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COLD IN-PLACE RECYCLING AND FULL-DEPTH RECYCLING WITH ASPHALT PRODUCTS (CIR&FDRWAP)

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A report of the findings of
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Cold In-Place and Full-Depth Recycling with
Asphalt Products (CI & FDR w AP)

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16. Abstract <p>In the 60's, 70's, and 80's, many Illinois local road agencies successfully used "conventional" asphalt emulsions for In-Place Recycling to produce Emulsion-Aggregate-Mixtures (EAMs). In more recent years, these emulsions have not been widely used for Cold-In-Place Recycling construction. A major constraint to the continued utilization of EAMs was the long "drying time" (loss of moisture following mixing and prior to compaction) associated with the process.</p> <p>The use of "foamed-asphalt" and improved emulsion compositions (called "engineered emulsions") has alleviated (some suggest eliminated) some of the concerns that have limited the use of emulsions for Cold-In-Place Recycling.</p> <p>The project objective is to evaluate and contribute to the facilitation and implementation of currently available CIR&FDRwAP (Cold-In-Place Recycling and Full-Depth Recycling with Asphalt Products) technology.</p> <p>An "information/data" survey was conducted, ten selected CI&FDIRwAP projects were documented and evaluated, mixture properties (modulus, strength, fatigue) were established, thickness design options were evaluated, mixture design approaches were evaluated, and construction aspects considered.</p> <p>The mixture design procedures currently used by SemMaterials for Engineered Emulsions and the Wirtgen procedure (or procedures similar to the Wirtgen procedure) for foamed asphalt mixtures are recommended for interim use.</p> <p>Typical successfully used specifications for Full-Depth Recycling and Cold-in-Place-Recycling are presented. It is recommended that a "Working Group" be established to refine/further adapt the mixture design procedures and construction specifications for Illinois Local Roads and Streets utilization.</p> <p>Project information/findings/results support the recommendation that the CIR&FDRwAP process be considered a "standard procedure." It currently is incorporated into a project as an "experimental feature."</p>					
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EXECUTIVE SUMMARY

In the 1960s, 1970s, and 1980s, many local road agencies in Illinois successfully used “conventional” asphalt emulsions for in-place recycling to produce emulsion-aggregate mixtures (EAMs). In more recent years, these emulsions have not been widely used for cold in-place recycling construction. A major constraint to the continued use of EAMs was the long “drying time” (loss of moisture following mixing and prior to compaction) associated with the process.

The use of “foamed-asphalt” and improved emulsion compositions (called “engineered emulsions”) has alleviated—some have suggested eliminated—some of the concerns that have limited the use of emulsions for cold in-place recycling.

The project objective is to evaluate and contribute to the facilitation and implementation of currently available CIR&FDRwAP (cold in-place recycling and full-depth recycling with asphalt products) technology.

For the project, an information and data collection survey was conducted, ten selected CI&FDRwAP projects were documented and evaluated, mixture properties (modulus, strength, fatigue) were established, thickness design options were evaluated, mixture design approaches were evaluated, and construction aspects considered.

The mixture design procedures currently used by SemMaterials (Tulsa, OK) for engineered emulsions and the Wirtgen procedure (or procedures similar to the Wirtgen procedure) for foamed asphalt mixtures are recommended for interim use.

Typical specifications for full-depth recycling and cold in-place recycling that were used successfully are presented.

It is recommended that a working group be established to refine and further adapt the mixture design procedures and construction specifications for use in local roads and streets in Illinois.

Project information, findings, and results support the recommendation that the CIR&FDRwAP process be considered a standard procedure. It currently is incorporated into a proposed project as an experimental feature.

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1.0 INTRODUCTION

In the 1960s, 1970s, and 1980s, many local road agencies in Illinois successfully used conventional asphalt emulsions for in-place recycling to produce emulsion-aggregate mixtures (EAMs). In more recent years, these emulsions have not been widely used for cold in-place recycling construction. A major constraint to the continued use of EAMs was the long “drying time” (loss of moisture following mixing and prior to compaction) associated with the process.

The use of foamed-asphalt” and improved emulsion compositions (called “engineered emulsions;” the SemMaterials products are called Fortress or ReFlex) has alleviated—some have suggested eliminated—some of the concerns that have limited the use of emulsions for in-place recycling.

There are two types of cold in-place recycling procedures:

- Full-depth recycling (FDR): The entire depth of the existing asphalt-treated material is incorporated into the mixture.
- Cold in-place-recycled (CIR): Only a portion of the entire depth of the existing asphalt-treated material is incorporated into the mixture. Thus, there may be a significant thickness of hot-mix asphalt (HMA) with varying (and largely unknown) distress remaining.

Additional material (primarily aggregate) may be added to the pavement surface to achieve desired gradations or thicknesses, or both.

The Asphalt Institute (2007) identifies three construction processes:

- Single-unit trains: “The single-unit train consists of a milling machine (*more appropriately called a soil stabilizer/reclaimer*) that does the milling, RAP sizing and blending at the cutting head.” (NOTE: Frequently, the pavement is pulverized in an initial pass and the asphalt is added in the second pass.)
- Two-unit trains: “The two-unit train consists of a milling machine and a pugmill-mixer-paver.” (NOTE: Some contractors have modified conventional “milling machines” to add the asphalt at the cutting head, thus eliminating the need for a pugmill-mixer. The stabilized material is picked up from the windrow and transferred to the paver.)
- Multi-unit trains: “A multi-unit train consists of a milling machine, a portable screening and crushing unit, and a portable pug-mill mixer.”

The majority of the projects involving full-depth recycling with asphalt products (FDRwAP) in Illinois are constructed using a stabilizer/reclaimer-type machine. A milling operation is used for projects involving cold in-place recycling with asphalt products (CIRwAP). Some agencies prefer the multi-unit train with the inclusion of a paver operation. Equipment innovation and development is constantly occurring.

In some projects, additional material (generally aggregate) is added to improve the gradation of the final mixture or to increase the thickness of the asphalt-stabilized layer. Typical thicknesses for the asphalt-stabilized layer are 3 to 8 inches. Many CIR projects are 3 to 4 inches in thickness. FDR projects generally are thicker. Current rotomills and stabilization equipment can effectively process to depths > 8 inches.

Surfacing options include surface treatments and variable HMA OL thickness (some as thin as 1.5 inches).

CIR&FDRwAP mixture design procedures, field mixing equipment, and construction procedures have been—and continue to be—improved. CIR&FDRwAP technology typically results in lower construction costs for flexible pavement reconstruction, rehabilitation, and resurfacing projects. Thus, CIR&FDRwAP has emerged as a viable and cost-effective in-place recycling alternative. The Illinois Department of Transportation (IDOT) has not focused on or directed any particular efforts toward thoroughly evaluating and implementing recently developed CIR&FDRwAP technology. This project addresses this situation.

2.0 THE PROJECT

The project objective is to evaluate and contribute to the facilitation and implementation of recently developed CIR&FDRwAP technology.

An information and data collection survey was conducted. Research papers and reports, technical manuals, recommended practices, equipment information, and typical specifications were collected, reviewed, and evaluated. Inputs from a Technical Review Panel (TRP) were solicited.

Selected CIR&FDRwAP projects (“foamed asphalt” and “engineered emulsions” [Fortress, Reflex, etc.]) were documented and evaluated. This activity included:

- Selecting projects (TRP participation);
- Collecting pertinent information and data (materials, asphalt product, mixture design, material characterization [strength/modulus], traffic, pavement design, construction quality control and quality assurance (QC/QA), post-construction testing data, performance data, etc.); and
- Conducting project evaluations.

This report contains preliminary recommendations based on this research, and a summary report will be prepared.

3.0 BDAT (Best Demonstrated Available Technology)

Best Demonstrated Available Technology (BDAT) was established.

Over 70 papers and reports were reviewed and short summaries of pertinent and relevant information and data were prepared for subsequent use.

Some excellent comprehensive references that were used are:

- *Wirtgen Cold Recycling Manual* (Wirtgen 2006)
- *Basic Asphalt Recycling Manual* (AR & RA 2001)
- *Cold In-Place Recycling State of Practice Review* (FHWA 2005)

Two pertinent and comprehensive research and development projects currently underway are:

- 1) A comprehensive South African study investigating the use of emulsified asphalt and foamed asphalt for cold in-place recycling that is scheduled for completion by late 2008 (Gauteng); and
- 2) A comprehensive, extensive, and well-funded study, Quality Base Material Produced Using Full-Depth Reclamation on Existing Asphalt Pavement Structure, is currently underway at the South Dakota School of Mines and Technology (DTFH61-06-C00038 – U.S DOT-FHWA). The five-year project started in 2006 and is scheduled for completion

in 2011. Per the Project PI, Task 1 (Literature Review) and Task 2 (Document State Specifications and Construction Experiences) have been completed and are under review at the FHWA. The results should be available in late 2008. The additional nine tasks include:

- Condition survey of existing test sections;
- Development of an FDR mix design guide;
- Development of a standardized laboratory testing manual;
- Establishment of field procedures to produce base materials meeting asphalt content and gradation specifications; and
- Establishment of laboratory testing and design procedures.

An additional significant activity is NCHRP Synthesis 20-05/Topic 40-13 (Recycling of Asphalt Pavements using In-Place Methods). The project, to be started in the fall of 2008, will consider CIR&FDRwAP.

These projects have considerable potential for contributing to the Illinois DOT's efforts to use CIR&FDRwAP in an effective and economical way.

4.0 CONDITION SURVEYS

4.1 GENERAL

A survey was conducted by the IDOT's Bureau of Local Roads and Streets (LR&S) to identify CIR&FDRwAP projects that had been constructed in the state. From these projects, 10 were selected for further study: three on foamed asphalt and seven on engineered emulsion. The projects and pertinent details are shown in Table 1.

Pertinent project data were collected. A visual condition survey (primarily related to cracking) was performed and rut depths (4-foot straight edge per the original AASHO Road Test device) were measured. Falling weight deflectometer (FWD) testing was conducted by the IDOT's Bureau of Materials and Physical Research.

Table 1. Follow-Up Project Condition Surveys

Project ID	Location	Construction Date	Surface (inches)	Stabilized Base (inches)	Stabilizers
1	CH-9 Champaign Co.	2005	ST in 2005 3-HMA (2006)	7 (FDR)	2.5 %Foam (PG64-22) + 1% FA
2	CH-1 Christian Co.	2006	3-HMA	8 (FDR)	3.2% SB-EE (160)
3	Pearl City Road Stephenson Co.	2006	3.75-HMA	8 (FDR)	3.5% SB-EE (275)
4	CH-16 Livingston Co.	2005	3.5-HMA	9 (FDR)	2% Foam (PG 58-22) + 1.5% PC
5	Shannon Route Carrol Co.	2005	3-HMA	8 (FDR)	SB-EE (275)
6	CH-47 Sangamon Co.	2003	ST	8 (FDR)	1.5% SB-EE + 2% PC
7	CH-47 Sangamon Co.	2003	ST	8 (FDR)	2% PC + 1% Foam
8	CH-15 Sangamon Co.	2005	ST	8	4.2% SB-EE (160)
9	Springfield Road* Tazewell Co.	1999	1.5-HMA	5 (CIR)	3.5% HFE-300P** (138)
10	Springfield Road*** Tazewell Co.	2003	3-HMA	3 (CIR)	2%-3% CIR-EE****

HMA – hot-mix asphalt concrete / ST - surface treatment
 SB-EE – engineered emulsion / PC – Portland cement
 FA - Fly Ash / * Dillon – CR 5100 N (Toboggan Road)
 ** - Identified as Quick ReFlex CIR
 *** CR 5100 N (Toboggan Road)- IL 122
 **** Identified as ReFlex
 (Penetration of residual asphalt)

4.2 CONDITION SUMMARY

A summary of the condition and rut depth data collected in 2007 is presented below.

- Only one project (Project 9 / Tazewell County) has experienced significant and/or extensive cracking (longitudinal and transverse). The emulsion used in this CIR project was identified as HFE-300P (a Koch materials product identified as Quick ReFlex CIR). The depth of asphalt in the existing pavement was about 12 inches. Only 5 inches was recycled and the HMA OL was 1.5 inches. The CIR project was constructed in 1999 and initial cracking developed as early as 2002. Periodic

crack sealing operations have been performed. In 2007, some sections of the road showed large amounts of longitudinal and transverse cracking.

- A subsequent Tazewell County project (Project 10, constructed in 2003) used an engineered emulsion identified as CIR-EE (ReFlex). The CIR depth was 3 inches. This project is not showing significant distress (cracking). It is important to note that the HMA overlay for Project 10 was 3 inches, compared to 1.5 inches for Project 9.
- In many of the projects, insignificant rutting (average rut depth < 0.1 inches; many measurements were 0) has developed. As demonstrated in Table 1, three of the projects (Projects 6, 7, 8) only had surface treatments. The typical HMA overlay was about 3 inches.
- Only one project (Project 2 – Christian County) has experienced significant rutting. The project was constructed in 2006. A large amount of heavy truck traffic from quarry operations on the south end of the project is experienced on the north-bound lanes. The average rut depth for the north-bound truck lane was 0.29 inches and for the south-bound lane (less truck traffic) the average was 0.17 inches. Significant rutting (ranging from 0.5 to 0.7 inches) had developed in the north-bound truck lane from location 6013 – 6963 (stationing in feet from the south end of the project) by the fall of 2007.
- None of the projects have developed any significant amount of classical fatigue cracking.

Typically, asphalt mixtures with high rutting potential demonstrate larger-than-normal rutting during the first summer of service. This is the case with Project 2 – Christian County.

5.0 FWD DATA and ANALYSIS

FWD data were analyzed using algorithms previously developed for IDOT and used in IDOT flexible pavement design procedures. The procedure is outlined in Appendix A. Of particular interest is the modulus of the asphalt-treated pavement layer. Back-calculated moduli of the asphalt-treated layer and the subgrade are summarized in Table 2.

