing the total fluid content to 7 percent, which is the Optimum Fluid Content. Obviously, many combinations of water and emulsion can be used to reach the Optimum Fluid Content depending on the original in situ moisture content. And, if the in situ moisture content is too high, pre-pulverization of the pavement would be required to dry it out before adding asphalt emulsion or compaction would be difficult or not possible.

A modified Superpave mix design technique from South Carolina is described in Appendix A. The procedure first determines the optimum moisture content and maximum dry density of the pulverized pavement materials using AASHTO T180. Then, asphalt emulsion at several percentages is added into the pulverized materials at the optimum moisture content and compacted in the Superpave gyratory compactor. These compacted test specimens are evaluated for air voids, stability, flow, and indirect tensile strength ratio to determine the optimum emulsion content.

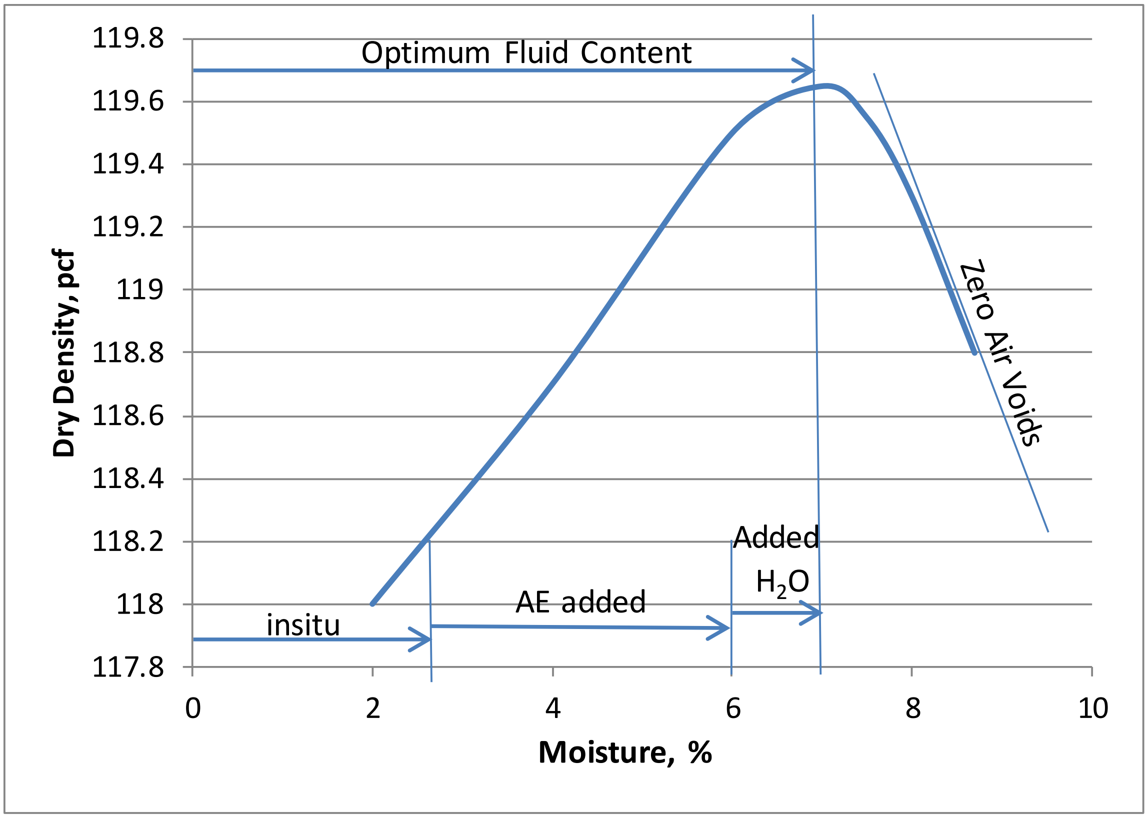


Figure 4. Determining Optimum Fluid Content for AEFDR Mixtures (Wirtgen)

Pavement Structural Design

The structural capacity of the new AEFDR layer must be known to determine what thickness of wearing surface to apply to complete the pavement. AASHTO layer coefficients of between 0.25 and 0.28 have been recommended by Kansas for cold in situ recycled materials, 0.26 by Nevada, and 0.35 in NCHRP Report 224 (Harrington 2008). Romanoschi et al. (2004) recommended a coefficient of 0.18 for AEFDR. The Ontario Ministry of Transport uses 0.20 to 0.28 for AEFDR (Thompson et al. 2009).

