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Synthesis Of Asphalt Recycling In Minnesota

Minnesota Local Road Research Board

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This report was produced for the Local Road Research Board (LRRB) and provides a summary of the use of recycled asphalt pavement within Minnesota. Included in this report is:

- A synthesis of a manual produced by the Asphalt Recycling and Reclaiming Association (ARRA) and endorsed by the Federal Highway Administration (FHWA) titled the Basic Asphalt Recycling Manual (BARM). The BARM provides a complete summary of various recycling techniques and the process for conducting a recycling project.

- A summary of a survey that was distributed to cities and counties throughout Minnesota. This survey was distributed to gather input on the amount of asphalt recycling done in Minnesota. Survey results are discussed throughout the report with a complete overview in the report appendix.

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Synthesis of Asphalt Recycling in Minnesota

Final Report

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EXECUTIVE SUMMARY

This report was produced for the Local Road Research Board and provides a summary of the use of recycled asphalt pavement within Minnesota. Included in this report is a synthesis of a manual produced by the Asphalt Recycling and Reclaiming Association (ARRA) and endorsed by the Federal Highway Administration (FHWA) titled the Basic Asphalt Recycling Manual (BARM). The BARM provides a complete summary of various recycling techniques and the process for conducting a recycling project and is one of the most current and comprehensive manuals on asphalt recycling.

Also included in this report is a summary of a survey that was distributed to cities and counties throughout Minnesota. This survey was distributed to gather input on the amount of asphalt recycling done in Minnesota. Survey results are discussed throughout the report with a complete overview in the report appendix.

BACKGROUND

The Local Road Research Board

Established in 1959 through state legislation, the Minnesota Local Road Research Board (LRRB) was created to sponsor research for local, generally low-volume, roads. Over the last 40 years, the LRRB has funded hundreds of projects on a variety of topics. This research generally falls into four main categories: materials and methods used in constructing and maintaining pavement drainage systems and other utilities under the pavement; management of the roadside environment; and bridge construction and maintenance.

The Board is comprised of Minnesota City and County Engineers, appointed by the Minnesota Department of Transportation (Mn/DOT) Office of State Aid, as well as representation from Mn/DOT. Qualified researchers from various sources – Universities, Mn/DOT and the private sector – conduct the research. The research topics generally originate from surveys and focus groups held with the units of local government within Minnesota.

Research sponsored by the LRRB helps to improve the quality of Minnesota's transportation systems. The LRRB works through its Research Implementation Committee (RIC) to make information available and to transfer research results into practical applications. The RIC uses a variety of methods to reach engineers and others with new developments, including electronic presentations, videos, Web sites, written reports, pamphlets, seminars, workshops, field demonstrations, CD-ROMs and on-site visits. For more information, visit the LRRB's Web site: http://www.lrrb.gen.mn.us/.

Project Summary

Research over the past ten years indicates that cold in-place and hot asphalt recycling can be effectively used in road maintenance and construction. The research also suggests that there are instances in which one method is preferred over the other. Because the amount of research that has occurred over the past ten years has been so voluminous, and because new modifications to the process frequently occur, it can be quite difficult for practitioners to identify the technique that is most suited to their needs.

The purpose of this document is to provide:

- Practitioners with a reference guide on asphalt recycling
- References for more specific information and where it can be located
- Compilation of Minnesota local government experiences

Process

Through a series of meetings with the project's Technical Advisory Panel (TAP), consisting of personnel from Cities, Counties, Mn/DOT, consultants and contractors the following research implementation steps were conducted:

- Literature review
- E-mail "quick" survey of local governments
- Follow-up detailed survey of local governments
- Synthesis of information

Literature Review

Although a detailed literature search was conducted with assistance from the Mn/DOT Library using the Transportation Research Information System (TRIS), it was discovered that the most current and comprehensive manual on asphalt recycling was in the process of being finalized during this project. The now completed manual, entitled ***Basic Asphalt Recycling Manual (BARM)***, was developed and published by the Asphalt Recycling and Reclaiming Association (ARRA).

The manual has been reviewed and endorsed by the FHWA. The manual has more than 250 pages and covers the four areas of asphalt recycling: hot in-place recycling, cold planning, full depth reclamation, and cold recycling.

As part of this research implementation report, the BARM has been synthesized into a brief 12-page summary for quick reference. This summary outlines the content of the BARM and provides brief summaries of each chapter. To obtain a copy of the BARM contact any member of the ARRA (www.arra.org or 410.267.0023).

A second part of the literature review involved obtaining the current Mn/DOT specifications for recycling. Included in the Appendix of this report are the four specifications currently used by Mn/DOT. For the most current version of this specification, please refer to the Mn/DOT web page (www.dot.state.mn.us/tecsup/spec/). The asphalt recycling specifications include:

- 2331 Cold In-place Recycle (CIR) Bituminous Mixture Full Recycling Train. Revised 11/15/1999. *This is Mn/DOT's standard specification for CIR*.
- 2331 Cold In-place Recycle (CIR) Bituminous Mixture Full Recycling Train Mix Design. New write up 1/15/2002. *This is Mn/DOT's new specification for CIR using an engineered emulsion*.
- 2331 Bituminous Pavement Reclamation. *This is Mn/DOT's standard specification for the reclamation process*.
- 3138 Aggregate for Surface and Base Courses. *This is Mn/DOT's standard specification for using RAP as a base material*.

E-mail "Quick" Survey of Local Governments

To gain a better understanding of the current use and understanding of asphalt recycling with the local governments of Minnesota the City and County engineers were surveyed via e-mail. [The four questions they were asked are as follows:]

1. Is asphalt recycling currently being practiced by your agency?
2. If yes, what methods do you use?
3. If no, why not?
4. What information of recycling would you like to know more about?

Of the 207 surveys sent out, 83 were returned. The responses have been tabulated and graphed in the Appendix C of this report.

Follow-up Detailed Survey of Local Governments

The second phase of the survey process included a follow-up detailed survey to those who responded to the original e-mail survey. The purpose of the detailed survey was to build a resource guide of users and their experiences in asphalt recycling. The questions asked in the follow-up surveys include:

- How much recycling have you done? *(years, miles, total budget and percent of construction program)*
- In general, how would you rate your experience? *(Pros, cons barriers, mistakes, lessons learned)*
- What types of recycling have you used? *(CIR, FDR, CP, HMA, etc.)*
- What are your costs for equipment, labor, and materials? Contract or internal work? *(per mile, per ton, etc.)*
- What project assessment and decision process are you using to determine your method of recycling? *(pavement assessment, historical review, economic analysis, etc.)*
- Are you using a mix design? If so describe.
- Are you following Mn/DOT's standard specification of construction or are you using your own? If Mn/DOT, which one?
- What type and percentage of oil/emulsion is being used?
- What types of project evaluation/assessment are you using prior to construction? *(pavement thickness, material type, subgrade strength, etc.)*
- What type of quality control / tests are being used during construction?
- Are you monitoring long-term performance? How? (*photos, video, strength testing, etc.)*
- Other comments.

The detailed results have been tabulated and are included in Appendix B of this report.

Synthesis

The BARM is one of the most comprehensive manuals on asphalt recycling and is a very good resource for Minnesota's city and county engineers. Although it covers four types of recycling, only two of the processes, cold in-place recycling (CIR) and full-depth reclamation (FDR), are used in Minnesota.

From the survey results, it appears that most agencies are pleased with their recycling experience. Some common responses include:

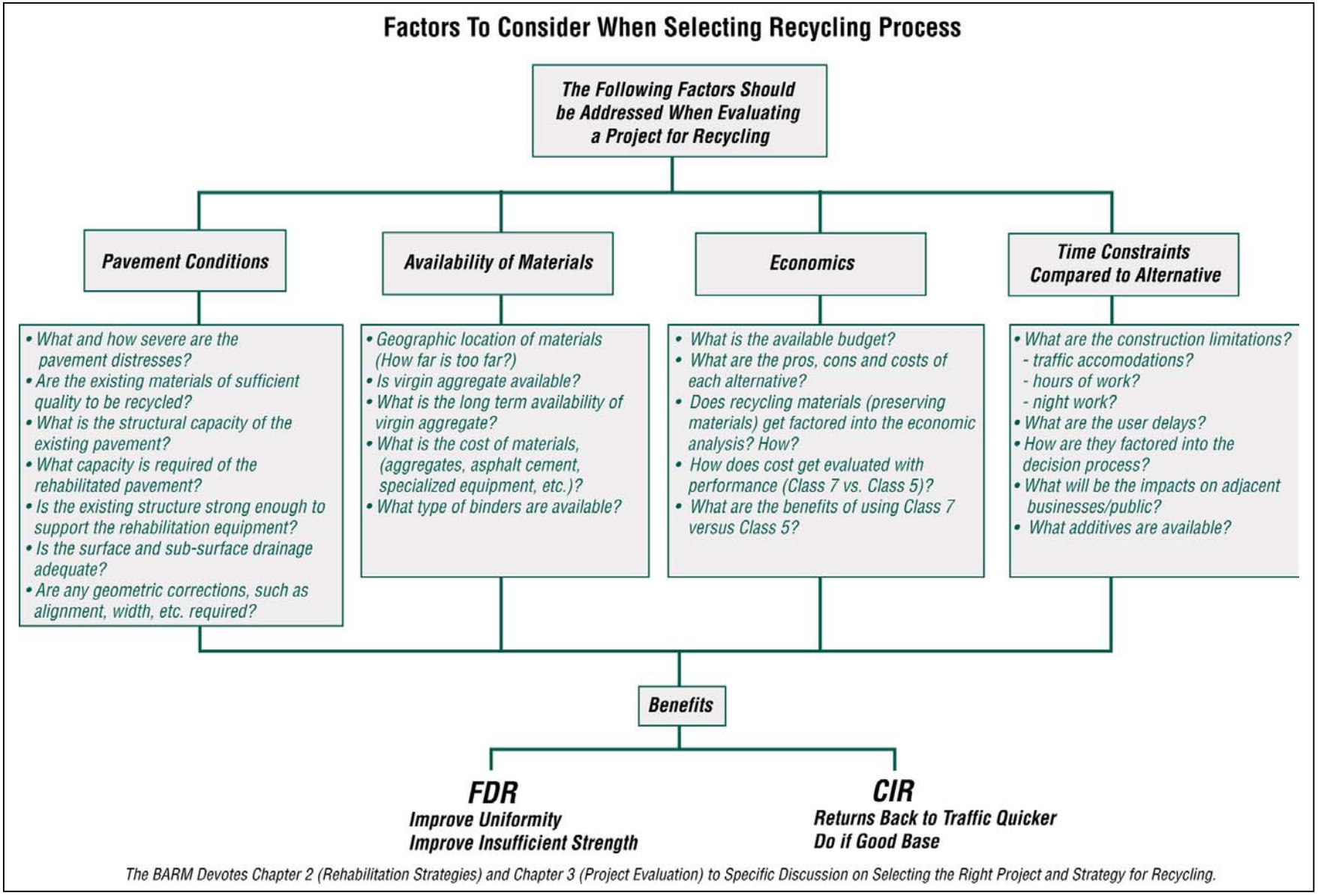
- Although full depth reclamation is the more commonly used process, there were numerous inquiries for additional information on cold in-place recycling. **A good resource on CIR was recently published by the LRRB, *report 2000-21 Cold In-Place Recycling Literature Review.***
- Although unsolicited, several agencies expressed in answers to other questions that they would not use recycled asphalt in the wearing course.
- Mn/DOT's specifications and mix design are generally used.
- The most common method of recycling is full depth reclamation (49 out of 83 responses).
- The most common information people wanted to know more about was Cold In-Place recycling (19 out of 83 responses).
- Visual inspection is the most common method of monitoring long-term performance

Project assessment/selection is one of the most important factors in achieving success in asphalt recycling. From discussions during the TAP meetings, it appears most perceived premature failures are caused due to incorrect project selection (i.e. the roadway that was recycled was not a good candidate for recycling). There are four main factors that should be considered in evaluating a project for recycling. They are as follows:

- Existing pavement condition
- Availability of construction material
- Economics
- Time constraints compared to other rehabilitation alternatives

The following chart was designed as a tool to assist project designers in addressing the main variables in selecting a recycling alternative. Generally, most agencies will have differing decision factors on what is important when making a rehabilitation choice. The chart was designed to have designers address each of the four main concerns based on the what the agency feels is important; the guide was not intended to be a process flow chart to draw a definite conclusion.

Figure 1: Recycling Process Selection



Summary of Basic Asphalt Recycling Manual (BARM)

General Overview

The BASIC ASPHALT RECYCLING MANUAL (BARM) is a comprehensive summary of four methods of recycling existing asphalt pavements:

- Hot In-Place Recycling (HIR)
- Cold Planing (CP)
- Full Depth Reclamation (FDR)
- Cold Recycling (CR) *The BARM defines Cold Recycling as both Cold In-Place Recycling (CIR) and Cold Central Plant Recycling (CCPR).*

The latter two being the most common recycling alternatives used in Minnesota.

The Manual presents the rationale for recycling, rehabilitation strategies with specific evaluation of individual projects, and methods for determining which maintenance or rehabilitation method is most appropriate for a given project.

The BARM consists of five parts with a total of seventeen chapters. It is more than 250 pages long and includes enough information to help an engineer:

- Decide if and what type of recycling to use
- Review mix design procedures
- Specify construction and inspection procedures, which will result in a well, designed and constructed recycling project.

The BARM is structured as follows:

Part 1: (Chapters 1 – 3)

- Introduction
- Rehabilitation Strategies
- Project Evaluation

Part 2: (Chapters 4 – 7)

- Hot In-place Recycling (HIR)

Part 3: (Chapters 8 – 9)

- Cold Planing (CP)

Part 4: (Chapters 10 – 13)

- Full Depth Reclamation (FDR)

Part 5: (Chapters 14 – 17)

- Cold Recycling

CHAPTER 2: REHABILITATION STRATEGIES

Rehabilitation strategies can be summarized using the following descriptions:

- Preventative Maintenance
- Corrective Maintenance
- Pavement Rehabilitation
- Pavement Reconstruction

To some extent, the various methods of recycling can be used in some way for each of the strategies. A consistent method of pavement evaluation should be used to establish which recycling method is needed and how to proceed with the design and construction specifications.