Table 2. Backcalculated Composite Moduli for Follow-up Projects

Project No.	Subgrade Modulus (ksi)	FWD Test Temperature (°F)	Composite Pavement Modulus (ksi)
1	11.5	44	500
1	10.1	86	140
2	8.7	88	175
3	7.3	81	200
4	5.7	83	225
4	10	45	575
5	5.2	74	170
6	4.3	91	175
7	3.1	92	150
8*	5.3	(41-44-48)	350
8**	6.1	(55-54-64)	300
9	***	***	***
10	No FWD test	No FWD test	No FWD test

(Air – Pavement Surface – Estimated @ 3.2 Inches)
 * North-bound
 ** South-bound
 *** Pavement section too complex to analyze. Significant amount of HMA remaining from original pavement section. See details in Appendix A.

6.0 PAVEMENT PERFORMANCE

The performance of Illinois emulsion aggregate mixtures (EAM) projects, which have been in significant use on rural roads beginning in the mid-1960s, has been very successful. The primary emulsion used in the Illinois projects was HFE-300. The surface course was typically a surface treatment. Anderson (Anderson 1993) indicated that:

EAMs are used extensively on the local roads and streets system (counties, townships, and cities) in Illinois. These roads are largely Class IV (less than 400 ADT), with some Class III (400 to 2000 ADT).

Illinois CIR and FDR projects considered in this project (see Table 1) have in most cases demonstrated good performance. The extensive cracking in the Tazewell County CIR project (Project 9) and the high rutting (about 0.7 inches) in some limited areas of the Christian County FDR project (Project 2) are not typical.

A comprehensive study (Lee and Kim 2007) of 26 CIR projects in Iowa (1 to 17 years in age) indicated that CIR projects had an estimated service life of 25 years:

CIR values are expected to be in fair condition (PCI value ranging from 55 to 40) between 21 and 25 years, respectively.

The Iowa study is of particular interest because of its proximity to Illinois.

Emery (2006) recently summarized the experience in the Western Hemisphere as, “The performance of quality CIR and FDR has been positive and cost effective.”

An extensive California study of foamed asphalt stabilized mixtures (Fu et al. 2008) indicates that the mixtures are providing satisfactory performance. The major factor contributing to the limited distress noted was “excessive” moisture content.

A summary of the results of a nation-wide survey conducted by the Transportation Research Board Committee AFD70 (TRB AFD70 2008) indicated:

While many of the states indicated it is too early to provide any rating about the performance of foamed asphalt projects, all but one of the remaining states indicated good to excellent performance.

The international technical literature indicates that CIR&FDRwAP performance experience has also been successful.

As cited above, CIR&FDRwAP pavements have a proven performance record. The technology related to emulsions, asphalt foaming techniques, mixture design, mix characterization, and construction equipment and procedures have considerably improved in recent years.

Engineered emulsion and foamed asphalt base stabilization should now be considered as standard procedures.

7.0 PAVEMENT DESIGN CONSIDERATIONS

7.1 MATERIAL PROPERTIES

Anderson and Thompson (1995) demonstrated dense-graded EAMs can be characterized as “improved granular material.”

The adopted rules-of-thumb of the Southern Africa Bitumen Association (SABITA) (Jooste and Long 2007) state, “Bitumen stabilized materials with low cement contents are assumed to act in a similar way to coarse granular materials, but with a higher cohesive strength.” Though the same source also notes, “The cohesion does provide a potential for accommodating ‘limited’ flexural/tensile stresses.”

Fu and Harvey (2007) concluded, “The significant stress dependency of resilient modulus indicates foamed asphalt mix’s nature as a weakly bonded granular material.”

Thomas and May (2007) suggest:

Current pavement design methods do not account for the unique properties of FDR. These mixes behave somewhat similar to granular materials in their early life. After curing, the mixtures exhibit visco-elastic and performance-related properties similar to asphalt concrete. The mixture behavior depends on the stabilized material and the properties of the asphalt emulsions with which they were stabilized.,,,,,it has been clearly demonstrated that these FDR mixes would be better characterized as less-aged asphalt concrete.

It is apparent that CIR&FDRwAP materials can demonstrate a wide range of characteristics.

7.2 THICKNESS DESIGN

FDR thickness design is more straightforward than for CIR. The thicknesses and properties of the material layers can be more accurately defined (there is no remaining HMA) for FDRs.

In CIR, it is difficult to assess the structural contributions of the material layers in the remaining pavement section after milling. The remaining HMA will have varying degrees of distress (cracking, rutting, patching, etc.) and it is not possible to consider the remaining fatigue life, if any, of the residual HMA. As a conservative approach, the remaining layers (those beneath the CIR depth) could be characterized as granular material. Thus, the pavement section is considered as a conventional flexible pavement (CFP). Current IDOT–LR&S policy limits CFPs to $TFs < 0.25$. Is this limit applicable to CIR? CIR thicknesses are frequently established by a “thickness policy,” such as that used by the New York DOT.

For FDR, there are two options for establishing thickness. They are:

- 1) The mechanistic-empirical (M-E) approach, which is the basis of the LR&S “new” flexible pavement design procedure (Chapter 37 of the *Illinois Bureau of Local Roads and Streets Manual*); and
- 2) An AASHTO-based structural number (SN) procedure (previously used by LR&S for New Pavements) and now used as an option for the design of HMA overlays for flexible pavements (Chapter 37 of the *Illinois Bureau of Local Roads and Streets Manual*).

7.3 M-E APPROACH

The M-E approach requires inputs concerning subgrade soil modulus, the CIR&FDRwAP modulus–temperature relation, CIR&FDRwAP strength properties (shear strength, tensile/flexural), and a CIR&FDRwAP fatigue algorithm.

Current IDOT–LR&S procedures, practices, and policies, as presented in Chapter 37 of the *Illinois Bureau of Local Roads and Streets Manual*, can be used to provide adequate subgrade inputs.

Current CIR&FDRwAP modulus–temperature relations are mostly based on lab samples cured under elevated temperature conditions. The resulting cured moisture content is not representative of pavement service conditions. As field curing progresses (loss of moisture from the mix), strength and modulus increases. Lee et al. (2008) demonstrated the significant effect of moisture content on the ITS of six foam-stabilized RAP mixtures. As moisture content decreases, the ITS increases, as shown in Figure 1. It is frequently noted that it is very difficult—indeed, almost impossible—to core CIR&FDRwAP layers a short time after construction. Coring is possible after curing progresses and strength increases. Modulus data based on back-calculation of FWD data are probably more representative of service conditions than lab-based data.

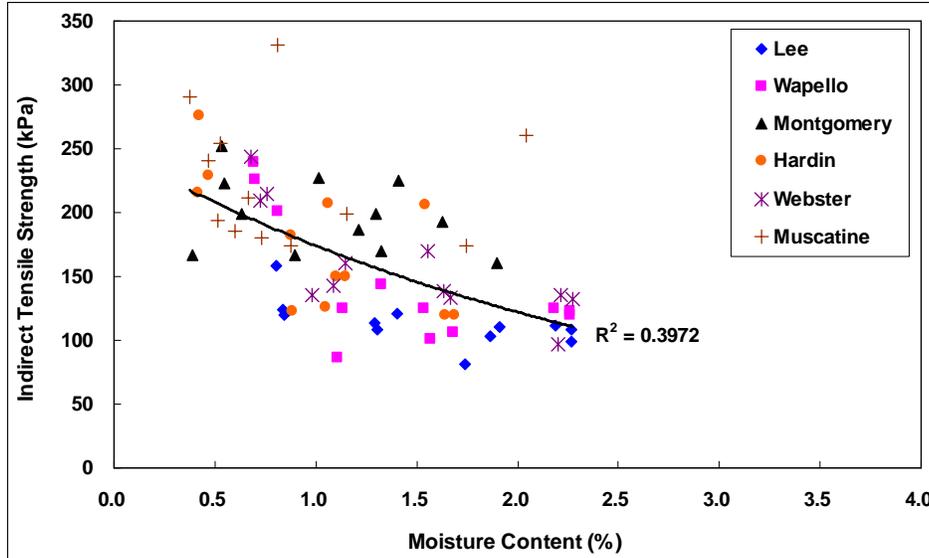


Figure 1. Moisture content effect on ITS (14).

7.3.1 Modulus–Temperature Relations

Moduli backcalculated from the IL FWD data are shown in Table 2. A range of pavement temperatures (44 to 92°F) were encountered during FWD testing. A modulus–temperature relation (log E as a function of temperature) was established for the data in Table 2. The relation is:

$$\log E = 3.14 - 0.0104 T$$

where:

E = backcalculated modulus (ksi)
 T = pavement temperature °F
 ($R^2 = 0.94$ / $SEE = 0.078$)

A comprehensive set of dynamic modulus data (30 separate emulsion-stabilized mixtures) was submitted to the NCHRP 1-40 project (May 2005) for review. The data included a range of temperatures and frequencies. For a 10 Hz frequency, the log E – Temperature algorithm is:

$$\log E \text{ (ksi)} = 3.606 - 0.014T(^{\circ}\text{F})$$

where ($R^2 = 0.997$ / $SEE = 0.038$).

Data from a comprehensive Iowa dynamic modulus study of foam-stabilized materials (Lee and Kim 2007) indicated (for 10 Hz frequency) the following log E – Temperature algorithm:

$$\log E \text{ (ksi)} = 3.582 - 0.012 T(^{\circ}\text{F})$$

where ($R^2 = 0.997$ / $SEE = 0.023$).

Note the similarity between the FWD backcalculated and the SEM and Iowa lab relations.

It is generally found that CIR&FDRwAP materials are less temperature sensitive than HMA. Emery (2006) indicates the reduced temperature susceptibility of CIR and FDR mixtures, compared to HMA. The current temperature coefficient for IDOT HMA is about 0.019, considerably higher than the coefficients previously shown for asphalt-treated materials.

It is important to note that the lab modulus studies were conducted for “as-cured” conditions. Thus, the estimated moduli are optimistic. They should be adjusted (decreased) for field moisture conditions.

The importance of the modulus of bituminous stabilized materials is noted in a recent South African study (Jooste and Long 2007), which indicated, “The load spreading potential of an individual layer is a product of its thickness and its effective long term stiffness under loading.” The study also notes that this concept is similar to the widely used “Odemark Transformation,” and that the “effective long term stiffness” is developed with extended curing.

CIR&FDRwAP strength and modulus data are generally developed for lab-as-cured conditions, but various soaking protocols (soaking or vacuum saturation) are used to assess CIRwAP durability (moisture resistance). Wet strengths, or retained strength as a percentage of dry strength, or both are normally used for selecting design asphalt contents.

Reasonable and approximate strength inputs can be established for strength inputs.

7.3.2 Fatigue Properties

CIR&FDRwAP fatigue testing is very limited and quite variable.

The IDOT fatigue algorithm is of the form:

$$N = K (1/\text{flexural strain})^n$$

N = number of load repetitions to failure

K and n = experimentally derived parameters from flexural fatigue testing

Figure 2 presents log K – n data for several mixtures. This includes a range of RAP and crushed stone combinations, and both emulsion and foamed asphalt (Twaga et al. 2006), and three SemMaterials emulsion mixtures (May 2005 and 2008). For the mixtures considered, the K – n relation is:

$$\log K = 4.87 - (3.49 * n)$$

The n values for the mixtures ranged from 3.48 to 7.36. The average was 5.6. The log K – n algorithm is similar to the one developed by Carpenter (2006). CIR&FDRwAP fatigue life is extremely sensitive to the assigned fatigue algorithm. Since the current fatigue database is limited, and the range of n values is large, it would be necessary to arbitrarily assign a very conservative CIR&FDRwAP fatigue algorithm. A value of 4 corresponds to a K of 8.12E-10. A value of 5 corresponds to a K of 2.63E-13. For HMA, the comparable K (for n = 4) is 2.65E-09 (3.3 times larger than for the asphalt-stabilized mixtures).

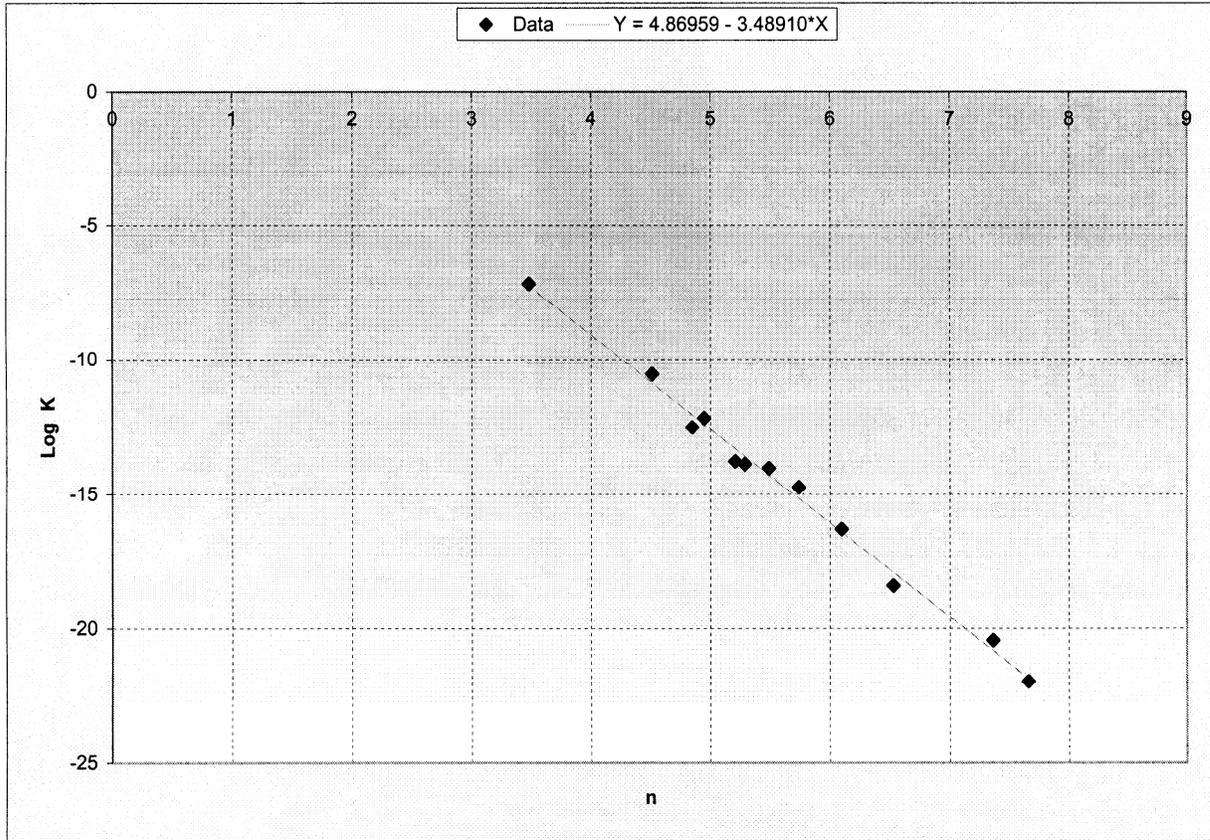


Figure 2. K - n relation for twelve mixes.