Wirtgen recommends three different structural design methods depending on traffic. For traffic under 5 million ESALS a structural number method based on AASHTO is recommended, for 5 to 10 million ESALS a mechanistic analysis is utilized, and for traffic over 10 million ESALS a method called Stress Ratio Limits is employed. Structural numbers are estimated for AEFDR mixtures based on several factors shown in Figure 5 and range from 0.13 to 0.36 per inch. For example, an A1a base and pulverized asphalt pavement with a soaked CBR of 70 before stabilizing, having approximately 2.5 percent emulsion added and indirect tensile strength of 470kPa (68 psi), should have a structural layer coefficient of 0.33 per inch of material.

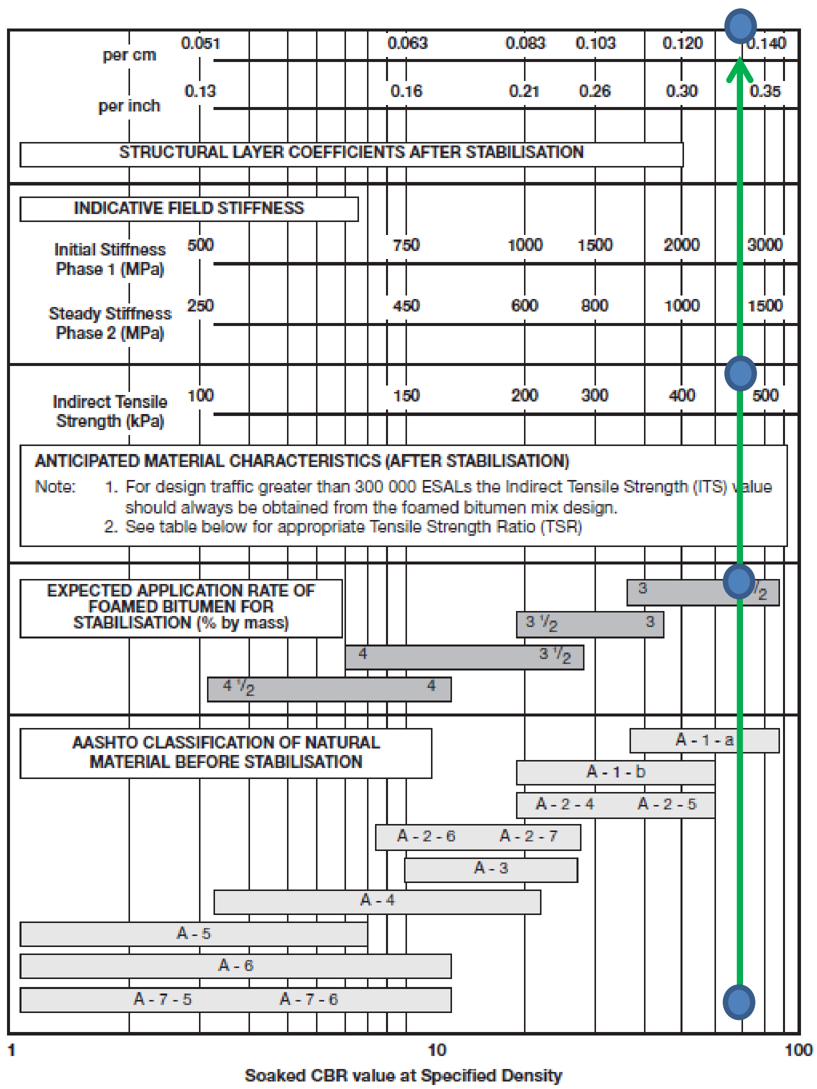


Figure 5. Interaction Between Material Properties and Structural Layer Coefficient (after Wirtgen)

Specifications

Construction specifications for AEFDR projects are similar to other types of paving construction and range from method, end result, performance and warranty to combinations of each. As with most relatively new technologies, states use specifications that have worked the best for past construction and adapt the AEFDR process to fit the current experience.