CHAPTER 3: PROJECT EVALUATION

The BARM presents a thorough summary of the elements of a good project evaluation procedure. The evaluation consists of an assessment of the pavement.

- A summary of the surface distresses
- Maintenance activities
- Base/subgrade problems
- Ride quality and safety features.

The **surface distresses** include:

- **Surface Defects** are generally related material and construction deficiencies and include: raveling, potholes, bleeding, skid resistance (friction) and lane/shoulder drop-offs. The descriptions are defined in terms of severity depending on the level of deterioration (**low, medium and high**).
- **Deformations** are generally related to traffic loading and material deficiencies and include: rutting, corrugations and shoving. These distresses result from a mixture that is unstable relative to the traffic.
- **Cracking** is generally subdivided into two categories load associated and non-load associated:
  - **Load Associated** cracks include fatigue (alligator cracking), edge cracking and slippage. Each of these indicates a lack of adequate strength or structure for the traffic.
  - **Non-Load Associated** cracks include block, longitudinal, transverse and reflective cracking). No-load cracks are due to weather (temperature and moisture), shrinkage/swelling of the subgrade due to variability of moisture in the soil, or differential movement of the various pavement layers.

Maintenance Activities can also cause changes in the pavement surface if not placed uniformly. Generally, a patched area does not perform as well as the original pavement. The presence of aged or poorly performing surface treatments such as fog seals, chips seals and micro surfacing can also cause non-uniformity. This uniformity should be evaluated during the recycling design process.

Base and Subgrade Problems often show up as severe cracking, pavement failures, settlements, depressions, and structural rutting, particularly with thinner pavements. These conditions can be compounded if the drainage of the section is not adequate. Base and subgrade problems can manifest themselves as swells, bumps, sags or depressions, which can cause surface cracking. Swells are caused by frost or changes in moisture content. Bumps may be caused by variations in moisture content in silt and clay type soils as a result of unsealed cracks. Sags may be due to weakening of the soil again because of infiltrating water. Base and subgrade problems must be fixed before any type of rehabilitation is performed. The size, location, and frequency of base and subgrade problems give a good indication of the overall structural integrity of the existing pavement structure.

- **Ride Quality** is what the public realizes must and should be evaluated to establish a severity level for roughness. The ride should be measured at the posted speed or by measuring longitudinal profile with one of a number of profilometers.
- **Safety** is evaluated using a measure of skid resistance (friction), overall roughness, condition of the surface, light reflectivity, side slopes and adjacent structures, lane markings and roadside hazards.

An **historic information review** should always be a part of the rehabilitation selection process. This will not only show the construction and maintenance history, but also how fast it has deteriorated. If the causes of the pavement distresses can be determined then selection of an appropriate rehabilitation technique will be more effective.

Pavement Assessment of the pavement's material properties through field and laboratory testing will help establish the structural integrity of the pavement section. Physical properties of the pavement, which should be measured include:

- **Roughness** is a distortion of the pavement, which contributes to an uncomfortable or undesirable ride. The devices and methods for collecting roughness data range from the traditional rod and level surveys, to high speed, non-contact methods. The International Roughness Index (IRI) is a measure of the profile used to correlate with **Serviceability**. **Ride** is most frequently the first factor, which indicates when a pavement should be a candidate for rehabilitation or reconstruction.
- **Rut Depth** as the severity of pavement rutting increases, there is a corresponding decrease. It is generally measured either using a straight edge; however, automated techniques are becoming more popular.
- **Skid Resistance** or **Friction** can be measured using many different methods. ASTM E274 is a method, which can be used to give a physical measurement of skid resistance. A poor level of skid resistance is also a reason to repair the pavement surface.

- **Pavement Strength** or **Load Carrying Capacity** can be estimated by an evaluation of the pavement materials, subgrade and thickness, or by direct field measurements. The ability of an existing pavement to carry the anticipated future traffic at a reasonable level of service is directly related to its structural capacity. Evaluation of the structural capacity of an existing pavement can be determined by either destructive or non-destructive methods.

The results of the visual assessment, historical information review and pavement property assessment are used to evaluate and determine the cause or causes of the pavement distresses. Figure 1 indicates the factors that contribute to the various distresses. Once the distresses and their causes are evaluated, a preliminary rehabilitation selection can be made. Figure 2 can then be used to select the Candidate Rehabilitation Techniques, which are appropriate for particular distress modes.

Figure 2: Potential Contributing Factors to Pavement Distress (BARM, pg. 49)

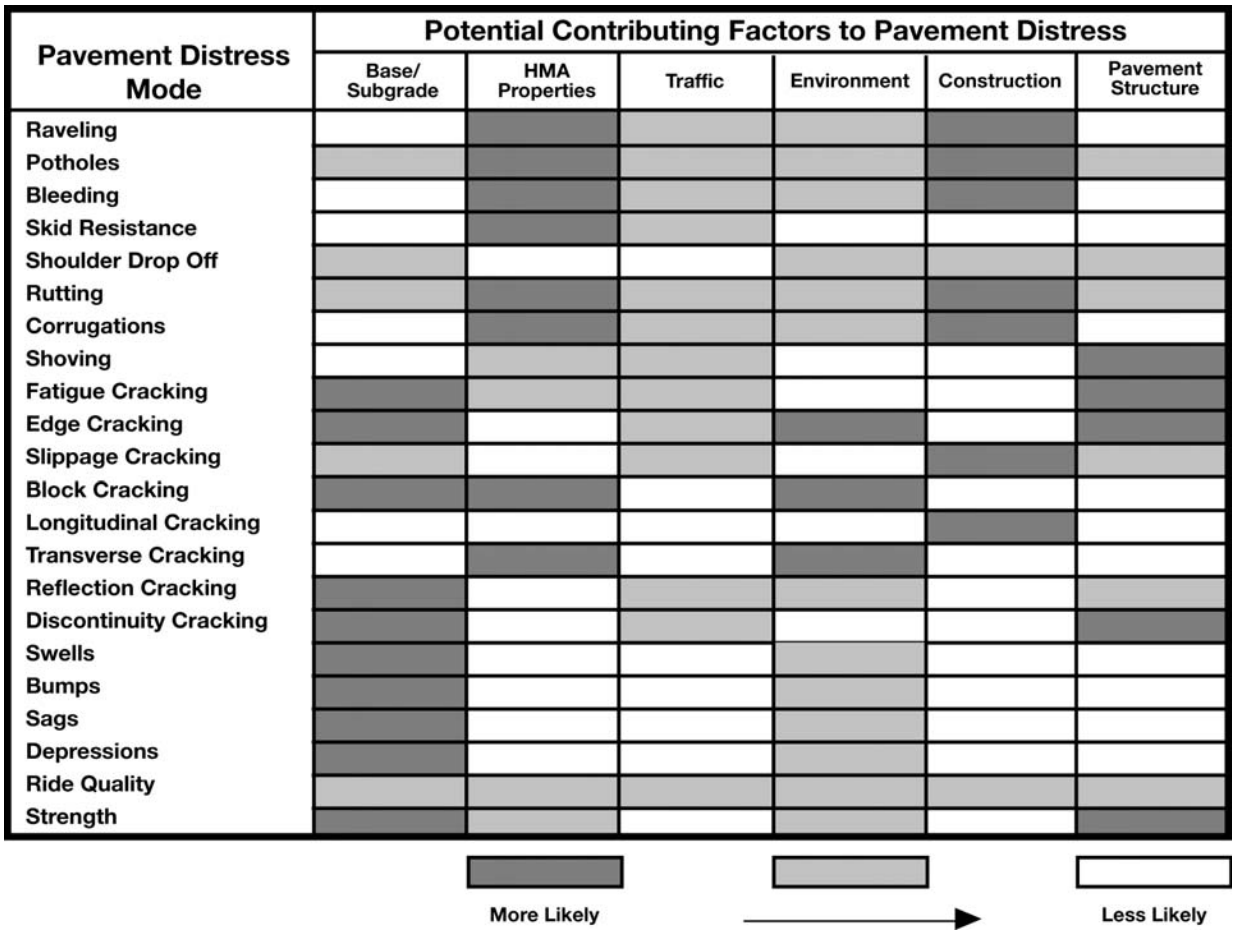
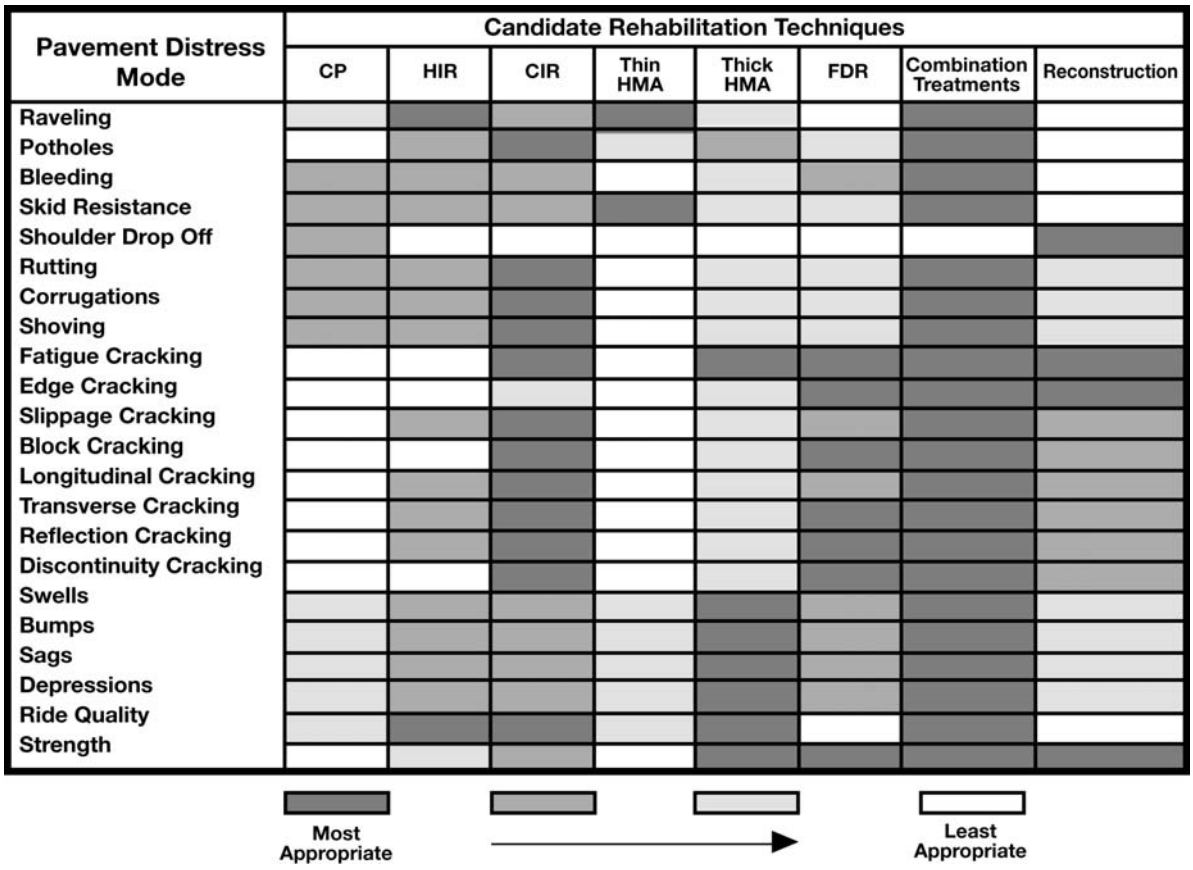


Figure 3: Candidate Rehabilitation Techniques (BARM, pg. 51)



ECONOMIC ANALYSIS

An economic analysis should then be done to compare the different rehabilitation techniques and determine which is the most cost effective. Generally, a comparison of life-cycle costs of the various rehabilitation alternatives is conducted. A typical life cycle cost analysis would include:

- Initial rehabilitative costs
- Future rehabilitative costs
- Maintenance costs
- Salvage value
- Administrative costs
- User costs

Although the economic analysis will provide a basis for selection of the rehabilitation technique, several other factors must be considered to make the decision. These factors are:

- Type and severity of the existing distresses
- Age and condition of the existing pavement materials
- Expected design life of the rehabilitation
- Traffic growth
- Structural capacity
- Environmental conditions
- Planned future maintenance activities
- Geometrics
- Drainage
- Underground and surface utilities
- Traffic safety
- Construction limitations
- Project location and size
- Contractor availability and experience
- Impacts on adjacent businesses and the public
- Available budget
- Good engineering judgment

A survey was distributed to all Minnesota city and county engineers to gather input regarding the use of asphalt recycling. Of the survey respondents, no one cited economics as a reason for not doing recycling projects. See Appendix B for complete survey results and information.

PARTS 2 – 5

The remainder of the BARM is a detailed description of each of the four types of asphalt recycling:

- Hot In-Place Recycling (HIR)
- Cold Planing (CP)
- Full Depth Reclamation (FDR)

- Cold Recycling (CR) *The BARM defines Cold Recycling as both Cold In-Place Recycling (CIR) and Cold Central Plant Recycling (CCPR).*

Hot In-Place Recycling (HIR)

Individual Project Analysis for Hot In-place Recycling (HIR) is presented in Chapters 4, 5, 6 and 7 respectively. In general, there are three types of HIR:

- Surface recycling
- Remixing
- Repaving

A table on page 58 lists the pavement distress modes that are best remedied with one the three HIR processes (**Surface Recycling, Remix** or **Repave**). HIR projects are predicted to last:

- 2 to 4 years for surface recycling
- 6-10 years for surface reapplication with a surface treatment
- 7-14 years for remixing
- 6-15 years for repaving

The HIR mix design process has remained the same for most agencies for along time. More recently, through the Strategic Highway Research Program (SHRP) and the development of the SuperPave System, an alternate approach may possibly be applied to HIR mix designs. The overall HIR mix design process, whether traditional or SuperPave, involves some or all of the following steps:

- Evaluation of the existing HIR including asphalt binder, aggregates and mix properties
- Determining whether the existing asphalt binder needs rejuvenation
- Selecting the type and amount of recycling agent
- Determining the need for and amount of admix including aggregate gradation, type and amount of soft, new asphalt binder
- Preparing and testing both asphalt binder and mix specimens in the laboratory
- Evaluating test results and determining the optimum combination of admix and recycling agent

The life expectancy is very dependent on local conditions, climate, traffic, quality of materials used and quality of workmanship.