To illustrate the M-E concept, the above inputs were used as inputs to the IDOT full-depth AC design procedure and HMA strain algorithms for $n = 4$ and $n = 5$. The estimated HMA fatigue lives (8-inch stabilized FDR layer – Champaign temperature data – subgrade $E_{Ri} = 5$ ksi) are shown in Table 3. Both the modulus algorithm and the fatigue algorithm ($n = 4$, $n = 5$) have an impact on the estimated fatigue life. However, the smallest estimated fatigue life is around 0.25 MESALs. Many LR&S pavement sections are designed for TFs less than 0.25. Obviously, an increase in thickness would increase the fatigue life estimates. A further refinement to account for the increased modulus of an HMA SP surface course (higher modulus) would also increase the estimated fatigue lives.

Table 3. Predicted Fatigue Lives for an 8-inch Foamed Asphalt /Engineered Emulsion Stabilized Layer (Champaign temperature data).

Model	a	b*	N-MESALs**	N-MESALs***
Project (Backcalculated)	3.14	0.0104	0.227	0.258
SEM	3.606	0.014	0.805	1.2
Iowa	3.582	0.012	2.14	4.2

* $\log E(\text{ksi}) = a - bT(^{\circ}\text{F})$
** MESALs – millions of 18-kip ESALs
** $N(\text{ESALs}) = 8.12\text{E-}10 * (1/\text{HMA Strain})^4$
*** $N(\text{ESALs}) = 2.63\text{E-}13 * (1/\text{HMA Strain})^5$
NOTE: subgrade $E_{Ri} = 5 \text{ ksi}$

In summary, the required inputs for M-E thickness design of FDRwAP layers, particularly modulus–temperature relations and fatigue properties), show considerable variability. However, the information presented in Table 3 suggests that M-E design (with conservative inputs) provides reasonable estimated fatigue lives.

7.4 AASHTO STRUCTURAL NUMBER (SN) APPROACH

The AASHTO inputs for subgrades and typical paving materials are available from previous IDOT–LR&S practice and policy (see “Flexible Pavement Design for Local Agencies,” August 1988). Only an “a” layer coefficient(s) needs to be established for CIR&FDRwAP materials. The SN approach is very sensitive to the layer coefficient assigned to a material layer. Suggested asphalt-treated material coefficients (based on Marshall Stability) are presented in Chapter 37 of the Illinois *Bureau of Local Roads and Streets Manual* (Figure 37-8F). The recommendations of Figure 37-8F are shown in Table 4 (The 1988 Illinois Local Roads and Streets policy assigned a coefficient of 0.18 to “asphalt (emulsion)-stabilized” materials [previous LR&S 310 Special Provision]).

Some typical layer coefficients are:

- A summary of the “a” values used in the design of some of the pavements included in this study is shown in Table 5.
- Typical Canadian practice (Emery 2006 and Hein 2006) assigns a granular base equivalent of about 1.8 to foamed asphalt stabilization. For the IDOT crushed aggregate base coefficient of 0.13, a GBE of 1.8 is equivalent to an “a” of about 0.23.
- Based on full-scale accelerated load testing, research by Kansas State University (Romanoschi et al. 2004) suggests an “a” of 0.18 for foamed asphalt mixtures. (NOTE: The “a” value for Kansas aggregate base is 0.14.)
- A Maine DOT study (Marquis 2003) of four projects indicated an “a” value range of 0.22 to 0.35; three of the values were around 0.23.
- Typical “a” values suggested by Wirtgen (2006) and included in a Transportation Research Board Committee AFD70 Circular (TRB AFD70 2008) are shown in Figure 3. Per Mike Marshall of Wirtgen (personal correspondence in January 2007), the ITS is generally for dry conditions, but soaked conditions are appropriate for poor drainage or high rainfall. Wirtgen (2006) recommends the use of the SN system for TFs < 5. For TFs > 5, they suggest doing an M-E design. An initial design based on the SN approach is

subsequently analyzed using M-E (linear elastic analysis) procedures to assure various design criteria are met.

- Per an FHWA technology review (FHWA 2005), the following “a” values have been used by state DOTs:
 - Kansas: 0.25 to 0.28
 - Nevada: 0.28

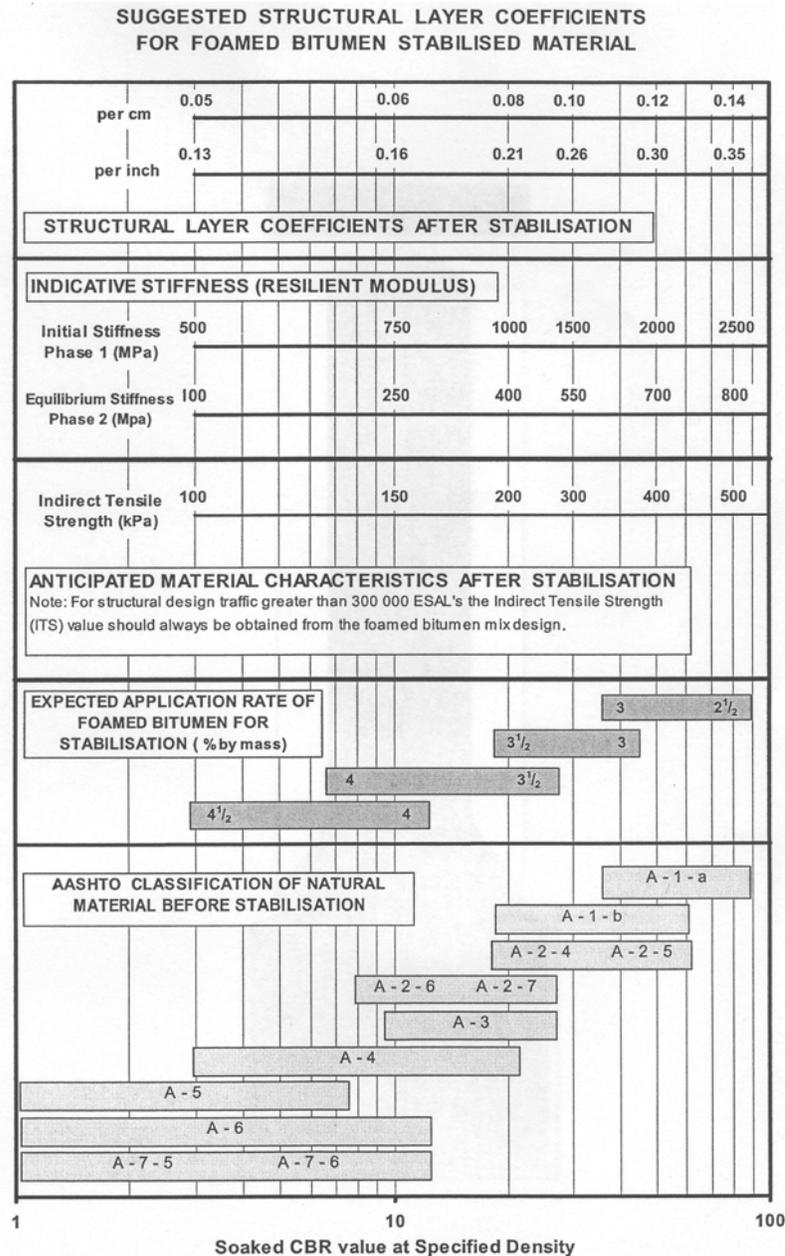


Figure 3. Wirtgen guidelines for selecting coefficients (2006).

There is a wide variation in the “a” values for cold in-place asphalt-treated materials. They typically are in the mid-0.20s.

Table 4. LR&S “a” Coefficients for New Construction.

Marshall Stability ¹ (lbs)	“a”
300	0.16
400	0.18
800	0.23
1,000	0.25
1,200	0.27
1,500	0.30
1,700	0.33
(1 - all Marshall values @ 72°F)	

Table 5. Follow-up Project “a” Coefficients.

Project*	Asphalt	TF	“a”
1. (Ch. Co.)	Foam	0.092	0.25(?)
2. (Chr. Co.)	EE	0.95	0.23
3. (St. Co.)	EE	1.49	0.28
4. (Liv. Co.)	Foam	0.196	0.23
5. (Carrol Co.)	EE	0.28	0.27
(* see Table 1)			

7.5 OVERVIEW

IDOT–LR&S should consider how to classify FDR and CIR relative to thickness design. FDRs are typically thicker than CIRs. The CIR process has remaining material in the pavement section following CIR.

FDR sections are more readily analyzed utilizing the M-E approach.

- The FDR + HMA surface (if used) could be analyzed as a full-depth-type pavement section. The primary design criterion would be fatigue at the bottom of the FDR layer. The subgrade stress ratio (indicative of rutting potential) for the section would also be checked considering the HMA layer, the FDR layer, and any remaining materials below the FDR layer. This concept is currently used in Chapter 37 of the Illinois *Bureau of Local Roads and Streets Manual* for full-depth HMA pavements.
- A very conservative approach would consider the stabilized section as a conventional flexible pavement (CFP). The stabilized layer plus the material below the stabilized layer would be considered as aggregate layers, and the HMA surface (if any) would be a fatigue-resistant layer. The design criteria would be HMA layer fatigue and the subgrade stress ratio for the section would also be checked. This concept is currently used in Chapter 37 of the *Bureau of Local Roads and Streets Manual*.

CIR sections are difficult to characterize and analyze.

- CIR pavements have remaining asphalt-treated material and perhaps additional paving material layers (probably aggregates) in the pavement section. The depths and properties and qualities of these materials are very difficult to establish. Some CIR projects are constructed over cement-treated layers with “build-ups” of asphalt materials (HMA overlays or surface treatments). The conservative CFP approach described above could be used.
- Some agencies establish thickness design policies and standard sections for CIR pavement design. M-E principles can be incorporated into the development of the policies and standard sections.

The AASHTO-based HMA overlay design approach (see Section 37-8 of Chapter 37 in *Bureau of Local Roads and Streets Manual*) is frequently used by Illinois local road agencies for FDR and CIR pavement thickness design.

8.0 LAYER THICKNESSES

8.1 SURFACE COURSE

Establishing surface course type and thickness must be addressed in the thickness design process. Anderson (1993) indicates that for many of the EAMs constructed in Illinois during the 1960s through the 1980s, a surface treatment was used. The 1988 LR&S thickness design manual indicated surface treatments were permitted for ADTs < 400. In other projects, variable- thickness HMA surface surfaces were used. The 1988 LR&S Flexible Pavement Design Policy recommended that the minimum surface thickness range from a 2-inch Class B “Road Mix” for SNs < 1.99 (low TFs) to a 4-inch Class I HMA for SNs > 3.99 (high TFs). Nevada (Carpenter 2006) also limits surface treatments to ADTs < 400.

The suggested practice in South Africa (Jooste and Long 2007) is as follows:

it is therefore strongly recommended that bituminous stabilized layers always be combined with an asphalt surfacing. An exception can perhaps be made in the case of pavements with design traffic less than 1 MESALs.

The recommended minimum asphalt surface thicknesses for this practice increases from 1.25 inches for <1 MESALs to 2 inches for traffic > 15 MESALs.

The New York State DOT (2002) uses “prescribed” thicknesses for CIR rehabilitation:

- Traffic < 4,000 ADT / 3-inch CIR + 1.5-inch HMA OL
- Traffic > 4,000 ADT / 3-inch CIR + 3.0-inch HMA OL

With a maintenance scenario of five-year transverse crack sealing and other cracks filled at two-year intervals, the NYDOT expects a service life of 15 years.

It is apparent that HMA surface requirements vary as a function of traffic. The stability of the bituminous stabilized layer is an important factor. For similar traffic, an increased HMA thickness is justified for a lower-stability mixture. IDOT performance data certainly indicate that surface treatments are adequate for lower traffic levels.

8.2 ASPHALT-TREATED LAYER THICKNESS

In the FDR procedure, the full depth of the in-place HMA (and in some conditions, the underlying base) is processed. Additional granular material may be added at the surface. A reasonable minimum thickness of added granular material + in-place HMA + underlying base to be stabilized is probably about 6 inches. (NOTE: IDOT's 1988 LR&S stabilized base thickness policy indicated the minimum base thickness was 6 inches (for SNs < 2.49) and a Marshall Stability (@ 72°F) of 300 pounds. EAMs were limited to pavements with SNs < 4.5.)

For CIR projects, minimum thicknesses of the stabilized layer of 4 inches are common. In CIR construction, a rotomill is typically used to mill the HMA thickness to be processed. (There will be a remaining HMA thickness.) The existing HMA thickness to be milled may vary considerably, but a rotomill can accommodate significant thicknesses (> 10 to 12 inches).