The subdivisions of many specifications are as follows:

Scope
Materials
Equipment
Construction
Acceptance Testing
Measurement and Payment

Scope

This section of the specification identifies the basis for the work to be performed and may outline specific operations included in the work. For example, an AEFDR specification might identify four major categories of the work as follows:

- Pulverize the asphalt pavement and specified thickness of aggregate base
- Import crushed stone or gravel where specified
- Mix pulverized asphalt pavement and crushed stone or gravel with asphalt emulsion
- Shape and re-compact new pavement layer

Since it is likely the pavement to be reclaimed is not uniform throughout the alignment, this section of the specification should identify the different operations anticipated. A table such as that shown below could be used for this purpose:

Table 4. Operations for Different Project Segments

No.	Start	End	Length, ft	Description
1	32+00	75+00	4300	Pulverize 10 inches, 2.5% emulsion, 0% water
2	75+00	125+00	5000	Pulverize 8.5 inches, 3% emulsion, 2% water
3	125+00	225+00	10,000	Pulverize 10 inches, 3% emulsion, 1% water

Sometimes it is desirable to outline the scope pictorially to avoid confusion. For example, the sequence of operations involved in a typical two step AEFDR project are shown in Figure 6.

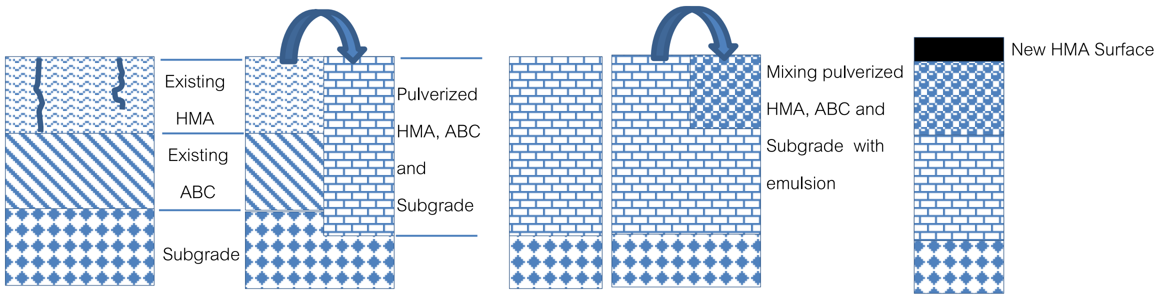


Figure 6. Typical Sequence of an AEFDR Process

Materials

The findings of the preconstruction investigations conducted to classify the materials should be included in this section. This would include the thicknesses of all layers, gradation analysis, Atterberg limits, soil classification and in situ moisture contents.

When virgin aggregates are required, the reasons for adding these materials should be included in the specifications. These reasons could be for one or a combination of the following:

- to make the pulverized materials meet the gradation requirements
- improve structural capacity
- improve cross section

The physical properties of the imported aggregates and the quantities must be specified.
The properties of the asphalt emulsion at the time of construction must be specified.
The water used for AEFDR should be clean and free from detrimental concentrations of acids, alkalis, salts, sugar and other organic or chemical substances. If the water used is not obtained from a public drinking water source, tests should be required to prove suitability.

Equipment

Appropriate equipment is necessary when constructing AEFDR projects to assure quality workmanship. Language suggested by Wirtgen for this section is as follows:

"Recycling shall be effected by utilizing a modified milling machine or purpose-built recycler to recover the material in the upper layers of the existing pavement and blend together with any imported material pre-spread as a uniform layer on the existing road surface. The machine employed shall be capable of achieving the required grading and consistency of mix in a single pass. As a minimum, the recycler shall have the following features:

- It shall be factory-built by a proprietary manufacturer having a demonstrable track record and manufacturing history in the particular type of equipment;
- If older than 10 years, the machine shall be certified by the manufacturer or manufacturer's authorized agent to confirm operational fitness-for-purpose dated not more than 3 months earlier than the date on which it commences work on the project;
- The milling drum shall have a minimum cut width of 2 meters (6 feet) with the capability of changing the speed of rotation. The machine shall be capable of recycling to a minimum depth of x mm in a single pass (include maximum recycling depth for the project);
- The machine shall have a level-control system that maintains the depth of milling within a tolerance of ± 10 millimeters (3/8-inch) of the required depth during continuous operation;
- The milling drum shall rotate in an up-cutting direction within an enclosed chamber inside which water and stabilizing agents are added to the recovered material at the rate required to achieve compliance with the specified laboratory design mixture during continuous operation;
- All spray systems fitted to the recycler shall be controlled by micro-processor to regulate the flow rate with the speed of advance of the machine. All spray systems will also have the ability to allow variable widths of application; and
- It shall have sufficient power to mix the recycled material together with all additives to produce a uniform homogeneous reconstituted material during continuous operation."
- To supply the bitumen emulsion at the required application rate during continuous operation to comply with the mix design;
- To regulate the application rate of bitumen emulsion in accordance with the speed of advance of the recycler and volume of material being recycled;
- To provide uniform application of the bitumen emulsion to the recycled material to produce a homogeneous mixture and
- A method for monitoring bitumen emulsion application during operation that can be reconciled by simple physical measurement for control purposes.