CHAPTER 5: HIR MIX DESIGN

Chapter 5 provides an overview of the details surrounding a Hot In-Place Recycling mix design. HIR mix designs generally are performed to restore the characteristics of the existing aged asphalt pavement similar to those of virgin Hot Mix Asphalt (HMA).

> *Although commonly done in warm weather climates, HIR has not been used in Minnesota largely because of the availability of equipment and contractors. Based on the survey results, HIR was a topic that city and county engineers were interested in knowing more about (see Appendix B).*

CHAPTER 6: HIR CONSTRUCTION PROCESS

The **Construction Process** for **HIR** presented in Chapter 6 includes detailed discussion of the three types of HIR.

Surface recycling has been known by a number of different names over the years including heater-scarification, heater-planing, reforming, resurfacing, etc. and has been in fairly common use since the mid-1960s. Compared to the other HIR processes, surface recycling is the most fundamental/least technologically complex process. It primarily consists of:

- Drying and heating the upper layers of the existing pavement
- Scarifying the heated/softened asphalt pavement
- Adding a recycling agent (if required by the mix design and job mix formula)
- Mixing the loose recycled mix
- Spreading and placing the recycled mix with a free floating screed
- Compacting the recycled mix using conventional HMA rollers and procedures.

Remixing is used when:

- Significant modification of the physical properties of the existing asphalt pavement must be undertaken to correct specific pavement distresses.
- The recycled mix is to function as the wearing course for higher traffic volume applications.
- A modest amount (less than 3/4-inch) of pavement strengthening is required.

HIR remix trains consists of:

- Drying and heating the upper layers of the existing pavement.
- Scarifying the heated/softened asphalt pavement.
- Adding a recycling agent and admix or HMA as required by the mix design.
- Thoroughly blending/mixing into a homogeneous recycled mix.
- Spreading and placing the recycled mix with a free-floating screed.
- Compacting the recycled mix using conventional HMA rollers. Specific temperatures and other conditions are discussed.

Repaving is used when:

- Surface recycling and/or remixing alone cannot restore the pavement profile or surface requirements.
- When a conventional HMA overlay operation is not practical.
- A very thin HMA or specialty mix, which is to act as the wearing course, is required.
- A significant amount (2-inches) of pavement strengthening is required.

Repaving trains consist of:

- HIR of the existing pavement.
- Simultaneously or sequentially placing the new HMA/specialty mix.
- Compacting the recycled mix and new material together using conventional HMA roller.

CHAPTER 7: HIR SPECIFICATIONS

Both Method and End Result Specifications are presented for HIR in Chapter 7. Appropriate quality control and quality assurance procedures, similar to those used on standard HMA projects, are also provided in Chapter 7.

> *Since HIR has not been used in Minnesota, Mn/DOT does not have a specification.*

CHAPTER 8: COLD PLANING

The construction procedures, specifications and inspection for Cold Planing (CP) are discussed in Chapter 8 and 9. CP is the controlled removal of the surface of the existing pavement to a desired depth using specially designed milling equipment to restore the pavement surface to a specified grade and cross-slope. CP can be used to remove part or all of the existing pavement layers. The amount of material removed can be varied to provide Structural Adequacy. The resulting textured surface can also be used as a surface preparation. The product of a CP operation is a crushed, somewhat gap-graded Reclaimed Asphalt Pavement (RAP), which acts like an asphalt-coated granular material. The RAP can be used for hot recycling, Cold Central Plant Recycling (CCPR) or as a granular base.

> *Because of requiring specially designed milling equipment, Cold Planning is not a common practice in Minnesota.*

The Project Analysis for CP must include an evaluation of Structural Capacity to determine if the current thickness is adequate for the predicted traffic.

The equipment required for CP includes:

- A modern self-propelled cold planer
- Haul trucks
- Water truck
- Sweeper or power broom

Specifications for CP must include repair of existing distress to remove surface irregularities, grade and slope control, and depth of the planing. Specification for cold planning should include:

- Milling depth
- Gradation of the RAP
- Surface texture
- Grade and cross-slope
- Smoothness

The milling depth needs to be physically measured. The maximum particle size of the **RAP** should be determined from random samples taken from the discharge conveyor. Texture can be assessed both visually and by measurement of striations. Grade, cross-slope and smoothness are checked based on what is required in the specifications. The preparation of the surface for subsequent **HMA** overlays or **HIR** should be included in the specifications.

CHAPTERS 10 – 13: FULL DEPTH RECLAMATION (FDR)

Full Depth Reclamation **(FDR)** is the process in which the full thickness of the asphalt pavement and a predetermined portion of the underlying materials (base, subbase, and/or subgrade) is uniformly pulverized and blended to provide an upgraded, homogeneous material. Often this blend of material alone, without any additional stabilizing additives, is sufficient to act as the base for a new surfacing course. However, if after the project evaluation it is determined that the reclaimed materials need improvement or modification, there are three different types of stabilization that can be used: mechanical, chemical or bituminous.

Pavement Distresses that can be improved by FDR include:

- Cracking
- Swells, bumps or sags and depression
- Rutting, corrugation and shoving
- Stripping
- Raveling and bleeding
- Potholes

Inadequate Structural Capacity can be improved with FDR with proper thickness design for the anticipated traffic. To design a FDR project existing material properties, geometrics, traffic, constructability and environment must be assessed.

For economic purposes, the expected service life of the FDR generally fall within the following ranges:

- Seven (7) to 10 years, FDR with a surface treatment
- Up to 20 years with FDR and an HMA overlay assuming the final structure is adequate for the anticipated traffic

Mix Design for FDR should include in most cases a Stabilizing Agent. The objective of the mix design is to establish the optimum percentage of stabilizers. The mix design process generally consists of:

- Determining the suitability of the reclaimed material
- Selecting the percentage of stabilizing agent to be added
- Determining the optimum moisture or fluids content
- Establishing the optimum bitumen content
- Confirmation of the mechanical properties of the stabilized reclaimed mix.

  Based on follow up information from the survey of Minnesota cities and counties, most agencies are using Mn/DOT Specification 2350 for their mix design.

FDR includes the pulverization of **all** the asphalt bound layers. Mixing with some or all of the underlying granular base, subbase or subgrade materials also occurs. How much of the underlying granular base to mix with the pulverized HMA depends on the quality of the materials and how uniform the thickness and material properties are.

Although the Equipment used for FDR varies, the same general steps are followed:

- Pulverization and sizing of the existing HMA
- Incorporation and mixing of the underlying materials
- Application of a stabilizing agent
- Mixing of the agent and pulverized materials
- Initial, intermediate and final compaction alternately with initial, intermediate and final grading and shaping
- Tight blading and removal of loose material
- Curing
- Application of a wearing course

A detailed description of each of the **FDR** construction phases and equipment is summarized in Chapter 12.

A very detailed list and description of the specification for FDR is in Chapter 13.

> *In Minnesota, Mn/DOT has developed Specification 2331 SP 2000-117 to be followed when doing FDR. A copy of this specification has been included in Appendix A of this report and can also be located at www.dot.state.mn.us/tecsup/spec/.*

CHAPTERS 14 – 17: COLD RECYCLING (CR)

Cold Recycling (CR) is the rehabilitation of asphalt pavements without the application of heat. The two subcategories of CR are Cold Central Plant Recycling (CCPR) and Cold In-Place Recycling (CIR). The later being a common rehabilitation practice in Minnesota. Chapters 14 – 17 present the details of project analysis, mix design, construction and specifications respectively. This review will focus mainly on the CIR process.

The **CIR Process** consists of the on-site rehabilitation of the asphalt pavement with a recycling train, which can range in size from a single unit to a multiunit train.

Although a wide range of distresses can be tracked using the CIR process, unless the cause(s) of the distresses are addressed, the distress will only be mitigated—not eliminated. Therefore, a detailed project analysis is necessary to develop an effective CIR design (including depth of recycling and required additional wearing course) to achieve the expected performance and design life. The project analysis should consist of:

- Historic assessment (construction and maintenance history)
- Pavement assessment
- Structural capacity assessment
- Materials property assessment
- Traffic assessment
- Economic assessment

Economic considerations and life-cycle analysis generally fall within the following ranges:

- CIR with surface treatment 6-8 years
- CIR with HMA overlay 7-15 years

> *According to the survey of Minnesota cities and counties, CIR was the recycling method for which most people would like to receive additional information.*

CHAPTER 15: MIXTURE DESIGN

The mix design serves as an initial job mix formula, just as for HMA construction. Adjustments are generally required for workability, coating and stability. Most mix designs for CIR involve the application of asphalt emulsions, emulsified recycling agents or cutbacks. The typical steps in developing a mix design are as follows:

- Sampling of the existing pavement
- Determination of the RAP properties (gradation, binder content, extracted gradation, aged binder)
- Selection of the amount and gradation of additional aggregate
- An estimate of new asphalt binder or other agent
- Determination of pre-mix moisture content for coating
- Manufacture and testing of trial mixes

The trial mixes must use proper procedures for batching, mixing, compaction, curing, and strength testing along with volumetric determination. The laboratory mix design results in a job mix formula, which indicates the materials characteristics and percentages to use in the mix. These should be considered as starting points for construction and may need to be adjusted in the field as conditions warrant.

CHAPTER 16: CONSTRUCTION OF CIR

Prior to construction, areas of non-uniform materials or pavement thickness must be identified. The equipment for CIR can consist of a single, two-unit or multi-unit train. With the single unit train the milling machine cutting head removes the pavement to the required depth and cross-slope, sizes the RAP and blends the recycling additive with the RAP. Single train units do not contain screening and crushing units, making control of the maximum particle size difficult.

A Two-Unit Train consists of a large, full lane milling machine and a pugmill mix-paver. A Multi-Unit Train consists of a milling machine, a trailer mounted screening and crushing unit, and a pugmill mixer. The Multi-Unit Train provides a more consistent RAP material.

Cold In-Place Recycling is a variable procedure. Changes in the gradation of the RAP result in changes in the workability of the mix. Field adjustments must be made as construction progresses. The primary concern is that the moisture and/or asphalt content be adjusted to provide proper uniform coating of the particles. Too much liquid will result in flushing of the mixture. Laydown, compaction and curing need to be monitored carefully during the process.

CHAPTER 17: SPECIFICATIONS AND QUALITY MANAGEMENT FOR CIR

Cold In-Place Recycling is a variable process; the variability of the process makes setting statistical based specifications limits difficult. Therefore, most CIR projects use a combination of method specifications and end result specifications. Suggested limits for these items are presented in Chapter 17. Table 17.1 is a summary of the field sampling and testing used for Quality Management of CIR mixtures and projects. A set of Guide Specifications for Cold Recycled Asphalt Pavements is also provided on pages 232-235.

Mn/DOT specifications for CIR are included in Appendix of this report and can also be located at www.dot.state.mn.us/tecsup/spec/.

APPENDIX A

SPECIFICATIONS

Local Road Research Board
Recycled Asphalt Pavement (RAP)
RAP Specifications

Mn/DOT currently has four specifications related to recycled asphalt pavement (RAP) projects. The four specifications are as follows:

- 2331 *Cold In-Place Recycle (CIR) Bituminous Mixture Full Recycling Train*
- 2331 *Cold In-Place Recycle (CIR) Bituminous Mixture Full Recycling Train Mix Design*
- 2331 *Bituminous Pavement Reclamation*
- 3138 *Aggregate for Surface and Base Courses*

Currently, the RAP specification included in the 2000 Edition of Mn/DOT's Standard Specifications for Construction is specification (2331) *Cold In-Place Recycle (CIR) Bituminous Mixture Full Recycling Train Mix Design*. This specification is primarily used in Minnesota as cold in-place recycling is the most common recycling method in Minnesota (see Recycling Survey Summary). This specification can be used for any standard emulsion.

As quality aggregates become more scarce and preservation of natural resources is an issue, a common use of recycled asphalt is to use it as base material. Mn/DOT Specification 3138 addresses the material properties/concerns for recycled asphalt materials used as base materials (Class 7).

In addition to specification 2331, a new special provision was added to include a new mix design for an engineered emulsion. Details of this specification are included in (2331) *Cold In-Place Recycle (CIR) Bituminous Mixture Full Recycling Train Mix Design*. Some agencies are beginning to use this mix design and Mn/DOT has included this special provision to assist in the process. The third specification dealing with RAP projects is (2331) *Bituminous Pavement Reclamation*.

All four Mn/DOT specifications are included as attachments to this appendix.

MN/DOT SPECIFICATION (2331):

REVISED 11/15/1999
SP5M-108.3

S- 2331 COLD IN-PLACE RECYCLE (CIR) BITUMINOUS MIXTURE FULL RECYCLING TRAIN

S-.1 DESCRIPTION

This work shall consist of milling the existing bituminous surface, to the depth and width shown on the Plans. The reclaimed asphalt pavement (RAP) shall be mixed with: an asphalt emulsion, water (if required), and other additives (if required). This cold in-place recycled bituminous mixture will then be placed and compacted in accordance with the plans and specifications and as directed by the Engineer.

S-.2 MATERIALS

Asphalt Emulsion: The Mix Emulsion shall be HFMS-2P or approved equal conforming to Mn/DOT 3151.2E.

Crushed/sized Bituminous Material: The crushed/sized bituminous material shall meet the following gradation requirements:

Sieve Size	Percent Passing
38.0 millimeter (1 1/2 inches)	100 percent
25.0 millimeter (1 inch)	90-100 percent

Mix Design: An asphalt emulsion add rate of two percent (2 percent) was used for estimating purposes. This rate may be adjusted at the start of construction.

Water: Shall be clear and free of deleterious materials, such as; acid, oil, alkali, organic material, salt, sugar, or other harmful materials.

Fog Seal Emulsion: If required, shall be CSS-1h, CSS-1 or approved equal conforming to Mn/DOT 3151.2E.

S-.3 CONSTRUCTION REQUIREMENTS

A. Equipment

A Full Recycling Train is required. This is a multi-unit train with milling, screening/crushing, and mixing units, used to process the material.