9.0 MIXTURE DESIGN

9.1 INTRODUCTION

The *Wirtgen Manual* (2006) suggests that, regarding the objective of mix design, “the added bitumen content that best meets the desired properties is regarded as the optimum bitumen.”

In some conditions, “active fillers” (generally lime, cement, or fly ash) are also used. Also per the *Wirtgen Manual*, “Bitumen stabilisation is normally carried out in combination with a small amount of active filler (cement or hydrated lime).”

The Wirtgen active filler guides are:

- PI < 10: 1% cement
- PI 10-16: 1% hydrated lime
- PI > 16: pre-treat with 2% hydrated lime

(NOTE: In Illinois, Portland cement (Projects 4, 6, and 7) and Type C fly Ash (Project 1) have been successfully used as active fillers.)

Laboratory test results can be used to establish if the use of an active filler is warranted.

Several mixture design procedures for establishing design asphalt content have been successfully used. The procedures are comprehensive (specimen preparation, curing, specimen conditioning prior to testing, and design criteria). Details of some of the more common procedures are presented in some of the references (Wirtgen 2006, Iowa DOT 2006, SemMaterials 2007, and CalTrans).

9.2 SAMPLE PREPARATION MATERIAL

A part of the mixture design process is to prepare the field-sampled materials for sample preparation. Though construction pulverization specifications are not restrictive (typical maximum size of pulverized in-situ material of 1.5 to 2 inches), it is common to achieve a desired gradation for preparation of laboratory test specimens.

The typical practice is to crush (if RAP particles are > 1 inch), dry, and sieve the field samples into various fractions. The various fractions are then reblended to achieve the target gradation. This approach facilitates the production of uniform test specimens.

The Iowa criteria for CIR (Iowa DOT 2006) with engineered emulsion (EE) is:

Sieve Size	% Passing
1 inch	100
¾ inch	85-95
No. 4	40-55
No.30	5-15
No. 200	0.5-3

The SemMaterials mix design procedure (2007) for EE requires:

Sieve Size	% Passing
1.25 in.	100
1 in.	90-100
¾ in.	80-97
No. 4	30-55
No.30	5-15

9.3 PROCEDURE COMPARISONS

The Iowa CIR procedure (Iowa DOT 2006) considers standard emulsions, foamed asphalt, and engineered emulsions. It is interesting to note that Iowa does not require a mix design for standard asphalt emulsion or foamed asphalt (unless required in the contract documents), but does require a mix design for “engineered emulsion.” Iowa has conducted comprehensive foamed asphalt research (Lee and Kim 2007; Kim et al. 2006) and extensively uses the foamed asphalt procedure. Iowa’s standard design for foamed asphalt is about 2% residual asphalt.

The SemMaterials procedure is only for engineered emulsions.

The SABITA mixture design approach (to be available in late 2009) will also consider both foamed asphalt and emulsion processes (Gauteng). Supposedly, the SABITA approach will use a standard procedure that is applicable to both EE and FA.

The major differences in some of the more widely used procedures are:

- Compaction method: Marshall compaction and gyratory methods are typically used.

Kim et al. (2006) indicate that Superpave™ Gyratory compaction $N = 30$ is equivalent to 75-blow Marshall compaction. They recommend gyratory compaction “due to its consistency in producing laboratory samples.”

Some current compaction practices are:

CalTrans – EE: 75 blow Marshall or $N = 0$
Iowa DOT – Foam: 4-inch Gyratory / $N = 25$
Iowa DOT – EE: 4-inch Gyratory / $N = 30$
SemMaterials – EE: 6-inch Gyratory / $N = 30$
Wirtgen – 75 blow Marshall
Ontario Ministry of Transportation – 75 blow Marshall
South Africa / SABITA: TBD

Curing: A broad range of specimen curing conditions are used. Some representative conditions are:

- CalTrans – EE: Cure @ 140°F to a constant weight
- Iowa DOT – Foam: 72 hours @ 105°F
- Iowa DOT – EE: 48 hours @ 140°F
- SemMaterials – EE: 72 hours @ 104°F
- *Wirtgen* - 72 hours @ 104°F. For high traffic (> 5 MESALs) the specimens are compacted at the equilibrium/field moisture content and cured in sealed containers for 48 hours @ 104°F prior to testing.
- Ontario Ministry of Transportation (Kim et al. 2006) – Foam: 48 hours @ 140°F / 24 hour soak @ 77°F / or vacuum saturate 60 minutes @ 50 mm Hg

Note that with the exception of the *Wirtgen* approach for specimens compacted at the equilibrium/field moisture content, the curing condition (open to the air) results in a “dry” specimen.

- Testing Procedures: Typical strength and modulus testing procedures are indirect tensile strength (ITS), resilient modulus (not DYNAMIC modulus), Marshall Stability (MS), and unconfined compressive strength (UCS). Moisture conditions at testing are “dry” or “wet.” The “wet” condition is achieved by soaking (typically 24 hours @ 77°F) or vacuum saturation (typically 55 minutes @ 55 mm of Hg). CalTrans (Lee and Kim 2007) vacuum saturates to 55-75% saturation followed by a 24-hour soak @ 77°F, followed by a 30 to 40-minute soak @ 104°F just prior to testing. Some representative testing procedures are:
 - CalTrans – EE: MS @ 104°F
 - Iowa DOT - Foam: ITS
 - Iowa DOT – EE: Marshall Stability @ 100°F
 - SemMaterials – EE: ITS / Modified Cohesimeter / resilient modulus
 - *Wirtgen*: ITS (dry and wet), UCS, and triaxial (optional)
 - Ontario Ministry of Transportation - Foam: ITS (dry and wet)

9.4 MIXTURE DESIGN CRITERIA

As the *Wirtgen Manual* (2006) indicates:

Ongoing research in South Africa has shown that a material stabilized with bitumen emulsion has strength and stiffness characteristics similar to those for foamed bitumen treatment.

Thus, there is some similarity in the criteria for EE and foamed asphalt.

The most common mixture design criteria are based on strength. Indirect tensile strength (ITS), Marshall Stability, and unconfined compressive strength (UCS) are most widely used. To capture the moisture sensitivity of the mix, the retained strength ratio (RSR) (“wet” strength / “dry” strength) or “wet strength” parameters are frequently used. It is very difficult to establish the equilibrium/field moisture content (as suggested by *Wirtgen*).

Some common criteria are:

- CalTrans (EE):
 - MS (dry)- 1,250 lbs
 - RSR – 70% minimum

- SemMaterials (EE):ITS: (dry) 35-40 psi, (wet) 20-25 psi
 - Resilient Modulus @ 77°F – 120-150 ksi minimum
 - RSR > 0.7

- Iowa DOT (EE)
 - MS @ 100°F > 1,000 lbs

- Ontario Ministry of Transportation(foam)
 - ITS – Dry: 50 psi
 - ITS – Wet: 25 psi
 - RSR: 50%

9.5 SUMMARY

The mixture design procedures considered above are comprehensive, and most include evaluation criteria. It is interesting to note that the Ontario Ministry of Transportation OPSS 334 (Construction Specifications for Cold Recycled Mix [Ontario 2005]) indicates that, “Currently, there is no standardized mix design methodology for CRM (cold recycled materials).”

Fu et al. (2008) considered the difficulty (or impracticality) of characterizing and simulating field service conditions and suggest:

The second approach is to test the specimens at conditions that are critical to the material’s performance in the field in a relatively conservative fashion

They recommend using “soaked tensile strengths as the objective function to optimize mix design variables.”

Since most failures are associated with excess moisture contents, Kim et al. (2006) proposed using the ITS for “wet specimens” (vacuum saturation - 20 mm Hg for 30 minutes).

9.6 DEVELOPING AN IDOT MIXTURE DESIGN PROCEDURE

To establish a good mixture design procedure for cold in-place recycled materials, several issues need to be carefully considered:

- Curing conditions: “open” or “sealed,” temperature, length of curing.
- Testing conditions: “as-cured” or “wet” (soaked or vacuum saturation).
- Testing procedures: Marshall, ITS, UCS, modulus
- Design criteria: Minimum strength (wet or dry) – retained strength (wet strength/dry strength)

The SemMaterials approach for engineered emulsions and the Wirtgen procedure (or procedures similar to the Wirtgen procedure) for foamed asphalt have been successfully used in several Illinois projects. It is suggested that these procedures be used as the starting points for developing an IDOT procedure. Based on the consideration of the comments previously presented in this report by an IDOT Working Group (contractors, materials suppliers, IDOT engineers, University of Illinois representatives) appropriate changes and modifications can be made. In the interim, it is recommended that the SemMaterials and Wirtgen procedures be considered acceptable.

(NOTE: A foaming device is needed to create the foamed asphalt used in the mixture design process. At this time, only the Dunn Co. in Decatur, Illinois has such a foaming device. The mixture design process for EE is more straightforward and does not require any special equipment other than what is typically available in an asphalt laboratory. Currently, SemMaterials provides mixture design support for Fortress and ReFlex EEs.)

It is encouraging to note that there is considerable ongoing research and development relating to mixture design and mixture criteria. These efforts should be helpful in developing future changes and modifications.

10.0 CONSTRUCTION CONSIDERATIONS

10.1 PULVERIZATION AND GRADATION

Many successful CIR&FDRwAP projects, some of which are listed in Table 1, have been constructed in Illinois. All of the specifications included a pulverization/gradation clause.

The condition of the processed material at the time of the addition of the asphalt product (foamed asphalt – engineered emulsion) is an important factor. Gradation and plasticity index (PI) are the properties generally considered. These factors can be controlled by the pulverization and milling equipment and procedure, the inclusion of crusher and screening units in the construction train, the amount of material below the HMA layer incorporated into the final mix, and the addition of material (aggregate of various gradations and fines [normally lime, Portland cement, or fly ash]). The most accurate gradation control is achieved when crusher and screening units are included in the construction process.

Gradation requirements for the pulverized material vary depending on whether an FDR or CIR reclamation process is used and the stabilizing agent is foamed asphalt or EE. Pertinent information that reflects current practice and policy is presented below.

In the use of foamed asphalt, the minimum amount of fines (-#200) is generally greater than 5%. *Wirtgen (2006)* indicates:

*Unlike hot-mix asphalt, material stabilized with foamed asphalt does not appear black. This results from the coarser particles of aggregate not being coated with bitumen. When foamed bitumen comes into contact with aggregate, the bitumen bubbles burst into millions of tiny bitumen particles that seek out and adhere to the fine particles, specifically the fraction smaller than 0.075 mm. The bitumen droplets can exchange heat only with the filler fraction and still have sufficiently low viscosity to coat the particles. The foamed mix results in a bitumen-bound filler that **acts as a mortar between the coarse particles**. There is only a slight in the color of the material after treatment.*

Wirtgen (2006) gradation guidelines for considering the suitability of materials for foamed asphalt treatment are shown in Figure 4.

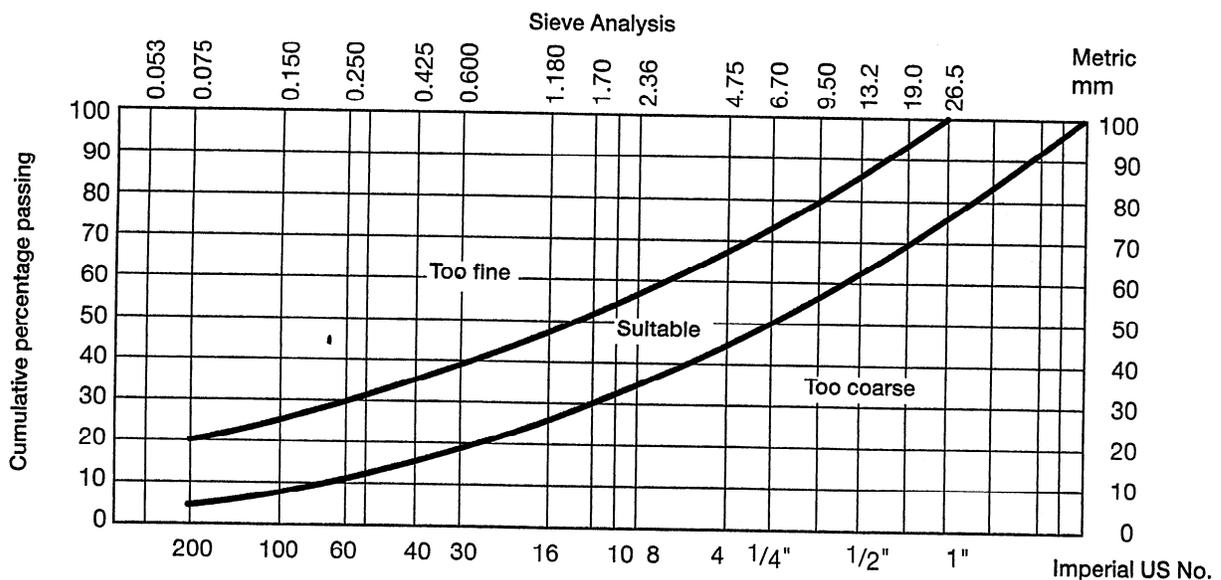


Figure 4. Wirtgen gradation guidelines for foamed asphalt (Wirtgen 2006).

The *Basic Asphalt Recycling Manual (BARM)* (AR & RA 2001) also indicates the importance of sufficient fines when foamed asphalt is the stabilizing agent:

The gradation requirements are more restrictive if foamed asphalt is to be used as the stabilizing agent. Reclaimed materials deficient in fines will not mix well with asphalt. When reclaimed materials have insufficient fines, the foamed asphalt will not disperse properly and tends to form “stringers” or bitumen rich agglomerations of fines. These stringers will vary in size according to the fines deficiency, with a large deficiency of fines resulting in many large stringers. These stringers will tend to act as a lubricant and result in a reduction in strength and stability of the reclaimed mix. The reclaimed material should have between 5 and 15 percent passing the No. 200 sieve.