The mixed material shall exit from the mixing chamber in a manner that prevents particle segregation and be continuously placed back in the excavation created by milling as the recycler advances. Spreading and placing to form the new layer shall be carried out by a motor grader only after the primary compaction has been achieved unless placed by a screed mounted on the rear of the recycling machine."

Rollers should be sized in accordance with the thickness of the layer to be reclaimed as shown in Table 5. Initial compaction after reclaiming should be done using a steel-wheel or pad-foot vibrating roller operated in high amplitude vibration mode never in excess of 2 miles per hour (176 feet per minute).

Table 5. Roller Requirements

Thickness of Compacted Layer, in	Static Mass of Roller, min tons
< 6	12
6 – 8	15
8 – 10	19
> 10	24

Construction

Weather

Work may not begin if wet weather is anticipated before work is completed. Work shall not occur when the ambient air temperature is at or below 50F except that finishing and compaction may occur when the ambient air temperature is greater than 40F.

Timing

Mixing pulverized materials with asphalt emulsion and compacting must occur before the emulsified asphalt breaks.

Virgin Aggregates

When virgin aggregates are required per the specifications, they shall be spread on the existing roadway prior to pulverization. These aggregates shall be spread by any means necessary to obtain a uniform thickness in the quantity specified.

Asphalt Emulsion

Asphalt emulsion shall be contained in mobile bulk tankers pushed in front of the pulverizing equipment. Any emulsion that has been heated above the maximum specified temperature shall not be used. A one quart sample of emulsion shall be taken from each tanker and retained in a sealed container for testing.

Moisture Content Control

Water shall be added during initial pulverization to cool the recycling head and provide necessary water to the pulverized layer to reach optimum fluid content. Water shall be added through the computerized control system on the pulverizing equipment with care taken to avoid excessive wetting. Any portion of the work exceeding the optimum fluid content will be rejected and will require drying prior to continuing work. The fluid content of the material during compaction shall not exceed the optimum fluid content. The fluid content shall be determined by summing the total amount of bitumen emulsion applied (not only the water fraction) to the in situ moisture content before mixing, plus any other water applied independent of the water fraction of the emulsion.

Pulverizing

A test section is required to determine if the contractor can produce a finished AEFDR meeting specification requirements. In addition, the test section will provide information regarding the gradation of the pulverized material as a function of the forward speed of the recycling equipment and the rotation rate of the milling drum. The sequence and rolling pattern will also be developed on the test section to determine minimum compaction requirements. The test section shall be a minimum of 600 feet in length and one lane wide. The contractor shall demonstrate consistent compliance with the specifications while completing the test section or further demonstration may be necessary until consistency is achieved.

Gradation and fluid content of the pulverized materials shall be obtained to determine that the pulverized materials meet the specified tolerances. The volume of emulsion used should be checked at the beginning and the end of several loads at the beginning of the project to verify the computer controls on the pulverizer are functioning properly and that the correct quantity of emulsion is being delivered to the pulverized pavement.

The depth of cut shall be verified during test section construction to verify the depth specified is achievable by the equipment.

Longitudinal joints should be constructed by overlapping each pass of the pulverizing equipment by a minimum of 6 inches. A cut line should be marked on the pavement surface to guide the pulverizer operator. The overlap width shall be confirmed before starting each new cut sequence. Adjustments should be made to the water and asphalt emulsion added to account for the reduced width.

The speed of the pulverizing equipment should be checked at least every 600 feet to assure compliance with the planned production rate. The rate should be between 10 and 35 feet per minute.

If track mounted pulverizers with screeds are used for the first pass pulverization process, motor graders should not be needed to shape the surface prior to compaction. However, if wheel-mounted pulverizers are used in the first pass of pulverization, shaping the surface to line and grade will be necessary prior to compaction.