Milling: The Contractor shall furnish a self-propelled machine capable of milling the existing bituminous surface to the depth shown on the plans, in a single pass, and to a minimum width of not less than 3.8 m (12.5 feet). This machine shall have automatic depth and cross-slope controls and maintain a constant cutting depth. The automatic depth controls shall maintain the cutting depth to within plus or minus 6 millimeter (1/4 inch) of the depth shown on the plans.

Crushing/sizing: The material will be crushed and sized prior to mixing with emulsion. The unit shall have a "closed circuit" system capable of continuously returning oversized material to the crusher.

Mixing: The pug mill type-mixing unit shall be equipped with a continuous weighing system of the milled and sized material, coupled/interlocked to a computer-controlled liquid metering device for the asphalt emulsion and other additives. The machine shall be capable of automatically metering liquids with a variation of not more than plus or minus 0.2 percent by weight of mix from the specified percentage. The unit shall be equipped with facilities so that the contractor can verify and calibrate these items by a method acceptable to the Engineer.

Pick-up machine: The pick-up machine shall be capable of removing the entire windrow of cold in-place recycled bituminous material down to the remaining underlying material.

Paver: The paver shall meet the requirements of Mn/DOT 2331.3C2a.

Rollers: The rollers shall meet the requirements of Mn/DOT 2331.3H3a. A minimum of two rollers shall be required. When cold in-place recycling depths of 75 millimeter (3in.) or more, one of the two rollers shall be a 28 to 33 metric ton (25 to 30 ton) pneumatic roller equipped with a watering device to prevent material from adhering to the tires. The 28 to 33 metric ton (25 to 30 ton) pneumatic roller should be used for breakdown rolling. The Steel-Wheeled rollers shall meet the requirements of Mn/DOT 2331.3H3a(1).

Distributor: The distributor shall meet the requirements of Mn/DOT 2321.3C1.

Broom: A rotary power broom may be used to remove the fillet of fine milled material produced by the milling operation. The broom must remove all loose material prior to placing and compacting the CIR bituminous mixture.

B. Construction Operations

Quality Control: Testing of the crushed/sized bituminous material will be performed at a rate of one per 4200 square meters (one per 5000 square yards) or a minimum of two (2) per day. These samples may be taken from the windrow of CIR bituminous mixture after the emulsion has been added. These samples will be taken and tested by the Agency.

Additional research samples: **The contractor will be required** to take two samples per day. One sample of the crushed/sized material will be taken prior to the addition of emulsion. The other sample will be taken after the emulsion has been added. The sample sizes will be approximately 11 kg. (25 lbs.) They will be in sealed cylinder mold containers. The samples will be given to the agency to be tested in the District Lab.

When commencing cold in-place recycling operations, the emulsified binder agent shall be applied to the milled bituminous material at the initial design rate as directed by the Mn/DOT Bituminous Office. The exact application rate of the emulsified binder agent will be determined and varied by the Engineer as required by existing pavement conditions. The temperature of the emulsified binder agent shall be within the temperature range specified for the mixing of the material being used, without overheating. An allowable tolerance of plus or minus 0.2 percent of the prescribed rate of application shall be maintained at all times. Variations beyond this range require the approval of the Engineer.

The Contractor may add water to the milled material to facilitate uniform mixing with the emulsified binder agent. Water may be added prior to or concurrently with the emulsified asphalt, provided that this water does not cause any adverse effect on the emulsified binder agent. The total liquid content of water added (during milling, crushing/sizing and mixing [if required]) plus asphalt emulsion should not exceed 4.0 percent to 4.5 percent, as tested on the material provided for above, as the "additional research samples".

Fillets of fine, milled material, which form adjacent to a vertical face, shall be removed prior to placing the CIR bituminous mixture. Fillets adjacent to existing pavement, which will be removed by overlapping during the next milling pass, do not need to be removed.

The CIR bituminous mixture shall be placed without segregation, to the lines and grades and cross slope shown on the Plans. Any field deviations from this requires the approval of the Engineer.

Breakdown rolling shall not begin until the emulsion begins to break, on the surface of the placed mixture, unless otherwise directed by the Engineer. This is signified by a distinct change in color from brown to black. Typically, this takes from one half to two (2) hours depending on the type of emulsion, lift thickness, and curing conditions of temperature, humidity, and wind velocity.

Compaction of the CIR bituminous mixture shall be by the "Ordinary Compaction Method" in accordance with Mn/DOT 2331.3H3 as modified below.

A control strip shall be used to establish a rolling pattern, which shall be used by the Contractor for the compaction of the CIR bituminous mixture until a new control strip is constructed. Each control strip shall have an area of at least 330 square meters (400 square yards), and shall be of the same thickness as the lift it represents. The control strips shall remain in-place and become a part of the completed work.

The equipment used in the construction of the control strip(s) shall be approved by the Engineer and shall be of the same type and mass used on the remainder of the CIR bituminous mixture represented by the control strip. The number, weight and type of rollers shall be sufficient to meet the minimum requirements in this specification and obtain the required compaction while the mixture is in a workable condition.

Construction of the control strips will be as directed by the Engineer. Compaction shall commence after the mixture has been spread to the desired thickness and the emulsion has broken. **Compaction typically begins with the pneumatic roller**. The pneumatic roller **shall** make six or more passes over an area until no further displacement of the mixture is evident. Compaction shall continue with the finish roller until no appreciable increase in density can be obtained by additional roller coverage. Densities will be determined by means of a portable nuclear testing device.

To determine when no appreciable increase in density can be obtained, two to four test points shall be established in the control strip. Determine the test points, on a random basis, after completion of the pneumatic rolling. The density at each point shall be measured by, averaging two readings (180 degrees outset), of a portable nuclear testing device after each finish (steel) roller pass. Care must be taken to ensure that the nuclear gauge rests on a flat surface. Rolling shall be suspended when the testing shows either (a) a decline in density with additional roller passes, or (b) when no increase in density is obtained by additional roller pass. The rolling operation (pattern and timing) shall be temporarily discontinued and reevaluated if surface cracking or checking occurs behind the roller.

After this testing is accomplished, rolling on the remainder of that course shall be done in accordance with the pattern developed in the test strip. Densities will be spot-checked with the nuclear testing device as ordered by the Engineer. These densities will be used for information only.

The Engineer will order a new control strip when there is a significant change in the RAP, or when the Engineer believes the control strip is not representative.

A nuclear testing device shall be furnished and operated by the Contractor. The furnishing of the nuclear testing device and operator shall be considered incidental to the furnishing and placing of the cold in-place recycled bituminous mixture and shall not be compensated for separately.

The Contractor shall reshape and compact the in-place aggregate shoulder prior to placing the first overlay course, in accordance with Mn/DOT 2105.3G. Compaction shall be achieved by the Quality Compaction Method in accordance with Mn/DOT 2211.3C2.

C. Restrictions

Recycling operations shall be performed when the atmospheric temperature is above 10 degrees Celsius (50 degrees Fahrenheit) and rising. Additionally, recycling shall not be performed when the weather is foggy or rainy or when weather conditions are such that proper mixing, spreading, and compacting of the recycled material cannot be accomplished in the judgment of the Engineer.

The cold milling operation shall be performed on one-half of the roadway at a time, so that the opposite lane may carry traffic.

After the recycled material has been spread and compacted, NO TRAFFIC (this includes Contractor's equipment) shall be permitted on the completed cold in-place recycled bituminous mixture for at least two hours. (The intent is to limit stopped or slow moving traffic on the newly placed surface. When traffic is allowed to resume normal speeds over the surface, such as at the end of the day or during train turnaround, the Engineer may allow traffic onto the surface before the two-hour period providing no adverse effects are encountered.)

The area shall be allowed to cure such that the moisture content is reduced to 1.5 percent or less, by total weight of mix, (this may take approximately seven to 10 days) before placing hot bituminous concrete surfacing. The moisture content shall be determined from a 1.5 kg (3.5 lb.) sample retrieved over the full-depth of the CIR layer. If the moisture content is above 1.5 percent by weight yet below 2.5 percent by weight, and has not changed by more than 0.2 percent over a period of five days, the Engineer may allow surfacing to proceed.

The hot mix bituminous overlay shall be placed on the CIR bituminous mixture within 30 days.

D. Thickness and Surface Requirements

Upon completion of placement and compaction, the finished surface of the cold in-place recycled bituminous mixture shall be smooth and not vary more than 15 millimeter (0.05 feet) from the elevations prescribed from that point as determined from the grade staked by the Engineer and the typical sections shown on the Plans. In addition, the finished surface shall show no variations greater than 6 millimeter (1/4 inch) from the edge of a three (3) meter (10 foot) straightedge resting on any two points and laid parallel to and/or at right angles to the centerline. *All deviations from this tolerance shall be corrected at no additional cost to the Department*.

During the curing period, the surface of the cold in-place recycled bituminous mixture may be sealed, if necessary, to prevent raveling, as determined by the Engineer. A minimum amount of emulsion should be employed since the intent is to not seal the surface such that curing is precluded. Fog sealing shall be accomplished with CSS-1h or CSS-1 emulsion applied at an approximate rate of 0.23 to 0.45 liters per square meter (0.05 to 0.10 gallons per square yard) of dilute

asphalt emulsion (50/50 mix of emulsion and water by volume). The fog seal, if required, shall be applied in accordance with Mn/DOT 2355.3. The Mn/DOT Bituminous Engineer shall be contacted prior to fog sealing. If, in the opinion of the Engineer, the recycled base surface is not subject to raveling prior to the application of the sealant, the Engineer has the right, as provided in Mn/DOT 1402, to delete the item, Fog Seal, from the contract and not be subject to a value engineering proposal by the Contractor.

The contractor shall be responsible for maintaining the finished surface of the cold in-place recycled material in a smooth, compacted condition free of ruts, distortion, potholes, loose aggregate, and to the grade and cross-section tolerances previously stated, until the first bituminous course required by the Contract is completed. All loose aggregate that develops on the surface of the recycled pavement shall be removed by power brooming. A rotary power broom capable of cleaning the road surface and removing loose particles shall be provided within 24 hours notice, if directed by the Engineer.

The Contractor shall repair any of the previously mentioned deficiencies to the completed cold in-place recycled bituminous mixture to the satisfaction of the Engineer. Said repair(s) shall be made at no additional cost to the Department. Failure to perform corrections shall be considered unacceptable work as per Mn/DOT specification 1512.

S-.4 METHOD OF MEASUREMENT

Cold In-place Recycle Bituminous Mixture shall be measured by the Square meter (Square yard).

The Bituminous Material for Mixture of the type shown on the Plans or as specified in the special provisions will be measured by the Metric ton (ton). Water added to aid mixing is incidental.

Bituminous Material for Fog Seal applied on the road will be measured by volume at 15 degrees Celsius (60 degrees Fahrenheit) in Liter (Gallon).

S-.5 BASIS OF PAYMENT

Payment for the accepted quantities of cold in-place recycle bituminous mixture at the Contract prices per unit of material will be compensation in full for all costs of constructing the cold in-place recycled bituminous mixture as specified, including any additives as permitted or required.

The accepted quantity of Cold In-place Recycle Bituminous Mixture will be paid for at the Contract bid price per Square meter (Square yard) complete and in place.

The accepted quantity of Bituminous Material for Mixture of the type shown on the Plans will be paid for at the Contract bid price per Metric ton (ton) complete and in place.

The accepted quantity of Bituminous Material for Fog Seal will be paid for at the Contract bid price per liter (gallon) complete and in place.

Payment for the cold in-place recycled bituminous mixture will be made on the basis of the following schedule:

Item No.	Item	Unit
2331.604	Cold In-place Recycle Bituminous Mixture	Square meter
2331.609	Bituminous Material for Mixture	Metric ton
2355.502	Bituminous Material for Fog Seal	Liter

Item No.	Item	Unit
2331.601	Cold In-place Recycle Bituminous Mixture	Square yard
2331.602	Bituminous Material for Mixture	Ton
2355.502	Bituminous Material for Fog Seal	Gallon

MN/DOT SPECIFICATION (2331):

S-1 (2331) COLD IN-PLACE RECYCLE (CIR) BITUMINOUS MIXTURE FULL RECYCLING TRAIN MIX DESIGN

New Write-up 1/15/2002

SP2000-119

This work shall consist of milling the existing bituminous surface, to the depth and width shown on the Plans. The reclaimed asphalt pavement (RAP) shall be crushed, screened, mixed with an asphalt emulsion, water (if required), and other additives (if required). This cold in-place recycled bituminous mixture shall then be placed and compacted in accordance with the applicable Mn/DOT Standard Specifications, the Plans, as directed by the Engineer, and the following:

S-1.1 MATERIALS

Asphalt Emulsion: The type of asphalt emulsion to be used shall be determined by the mixture design. A representative from the asphalt emulsion supplier shall 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 shall be available to check on the Project and make adjustments to the asphalt emulsion formulation as required.

Crushed/sized Bituminous Material: The crushed/sized bituminous material shall meet the following gradation requirements:

Sieve Size	Percent Passing
31.5 millimeter [**1-1/4 inch**]	100 percent

Note: A 100 percent passing a 25.0-millimeter [**1 inch**] sieve size may be used when a finer gradation 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 63.5 millimeter [**2.5 inches**], whichever is greater, and to a maximum of 127 millimeter [**5 inches**].

Mix Design: A preconstruction mix design shall be submitted by the Cold In-Place Recycling Contractor tested in accordance with Appendix 1, using the materials that will be recycled, which was 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.

Table 1

Property	Criteria	Purpose
Compaction effort, Superpave Gyratory 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 minimum	Stability Indicator
Retained stability based on cured stability **	70 percent minimum	Ability to withstand moisture damage
Indirect Tensile Test, AASHTO TP9-96, Modified in Appendix 2	See Note in Appendix 2	Cracking (Thermal)
Raveling Test, Method Attached, Ambient, Appendix 3	2 percent maximum	Raveling Resistance
* Cured stability tested on compacted specimens after 60°C (140°F) curing to constant weight.		
** Vacuum saturation of 55 to 75 percent, water bath 25°C 23 hours, last hour at 40°C water bath		

Note: An emulsion content of 3 percent 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.

Water: Shall be clear and free of deleterious materials, such as: acid, oil, alkali, organic material, salt, sugar, or other harmful materials.