In the FDR process, 100% of the existing asphalt pavement is used along with a predetermined percentage of the underlying materials. Therefore, the variation or consistency of the existing asphalt pavement and underlying materials will have the greatest influence on the variation or consistency of the reclaimed mix. Typically, there are no specified gradation requirements for the intermediate sieve sizes, since these are determined by the gradation of the existing materials.

Per the Iowa DOT specification (2006) for CIR:

The processed recycled asphalt pavement (RAP) is intended to conform to the following gradation. The gradation may be revised with the approval of the Engineer, but the top size of the material shall not exceed 50% of the depth of the compacted recycled mat.

98-100% / -1.5 inch

90-100% / - 1 inch

A similar maximum size clause is included in the Iowa DOT specification for FDR (Iowa DOT 2003).

The typical SemMaterial pulverization specification for EE is:

98-100% passing 2-inch

The BARM (AR & RA 2001) suggests that the maximum size of the reclaimed material is generally 1.5 to 2 inches. It is indicated that for FDR, the maximum amount passing the #200 sieve should be 20 to 25%. The -#200 requirement addresses the concern that an excessive amount of fine-grained subgrade may be incorporated into the recycled mix. The -#200 requirement is not needed for CIR, since the pulverized material is all RAP; however the minimum -#200 requirement for foamed asphalt is still applicable.

Some comments concerning pulverization are as follows:

- In the Livingston County foamed asphalt project (Project 4), the construction specification required 100% to pass through the 2-inch sieve and 5 to 20% pass the #200. A similar requirement was used in a more recent (2007) Livingston County foamed asphalt project (4H Road).
- In the Champaign County foamed asphalt project (Project 1), the construction specification required 97% to pass through the 1.5-inch sieve.
- Maine's specification for full-depth recycled pavement calls for 100% passing through the 2-inch sieve.
- In the Stephenson County project (Project 3 – engineered emulsion), the pulverization requirement was 100% passing through the 2-inch sieve and 97 to 100% passing through the 1.75-inch sieve.

Note that the engineered emulsion pulverization specifications normally only have a maximum size clause. Typically, the maximum size clause is 100% passing through the 1.5-inch-to 2-inch sieve. A foamed asphalt specification should also include a -#200 requirement.

As previously presented in the mixture design section of this report, the gradation of the material used in preparing the test specimens is typically controlled. Typical construction specifications do not ensure compliance with the gradation(s) used in mixture design. However, field construction experience has demonstrated that the maximum size requirement for EE plus the inclusion of the -#200 requirement for foamed asphalt are adequate to produce quality asphalt-stabilized material.

10.3 CONSTRUCTION STABILITY CONDITIONS

The typical full-depth and partial depth construction process includes the pre-pulverization of the existing pavement. In most situations, the existing pavement is stable. The pulverized material may include pulverized HMA and underlying base and subbase material or pulverized HMA, some remaining HMA, and underlying base and subbase layers. The structural capacity of the pavement following pulverization is reduced relative to the original pavement. The post-pulverized pavement section may not be stable under subsequent construction operations. Marginal subgrade conditions (strength/modulus) exacerbate the issue since construction load-induced stresses will increase under the post-pulverization conditions. This issue should be addressed during the project planning and engineering stage. The most critical elements are layer thicknesses of the post-pulverized pavement section and the subgrade strength and modulus. Subgrade strength and modulus are frequently characterized from FWD and/or dynamic-cone-penetrometer (DCP) testing. Some recent (2007-2008) Illinois projects have encountered stability problems.

10.4 SPECIFICATIONS

CIR&FDRwAP specifications have evolved over recent years. Some current typical specifications are presented in Appendix B (FDR - engineered emulsion – SemMaterials specification), Appendix C (FDR - foamed asphalt – Project 1 – Champaign County), and Appendix D (CIR – foamed asphalt – Livingston County). Additional useful information is available in References 1 and 2. Since the specifications presented in Appendices B, C, and D have proven to be adequate, it is proposed that they be used as typical specifications that can be adapted to local project conditions. IDOT–LR&S should refine and modify the specifications as additional projects are constructed and areas of improvement are identified.

11.0 SUMMARY AND RECOMMENDATIONS

- Illinois, United States, and international experiences demonstrate that cold in-place recycling with foamed asphalt and asphalt emulsions is a proven technology. Developments in emulsion formulations (engineered emulsions, or EE), asphalt foaming equipment, CIR&FDRwAP mixture design procedures, field mixing equipment, and construction procedures have been and continue to be improved. CIR&FDRwAP technology typically results in lower construction costs for flexible pavement reconstruction, rehabilitation, and resurfacing projects. CIR&FDRwAP has emerged as a viable and cost-effective in-place recycling alternative. IDOT has not focused or directed any particular efforts toward thoroughly evaluating and implementing recently developed CIR&FDRwAP technology. This project addresses this situation.

- The findings and results of this project, particularly the performance data, indicate that these cold in-place recycling procedures have developed and evolved to the degree that they need not be considered as experimental projects by IDOT–LR&S. The current technology is adequate to support routine use of the procedures.
- CIR&FDRwAP asphalt-stabilized materials have been characterized as “improved granular materials” to “asphalt-bound materials.” The projects considered in this study (Table 1) indicate that based on backcalculated modulus and rutting performance data, these engineered emulsion and foamed asphalt projects display properties more like asphalt-bound materials.
- Based on the backcalculated moduli for the Table 1 projects and dynamic moduli data from SemMaterials (May 2005) and Iowa (Lee and Kim 2007), moduli-temperature relations were successfully established. The relations were of the form:

$$\log E \text{ (ksi)} = a - bT \text{ (}^\circ\text{F)}$$

Typical “a” and “b” values are presented in Table 3. The asphalt-stabilized materials displayed, compared to conventional HMA), reduced temperature susceptibility (“b” coefficients were lower).

- Based on fatigue testing results for twelve different asphalt-stabilized mixtures, the validity of the traditional fatigue algorithm was confirmed. The form of the algorithm is:

$$\log N = K (1/\text{flexural strain})^n$$

A K-n relation was established that successfully captured the range of n’s (from 3.48 to 7.364) and K’s. The relation is:

$$\log K = 4.87 - (3.49*n)$$

Compared to conventional HMA, the asphalt-stabilized materials have a shorter fatigue life.

- The IDOT full-depth HMA design approach was used to demonstrate and semi-quantify the potential fatigue life of an 8-inch asphalt-stabilized pavement. The results for Champaign, Illinois temperature data are shown in Table 3. It is apparent that asphalt-stabilized pavements can achieve significant fatigue lives. The fatigue life estimates are sensitive to the modulus–temperature relation and the fatigue algorithm. To use a mechanistic-empirical approach to thickness design, conservative inputs for the modulus–temperature relation and the fatigue algorithm should be used.
- The AASHTO Structural Number approach for flexible pavement design is frequently used for asphalt-stabilized layer thickness design. The assigned coefficients show considerable variability but are typically in the mid-20’s.
- IDOT–LR&S should consider and establish thickness design procedures for FDR and CIR pavements. FDRs are typically thicker than CIRs and are more readily and appropriately analyzed using M-E concepts. The procedures should reflect the best of past IDOT practice and recognize the good (outstanding??) performance of EE and FA that has been achieved in Illinois projects.
- For mixture design, the SemMaterials approach for engineered emulsions and the Wirtgen procedure (or procedures similar to the Wirtgen procedure) for foamed asphalt are considered acceptable. Both have been successfully used in several

Illinois projects. It is suggested that these procedures be used as the starting points for developing an IDOT procedure.

The specifications presented in Appendices B, C, and D have proven to be adequate. It is proposed that they be used as “typical specifications” that can be adapted to local project conditions. A specification for foamed asphalt should include a -#200 sieve clause. IDOT–LR&S should refine and modify the specifications as additional projects are constructed, areas of improvement identified, and additional technical data and information become available (see BDAT Section 3.00).

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APPENDIX A: MODULUS CALCULATIONS

Falling weight deflectometer (FWD testing 9-kip loading) was conducted for the projects. The data were typically collected in the outer wheel path at 500-foot intervals (staggered in adjacent lanes).

The FWD deflection sensor spacings were:

- load plate center (D_0),
- 12 inches (D_1),
- 24 inches (D_2), and
- 36 inches (D_3).

Pavement temperature data at various depths were monitored during the testing period.

The average of the deflections (mils) for each sensor offset were calculated and are considered to be a REPRESENTATIVE DEFLECTION BASIN. In addition to the FWD deflections, a DEFLECTION BASIN PARAMETER (AUPP) was calculated. The AUPP equation is:

$$\text{AUPP} = (5 \cdot D_0 - 2 \cdot D_1 - 2 \cdot D_2 - D_3) / 2$$

A small AUPP is an indicator of a “STIFF” (higher moduli paving material layers) pavement.

D_3 (36-inch offset sensor) can be used to estimate the subgrade modulus (E_{Ri}). E_{Ri} is the resilient modulus of the soil at a repeated deviator stress of about 6 psi. The E_{Ri} equation is:

$$E_{Ri} \text{ (ksi)} = 24.7 - 5.41 \cdot (D_3)^2 - 0.31 \cdot D_3$$

(D_3 in mils)

The subgrade unconfined compressive strength (Q_U) can be estimated from E_{Ri} using the following equation:

$$Q_U \text{ (psi)} = (E_{Ri} - 0.86) / 0.31$$

The cohesion (C) is $Q_U / 2$.

The E_{Ri} and C values are inputs needed for subsequent ILLI-PAVE analyses.

It was assumed that the stabilized base plus the HMA surface made up a “COMPOSITE LAYER.” Iterative ILLI-pave analyses (the modulus of the “COMPOSITE LAYER” was changed) until a good match was achieved for D_0 and AUPP.

**APPENDIX B: SEMMATERIALS SPECIFICATION FOR FULL-DEPTH
RECLAMATION (VERSION 2A-3 / MAY 2007)**

**GUIDELINES FOR
ASPHALT EMULSION FULL DEPTH RECLAMATION (FDR)**

1. Description

Asphalt emulsion full-depth reclamation (FDR) consists of reclaiming the existing road with a reclaimer to obtain the width and depth specified in the plans. Asphalt emulsion will be added to the blend of materials; water and other materials will be added as needed. The material will be spread and compacted, resulting in a finished bituminous base in accordance with the plans and these specifications. This specification applies to a road that has had a site selection and material evaluation performed by the Agency or its representative.

2. Materials

2.1 Asphalt Emulsion - The properties of the asphalt emulsion to be used shall be determined by the mix design in order to meet the requirements in Table 1.

2.2 Aggregate – The amount and type of added aggregate or recycled asphalt pavement (“add rock”), if any, will be determined by the mix design in order to meet the requirements in Table 1.

2.3 Reclaimed Material – A mix design is required before the start of the project. (Refer to Appendix 1.) The reclaimed material at the recommended emulsion content shall meet the properties in Table 1. Based on road variability, more than one design may be required. The properties and quantity of asphalt emulsion, add rock, and water shall be determined by the mix design. The Contractor shall submit the mix design to the Engineer for approval prior to the start of the project.

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

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

<i>Table 1(FDR Type 2) – For mixtures containing ≥8% passing No. 200 or for all granular mixtures</i>	
150-mm diameter specimens shall be prepared in a Superpave™ gyratory	

compactor	
Property	Criteria
Superpave TM gyratory compaction, 1.25° angle, 600 kPa, gyrations	30
Short-term strength test, 1 hour – modified cohesiometer, ASTM D 1560-92 (Part 13), g/25mm of width (see Appendix 1 for modifications)	150 min.
Indirect tensile strength (ITS), ASTM D 4867 Part 8.11.1, 25°C, psi	35 min.
Conditioned ITS, ASTM D 4867 (see Note 1), psi	20 min.
Resilient modulus, ASTM D 4123, 25°C, psi x 1000	120 min.
Thermal cracking (IDT), AASHTO T-322 (Based on LTPPBind for climate)*	See note in appendix

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

2.4 Other Additives – If necessary, additives may be used to meet the requirements in Table 1. In the case that an additive is used, the type and allowable usage percentage must be described in the submitted design recommendation.

The material for the prime coat shall meet the applicable local requirements and can be applied at Engineers discretion.

3. Equipment

All equipment for asphalt emulsion FDR described below used on the project shall be in proper working condition and approved by the Engineer.

3.1 The self-propelled reclaimer shall be capable of fully reclaiming the existing road to the depth required, incorporate the asphalt emulsion and water, and mix the materials to produce a homogeneous material. The recommended minimum power of the reclaimer is 400 hp. The machine shall be capable of reclaiming up to 12 inches deep in each pass. The reclaimer shall have a system for adding asphalt emulsion with a full width spray bar consisting of a positive displacement pump interlocked to the machine speed so that the amount of emulsion being added is automatically adjusted with changes in machine speed. The additive system shall be capable of incorporating up to 7 gallons per square yard of emulsion. Individual valves on the spray bar shall be capable of being turned off as necessary to minimize emulsion overlap on subsequent passes.

3.2 A motor grader for preshaping, aerating, spreading, and final shaping of the material is necessary. The motor grader shall have a cross slope indicator.

3.3 A vibratory padfoot roller with 84-inch-wide drum and 10-ton minimum weight is required; a blade is recommended for back-dragging. A pneumatic tire roller with 20-ton minimum weight with water spray system is required. A double drum vibratory steel roller with 10-ton minimum weight with water spray system is required.

If the reclamation depth is 4 inches or less, then a padfoot roller is optional. If no padfoot roller is used, then the pneumatic roller shall be 25-ton minimum weight with water spray system.

3.4 A water truck for supplying water to the reclaimer or road for addition of moisture, as required, during the FDR operation shall be used. The water truck shall be capable and set up for a controlled spray on the road before compaction.