Periodic Weak Subgrade

When the subgrade demonstrates weak behavior either during preliminary investigations or during the pulverizing process, the affected area(s) should be repaired by removing the overlying pavement and base, excavating the weak subgrade and replacing the affected soils with select fill or base, and compacting to 95 percent of AASHTO T180 optimum moisture and density.

Compacting and Finishing

Compaction after the first pass of the pulverizer should be done using any type of sheep's-foot, pad-foot, taper-foot, or club-foot vibratory roller. These rollers should be operated in high-amplitude vibrating mode to transmit maximum energy to the pulverized layer. If additional moisture is needed to achieve the specified compaction, it should be added in the quantity required so that during the second pass of the pulverizer the optimum fluids content is achieved after adding the asphalt emulsion. Asphalt emulsion is added during the second pass of the pulverizer at the rate determined by the mixture design to achieve optimum fluids content in the pulverized mixture. A smooth-drum vibratory roller, operated at low amplitude and high frequency, is used to compact this layer. Intermediate rolling should be accomplished with pneumatic-tired rollers, and finish rolling done with smooth-drum, static, steel-wheeled rollers. Compaction should continue until the asphalt treated layers achieve a density of 94 to 96 percent of the maximum theoretical specific gravity measured for the same materials during the mixture design process. It is advantageous to obtain a final surface profile utilizing a concrete paving trimmer or grader with electronic grade controls.

Acceptance Testing

Requirements for quality control and quality assurance include testing materials and methods for compliance for example:

- Emulsion
  - Residue percent by distillation
  - Oil distillate by distillation
  - Sieve Test
  - Penetration of residue
- Additional Aggregates
  - Same materials used in mixture design
    - Quality, quantity, gradation, moisture content
- Compaction of pulverized materials prior to emulsion addition
  - Minimum of 95 percent of T180 optimum dry density and moisture content
- Compaction of asphalt emulsion treated materials
  - 92 to 96 percent of the maximum theoretical specific gravity
- Properties of asphalt-emulsion treated materials, (Lane and Kazmierowski 2005a
  - Dry indirect tensile strength, minimum 43 to 50 psi
  - Wet indirect tensile strength, minimum 22 to 25 psi wet
  - Retained indirect tensile strength, minimum 70 percent field produced

Measurement and Payment

Descriptions of how the project is measured and paid for vary considerably depending on the owner-agency, as would be expected. Some specifications separate each activity in the AEFDR process and pay for each step separately. For example, the first pulverizing step might be paid for in square yards of treatment for a specified depth. Then, the imported aggregates, if used, paid for by the ton, the asphalt emulsion paid by the gallon, the pulverized layers in the second pass paid for by the square yard per specified depth and finally, the hot mix asphalt overlay paid by the ton or square foot area. Other specifications are simpler and compensate for the completed work from start to finish, stating, for example: "…including cutting of the existing asphalt mat, pulverizing the existing asphalt mat, mixing the pulverized asphalt mat into existing subgrade or base course, wetting and compacting the mixed pulverized asphalt mat, and subgrade and/or base course, blading, shaping, haul, and water" (CDOT Revision of Section 310, Standard Specifications).

CONSTRUCTION

There are two ways to reclaim an asphalt pavement using full-depth reclamation with asphalt emulsions (AEFDR). One method pulverizes the existing asphalt pavement, base course, and, sometimes, a portion of the subgrade, mixing in the asphalt emulsion in one pass. The pulverizing and mixing is followed by compaction, that is followed by the new hot mix asphalt surface course. Another method pulverizes the existing asphalt pavement, base course, and, sometimes, a portion of the subgrade; compacts this layer, then during a second pass of the pulverizer, the asphalt emulsion is added. Shaping and compaction follow, and then the new overlay is placed.

There are advantages and disadvantages with both processes. The advantage of doing the AEFDR process with one pass of the pulverizer is speed. The roadway can be opened to traffic sooner. The disadvantage of this method is control. If moisture content or materials in the existing roadway are not uniform, these variations may not be noticed in time so that adjustments can be made. Obviously, the disadvantage of the two-pass pulverization process is speed, but the advantage is better control as construction progresses. If moisture content, weak areas, or gradation of the materials changes along the alignment, alterations in the process can be made to compensate. A disadvantage cited by Wirtgen (2009) to the two-step process involves not pulverizing deep enough during the first pass, that could leave a thin layer of weak, uncompacted pavement or base course under the new pulverized layer. However, it seems that a thorough subsurface investigation conducted prior to construction activities could identify layer thicknesses so this possibility could be avoided.