Fog Seal Emulsion: If required, shall be CSS-1h, CSS-1 or approved equal conforming to Mn/DOT 3151.2E.

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.

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 "Crushed/sized bituminous material", and when blended with the design millings shall produce a product, which meets the specifications given in Table 1.

Table 2: Additional Crushed RAP

Tests	Method	Limit
Deleterious Materials: Clay Lumps and Friable Particles in Aggregate, Percent maximum	ASTM C 142 or AASHTO T112	0.2 recommended
Maximum size, 100 percent Passing, Sieve Size	ASTM C 136 or AASHTO T 27	31.5 millimeter [**1-1/4 inch**]

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 that meets the specification given in Table 1.

Table 3: Additional Aggregate

Tests	Method	Limit
Los Angeles abrasion value, Percent (%) loss	AASHTO T 96	40 max for Surface mix 50 max for Base mix
Sand Equivalent, Percent (%)	ASTM D-2419	60 minimum
Maximum size, 100 Percent Passing, Sieve Size	ASTM C 136 or AASHTO T 27	31.5 millimeter [**1-1/4 inch**]
Water absorption percent (%)	AASHTO T 85	5 max.

S-1.2 CONSTRUCTION REQUIREMENTS

A. Equipment

A Full Recycling Train is required. This is a multi-unit train with milling, screening/crushing, and mixing units, used to process the material.

Milling: The Contractor shall furnish a self-propelled machine capable of milling the existing bituminous surface to the depth shown on the Plans, in a single pass, and to a minimum width of not less than 3.8 m [**12.5 feet**]. This machine shall have automatic depth and cross-slope controls and maintain a constant cutting depth. The automatic depth controls shall maintain the cutting depth to within plus or minus 6 millimeter [**1/4 inch**] of the depth shown on the Plans.

Crushing/sizing: The material shall be crushed and sized prior to mixing with emulsion. The unit shall have a "closed circuit" system capable of continuously returning oversized material to the crusher. All of the reclaimed asphalt pavement (100 percent) shall be processed to the maximum size requirements as specified.

Mixing: The pug mill type mixing unit shall be equipped with a continuous weighing system of the milled and sized material, coupled/interlocked to a computer controlled liquid metering device for the asphalt emulsion and other additives. The machine shall be capable of automatically metering liquids with a variation of not more than plus or minus 0.2 percent by weight of mix from the specified percentage. The asphalt emulsion pump should be of sufficient capacity to allow emulsion contents up to 3.5 percent by weight of pulverized bituminous material. The unit shall be equipped with facilities so that the Contractor can verify and calibrate these items by a method acceptable to the Engineer.

Pick-up machine: The pick-up machine shall be capable of removing the entire windrow of cold in-place recycled bituminous material down to the remaining underlying material.

Paver: The paver shall meet the requirements of Mn/DOT 2331.3C2a.

Alternatively, to the equipment listed in Mixing, Pick-up machine, and Paver, 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 shall be displayed for both the flow rate and total amount of pulverized bituminous material and asphalt emulsion in appropriate units of weight and time.

Rollers: The rollers shall meet the requirements of Mn/DOT 2331.3H3a. A minimum of two rollers shall be required. When cold in-place recycling depths of 75 millimeter [**3 inches**] or more, one of the two rollers shall be a 28 to 33 metric ton [**25 to 30 ton**] pneumatic roller equipped with a watering device to prevent material from adhering to the tires. The 28 to 33 metric ton [**25 to 30 ton**] pneumatic roller should be used for breakdown rolling. The Steel-Wheeled rollers shall meet the requirements of Mn/DOT 2331.3H3a(1).

Distributor: The distributor shall meet the requirements of Mn/DOT 2321.3C1.

Broom: 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.

B. Construction Operations

Vegetation: 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.

Milling: 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 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. 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 percent) of the shredded fabric in the recycled material is no more that 3200 millimeter^2 [**5 square inches**]. Additionally, no fabric piece shall have any dimension exceeding a length of 100 millimeter [**4 inches**]. 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, than the Contractor shall receive additional payment for any necessary adjustments in equipment and operations.

Mixing: The recycled material shall be produced through a mixing unit capable of processing the pulverized material and asphalt emulsion and water to a homogeneous mixture. The asphalt emulsion and water shall be incorporated into the pulverized bituminous material at the initial rate determined by the mix design(s) and approved by the Engineer. The total water content may include that amount added at the milling head, and may also include addition at the mixing unit if available. Sampling and mix design may determine different levels of asphalt emulsion at various portions of the Project.

Paver: The material shall be spread using a self-propelled paver meeting the requirements in Section A. 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. The pickup machine must be within 45 meters [**150 feet**] of the mixing unit. The recycled material shall be spread in one continuous pass, without segregation and to the lines and grades established by the Engineer.

Compaction: Compacting of the recycled mix shall be completed using rollers meeting the requirements of Section A. 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. Double drum steel roller(s), either operating in a static or vibratory mode, shall do final rolling to eliminate pneumatic tire marks and to achieve density. 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.

The nuclear testing device shall be furnished and operated by the Contractor. The furnishing of the nuclear testing device and operator shall be considered incidental to the furnishing and placing of the cold in-place recycled bituminous mixture and shall not be compensated for separately.

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 (2) 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.

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.

The completed cold recycled material surface shall not vary more than six millimeter (6 mm) [**1/4 inch**] from the lower edge of a three-meter (3m) [**10 foot**] straight edge placed on the surface parallel and transversely to the centerline.

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.

The Contractor shall reshape and compact the in-place aggregate shoulder prior to placing the first overlay course, in accordance with Mn/DOT 2105.3G. Compaction shall be achieved by the Quality Compaction Method in accordance with Mn/DOT 2211.3C2.

C. Quality Control/Quality Assurance

The Contractor or supplier shall be responsible for the quality control.

Mn/DOT shall be responsible for quality assurance.

Quality Control

Pulverized Bituminous Material Sizing: Two (2) gradations shall be performed each day on the moist millings (which must be air dried) using the following sieves: 31.5 millimeter [**1.25 inch**], 25.0 millimeter [**1.0 inch**], 19.0 millimeter [**3/4 inch**], 12.5 millimeter [**1/2 inch**], 9.5 millimeter [**3/8 inch**], 4.75 millimeter [**No. 4**], 2.36 millimeter [**No. 8**], 1.18 millimeter [**No. 16**], and 600 μm [**No. 30**]. The resulting gradation shall be compared to the mix design gradations to determine any necessary changes to emulsion content (see Appendix 1). Sampling procedures shall generally be in accordance with ASTM D979 or AASHTO T168.

In addition to the two gradations per day, a sample shall be obtained each 0.8 km [**1/2 mile**] before emulsion addition and screened using a 31.5-millimeter [**1.25 inch**] sieve (or smaller sieve if required) to determine if the material is meeting the maximum particle size requirement.

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.

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.

Mixture Testing: On the first full day of recycling, samples will be gathered for testing mixture results from the design given as described in Table 1. 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 25.0-millimeter [**1 inch**] screen if 100-millimeter [**4 inch**] 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. The results shall be provided to the Project Engineer. If the results fail to meet the design criteria, daily sampling will continue until the mix meets the design specifications.

Depth of Pulverization (Milling): The nominal depth shall be checked on both outside vertical faces of the cut each 0.2 km [**1/8 mile**]. The station and depth shall be recorded.

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.

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 six millimeter (6mm) [**1/4 inch**] from the lower edge of a three-meter (3 m) [**10 foot**] straight edge placed on the surface parallel and transversely to the centerline after rolling is completed.

Quality Assurance

Pulverized Bituminous Material Sizing - One gradation shall be performed each day on the moist millings (which must be air dried) using the following sieves: 31.5 millimeter [**1.25 inch**], 25.0 millimeter [**1.0 inch**], 19.0 millimeter [**3/4 inch**], 12.5 millimeter [**1/2 inch**], 9.5 millimeter [**3/8 inch**], 4.75 millimeter [**No. 4**], 2.36 millimeter [**No. 8**], 1.18 millimeter [**No. 16**], and 600 μm [**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.

Asphalt Emulsion – The asphalt emulsion shall be received on the job site at a temperature no greater than 49ºC [**120ºF**]. Sample the first shipment, then submit one sample per 189 271 liters [**50,000 gallons**] (approximately 180 metric tons [**200 tons**]). 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, percent	ASTM D244[1]	64.0	66.0
Oil distillate by distillation, percent	ASTM D244[1]		0.5
Sieve Test, percent	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 [**350 degrees Fahrenheit**] 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.

D. Restrictions

Cold In-Place recycling operations shall be completed when the atmospheric temperature measured in the shade and away from artificial heat is 10 degrees Celsius [**50^0 F**] 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.

The hot mix bituminous overlay shall be placed on the CIR bituminous mixture within 30 days.

E. Thickness and Surface Requirements

Upon completion of placement and compaction, the finished surface shall show no variations greater than six millimeter (6 mm) [**1/4 inch**] from the edge of a three-meter (3m) [**10 foot**] straightedge resting on any two points and laid parallel to and/or at right angles to the centerline. *All deviations from this tolerance shall be corrected at no additional cost to the Department*.

During the curing period, the surface of the cold in-place recycled bituminous mixture may be sealed, if necessary, to prevent raveling, as determined by the Engineer. A minimum amount of emulsion should be employed since the intent is to not seal the surface such that curing is precluded. Fog sealing shall be accomplished with CSS-1h or CSS-1 emulsion applied at an approximate rate of 0.23 to 0.45 liters per square meter [**0.05 to 0.10 gallons per square yard**] of dilute asphalt emulsion (50/50 mix of emulsion and water by volume). The fog seal, if required, shall be applied in accordance with Mn/DOT 2355.3. The Project Engineer shall be contacted prior to fog sealing. If, in the opinion of the Engineer, the recycled base surface is not subject to raveling prior to the application of the sealant, the Engineer has the right, as provided in Mn/DOT 1402, to delete the item, Fog Seal, from the Contract and not be subject to a value engineering proposal by the Contractor.

The Contractor shall be responsible for maintaining the finished surface of the cold in-place recycled material in a smooth, compacted condition free of ruts, distortion, potholes, loose aggregate, and to the grade and cross-section tolerances previously stated, until the first bituminous course required by the Contract is completed. All loose aggregate that develops on the surface of the recycled pavement shall be removed by power brooming. A rotary power broom capable of cleaning the road surface and removing loose particles shall be provided within 24 hours notice, if directed by the Engineer.

The Contractor shall repair any of the previously mentioned deficiencies to the completed cold in-place recycled bituminous mixture to the satisfaction of the Engineer. Said repair(s) shall be made at no additional cost to the Department. Failure to perform corrections shall be considered unacceptable work as per Mn/DOT 1512.

S-1.3 MEASUREMENT

Cold In-place Recycle Bituminous Mixture shall be measured by the Square meter [**Square yard**].

The Bituminous Material for Mixture of the type shown on the Plans or as specified in the Special Provisions will be measured by the Metric ton [**ton**]. Water added to aid mixing is incidental.

Bituminous Material for Fog Seal applied on the road will be measured by volume at 15 degrees Celsius [**60 degrees Fahrenheit**] in Liter [**Gallon**].

S-1.5 PAYMENT

Payment for the accepted quantities of cold in-place recycle bituminous mixture at the Contract bid prices per unit of material shall be compensation in full for all costs of constructing the cold in-place recycled bituminous mixture as specified, including any additives as permitted or required.

The accepted quantity of Cold In-place Recycle Bituminous Mixture will be paid for at the Contract bid price per Square meter [**Square yard**] complete and in place.

The accepted quantity of Bituminous Material for Mixture of the type shown on the Plans will be paid for at the Contract bid price per Metric ton [**ton**] complete and in place.

The accepted quantity of Bituminous Material for Fog Seal will be paid for at the Contract bid price per liter [**gallon**] complete and in place.

Payment for the cold in-place recycled bituminous mixture will be made on the basis of the following schedule:

Item No.	Item	Unit
2331.604	Cold In-place Recycle Bituminous Mixture.....	Square meter [**Square yard**]
2331.609	Bituminous Material for Mixture	Metric ton [**Ton**]
2355.502	Bituminous Material for Fog Seal	Liter [**Gallon**]

S-1.5 APPENDIX 1

Mix Design Procedures for CIR (Cold In-place Recycling) Material

Sampling and Processing: Obtain cores from the areas to be recycled. If cores show significant differences in various areas, such as different type or thickness of layers between cores, then separate mix designs shall be performed for each of these pavement segments. It is recommended to take, at a minimum, one core for each lane mile and where visual differences in the pavement are noticed. Cores shall be cut in the laboratory to the depth specified for the CIR Project. Cores shall be crushed in the laboratory. Perform a mix design using the medium gradation and a minimum of one of the fine or coarse gradations using the following recycled asphalt pavement millings criteria.

	Fine	**Medium**	**Coarse**
31.5 millimeter [**1.25 inch**]	100	100	100
25.0 millimeter [**1.0 inch**]	100	100	85-100
19.0 millimeter [**3/4 inch**]	95-100	85-96	75-92
4.75 millimeter [**No. 4**]	55-75	40-55	30-45
600 μm [**No. 30**]	15-35	4-14	1-7
75 μm [**No. 200**]	1-7	0.6-3	0.1-3

The mix design shall be performed on these crushed millings. Gradation of the millings after crushing shall be determined by ASTM C117 and C136 (dried at no greater than 40 degrees Celsius [**104 degrees Fahrenheit**]).

Samples shall be prepared with a sample splitter. An alternative method is to dry, screen and recombine millings in the laboratory to target gradation. Suggested screens are 12.5 millimeter [**1/2 inch**], 9.5 millimeter [**3/8 inch**], 4.75 millimeter [**No. 4**], 2.36 millimeter [**No. 8**], 600 μm [**No. 30**], and pan. Scalp oversize with a 25.0 millimeter [**1 inch**] screen when using 100 millimeter [**3.94 inch**] diameter compaction molds.

Mixing: Specimen size: the amount that will produce a 61.0 millimeter to 66.0 millimeter [**2.4 to 2.6 inch**] tall specimen; use ASTM D2041 to determine the size for Rice specific gravity.

Number of specimens: Four (4) per emulsion content for a total of six (6) for long-term stability and six (6) for moisture testing for three (3) emulsion contents. Two (2) specimens are required for Rice specific gravity; test at the highest emulsion content in the design and back calculate for the lower emulsion contents.