3.5 When the existing roadway is to be widened, use a trenching machine or a motor grader with blade attachment to lay back vegetation and excavate the trench. Use a trench roller or other approved compacting device to compact the bottom of the trench. Equipment and methods of widening shall be subject to the Engineer's approval.

4. **Construction Methods**

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

4.1 When the Contract includes excavating for widening, first lay back vegetation, then excavate the shoulder from the edge of the existing pavement to at least 0.5 feet beyond the new width of base shown on the plans. In residential and commercial areas, do not waste vegetation and excess soil on the unpaved right-of-way. Dispose of it in a manner approved by the Engineer. Keep the bottom of the trench free of loose soil and vegetation and compact. Place the aggregate for widening into the excavation by means of a road widener designed to obtain a uniform, correct layer thickness. Alternatively, when approved by the Engineer, pulverize the existing road to the depth required to spread into the trenched areas. Place new material into the excavation uniformly, without loss or contamination. Correct all areas of irregular grade or deficient thickness and remove and replace material contaminated with soil, vegetation, or debris. After the final pass of the reclaimer, draw the soil up against the base layer to close the excavation, and grade and compact the shoulder to produce a firm, even surface. Remove and dispose of excess soil and vegetation in accordance with local and state regulations.

4.2 Preshaping – The road shall be shaped by the reclaimer and/or motor grader to correct for profile, crown, and contour, according to the plans, before the addition of emulsion. Water and add rock can be added during this operation. The material shall then be compacted to support equipment and/or traffic and to provide depth control during reclaiming; compaction with a steel roller should be sufficient unless otherwise determined by the Engineer.

4.3 Reclaiming – Moisture content before emulsion addition shall be within 1% from the mix design recommendation and as measured in Section 5.4; aerate if too wet and add water if too dry. The amount of asphalt emulsion used shall be as recommended from the mix design. The required depth of reclamation shall be monitored regularly. Prior to

spreading and compacting, the material shall have a gradation meeting the requirement of Section 5.3.

4.2a – The entire operation of reclaiming the existing road, incorporating add rock, water, and asphalt emulsion can be completed in one pass if adequate mixing is achieved.

4.2b – If the entire operation cannot be completed in one pass, then the existing road shall be reclaimed to the depth on the plans, and during this first pass, water and add-rock shall be added; preshaping can also be accomplished at this time. After completion of the first pass, the road shall be shaped with a motor grader and compacted with a steel roller to provide better depth control. A second pass of a reclaimer shall be completed with the required amount of asphalt emulsion added.

4.4 Initial Compaction – The breakdown roller (padfoot or pneumatic) shall not be behind the reclaimer by more than 500 feet. The padfoot roller, applying high amplitude and low frequency, or the pneumatic roller shall perform initial compaction at enough passes until it walks out of the material. Walking out for the padfoot roller is defined as light being clearly evident between all of the pads at the material–padfoot drum interface and being no more than 3/16 inch deep. Walking out for the pneumatic roller is defined as no significant wheel impressions being left on the surface.

4.5 Shaping – After the completion of padfoot rolling, any remaining pad foot marks shall be removed and the material spread using a motor grader cut no deeper than necessary to remove the padfoot marks. Desired slope and shape shall be achieved. After the first day of emulsion addition, the reclaimed base shall not be shaped or significant chunking will result.

4.6 Intermediate and Final Compaction – The vibratory double-drum steel roller and pneumatic roller shall compact the bladed material. The best combination of number of passes and order of rollers shall be used to meet compaction requirements. Do not finish roll in vibratory mode. A light spray of water may aid in final compaction density and appearance.

4.7 Proof roll the compacted material according to Engineer’s approval. It is recommended that proof rolling represent the type of traffic expected on the road. If deformation does not occur, moving truck traffic can be allowed on the reclaimed base. If deformation does occur, truck traffic should be kept off until the reclaimed material is firm enough. It is expected that the reclaimed base can support moving car traffic after finish rolling has occurred.

4.8 Before placing any surfacing, the reclaimed base shall be allowed to cure until the moisture content in the material is reduced to 50% or less of the optimum moisture content (from the mix design) or 2.5% or less, or at the discretion of the Engineer. Sample to the depth of recycling and in a way that represents the length of the road. The reclaimed base shall be surfaced before winter.

5. Quality Control

Supervisory personnel of the Contractor and crew and the testing laboratory shall meet a representative(s) of the Agency at a mutually agreed time prior to the start of the project to discuss methods of accomplishing all phases of the project. If needed, a representative of the asphalt emulsion supplier shall be present to discuss handling of emulsions and delivery issues.

The Contractor shall be responsible for quality control (QC) of the FDR process and the completed reclaimed base. Quality control shall include the following activities, and the results of the QC reported daily in writing to the Engineer. (See Appendix 2 for data sheets.)

5.1 Asphalt Emulsion – A representative from the asphalt emulsion supplier will check the mixing and setting properties as needed and will make adjustments to the asphalt emulsion formulation if necessary. Changes shall comply with Table 2. Testing, sampling, sampling frequency, and testing lab shall be in accordance with the Engineer’s requirements and be established prior to the start of the project. The testing shall meet the requirements in Table 2.

Table 2			
Test		Minimum	Maximum
Residue from distillation, %	ASTM D244 ¹	63	
Oil distillate by distillation, %	ASTM D244 ¹		0.5
Sieve test, %	ASTM D244 ¹		0.1
Penetration (TBD ²), 25°C, dmm	ASTM D5	-25%	+25%

¹ Modified ASTM D244 procedure – distillation temperature of 177°C with a 20-minute hold. The ASTM D244 vacuum distillation procedure may be substituted once the maximum oil distillate is satisfied.

² TBD – To be determined from the mix design prior to emulsion manufacture for project. Penetration range will be reported on the submitted mix design.

5.2 Added Rock or Dry Additive – The spread rate of the add-rock or dry additive (cement, lime, etc.) shall be checked and will conform to the quantity required by the mix design. The type of add-rock or dry additive shall conform to the type used in the mix design. Rates shall be checked by yield at a frequency to be decided by the Engineer.

5.3 Maximum Material Size – Samples of the reclaimed material shall be obtained before beginning compaction and sieved over the sieves to determine compliance with the following maximum particle size requirements:

<u>Sieve Size</u>	<u>Percent Passing</u>
2.0 in. (50 mm)	98 — 100

Sample size shall be 40 pounds. Sampling frequency shall be at the Engineer's discretion.

5.4 Moisture Content Before Emulsion – Prior to emulsion addition, moisture content shall be checked by microwave oven according to ASTM D 4643 or equivalent procedure. Other suitable methods are acceptable, such as a nuclear gauge, direct heating, or infrared. Minimum sample size recommended is 700 grams for the microwave procedure after screening through a 3/4-inch sieve. Check the moisture content on the same day that emulsion will be added. If rain has occurred after testing and before emulsion addition, recheck the moisture content. If the average moisture content is not within 1% of the mix design recommendation, then it shall be adjusted by moisture addition (water truck) or by aeration. If the moisture content has been manipulated, it shall be rechecked. The sample shall be to the depth of reclamation by any suitable method; make sure the sides of the sample hole are perpendicular to the road surface. Keep samples sealed until they are ready for testing. The moisture content shall be checked on at least each of three reclaimer passes on the first day of FDR. Moisture content sampling frequency shall be at the Engineer's discretion after the first day.

5.5 Emulsion Content – The amount of asphalt emulsion used shall be as recommended from the mix design. Any changes in asphalt emulsion content must be approved by the Engineer. The percentage of emulsion added shall be checked by determining the amount used by meter readings or truck weight tickets and by estimating the quantity of road reclaimed – depth, width, length, and estimated in-place density by Proctor density (mix design or field check) or nuclear density. On the first day of FDR, emulsion content shall be determined at a minimum on the first emulsion transport. Adjustments in equipment calibration shall be made if necessary. If adjustments are made, emulsion content shall be checked again. Thereafter, emulsion content shall be determined at a sampling frequency at the Engineer's discretion.

5.6 Depth Control – The reclaiming depth during all operations shall be monitored regularly to determine compliance with the plans. The depth shall be determined on each side of the reclaimer pass and shall be adjusted immediately as necessary.

5.7 Compaction

5.7a. If density measurements are not required, then Sections 4.4 – 4.6 shall be followed. Finish rolling will be performed until there is no further evidence of consolidation.

5.7b. It is recommended that moisture and emulsion contents be checked and established before determination of reference density.

Refer to ASTM D 1557, Method C or equivalent for determination of the modified Proctor reference density; the 6-inch diameter mold is required. Sample for the Proctor density at the same location as the nuclear gauge reading. Obtain the samples to the depth of reclamation before rolling and store in a sealed container or sealable bag for no longer than one hour before Proctor compaction. Place the mold on a firm surface during

compaction. Determine wet density and correct for the moisture content to determine dry density. Moisture contents on the material shall be obtained by microwave oven or equivalent procedure (Section 5.4). Use the mix design Proctor density, if needed, until field density values are determined.

After checking the nuclear density gauge on the standardizing block, prepare the test area for nuclear density testing by creating a surface free of loose material and deformations. Test the nuclear density, generally following ASTM D 2950 (direct transmission mode); this will measure a wet density. Make sure the depth of the hole is 2 inches greater than the reclamation depth. Measure the density at the same depth as the FDR depth. Correct to dry density by direct moisture measurement (microwave oven or equivalent; see Section 5.4) of a sample from the nuclear gauge testing location. In-place material shall be compacted to a minimum of 97% reference density of the Modified Proctor reference density. Use the sand cone apparatus (ASTM D 1556) to check the nuclear density results, if necessary, or at the discretion of the Engineer.

The number and frequency of density measurements should be determined by the Engineer. It is recommended that at a minimum, for Proctor and nuclear density testing, four locations be measured the first day, representing various locations. Thereafter, at a minimum, two to four nuclear density measurements should be obtained per day. It is permissible to use an average of the Proctor density values from the first day if materials and moisture contents do not change significantly.

5.8 Reclaimed Base Contour and Profile – The contour and profile and their methods and tolerances shall be as indicated on the plans or as required by the Engineer.

5.9 Moisture Content Before Overlay - Prior to placing the overlay or seal, moisture content shall be checked by microwave oven according to ASTM D 4643 or equivalent procedure. Other suitable methods are acceptable, such as direct heating. Minimum sample size recommended is 700 grams for the microwave procedure. If rain has occurred after testing and before the overlay, recheck the moisture content. The sample shall be taken to the depth of reclamation by any suitable method; make sure the sides of the sample hole are perpendicular to the road surface. Keep the samples sealed until they are ready for testing. Ensure that the average of three measurements per day of paving meet the requirements of Section 4.8 or the discretion of the Engineer.

6. Measurement

Mobilization shall be a lump sum.

Traffic control shall be a lump sum.

Excavation for widening is measured as the length along the centerline times the width of widening shown on the plans.

FDR work as described for this item will be measured by the square yard of the completed sections for the depth specified. It includes the reclaiming of the existing road, including furnishing, preparing, hauling and placing new materials, such as water and aggregate; all

freight involved; all manipulations, including blading and rolling; all labor, tools, equipment, and incidentals necessary to complete the work; and quality control.

Asphalt emulsion will be measured by the gallon or ton.

Add-rock or dry additive shall be measured by the ton.

Furnishing and spreading prime coat is measured by the gallon.

Item reference number	Item description	Unit
1	Mobilization	Lump sum
2	Traffic control	Lump sum
3	Excavation for widening	Square yard
4	Full depth reclamation	Square yard
5	Asphalt emulsion	Gallons or ton
6	Add rock	Ton
7	Dry additive	Ton
8	Prime coat	Gallon

7. Payment

Mobilization will be paid for as a lump sum at the price bid.

Traffic control will be paid for as a lump sum at the price bid.

Excavation for Widening will be paid for by lump sum or at the Contract Price per square yard, as provided in the Contract.

FDR will be paid for by the square yard processed and the unit price bid. It shall include all items described under "Measurement."

Asphalt emulsion shall be paid for separately at the unit price in the "Asphalt Emulsion Full Depth Reclamation" bid. An emulsion content of X% (X = 4.5 for Type 1 and X = 6 for Type 2) by weight of the material shall be used for bidding purposes prior to the completed design. The actual emulsion content will be adjusted based on the quantity necessary to meet the design requirements in Table 1.

Add-rock or dry additive shall be paid for separately at the unit price in the "Asphalt Emulsion Full Depth Reclamation" bid.

Furnishing and mixing prime coat will be paid at the Contract Price per gallon as indicated in the pay item.

APPENDIX C: TYPICAL FOAMED ASPHALT SPECIFICATION (LUDLOW ROAD, CHAMPAIGN COUNTY)

Section # 05-00398-00-RS
Champaign County

FOAMED ASPHALT BASE STABILIZATION, 7"

This work consists of constructing a stabilized base course composed of reclaimed asphalt pavement (RAP), CA-07/11 material, and fly ash, stabilized with foamed asphalt binder.

1. Foamed Asphalt Recycled Base Course

- a) Pulverize and reuse materials in the existing roadway structural section.
- b) Change the grading of the existing section to be recycled by the addition of a 2" lift of CA 07/11, and a 2" lift of RAP.
- c) Procure, furnish, and mix in, a combination of foamed asphalt and cementitious stabilizing agents together to a depth of 7" with sufficient water to approximate the optimum moisture content.
- d) Shape and compact to achieve a new structural section, as shown on plans.

2. Materials

- a) Fly Ash, 1.0% shall be spread on the existing grade prior to recycling, and it shall conform to ASTM C618, which describes a Class C Fly Ash.
- b) Foamed asphalt shall be the only bituminous stabilizing agent used in the recycling process. The specific asphalt to be used shall be determined during the mix design phase. It will be the Contractor's responsibility to perform all required tests and obtain necessary samples for the mix design, as well as during the production stage. The cost for this work shall be incidental to the FOAMED ASPHALT BASE STABILIZATION, 7", and no additional compensation shall be allowed.