Equipment and Operations

There are several pieces of equipment needed in the AEFDR process. These are the pulverizer, water tanker, emulsion tanker, and rollers. If the pulverizer is track-driven with a screed, a grader may not be required. However, if the pulverizer is wheel-driven, a grader will be required to reshape the pulverized layer before compaction. If virgin aggregates are added during the process, a means of spreading the aggregates in a uniform layer in front of the pulverizer will be needed.

Planning the Cuts for Longitudinal Joint Placement

Planning the sequence of cutting the existing pavement is important so that all of the existing pavement is reclaimed and so longitudinal joints occur in areas outside the wheel paths. Longitudinal joints should be at least 6 inches in width. A profile of how a typical 26–foot-wide two-lane pavement could be reclaimed is shown in Figure 7 below.

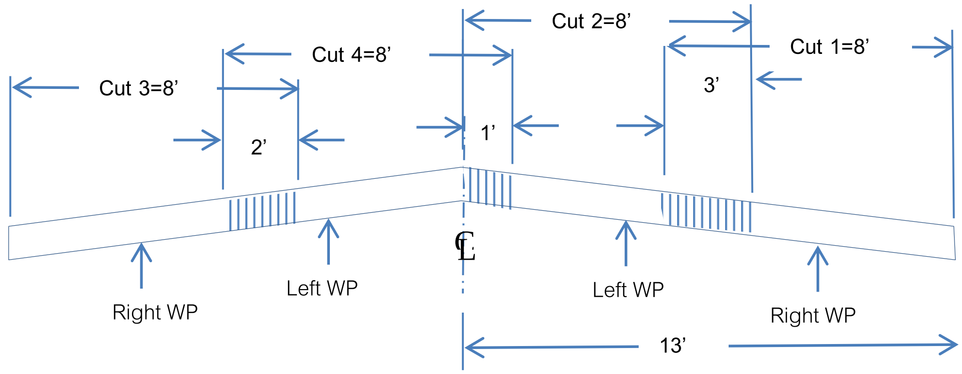


Figure 7 – Typical Cut Detail Indicating Location for Longitudinal Joints

Water and Emulsion Quantities

The amount of water and emulsion added for each cut is dependent on the width of untreated cut. For example in Figure 7, the first cut is 8 feet wide and is all untreated. However, cut 2 is pulverizing only 5 feet of untreated material due to the 3-foot overlap, cut 3 is again treating 8 feet of untreated material, and cut 4 is treating 5 feet. Therefore, the quantity of water in cuts 2 and 4 is 5/8 that of cuts 1 and 3.

Pavement Gradient

When pavement grades or cross slopes are greater than 4 percent the asphalt emulsion and water added to the pulverized materials will tend to flow downward. Therefore, after the first pass of the sheep's-foot or breakdown roller, a grader should be used to bring the materials back to the correct shape before making the adjacent cut. This will ensure a proper longitudinal joint is constructed. Pulverizing downhill may be necessary in some situations if the pulverizer is not capable to pulling or pushing the tankers supplying water and emulsion.

Transverse Joints

Stopping and starting the pulverizer should be done slowly. However, this may cause a lower quantity of water or emulsion to be applied to the materials in these areas due to operating characteristics of the equipment. That is, although computer controlled in most cases, the physical ability of the spraying equipment may cause lower quantities than desired. Therefore, it is recommended to enrich the joint area by reversing the pulverizer at one diameter of the milling head back into the previously recycled material. Of course, not stopping is the best practice, although unavoidable at times.

Uniform Compaction

Prior to grading the surface of the pulverized pavement compaction must be uniform either during the first pass with water or during the second pass with asphalt emulsion. Uniform compaction is a challenge when wheel-driven pulverizers are used because the wheels compact the pulverized materials leaving an un-compacted layer between the wheels as shown in Figure 8.

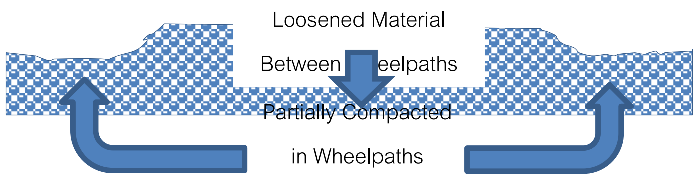


Figure 8 – Differential Compaction for Wheel Driven Pulverizers

As the rollers compact the center of the reclaimed pavement, care must be taken to ensure that compaction achieved between the wheel paths is equal to that within the wheel paths. This can be an issue since the rollers may be wider than the width of the loosened material and as they compact the center of the reclaimed pass the outside edges of the drum will eventually be riding on the wheel paths compacted by the pulverizer. This is not an issue when track driven pulverizers are used since the pulverized material is placed behind the pulverizer under the screed and the tracks never contact the loose material.