Recommended emulsion contents: 1.5 percent, 2.0 percent, 2.5 percent, 3.0 percent, 3.5 percent and 4.0 percent. Choose three (3) emulsion contents that bracket the estimated recommended emulsion content.

Add moisture that is expected to be added at the milling head, typically 1.5 to 2.5 percent.

If any additives are in the mixture, introduce the additives in a similar manner that they will be added during field production.

Mixing of test specimens shall be performed with a mechanical bucket mixer. Mix the CIR RAP millings thoroughly with water first, then mix with emulsion. Mixing shall occur at ambient temperature. One specimen shall be mixed at a time. Mixing time with emulsion should not exceed 60 seconds.

Compaction: Specimens shall be compacted immediately after mixing. Place paper disks on the top and bottom of the specimen before compaction.

Specimens shall be compacted with a Superpave gyratory compactor (SGC) in a 100-millimeter mold at 1.25° angle, 600-kPa ram pressure, and 30 gyrations. The mold shall not be heated.

Curing after compaction: Extrude specimens from molds immediately after compaction. Carefully remove paper disks.

Place specimens in 60 degrees Celsius [**140 degrees Fahrenheit**] forced draft oven with ventilation on sides and top. Place each specimen in a small container to account for material loss from the specimens.

Specimens for Rice specific gravity should be dried to constant weight (less than 0.05 percent weight loss in 2 hours). Care should be taken not to over-dry the specimens.

Cure compacted specimens to constant weight but no more than 48 hours and no less than 16 hours. Constant weight is defined here as 0.05 percent change in weight in 2 hours. After curing, cool specimens at ambient temperature a minimum of 12 hours and a maximum of 24 hours.

Measurements: Determine bulk specific gravity (density) of each compacted (cured and cooled) specimen according to ASTM D2726 or equivalent; however, the mass of the specimen in water (measurement C) can be recorded after one minute submersion.

Determine specimen heights according to ASTM D3549 or equivalent. Alternatively, the height can be obtained from the SGC readout.

Determine Rice (maximum theoretical) specific gravity, ASTM D2041, except as noted in Item 4 of this procedure, and do not break any agglomerates which will not easily reduce with a flexible spatula. It is normally necessary to perform the supplemental dry-back procedure to adjust for uncoated particles.

Determine air voids at each emulsion content.

Determine corrected Marshall stability by ASTM D1559 at 40 degrees Celsius [**104 degrees Fahrenheit**] after 2 hour temperature conditioning in a forced draft oven. This testing shall be performed at the same time that the moisture conditioned specimens are tested.

Moisture Susceptibility: Perform same conditioning and volumetric measurements on moisture-conditioned specimens as on other specimens. Vacuum saturate to 55 to 75 percent, soak in a 25 degrees Celsius [**77 degrees Fahrenheit**] water bath for 23 hours, followed by a one-hour soak at 40 degrees Celsius [**104 degrees Fahrenheit**]. Determine corrected Marshall stability. The average moisture conditioned specimen strength divided by the average dry specimen strength is referred to as retained stability.

Thermal Cracking: see Appendix 2

Raveling: see Appendix 3

Emulsion Content Selection: The properties of the specimens at design emulsion content shall meet the properties in Table 1.

Report: The report shall contain the following minimum information: Gradation of RAP; amount and gradation of virgin aggregate or additional RAP, if any; recommended water content range as a percentage of dry RAP; optimum emulsion content as a percentage of dry RAP and corresponding density, air void level, and absorbed water; Marshall stability and retained stability at recommended moisture and emulsion contents, Raveling percent, and Thermal Cracking initiation temperature. Include the emulsion designation, company name, plant location, and residue content.

S-1.6 APPENDIX 2

Procedures for performing AASHTO TP9-96 for CIR Design Specimens

NOTE: Procedure for critical cold temperature selection

Specification temperature shall be chosen using FHWA LTPPBind software (Version 2.1) using the weather station closest to the Project. The required temperature for the specification is the coldest temperature at the top of the CIR layer in the pavement structure. Use 98 percent reliability.

Perform the indirect tensile testing (IDT) according to AASHTO TP9-96 with the following exceptions:

1. Specimens using the medium gradation shall be 150 millimeter [**6 inches**] in diameter and at least 115 millimeter [**4.5 inches**] in height and compacted to air voids +/- 1 percent of design air voids at the design emulsion content. A trial specimen is suggested for this. Test specimens shall be cured at 60ºC [**140 degrees Fahrenheit**] no less than 48 hours and no more than 72 hours. Check specimen mass every two hours after 48-hour cure to check with compliance of no more than 0.05 percent change in mass in two hours. After curing, two specimens shall be cut from each compacted specimen to 50 millimeter [**2 inches**] in height. Perform bulk specific gravity after cutting.

2. Instead of three specimens, two specimens are the minimum required at each of three temperatures.

3. Select two temperatures at 10ºC [**50 degrees Fahrenheit**] intervals that bracket the required specification. For example, if the required specification temperature is –25 degrees Celsius [**-13 degrees Fahrenheit**], then select testing temperatures of –20 degrees Celsius [**-4 degrees Fahrenheit**] and –30 degrees Celsius [**-22 degrees Fahrenheit**]. A temperature of –10 degrees Celsius [**14 degrees Fahrenheit**] or –40 degrees Celsius [**-40 degrees Fahrenheit**] should then be selected to complete the third required temperature.

4. The tensile strength test shall be carried out on each specimen directly after the tensile creep test at the same temperature as the creep test.

5. The environmental chamber must be capable of temperatures down to -40 degrees Celsius [**-40 degrees Fahrenheit**].

6. The critical cracking temperature is defined as the intersection of the calculated pavement thermal stress curve (derived from the creep data) and the tensile strength line (the line connecting the results of the average tensile strength at the two temperatures).

S-1.7 APPENDIX 3

Procedures for Performing the Raveling Test on Recycled Asphalt Specimens

The apparatus used for the raveling test is a modified A-120 Hobart mixer and abrasion head (including hose) used in the Wet Track Abrasion of Slurry Surfaces Test (ISSA TB-100). The rotation speed for the raveling test is not modified from ISSA TB-100. The ring weight is removed from the abrasion head for the raveling test below. The weight of the abrasion head and hose in contact with the specimen should be 600 +/- 15g [**21.2 +/- 0.5 ounces**]. The prepared sample must be able to be secured under the abrasion head, and centered for accurate result, allowing for free movement vertically of the abrasion head. The device used for securing and centering the sample must allow a minimum of 10 millimeter [**0.4 inch**] of the sample to be available for abrasion. The Hobart mixer will need to be modified to allow the sample to fit properly for abrasion. The

modification may be accomplished by adjusting the abrasion head height, or the height of the secured sample. A Raveling Test Adapter can be purchased through Precision Machine and Welding, Salina, KS, (785) 823-8760. Please reference the Hobart Model number A-120 when ordering. The C-100 and N-50 Models are not acceptable for this test procedure due to differences in size and speed of rotation.

1. Split out two recycled asphalt samples from the medium gradation, or field sample, to a quantity of 2700 grams [**6 pounds**] in mass [**weight**]. The 2700 grams [**6 pounds**] is an approximate weight to give 70 +/- 5 millimeter [**2.8 +/- 0.2 inches**] of height after compaction.

2. The recycled asphalt sample should be placed in a container of adequate size for mixing.

3. Field or design moisture contents should be added to each of the recycled asphalt samples and mixed for 60 seconds.

4. The design emulsion content shall be added to each of the recycled asphalt samples and mixed for 60 seconds.

5. The samples shall be placed immediately into a 150-millimeter [**6 inch**] gyratory compaction mold and compacted to 20 gyrations. If the sample height is not 70 +/- 5 millimeter [**2.8 +/- 0.2 inches**], the recycled asphalt weight should be adjusted.

6. After compaction, the samples shall be removed from the compaction mold and placed on a flat pan to cure at ambient lab temperature (18-24 degrees Celsius [**65-75 degrees Fahrenheit**]) for 4 hours +/- 5 minutes.

7. The specimens shall be weighed after the curing, just prior to testing.

8. The specimens shall be placed on the raveling test apparatus. Care should be taken that the specimen is centered and well supported. The area of the hose in contact with the specimen should not have been previously used. It is allowable to rotate the hose to an unworn section for testing. The abrasion head (with hose) shall be free to move vertically downward a minimum of 5 millimeter [**0.2 inches**] if abrasion allows.

9. The samples shall be abraded for 15 minutes and immediately weighed.

10. The percent Raveling loss shall be determined as follows: ((Wt. Prior to test – Wt. After abrasion)/Wt. Prior to test) * 100.

11. The average of the two specimens shall be reported as the percent Raveling loss. There should not be a difference of 0.5 percent Raveling Loss between the two test specimens for proper precision. A difference of >0.5 percent will require the test to be repeated. If both of the samples have a Raveling Loss of >10 percent the numbers shall be averaged and the precision rule will be waived.

Note: If field mix samples are taken, Steps 2, 3, and 4 shall be omitted.

S-1.8 For questions about the CIR process contact Jerry Geib at (651) 779-5937.

MN/DOT SPECIFICATION (2331):

S-1 (2331) BITUMINOUS PAVEMENT RECLAMATION
SP2000-117

This work shall consist of inplace pulverizing and mixing of the existing bituminous pavement structure and a predetermined portion of the underlying aggregate base materials, where these materials exist, to the depths shown on the Plans to produce a homogenous dense graded aggregate base.

This work will include spreading, shaping, compacting and maintaining the blended base course material to the proper grade, line and cross-sections as shown on the Plans and as provided herein, unless otherwise directed by the Engineer.

S-1.1 MATERIALS

The pulverized material shall meet the following gradation:

Sieve Size	Percent Passing (by weight)
40 mm [**1.5 inch**]	100%
25 mm [**1.0 inch**]	90-100%
9.5 mm [**3/8 inch**]	50-90%
75µm [**No. 200**]*	10% max.

* (The 75µm [**No. 200**] sieve requirement will be applied when there is no aggregate base immediately beneath the bituminous pavement.)

If it is necessary to add aggregate base material in order to meet the established gradeline and cross-section, the aggregate material shall consist of either 100 percent salvage bituminous material (which meets the above gradation requirements and is approved by the Engineer) or Mn/DOT 3138 Aggregate Base, Class 5.

S-1.2 CONSTRUCTION REQUIREMENTS

A EQUIPMENT REQUIREMENTS

A1 Reclaiming Machine

The road reclaimer shall be a self-propelled machine capable of effectively pulverizing the inplace bituminous pavement structure and blending a portion of the underlying aggregate base material to the depths shown on the Plans. The machine shall have either an upward or downward rotational cutting head and controls to maintain a constant cutting depth so as to produce a uniformly blended aggregate mixture. The machine shall be approved by the Engineer prior to the start of the pulverizing operation.

A2 Rollers

The following requirements shall apply:

A2.(a) Pneumatic-Tired Roller

Pneumatic-tired roller shall be self-propelled, mass [**weight**] a minimum 22.7 metric ton [**25 tons**], and have 620 kPa [**90 psi**] tire pressure. The tire arrangement shall be such that compaction will be obtained over the full width of the roller with each pass.

A2.(b) Pads Foot Vibratory Roller

The pad foot roller shall weigh at least 11300 kg [**25,000 pounds**].

A2.(c) Steel-Wheeled Rollers

The steel-wheeled rollers shall meet the requirements of Mn/DOT 2123.3J.

A2(d) Vibratory Rollers

The vibratory rollers will be allowed for use on a performance basis in accordance with Mn/DOT 1805.

(B) PULVERIZING OPERATION

Prior to the start of pulverization, all sod and/or topsoil that is adjacent to the existing surface (mainline or shoulder) that is to be reclaimed shall be bladed off and removed, as directed by the Engineer, so that it does not become incorporated into and contaminate the final product.

Any existing bituminous and/or aggregate base materials in the shoulder section may be bladed onto the mainline pavement prior to pulverization when approved by the Engineer. These materials shall be uniformly spread across the pavement surface. In narrow pavement situations, the remaining shoulder may be trenched for increasing the pavement width and placement of the pulverized blended mixture as shown in the typical cross sections.

The existing pavement and base material (mainline and shoulder material as specified) shall be pulverized and blended to the width and depth shown on the Plans in one or more passes so that the entire mass of material is uniformly blended/mixed. The blended material shall meet the previously specified gradation requirements, based on the results of gradation tests runs on aggregate samples obtained after mixing and prior to compaction.

The Contractor shall not pulverize any more pavement than that which can be spread, shaped and compacted by the end of the workday.

The Contractor shall take care to avoid disturbing or damaging any existing drainage or utility structures on the Project. Any damage resulting from the Contractor's operation shall be repaired by the Contractor at no expense to the Department.

(**C**) GRADING AND SPREADING

The reclaimed material shall be spread and compacted to the grade, width and slope shown on the Plans and typical cross-sections or as directed by the Engineer.

In the event that additional aggregate material is required to attain the Plan grade and/or cross-section, the materials used shall meet the previously stated requirements and may be added, either:

(a) on the surface of the undisturbed road prior to reclaiming, or

(b) after the roadway has been reclaimed; with this option, the add material shall be blended with an additional pass(es) of the reclaiming machine so as to obtain a reasonably uniform mixture.

If the bitumen content of the reclaimed mixture exceeds three percent (3%) by weight (mass), then any additional aggregate base lift(s)/course(s) placed above the reclaimed mixture shall be incorporated into the reclaimed mixture so that it is uniformly blended through the entire lift of reclaim mixture.

(D) COMPACTION

Compaction of each layer of the reclaimed mixture shall be by the Quality Compaction Method (Mn/DOT 2211.3C2).

Water shall be added prior to and during compaction as required.

A minimum 22.7 metric ton [**25 ton**] pneumatic-tired roller with 620 kPa [**90 psi**] tire pressure or 11,300 kg [**25,000 pound**] pads foot vibratory roller shall be used for the initial rolling and a vibratory or static smooth steel-wheeled roller for intermediate and/or finished rolling.