Foamed Asphalt Stabilized Base Course Mix Requirements

Design Parameters	Value
Marshall Compacted Specimen, AASHTO T 245	
(1) Compaction, number of blows	75
Indirect Tensile Strength, AASHTO T283	
(1) Tensile Strength Wet, min. kPa	350
(2) Tensile Strength Ratio, (TSR), min. %	70
Foamed Asphalt Expansion Characteristics @ 160, 170 and 180 deg. C	
(1) Half-life of Foamed Expansion, min. sec	12
(2) Expansion Ratio, min.	15

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Champaign County

Notes:

A minimum total of five (5) Marshall specimens compacted to 75 blows with asphalt contents 0.5% apart will be required.

Perform Indirect Tensile Strength (ITS) by AASHTO T 283 of both dry and soaked specimens at each asphalt content. Graph of ITS versus asphalt content for both dry and soaked specimens.

Provide a percentage of foamed asphalt binder to be added based on the total mass of the mixture.

c) All process water shall be clean and free from deleterious concentrations of acids, alkalis, salts, sugars, silts, or debris, and other organic or chemical substances.

3. Foamed Asphalt Recycling Machine

Recycling shall be performed utilizing a machine capable of pulverizing to a depth shown on the plans, the existing structural section, along with any imported materials, in a *single pass*. Equipment employed shall be of adequately rated capacity and in good working order. For safety reasons, at no time shall asphalt be circulated back to the tanker, nor shall diesel or other solvents be used for a cleaning or softening agent. Contractor must be able to refer to completion of a least five (5) successful jobs using the same proposed equipment.

Obsolete, poorly maintained, or dilapidated, equipment shall not be allowed on the job site. The recycler shall be a Wirtgen WR2500 or equal and as a minimum have the following features.

- a) A minimum power capability of 600 horsepower.
- b) Where the recycling depth exceeds 5" the effective volume of the mixing chamber shall be increased in relation to the depth of the cut.
- c) Two microprocessor-controlled systems, complete with 2 independent pumping systems and spraybars. One system to regulate the application of the foamed asphalt-stabilizing agent, the second system for application of additional water (for increasing the moisture content of the recycled material). The systems shall vary the application of both in relation to the forward speed and mass of the material being recycled.
- d) The two spraybars shall each be fitted with nozzles at a maximum spacing of one nozzle for each 7.5" width of the chamber. The spraybar used for addition of moisture into the recycled section shall have self-cleaning nozzles.
- e) The foamed asphalt shall be produced at the spraybar in individual expansion chambers into which both the hot asphalt and water are injected under pressure through individual and separate orifices that promote atomization. The rate of addition of water into the hot asphalt shall be kept at a constant rate (percentage by mass of asphalt) by the microprocessor.
- f) An inspection (or test) nozzle shall be fitted at one end of the spraybar that produces a representative sample of foamed asphalt.
- g) An electrical heating system capable of maintaining the temperature of all asphalt flow components above 340°F.
- h) A single asphalt feed line installed between the recycling machine and the supply tanker. Circulating systems that incorporate a return line to the supply tanker shall not be used.
- i) The operator cabin shall be movable from right to left.
- j) A printer shall be included to record amounts of materials used.

4. Compaction Equipment

The method and equipment used to compact the newly placed structural section shall be determined by the engineer responsible for the mix design and shall take into account issues specific to each job. Compaction equipment may include any or all of the following:

- a) Static sheep's foot (static mass to exceed 20 tons)
- b) Vibratory sheep's foot (static mass to exceed 15 tons)
- c) Smooth drum vibratory (static mass to exceed 15 tons)
- d) Pneumatic tired roller (static mass to exceed 25 tons)

Section # 05-00398-00-RS
Champaign County

5. Supply Tanker for Asphalt Stabilizing Material

Only tankers with a capacity exceeding 2,650 gallons shall be used to supply the recycling machine with asphalt. Each tanker shall be fitted with a rear mounted recessed pin-type tow hitch, thereby allowing the tanker to be pushed from behind by the recycling machine. No leaking tanker will be permitted on the job site. In addition, each tanker shall be equipped with the following:

- a) A thermometer to show the temperature of the contents in the bottom third of the tank.
- b) A rear feed valve, with a minimum internal diameter of 3", capable of draining the contents of the tank when fully opened.
- c) All-round cladding to retain heat.
- d) A heating system capable of raising the temperature of the contents in the tank by at least 70° F per hour.
- e) An externally mounted gauge to indicate the volume of material remaining in the tanker, calibrated in 50-gallon intervals.

6. Weather Limitations

No foamed asphalt recycling work shall be performed during wet conditions, nor started without completing before wet conditions set in. No recycling work shall be performed if the ambient air temperature is below 40° F. Spreading of cementitious stabilizing agents on the area to be recycled ahead of the recycling machine will not be allowed when windy conditions adversely affect the operation.

7. Time Limitations

The maximum time period between the mixing of recycled material with the stabilizing agents and full compaction of the placed material shall be no more than 2 hours.

8. Surface Preparation

Before any recycling work begins, the surface of the existing area to be recycled shall be prepared by:

- a) Clearing all vegetation and other foreign matter from the entire area.
- b) Removing all standing water.
- c) Accurately pre-marking the proposed longitudinal cut lines in the area to be recycled.

9. Cementitious Stabilizing Agents

A uniform layer of powdered cementitious stabilizing agents, i.e. fly ash, 1.0%, shall be spread on the surface to be recycled prior to the actual recycling taking place. Exact amounts and materials to be used, as well as the timing of their application, shall be the responsibility of the Engineer doing the mix design. The material shall be spread uniformly over the area to be recycled by the use of a mechanical spreader. If required by the engineer, samples of the flyash shall be taken and delivered to the engineer.

10. Asphalt Stabilization Agents

Asphalt stabilization agents shall be added to the recycling process by pumping from a supply tanker that is pushed from behind by the recycling machine. Supply tankers shall be equipped with a built in thermometer, and heating facilities to ensure that the asphalt can be maintained at or above the minimum required temperature of 310° F. Asphalt that has been heated above 430° F shall not be used for producing foamed asphalt, and shall be removed from the site. If required by the engineer responsible for the mix design, samples of the asphalt stabilizing agent shall be taken and recorded at the loading facility during the loading of each tanker and delivered to the Engineer.

11. Moisture Content Control for Recycled Material

Sufficient water shall be added during the recycling process to meet the moisture requirements specified in the mix design. Water shall be added only by the means of the microprocessor-controlled spraybar on the recycling machine. The water used in this procedure shall meet the requirements of Section 1002 of the Standard Specifications.

12. Gradation of the Recycled Material

The forward speed of the recycling machine, the rotation rate of the milling drum, and the position of the gradation control beam shall be set to break down the in-situ material to 98% passing 1-1/2" sieve.

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13. Addition of Water and Foamed Asphalt Stabilization Agent

The microprocessor control system for the addition of water and foamed asphalt shall be set and carefully monitored to meet the required compaction moisture and stabilizer content. Supply tankers shall be checked at the end of each cut in order to determine the actual usage against the calculated theoretical demand.

14. Control of Cut Thickness

The actual depth of cut shall be physically measured at both ends of the pulverizing drum at least once every 330 ft.

15. Overlap of Longitudinal Joints

To ensure complete recycling across the full width of the area being treated, longitudinal joints between successive cuts shall overlap a minimum of 2". Where it is necessary to recycle a section less than the full width of the drum, adjustments shall be made to the nozzles applying the moisture and foamed asphalt to ensure that the amounts added to the section are reduced proportionately by the width of the overlap.

16. Level and Shape Control

Processed material shall be spread to fill the cut void. Such spreading shall be achieved by a motor grader following behind. Care should be exercised while spreading to prevent undue material segregation.

17. Compaction of Recycled Material

After placing and shaping the compacted recycled material shall have a relative compaction of not less than 98% of Modified Proctor as tested by the nuclear density gauge.

18. Profile and Cross Slope Requirements

The proposed finished cross slope of the roadway in Section 2 is 2.0%. After final rolling and profiling, measure the profile and cross slope of the foamed asphalt stabilized base course. Use a 10 ft metal straightedge to measure at right angles and parallel to centerline. Defective areas are surface deviations in excess of ¼ inch in 10 feet between any two contacts of the straightedge with the surface. Any defective areas shall be corrected to the satisfaction of the Engineer, and no additional compensation will be made thereof.

19. Watering, Finishing and Curing

After compaction, the recycled surface shall be treated with a light application of water, and rolled with pneumatic-tired rollers to create a close-knit texture. The finished surface of the recycled layer shall be kept continuously damp by frequent *light* watering. The tack coat or wear course shall not be applied to the surface until the moisture content of the recycled layer is at least 2 percent below the saturation moisture content.

20. Protection and Maintenance

The contractor shall protect and maintain the recycled layer until the wearing surface has been applied. Frequent light watering shall be performed to prevent the surface from drying out.

21. Basis of Payment

This work will be paid for at the contract unit price per square yard for FOAMED ASPHALT BASE STABILIZATION, 7", which will include all construction procedures described herein, and all sampling, laboratory tests and field tests for the mix design, and during the production stage. The cementitious and bituminous stabilizing agents will be paid for separately at contract unit prices per ton for FLY ASH, 1.0% and ASPHALT CEMENT, respectively. Final profiling of the foamed asphalt stabilized base will be paid for at a contract unit price per square yard for BITUMINOUS SURFACE REMOVAL, 0.5".

APPENDIX D: TYPICAL ENGINEERED EMULSION ASPHALT SPECIFICATION (MACON COUNTY)

Mason County
 CH-15
 Sec. 02-00037-04-RS
 Proj. No. RS-0571 (112)

DRAFT
 COLD RECYCLING OF BITUMINOUS MATERIAL (Partial Depth)
 CIR (Cold In-Place Recycling)

1. Description
 This work shall consist of pulverizing, crushing, and screening the in situ bituminous materials to the depth and width shown on the plans; an emulsified asphalt binder agent, water, and other additives, if required, will then be incorporated into the pulverized material. This material will then be spread and compacted in accordance with the plans and specifications and as directed by the engineer.
2. Materials
 - 2.1 Asphalt Emulsion - The type of asphalt emulsion to be used shall be determined by the mixture design. A representative from the asphalt emulsion supplier will be at the job site at the beginning of the project to monitor the characteristics and performance of the asphalt emulsion. Throughout the job, the representative will be available to check on the project and make adjustments to the asphalt emulsion formulation as required.
 - 2.2 Cold Pulverized Material - The cold pulverized material shall meet the following gradation requirement prior to the addition of the asphalt emulsion.

STANDARD		METRIC	
Sieve Size	%Passing	Sieve Size	%Passing
1.25" (or 1.00")	100	31.5mm (or 25.4mm)	100-

Note: the 100% passing the 1.00" Sieve Size is optional, and only to be used when a finer gradation of RAP is required.

The compacted product shall be placed at a thickness of a minimum of two (2) times the nominal size of crushed millings or 2.5 inches, whichever is greater, and to a maximum of 5 inches.

- 2.3 Mixture Design - A preconstruction mix design shall be submitted by the Cold In-Place Recycling contractor tested in accordance with Appendix 1 using materials obtained directly from the project site. Based on cores taken before the project, more than one mix design may be required. The job mix formula shall meet the criteria of Table 1 and be approved by the project engineer or agency. Refer to Appendix 1 - Mix Design Procedures for CIR.

Property	Criteria	Purpose
Compaction effort, Superpave Gyrotory Compactor	1.25° angle, 600 kPa stress, 30 gyrations	Density Indicator
Density, ASTM D 2726 or equivalent	Report	Compaction Indicator
Gradation for Design Millings, ASTM C117	Report	
Marshall stability*, ASTM D 1559 Part 5, 40°C	1,250 lb min.	Stability Indicator
Retained stability based on cured stability**	70 % min.	Ability to withstand moisture damage
Indirect Tensile Test, AASHTO T-322, Modified in Appendix 2	See Note in Appendix 2	Cracking (Thermal)
Raveling Test, 4 hour cure @ 10°C and 50% humidity, ASTM D7196 or Appendix 3	2% max.	Raveling Resistance

2.4 Other Additives - If necessary, additives may be used to meet the requirements in Table 1. In the case that an additive is used, the type and allowable usage percentage must be described in the submitted design recommendation.

2.5 Addition of crushed Reclaimed Asphalt Pavement (RAP) material - If available, RAP material may be added at the discretion of the engineer if the RAP material meets the requirements in Table 2.

The crushed RAP shall be free from vegetation and all other deleterious materials, including silt and clay balls. It shall meet the requirements for Deleterious Materials given in Table 2. The crushed RAP shall not exceed the maximum size requirement in Section 2.2, and when blended with the design millings shall produce a product which meets the specifications given in Table 1.

Tests	Method	Limit
Deleterious Materials: Clay Lumps and Friable Particles in Aggregate, % max	ASTM C 142 or AASHTO T 112	0.2 recommended
Maximum size, 100% Passing, Sieve Size	ASTM C 136 or AASHTO T 27	Section 2.2

2.6 Additional aggregate - Based on the results of the mix design or other requirements, the bidder shall determine if additional aggregate is required. Any additional aggregate shall meet the requirements in Table 3, and it shall be graded to produce a product which meets the specification given in Table 1.

Tests	Method	Limit
Los Angeles abrasion value, % loss	AASHTO T 96	40 max for Surface mix 50 max for Base mix
Sand Equivalent, %	ASTM D-2419	60 minimum
Maximum size, 100% Passing, Sieve Size	ASTM C 136 or AASHTO T 27	Section 2.2
Water absorption %	AASHTO T 85	5 max.

3. Equipment

The Cold In-Place recycling shall be completed with the following required equipment.