Quality Control and Quality Assurance

As mentioned previously in the section on specifications, there are numerous observations and tests to perform during construction. Perhaps the most important continuous check to conduct is visual observation of the process itself to make sure the equipment is operating properly, cutting to the desired depth, and that the line is correct along the alignment to assure correct overlap of longitudinal joints. Since water and asphalt emulsion will be added to the pulverized layer, and since the quantities used will vary with the width of the virgin cut, a process must be established to check this and verify that desired quantities are being applied. Since asphalt emulsion flow characteristics are temperature dependent, the temperature of the emulsion as it is being introduced to the pulverized layer must be checked. If the temperature is too low, the emulsion will not flow adequately and the quantity being introduced could be reduced. A simple check of temperature using hand held infrared thermometers is recommended. A simple check of emulsion quantities being introduced into the pulverized layer can be done by calculating what distance and width of pulverized material a tanker load of emulsion should be capable of treating.

The forward speed of the pulverizer should be between 20 and 40 feet per minute to obtain high quality pulverizing and mixing. Pulverized material behind the machine should be constantly observed and assessed for uniformity. Moisture contents must be taken frequently and density measurements should be taken between and in the wheel paths periodically to make sure compaction requirements are being met. Wirtgen (2009) recommends that after emulsion addition, the material should be compacted into a ball using both hands to determine if it will hold together, and goes on to recommend that temperature variations should be monitored across the width of the pulverized layer using a thermometer.

APPENDIX A – GUIDE SPECIFICATION FOR AEFDR

SECTION 413
FULL DEPTH RECLAMATION WITH ASPHALT EMULSION (AEFDR)

DESCRIPTION

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

MATERIALS

413.02 The asphalt emulsion shall be a CMS-2P, HFMS-2P, or HFMS-2sP meeting the requirements of subsection 702.03.
The pulverized material shall meet the following gradation requirements:

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

CONSTRUCTION REQUIREMENTS

413.03 Weather Limitations. Daily recycling operations shall not begin until the atmospheric temperature is 55 ºF and rising. Recycling operations shall be discontinued when the temperature is 60 ºF and falling. Recycling operations shall not be performed when the weather is foggy or rainy, or when weather conditions are such that the proper mixing, spreading, compacting, and curing of the recycled material cannot be accomplished. Cold recycled pavement damaged by precipitation shall be reprocessed or repaired by methods approved by the Engineer, at the Contractor’s expense.

The construction of AEFDR pavement will not be allowed from September 16 through May 14 unless otherwise approved. The Contractor's Progress Schedule shall show the methods to be used to comply with this requirement.

413.04 Pulverizing-First Pass. The existing asphalt surfacing, base course and, if shown on the plans, subgrade, and added virgin aggregates shall be pulverized. Adjacent recycling passes shall overlap at the longitudinal joint a minimum of 6 inches. An example of the sequence of pulverizing that satisfies this requirement for a 26 foot wide roadway is shown in Figure A1.