The maximum reclaimed layer thickness for compaction shall be 150 millimeters [**6 inches**]. If the layer thickness is greater than 150 millimeters [**6 inches**], the portion of the reclaimed material in excess of 150 millimeters [**6 inches**] shall be bladed to one side of the roadway and the remaining inplace material shall be compacted. The material, which was bladed to the side, shall be spread back and compacted before the end of the working day.

Each 150-millimeter [**6 inch**] layer of reclaimed material shall be of uniform thickness and compacted until there is no evidence of further consolidation.

(E) SURFACE REQUIREMENTS

Upon completion of the final shaping and compaction, the finished surface of reclaimed aggregate base course shall be smooth and not vary more than 15 millimeter [**0.05 feet**] from the elevation prescribed for that point as determined from the grade staked by the engineers and the typical sections shown in the Plans. If any area(s) is found to lack the required smoothness and/or out of tolerance, such areas(s) shall be reshaped and recompacted until the required smoothness and tolerance is obtained.

When fine grading operations are required on the finished base prior to constructing the pavement thereon, the surface elevation tolerance shall be met at the time of the completion of the fine grading operation. Any excess materials deposited on the shoulders as a result of those operations that is contaminated to the extent that it does not meet the specification requirements for use as aggregate shouldering shall be removed and disposed off the Right of Way in accordance with Mn/DOT 2104.3C3, when directed by the Engineer.

The Contractor shall be responsible for maintaining the finished surface of the aggregate base course in a smooth, compacted condition, free of ruts and distortions, and to the grade and cross-section tolerances previously stated until the first bituminous course required by Contract is placed thereon. The application of water may be required to maintain the compacted surface. The necessary maintenance shall be performed at no additional cost to the Department.

In the event that a weak area(s)/soft spot(s) is encountered during the reclamation process, this area(s) shall be corrected at the direction of the Engineer. Measurement and payment for the correction(s) will be in accordance with Mn/DOT 2105.

S-1.3 METHOD OF MEASUREMENT

Bituminous Pavement Reclamation will be measured by the square meter [**square yard**] of the completed length and width for each depth shown on the Plans.

When additional aggregate material is required, it will be measured by volume in cubic meters [**cubic yards**], loose measure or by mass [**weight**] in metric tons [**tons**] in accordance with Mn/DOT 1901. No deduction will be made for the mass or volume of water.

S-1.4 BASIS OF PAYMENT

Payment for Bituminous Pavement Reclamation at the Contract bid price will be compensation in full for all labor, equipment, and material costs required to construct the aggregate base course as specified including the costs of trenching, scarifying, pulverizing, grading, shaping, rolling and compacting of existing bituminous pavement and aggregate base course. Also included in the Bituminous Pavement Reclamation payment item is the cost associated with movement of the pulverized blended material to accomplish the maximum compaction layer thickness.

Additional aggregate will be paid for separately under Pay Items 2211.501 (Aggregate Base Class 5) or 2211.502 (Aggregate Base (LV) Class 5). If not included in the Contract as a pay item, it will be paid for as extra work.

Excess pulverized material from other locations on the Project may be utilized to attain the Plan grade or cross-section as directed by the Engineer. Where the excess pulverized material is nearby and it is not necessary to load and haul the material with trucks, the cost incurred in transporting such material will not be paid for separately, but will be included in the pay item for Bituminous Pavement Reclamation. Where the excess pulverized material is at a location requiring the material to be loaded into trucks and transported to some other location on the Project, as directed by the Engineer, the cost of loading, hauling, unloading, spreading and compacting the material will be paid for in cubic meters [**cubic yards**], loose measure, at point of delivery. The work will be paid for under Item 2331.607 (Haul Bituminous Pavement Reclamation). If this work is not included in the Contract as a pay item, it will be paid as extra work.

No direct compensation will be made for water used in conjunction with the operations associated with pulverizing, blending, placing, shaping and compacting the reclaimed material or for water used in maintaining the finished surface.

ITEM NO.	**ITEM**	**UNIT**
2331.604	Bituminous Pavement Reclamation	square meter [**square yard**]
2331.607	Haul Bituminous Pavement Reclamation	cubic meter [**cubic yard**]

MN/DOT SPECIFICATION (3138):

(3138) AGGREGATE FOR SURFACE AND BASE COURSES

3138.1 SCOPE

This Specification covers the quality of aggregates used in construction of aggregate surfaced roads, shoulders and dense graded base courses.

3138.2 REQUIREMENTS

A. Aggregate Composition

The source of supply and quality of the material is subject to approval by the Engineer in accordance with 1601.

A1. Virgin Aggregate Composition

Classes 1, 2, 3, 4, 5 and 6 shall meet the following requirements:

All aggregate sources (pits and quarries) from which surface and/or base course aggregates are produced shall be stripped to uncover suitable materials for use. In quarries, all weathered rock will be removed prior to production of the face.

The mixture shall consist of 100 percent virgin aggregates (unless noted otherwise), and shall consist of sound durable particles or fragments of gravel and sand, crushed quarry or mine rock, crushed gravel or stone or any combination thereof; except that, Class 2 aggregates shall consist of 100 percent crushed quarry or mine rock.

The Engineer may allow aggregates containing a limited quantity of binder soil; however, the aggregates shall not contain sod, roots, plants, other organic All materials shall be free from lumps or balls of clay.

A2. Salvaged/Recycled Aggregate Mixtures

Class 7

Salvaged/recycled aggregate materials may be used or blended with a combination of virgin and salvaged/recycled aggregates or 100 percent salvaged/recycled aggregate materials as permitted in accordance with the following requirements. These composite mixtures/ blends shall be designated as Class 7.

The composite mixture/blend shall meet the following requirements:

(a) A salvage/recycled mixture shall have a minimum of 10 percent by mass (weight) salvage/recycle aggregate material incorporated into the mixture to be considered a salvage/recycled mixture.

(b) Virgin aggregates that are incorporated into the mixture shall meet the requirements in Sections 3138.2A1, 3138.2D, and 3138.2E.

(c) The salvaged/recycled aggregate portion of the mixture shall consist of sound durable particles produced by crushing, screening and grading to the required sizes from materials which were salvaged from the following sources: Portland cement concrete pavement removal and/or other concrete structural elements, bituminous pavement removal, aggregate bases underlying bituminous and concrete pavements. Incorporation of recycled glass into the aggregate mixture during production will be permitted. The composite mixture may be produced from any combination of these salvaged/recycled aggregate materials (including glass), unless otherwise specifically modified or prohibited in the plans and/or special provisions.

(d) The Engineer may allow aggregate containing a limited quantity of binder soil. However, the composite aggregate mixture/blend shall not contain sod, roots, plants, building rubble, building brick, wood, plaster, reinforcing steel or other similar objectionable or deleterious materials and shall be free of lumps or balls of clay.

(e) The requirements of 3138 A2(a), Salvaged Bituminous Aggregate Mixtures; 3138 A2(b), Salvaged Crushed Concrete Aggregate; and 3138 A2(c), Reclaimed Glass.

(f) Blending of the various types of aggregates (virgin and recycle/salvage aggregates), shall be done during production. The final product shall consist of a uniform blend of all the composite materials.

Class 7 may be substituted for Classes 1, 3, 4, 5 and 6 unless otherwise specifically modified or prohibited in the plans and/or Special Provisions.

A2(a). Salvaged Bituminous Aggregate Mixtures

Salvaged bituminous aggregate mixtures may be used in accordance with the following applications and requirements:

(a) Aggregate base course.

Salvaged bituminous mixture may be used either alone or in combination with other aggregate materials (virgin and/or salvaged/recycled) in the production of the base course mixture. However, the bitumen content of the composite mixture shall not exceed three percent by mass (by weight).

(b) Surfacing aggregate (travel lanes and/or shoulders).

Up to 100 percent salvaged bituminous mixture may be used. (No limit on bitumen content)

A2(b). Salvaged Crushed Concrete Aggregate

Crushed concrete aggregate may be used singularly or blended with virgin and/or other permitted salvaged/recycled aggregate materials in accordance with the following applications and requirements:

(1) Aggregate base course applications.

(a) Where drainage layers and/or perforated drainage pipes are not installed or will not be installed:

i. Crushed concrete may be used in the production of aggregate base course mixtures provided that the final product meets all other requirements of this specification.

(b) Where drainage layers and/or perforated drainage pipes are installed or will be installed.

i. Crushed concrete, blended with other permitted aggregates (virgin and/or recycled), may be used on any type of subgrade soil provided that at least 95 percent of the crushed concrete aggregate particles are retained on the 4.75 mm (#4) sieve.

ii. Crushed concrete aggregates may be used singularly or blended with other permitted aggregate materials when placed over material meeting the requirements of 3149.2B2, Select Granular, provided that the amount crushed concrete aggregate does not exceed the equivalent of 75 mm (3 inches) of 100 percent crushed concrete; such as, 150 mm (6 inches) of a 50/50 blend of crushed concrete and permitted aggregate material. If crushed concrete aggregate is used (singularly or blended) for the base course and for stabilizing the subgrade at the same location, the total equivalent application rate shall not exceed a 75 mm (3 inch) thickness (approximately 160 kg per square meter (300 pounds per square yard) of surface area)).

iii. Crushed concrete may be used up to 100 percent in construction of the filter/separation layer under a permeable aggregate base drainage layer (i.e. OGAB, PASB, PCSB) in accordance with the applicable drainage specifications.

(2) Other Applications.

With and without drainage layer and/or perforated pipe installation, crushed concrete may be used for:

i. Surfacing and base course(s) in the shoulder area.

ii. Surfacing aggregate-surfaced roads (including shoulders).

A2(c) Reclaimed Glass

Unless otherwise specifically modified or prohibited in the Plans and/or Special Provisions, up to 10 percent by mass (weight) reclaimed glass may be mixed/blended with virgin and/or salvaged/recycled aggregate materials during the crushing operation in the production of the aggregate base course mixture in accordance with the following:

1. Sources

Reclaimed glass shall consist of eligible secondary glass available from any source willing and able to certify their supply sources and composition of glass as required in paragraph 7, below.

2. Composition

Reclaimed glass shall consist only of the following eligible types of glass products: a. container glass used for consumer food and beverages; b. beverage drinking glasses; c. plain ceramic or china dinnerware; d. building window glass free of any framing material; and e. other types of glass that can be certified and approved by Mn/DOT's Office of Environmental Services on an individual source basis.

Reclaimed glass or other salvaged aggregates shall not consist of the following prohibited types of materials: a. any hazardous waste as defined in MPCA Rules 7045; b. hazardous substance in regulated quantities listed in 40 CFR, Table 302.4; c. automobile windshields or other glass from automobiles; d. light bulbs of any type; e. porcelain products; f. laboratory glass; and g. television, computer or other cathode ray monitor tubes.

3. Debris Content

The reclaimed glass shall not contain more than 5 percent debris, by visual inspection. Debris includes any non-glass material such as: paper, foil, plastics, metal, corks, wood debris, food residue, or other deleterious materials. The percentage of debris shall be estimated using the American Geophysical Institute Visual Method. (AGI Data Sheet 15.1 and 15.2 Comparison Chart for Estimating Percent Composition, 1982.)

4. Storage

   Interim storage of reclaimed glass stockpiles shall be on locations with: a. minimum of 1.2 meters (four feet) depth of suitable soils separating groundwater; b. a minimum of 50 meters (150 feet) away from any surface water body; and c. a maximum slope for four percent (4%) if sloped to any surface water body.

5. Ratio of Reclaimed Glass

   Up to ten percent (10%) by mass (weight) reclaimed glass may be mixed virgin and/or other salvaged/recycled aggregate materials during the crushing operation in the production of the aggregate mixture.

6. Applications

   Reclaimed glass blended with other aggregates may be used for aggregate base course mixtures. Reclaimed glass shall not used in aggregate surfacing applications including shoulder surfacing.

7. Certification

   a. The contractor shall provide documentation certifying that the reclaimed glass: (i) is only from sources that have given the contractor the certification required in paragraph b) below, sub-item (ii), is comprised of only eligible types of reclaimed glass; (iii) does not contain any prohibited materials; (iv) meets debris content requirements; (v) meets the blending ratio requirements; and (vi) is or will be stored according to storage requirements described in paragraph 4 above.

   b. Documentation shall include, at a minimum: (i) written certification from sources of reclaimed glass, such as recycling centers, that a good faith effort of public education was used to inform resident and business of the eligible and prohibited types of glass to be included for recycling, (ii) written certification by recycling centers that their independent sources of reclaimed glass, such as private recyclables haulers, have been notified in writing of these composition and public education requirements and have agreed in writing to comply with them; and (iii) description of the reclaimed glass blending methods used to assure required blending ratios.

A3 Limestone and/or Dolostone

The following provisions shall apply in these listed counties:

Anoka – 02	Ramsey - 62
Carver – 10	Scott - 70
Dakota – 19	Washington - 82
Hennepin - 27	

All counties in Mn/DOT's Districts 6

(a) If crushed carbonate (limestone or dolostone) quarry/bedrock is used in total or in part for base applications, unless exempted below, the portion passing the 75 ?m (#200) sieve of the carbonate aggregate insoluble residue shall not exceed 10 percent.

(b) An exemption to this 10 percent insoluble residue Specification will be made for carbonate rock to be used as temporary by-passes and parking lots. Use on other specific non-exempted applications must be approved by the Engineer. For these exempted applications, the portion passing the 75 ?m (# 200) sieve of the carbonate aggregate insoluble residue test shall not exceed 16 percent.

B. GRADATION ..... TABLE 3138-1

In the event that it is necessary to add a portion of the overburden or binder soil from an outside source, the materials shall be introduced into the aggregate producing plant at a uniform rate by a separate conveyor simultaneously with the base aggregate. The binder soils or overburden shall meet 3146.

Class 7 aggregate mixtures shall meet the gradation requirements shown in Table 3138-1; except that, when salvaged/recycled bituminous mixture is incorporated into the production of the aggregate base mixture, up to 5 percent by mass (weight) of the total composite mixture may exceed 25.0 mm, (1 inch) provided that these larger particles are bituminous mixture and not other aggregate types, and are not larger than 37.5 mm (1.5 inch). (All gradations will be run on the composite mixture before extraction of the bituminous material.)

If reclaimed glass is incorporated into the aggregate base material, the final product shall conform to the requirements of Class 7.

In the production of Class 7 aggregate materials, the different aggregate types shall be blended at uniform proportions/rates.