- 3.1 A self-propelled cold milling machine that is capable of pulverizing the existing bituminous material in a single pass to the depth shown on the plans and to a minimum width of not less than 12.5 feet (3.8 m). The machine shall have automatic depth controls to maintain the cutting depth to within $\pm 1/4$ in (6 mm) of that shown on the plans, and shall have a positive means for controlling cross slope elevations. The use of a heating device to soften the pavement will not be permitted.
- 3.2 A material sizing unit having screening and crushing capabilities to reduce the pulverized bituminous material to the size required by Section 2.2 prior to mixing with asphalt emulsion. The screening and crushing unit shall have a closed circuit system capable of continuously returning oversized material to the crusher. All of the reclaimed asphalt pavement (100%) shall be processed to the maximum size requirements as specified.
- 3.3 A mixing unit equipped with a belt scale for the continuous weighing of the pulverized and sized bituminous material and a coupled/interlocked computer controlled liquid metering device. The

mixing unit shall be an on-board completely self-contained pugmill. The liquid metering device shall be capable of automatically adjusting the flow of asphalt emulsion to compensate for any variation in the weight of pulverized material coming into the mixer. The metering device shall deliver the amount of asphalt emulsion to within ± 0.2 percent of the required amount by weight of pulverized bituminous material (for example, if the design requires 3.0 percent, the metering device shall maintain between 2.8 percent to 3.2 percent). The asphalt emulsion pump should be of sufficient capacity to allow emulsion contents up to 3.5% by weight of pulverized bituminous material. Also, automatic digital readings will be displayed for both the flow rate and total amount of pulverized bituminous material and asphalt emulsion in appropriate units of weight and time.

- 3.4 A pick-up machine may be used for transferring the recycled material from the windrow to the receiving hopper of the bituminous paver. The pick-up machine shall be capable of removing the entire windrow down to the remaining underlying material.
- 3.5 A self-propelled conventional bituminous paver having electronic grade and cross slope control for the screed. The equipment shall be of sufficient size and power to spread and lay the mixture in one smooth continuous pass to the specified section and according to the plans.
- 3.6 Alternatively to the equipment listed in Sections 3.3, 3.4, and 3.5, a self-propelled paver with on-board pugmill and emulsion tank can be used. Millings must be added directly to the hopper. The paver shall be equipped with a belt scale for the continuous weighing of the pulverized and sized bituminous material and a coupled/interlocked computer controlled liquid metering device. The mixing unit shall be an on-board completely self-contained pugmill. The liquid metering device shall be capable of automatically adjusting the flow of asphalt emulsion to compensate for any variation in the weight of pulverized material coming into the mixer. The metering device shall deliver the amount of asphalt emulsion to within ± 0.2 percent of the required amount by weight of pulverized bituminous material (for example, if the design requires 3.0 percent, the metering device shall maintain between 2.8 percent to 3.2 percent). Also, automatic digital readings will be displayed for both the flow rate and total amount of pulverized bituminous material and asphalt emulsion in appropriate units of weight and time.
- 3.7 Any additives such as water, lime slurry, etc. added by the equipment in sections 3.1-3.6 at the mill head or mixing unit shall be controlled through liquid metering devices capable of automatically adjusting for the variation in the weight of the pulverized material going into the mixing unit. The metering devices shall be capable of delivering the amount of additive to within ± 0.2 percent of the required amount by weight of the pulverized bituminous material. A capability of adding up to 5% water by weight of the pulverized bituminous material, if necessary based on environmental and material requirements, is mandatory. It will not be required to meter the water added at the milling machine to control dust in the screens, belts, or crusher/material sizing unit.
- 3.8 All rollers shall be self-propelled. The number, weight and types of rollers shall be as necessary to obtain the required compaction. At least one pneumatic roller shall have a minimum gross operating weight of not less than 50,000 lbs. (22,600 kg). Pneumatic rollers must have properly working scrapers and water spraying systems. At least one double drum vibratory roller shall have a gross operating weight of not less than 20,000 lbs. (9,000 kg) and a width of 78 inches (1980 mm). Double drum vibratory rollers must have properly working scrapers and water spraying systems.
- 3.9 A self-propelled power broom for removal of loose particles and other materials from the CIR surface. The broom shall have positive control on the downward pressure applied to the surface.

4. Construction Methods

- 4.1 Grass and other vegetation shall be removed from the edge of the existing pavement to prevent contamination of the pulverized bituminous material during the milling operation.
- 4.2 The existing pavement shall be milled to the required depth and width as indicated on the plans. Recycling shall be in a manner that does not disturb the underlying material in the existing

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roadway. The milling operation shall be conducted so that the amount of fines occurring along the vertical faces of the cut will not prevent bonding of the cold recycled materials. The pulverized bituminous material shall be processed by screening and crushing to the required gradation specified in Section 2.2. When a paving fabric is encountered during the CIR operation, the Contractor shall make the necessary adjustments in equipment or operations so that at least ninety percent (90%) of the shredded fabric in the recycled material is no more than 5 in² (3200 mm²). Additionally, no fabric piece shall have any dimension exceeding a length of 4 inches (100 mm). These changes may include, but not be limited to, adjusting the milling rate and adding or removing screens in order to obtain a specification recycled material. The Contractor shall be required to waste material containing over-sized pieces of paving fabric as directed by the Engineer. When the Contractor is aware that paving fabric exists, such as indicated on the plans, the Contractor will not receive additional payment. However, if the Contractor is not made aware of the paving fabric, then the Contractor shall receive additional payment for any necessary adjustments in equipment and operations.

- 4.3 The recycled material shall be produced through a mixing unit capable of processing the pulverized material, asphalt emulsion and any additives to a homogeneous mixture. The asphalt emulsion shall be incorporated into the pulverized bituminous material at the initial rate determined by the mix design(s) and approved by the Engineer. Sampling and mix design may determine different levels of asphalt emulsion at various portions of the project.
- 4.4 The material shall be spread using a self-propelled paver meeting the requirements of either paver in Sections 3.5 or 3.6. Heating of the paver screed will not be permitted. A pick-up machine may be used to transfer the windrowed material into the paver hopper if using a conventional paver as listed in Sections 3.4 and 3.5. The pickup machine must be within 150 feet (45 m) of the mixing unit described in Section 4.4. The recycled material shall be spread in one continuous pass, without segregation and to the lines and grades established by the Engineer.
- 4.5 Compacting of the recycled mix shall be completed using rollers meeting the requirements of Section 3.7. Rolling patterns shall be established to achieve a maximum density determined by nuclear density testing. Rolling shall be continued until no displacement is occurring or until the pneumatic roller(s) is (are) walking out of the mixture. Final rolling to eliminate pneumatic tire marks and to achieve density shall be done by double drum steel roller(s), either operating in a static or vibratory mode. Vibratory mode should only be used if it is shown to not damage the pavement. The selected rolling pattern shall be followed unless changes in the recycled mix or placement conditions occur and a new rolling pattern is established at that time. Rolling or roller patterns shall change when major displacement and/or cracking of the recycled material is occurring. Rolling shall start no more than 30 minutes behind the paver. Finish rolling shall be completed no more than one hour after milling is completed. When possible, rolling shall not be started or stopped on uncompacted material but with rolling patterns established so that they begin or end on previously compacted material or the existing pavement.
- 4.6 After the completion of compaction of the recycled material, no traffic, including that of the contractor, shall be permitted on the completed recycled material for at least two (2) hours. After two hours rolling traffic may be permitted on the recycled material. This time may be adjusted by the Engineer to allow establishment of sufficient cure so traffic will not initiate raveling. After opening to traffic, the surface of the recycled pavement shall be maintained in a condition suitable for the safe movement of traffic. All loose particles that may develop on the pavement surface shall be removed by power brooming.
- 4.7 Any damage to the completed Cold In Place Recycled bituminous material shall be repaired by the contractor prior to the placement of the hot mix asphalt concrete surface course, or other applicable surface treatment, and as directed by the Engineer. Damage unrelated to contractor construction procedures or quality of work, such as due to poor base conditions, shall be paid for under the pay item, "Recycled Material Patching."
- 4.8 The completed cold recycled material surface shall not vary more than ¼ in (6 mm) from the lower edge of a 10-foot (3-meter) straight edge placed on the surface parallel and transversely to the centerline.

- 4.9 Before placing the hot mix asphalt concrete surface course, or other applicable surface treatment, the Cold In Place Recycled bituminous material shall be allowed to cure until the moisture of the material is reduced to 2.0 percent or less, or approval of the project engineer. Under dry conditions the Cold In-Place Recycling should meet the moisture requirements within 48 hours.

5. Quality Assurance/ Quality Control

The Agency shall be responsible for quality assurance of the materials and cold recycling process. The Agency may choose to test, or to delegate to the contractor or supplier, prior to bidding, the schedule of testing to be completed on the items listed below:

- 5.1 Pulverized Bituminous Material Sizing - A sample shall be obtained each ¼ mile (0.8 km) before emulsion addition and screened using a 1.25 in. (31.5mm) sieve (or smaller sieve if required) to determine if meeting the maximum particle size requirement. Additionally, two gradations shall be performed each day on the moist millings using the following sieves: 1.25 inch, 1.0 inch, ¾ inch, ½ inch, 3/8 inch, No.4, No.8, No.16, and No.30. The resulting gradation shall be compared to the mix design gradations to determine any necessary changes to emulsion content. Sampling procedures shall generally be in accordance with ASTM D979 or AASHTO T168. The testing schedule to meet these requirements shall also be at the discretion of the Engineer.

- 5.2 Asphalt Emulsion - The asphalt emulsion shall be received on the job site at a temperature no greater than 120°F. The sampling rate shall be determined by the Agency. Samples shall be obtained from the shipping trailers prior to unloading into the contractor's storage units. The testing shall meet the following requirements:

Test		Minimum	Maximum
Residue from distillation, %	ASTM D244 ¹	64.0	66.0
Oil distillate by distillation, %	ASTM D244 ¹		0.5
Sieve Test, %	ASTM D244 ¹		0.1
Penetration (TBD ²), 25°C, dmm	ASTM D5	-25%	+25%

¹ Modified ASTM D244 procedure - distillation temperature of 177°C with a 20 minute hold. The ASTM D244 vacuum distillation procedure may be substituted once the maximum oil distillate is satisfied.

² TBD - to be determined by the CIR design prior to emulsion manufacture for project. Penetration range will be determined on the design requirements for the project and will be submitted to the Agency for approval prior to project start.

- 5.3 Asphalt Emulsion Content - Emulsion content shall be checked and recorded for each segment in which the percentage is changed. Emulsion content changes shall be made based upon mix design recommendations, which are based upon different mix designs for road segments of varying construction. Asphalt emulsion content can be checked from the belt scale totalizer and asphalt pump totalizer.
- 5.4 Water Content - Water content at the milling head shall be checked and recorded for each segment in which the percentage is changed. This information shall be gathered from the water metering device, which can be checked from the belt scale totalizer to verify daily quantities used. Water content changes shall be made based on mixture consistency, coating, and dispersion of the recycled materials.
- 5.5 Mixture Testing - Samples will be gathered for testing mixture results from the design given as described in Table 1 at the Agency's discretion. The samples should be taken following ASTM D3665 and D979. If samples of the emulsion/recycled asphalt pavement mixture are taken, the specimens must be compacted within 15 minutes of sampling and tested as required in Table 1. The samples must be screened through a 1" (254mm) screen if 100mm specimens are to be compacted. If samples of the recycled asphalt pavement prior to emulsion addition are taken, they must be put into a sealed plastic container to not allow any loss of moisture. Samples must be mixed with the field emulsion within 24 hours and tested as required in Table 1.

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5.5 Depth of Pulverization (Milling) - The nominal depth shall be checked on both outside vertical faces of the cut each 1/8 mile (0.2 km).

5.6 Recycled Material Compacted Density - A wet density shall be determined using a nuclear moisture-density gauge generally following the procedures for ASTM D2950, backscatter measurement. A rolling pattern will be established such that a maximum density is achieved with the rollers specified, based on relative nuclear density readings. However, care should be taken not to over-roll the mat based on visual observations of check cracking or shoving. A new rolling pattern shall be established if the material being recycled changes.

5.7 Cold Recycled Material Cross Slope / Smoothness - The cold recycled material cross slope shall be checked regularly during spreading using a level. The smoothness shall not vary more than 1/4 in (6 mm) from the lower edge of a 10-foot (3-meter) straight edge placed on the surface parallel and transversely to the centerline after rolling is completed.

6. Weather Limitations

Cold In-Place recycling operations shall be completed when the atmospheric temperature measured in the shade and away from artificial heat is 50° F (10°C) and rising. Also, the weather shall not be foggy or rainy. The weather forecast shall not call for freezing temperature within 48 hours after placement of any portion of the project.

7. Measurement

Work as described for this item will be measured by the square yard (or square meter) of the completed sections for the depth specified. The asphalt emulsion will be measured by the gallon. Water used in this operation will not be paid for directly but shall be considered a subsidiary to this bid item. Recycled Material Patching will be measured by the ton (or metric ton).

8. Pavement

The work performed and materials furnished, as prescribed by this item and measured as provided under "Measurement," will be paid for at the unit prices bid for COLD IN-PLACE RECYCLING, BITUMINOUS CONCRETE PAVEMENT of the depth specified. Prices shall be full compensation for the removal and processing of the existing pavement; for preparing, hauling, and placing all materials; for all freight involved; for all manipulations, including rolling and brooming and for all labor, tools, equipment and incidentals necessary to complete the work. Asphalt emulsion shall be paid for separately at the unit price per gallon for BITUMINOUS MATERIALS (COLD IN-PLACE RECYCLING). An emulsion content of 3 % by weight of the milled bituminous material shall be used for bidding purposes prior to the completed design. The actual emulsion content will be adjusted based on the quantity necessary to meet the design requirements in Table 1.
Mason County