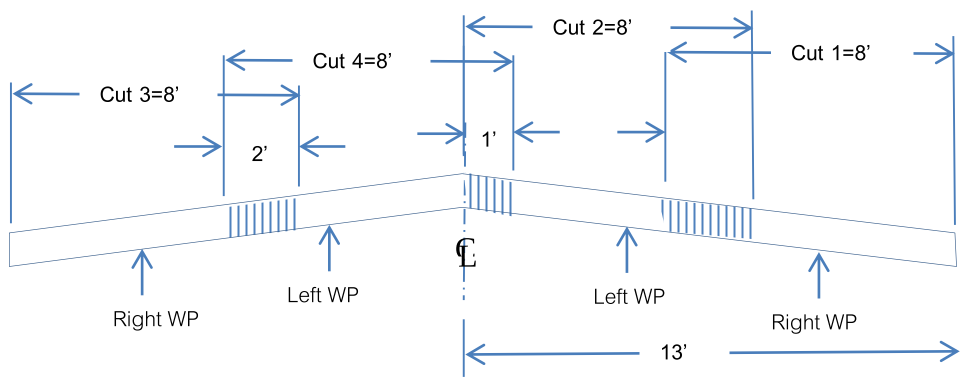


Figure A1. Example of Pulverizing Cut Sequence for 26 foot Width

The beginning of each day's recycling operation shall overlap the end of the preceding recycling operation a minimum of 100 feet unless otherwise directed. Any fillet of fine, pulverized material that forms adjacent to a vertical face shall be removed prior to spreading the mixed material, except that such fillet adjacent to existing pavement that will be removed by a subsequent overlapping milling operation need not be removed. Vertical cuts in the roadway shall not be left overnight.

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

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

413.06 Compacting-First Pass. After the recycled material has been graded to conform to planned elevations, initial compaction of the pulverized layer shall be by vibratory pad foot roller. The roller shall be operated at maximum amplitude and shall continue until the density of the pulverized layer is not less than 95 percent of the maximum density achieved by AASHTO T180 (CP53). Moisture content shall be the amount determined during mixture design prior to the addition of the asphalt emulsion. If the area tested fails to meet the required density, the area shall be reworked until it attains 95 percent compaction. The frequency of density testing for project acceptance will be one per 5000 square yards. The Engineer will perform one CP 53 for calculation of the percent relative compaction with each field density taken.

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

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

413.09 Compacting and Finishing-Second Pass. After the recycled material has been graded, traffic, including Contractor's equipment, shall not be allowed on the recycled material until it starts its initial break as determined by the Engineer. However, if precipitation is imminent, compaction may proceed to seal the surface from additional moisture. Initial rolling shall be performed with one or more steel-wheeled vibratory rollers operated at the lowest amplitude setting. Intermediate pneumatic tire rollers shall be used to knead the surface closed prior to finish rolling. Final rolling to eliminate pneumatic tire marks and achieve the required density shall be done by steel wheel rollers in static mode. The use of vibratory rollers shall be approved by the Engineer. If rollers are used in the vibratory mode, vibration shall be at low amplitudes to prevent transverse cracks. The recycled material shall be compacted to 92 to 96 percent of the maximum theoretical density of laboratory specimens compacted from project materials. If the area tested fails to meet the required density, the area shall be reworked until it attains the required compaction. The frequency of density testing for project acceptance will be one per 5000 square yards. The Engineer will perform one maximum theoretical density for calculation of the percent relative compaction with each field density taken. Rollers shall not be started or stopped on un-compacted recycled material. Rolling shall be accomplished so that starting and stopping will be on previously compacted pulverized pavement or existing pavement. Any type of rolling that results in cracking, movement, or other types of pavement distress shall be discontinued until the problem is resolved. After the recycled material has been compacted, traffic, including the contractor's equipment, shall not be permitted on the pulverized pavement for at least two hours unless otherwise approved.

Before placing the hot mix asphalt overlay, the pulverized pavement shall be allowed to cure until the free moisture is reduced to 1 percent free moisture or less, by total weight of mix. Free moisture will be measured according to CP 57. After the free moisture content of the pulverized pavement has reached the acceptable level, the hot mix asphalt overlay shall be placed. However, unless otherwise approved by the Engineer, the pulverized pavement shall be covered with a minimum thickness of 2 inches of hot mix asphalt within ten calendar days after it is mixed and compacted.

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

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

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

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

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

413.12 Smoothness. The longitudinal surface smoothness of the roadway prior to and after pulverization shall be tested by the Contractor in accordance with subsection 105.07.

METHOD OF MEASUREMENT

413.13 AEFDR pavement will be measured by the square yard of paved surface actually recycled, complete in place and accepted. Repair of AEFDR pavement will be measured by the square yard of paved surface repaired and accepted.

BASIS OF PAYMENT

413.14 The accepted quantity of AEFDR pavement will be paid for at the contract unit price per square yard. Payment will be made under:

*****

Pay Item	**Pay Unit**
AEFDR	Square Yard
Repair of AEFDR	Square Yard

Asphalt materials will be measured and paid for in accordance with Section 411.

Water will not be measured and paid for separately, but shall be included in the work.

Repair of AEFDR pavement damaged by the Contractor or by weather will not be measured and paid for separately, but shall be included in the work. Overlaps of preceding recycling operations will not be measured and paid for separately, but shall be included in the work.

APPENDIX B - REFERENCES

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