At the time of testing Class 7 ( ) shall be further identified as to the type of recycle/salvage aggregate materials that are incorporated into the final product by the following designations:

B - Bituminous Mixture ..... 7(B)
C – Concrete..... 7(C)
BC - Bituminous and Concrete ..... 7(BC)
G – Glass ..... 7(G)
BG ..... 7(BG)
CG ..... 7(CG)
BCG..... 7(BCG)
M - Misc. - must be specified in Special Provisions

C CRUSHING

Crushing will be required for Class 5 and 6 aggregates. For these classes of aggregate, crushing will be required of all stones larger than the maximum size permitted by the gradation requirements and that will pass a grizzly or bar grate having parallel bars spaced 200 mm (8 inch) apart. However, the Engineer may allow rejection of oversize material when excessive crushing results in an unsatisfactory gradation.

Class 6 aggregates shall contain at least 15 percent crushed material. Class 5 aggregates shall contain at least ten percent crushed material. The percentage of crushing shall be determined by the procedures described in the Grading and Base Manual. A tolerance of 2 percent will be allowed on each individual test, but the average of all material tested for the project shall meet the specification requirements. It may be necessary to add stones or crushed rock from another source to meet the crushing requirements.

D LOS ANGELES RATTLER LOSS

The Los Angeles Rattler Loss requirements shall apply only to the crushed quarry or mine rock portion of the aggregate.

CLASS OF AGGREGATES	LOS ANGELES RATTLER LOSS
1, 2, 3, 4, 5, 7	40% maximum
6	35% maximum

The LAR maximum loss shown for Class 7 shall be determined on the virgin aggregate portion of the mixture prior to the incorporation of the salvage/recycle materials into the final composite mixture.

E SHALE

Class 3, 4 and 5 aggregate shall contain not more than 10 percent shale in the total sample; except that, when the part passing a 75-?m (# 200) sieve exceeds 7 percent, the percentage of shale in the total sample shall not exceed 7 percent.

Class 6 aggregate shall contain not more than 7 percent shale in the total sample.

The virgin aggregate portion of the Class 7 mixture shall not contain more shale than allowed for the Class of aggregate that the substitution is being made. Testing for compliance shall be performed prior to the incorporation of the salvage/recycled materials into the final composite mixture.

3138.3 SAMPLING AND TESTING

Samples for testing to determine compliance with the aggregate gradation specifications for base and shoulder surfacing will be obtained from the roadway at a time when the material is ready for compaction. The samples may be obtained from the windrow or after blending and spreading of the material on the roadway. However, Classes 1, 2 and 7 shoulder surfacing aggregates may be sampled from a stockpile, tested, and accepted before roadway placement, provided that:

(a) No more than 25 percent of the stockpile samples fail to meet gradation requirements.

(b) The average of all stockpile tests meet requirements.

(c) The contractor mixes the material during placement to the satisfaction of the Engineer.

The stockpile shall be sampled at the rate of one field gradation test per 1000 metric tons (ton) of aggregate used on the project.

If additives such as calcium chloride or bituminous material are incorporated in a central mixing plant, the aggregate will be sampled before such materials are added.

A Sampling, Sieve Analysis, Shale, and Crushing Test ..... Mn/DOT Grading and Base Manual

B Los Angeles Rattler Loss .....AASHTO T 96

C Sampling and Shale Tests ..... Mn/DOT Laboratory Manual

D Bitumen Content: ..... Mn/DOT Laboratory Manual

a) By Extraction .....Methods 1851 or 1852, or
b) Incineration Oven..... Methods 1853

E Insoluble Residue..... Mn/DOT Laboratory Manual ..... Method 1221

F Reclaimed Glass.....American Geophysical Institute

Visual Method (AGI Data sheet 15.1 and 15.2, Comparison chart for Estimating Percent Composition 1982)

TABLE 3138-1

BASE AND SURFACING AGGREGATE

Total Percent Passing Sieve Size	**Class 1**	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6**	**Class 7 (a) (b) (c)**
75mm (3 inches)	---	---	---	---	---	---	---
50mm (2 inches)	---	---	100	100	---	---	---
37.5 mm (1 inch)	---	---	---	---	---	---	---
25.0 mm (1 inch)	---	---	---	---	100	100	---
19.0 mm (3/4 inch)	100	100	---	---	90-100	90-100	---
9.5mm (3/8 inch)	65-95	65-90	---	---	50-90	50-85	---
4.75 mm (No. 4)	40-85	35-70	35-100	35-100	(A) 35-80 (B) 35-70	35-70	---
2.00 mm (No. 10)	25-70	25-45	20-100	20-100	(A) 20-65 (B) 20-55	20-55	---
425 ?m (No. 40)	10-45	12-30	5-50	5-35	10-35	10-30	---
75 ?m (No. 200)	8-15	5-13	5-10	4-10	3-10	(A) 3-7 (B) 3-8	---

NOTES:

(A) Applies when the aggregate contains 60 percent or less of crushed quarry rock.

(B) Applies when the aggregate contains more than 60 percent crushed quarry rock.

(a) Refer to Section 3138.2B

(b) Class 7 shall meet the gradation requirements for Class 5 when it is being substituted for Classes 1,3,4 and 5.

(c) Class 7 shall meet the gradation requirements for Class 6 when it is being substituted for Class 6.

APPENDIX B

SURVEY OF MINNESOTA EXPERIENCE

Survey Overview

During the summer of 2001, an e-mail survey was conducted of Minnesota cities and counties. This survey was conducted to obtain a perspective of local government's use of Recycled Asphalt Pavement (RAP). Specifically, the survey inquired into the types of recycling being performed, the amount of recycling (years and miles), reasons agencies are not using RAP techniques and an inquiry as to what specific RAP information they would like to know more about.

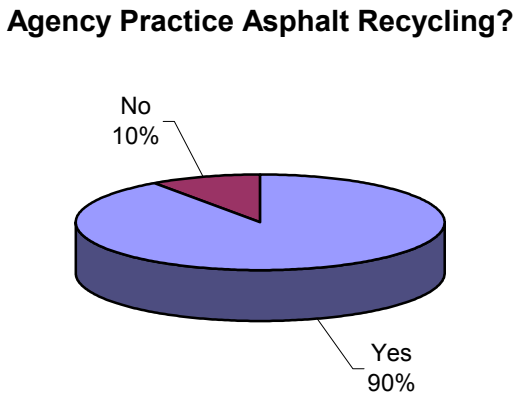
Afterwards, a follow-up survey was mailed to respondents to gain more specific information about their RAP practices. Detailed questions regarding the amount of recycling, the methods being performed and recycling cost information were obtained. A summary of the initial and follow-up surveys can be found on the following pages.

Local Road Research Board
Recycled Asphalt Pavement (RAP)
Survey Summary

A survey was conducted amongst city and county engineers to gather information on the number and percentage of municipalities that practice asphalt recycling and the methods that are most commonly used. The survey was distributed via email in June 2001; 83 surveys were returned.

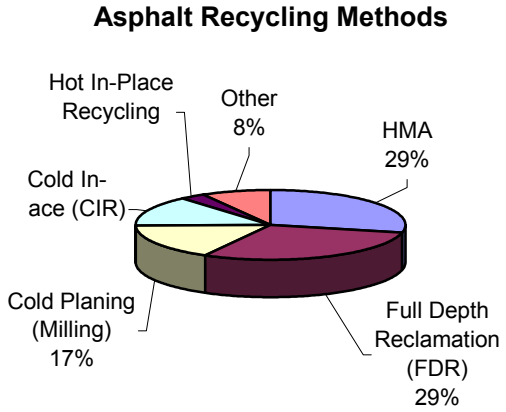
1. Is asphalt recycling currently being practiced by your agency?

Yes	75
No	8
TOTAL	83



2. If yes, what methods of recycling do you use?

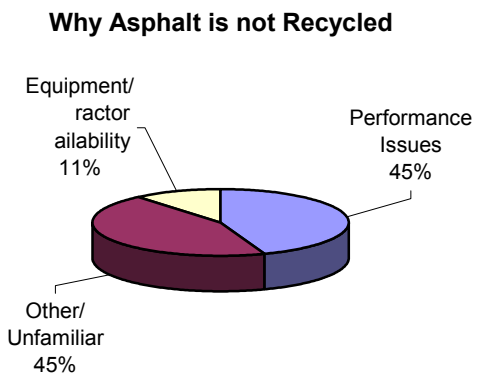
Cold In-Place	23
Hot In-Place Recycling [1]	0
Full Depth Reclamation	49
Cold Planing	28
HMA	48
Other	14
TOTAL	162



[1] Hot in Place Recycling has not been used in Minnesota because of availability of equipment/contractor

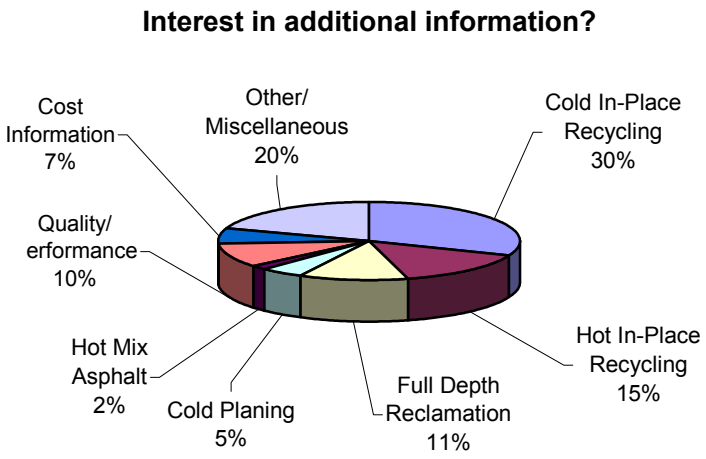
3. If no, why not?

Economics	0
Performance Issues	4
Equipment/contractor availability	1
Other	4
TOTAL	9



4. What information of recycling would you like to know more about?

Cold In-Place Recycling	19
Hot In-Place Recycling	9
Full Depth Reclamation	7
Cold Planing	3
Hot Mix Asphalt	1
Quality/Performance	6
Cost Information	4
Other/Miscellaneous	12



APPENDIX C

COMPILATION OF MINNESOTA EXPERIENCE

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Anoka County	Brown County
How much recycling have you done? *Years:*	6 Yrs	2 Yr CIR
Miles:	5 miles	11 miles (2000); 6 miles (2001)
Ttl. Budget/Percent of Const. Program:	$1.8 mil/yr / 15%	
In general, how would your rate your experience?	We found that Cold-in-Place recycling does not work well with high traffic roads, rutting and shoving is significant while emulsion is setting up. We have gone to reclaiming old bituminous, using as Class V base, then overlay with 2 layers of Hot Mix.	Construction has worked well with our medium volume roads. The first project is 2 yrs old and appears to be as expected and appears to reduce the reflective cracking. With CIR, we can improve the slope and rideability over a one lift HMA overlay. On our low-volume roads, we are able to do CIR and a one lift overlay, reducing the stacking elevation and narrowing of shoulders or making the ditch in slope steeper.
Types of recycling used?		CIR: 2000 & 2001. HMA in previous years in the base and level course.
Costs for equipment, labor, materials? Contract or internal work?	$3,000 per mile/foot (width) contract	2000 CIR: $0.48 SY; Mix 2350-$24/ton 2001 CIR: $1.20 to $3 SY; Mix 2350-$24/ton
What project assessment and decision process are you using to determine your method of recycling?	Pavement Management system with pavement rating by Mn/DOT every 2 yrs. If project is not in a 20 yr plan, we reclaim /overlay. If it is in a 20 yr reconstruction plan, overlay only.	Improved rideability and road strength. Length life cycle appears to be reducing reflective cracking.
Are you using a mix design?	2350	Yes, we cut cores and provide inplace typical section details to Koch Products to provide us with a project specific CIR design.
Are you following the Mn/DOT Specifications or using your own?	Mn/DOT	Mn/DOT 2350: MV or LV mix design for the HMA overlays. Mn/DOT Spec for CIR Mixture, Full Recycle Train spec S-2331 (1999)
Type & percentage of oil/emulsion being used?	N/A	**HFMS:** 2P @ 2% emulsion includes 1% water. **CSS-1:** at 2%, emulsion includes 1% water.
What types of project evaluation/ assessment are you using prior to construction?	?	Age and condition of driving surface, Pavement Strength Evaluation and Bituminous Core Sampling.
What quality control/tests are being used during construction?	Gradation; Profilograph; QA/QM	Percent Crushing: 100% passing @ 1.5 inches; 90-100% passing @ 1 inch. Moisture Test: 1.5% or less before placement of HMA overlay. Control Strip for compaction.
Are you monitoring long-term performance? How?	Photos; Pavetech Van	Post-construction Pavement Strength Evaluation: visual Inspection.
Other Comments:		Need more time to determine cost effectiveness of CIR for long-term life cycle.

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Goodhue County	Hubbard County
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	5 Yrs 50 miles	8 Yrs 50 miles 2%
In general, how would your rate your experience?	Good results Stay within recommended maximum allowances	The best process for us has been milling inplace and the use of a like gravel base.
Types of recycling used?	HMA Inplace reclaiming – no add oil	N/A. Cold-in-place Mill and crush
Costs for equipment, labor, materials? Contract or internal work?		$0.60 to $0.90/SY
What project assessment and decision process are you using to determine your method of recycling?	**Economic Analysis:** Fairly limited on virgin aggregates due to limestone quality in area (insoluble residue). Available RAP allows for more paving with available money.	Pavement Assessment.
Are you using a mix design?	**2350:** Mostly low volume type 3 Aggregate. 58-28 Oil	N/A
Are you following the Mn/DOT Specifications or using your own?	Latest version of 2350 each year.	Own. (N/A)
Type & percentage of oil/emulsion being used?	**Type:** 58-28; CRS-2; CSS-1H **Percent:** 2350 Guidelines	N/A.
What types of project evaluation/ assessment are you using prior to construction?	Typically, we build with 4-5' HMA and overlay with 3" @ 12-15 yrs.	Pavement thickness, material type, subgrade strength.
What quality control/tests are being used during construction?	All quality control and contractor testing is provided for under 2350.	N/A. Mainly crushing requirements.
Are you monitoring long-term performance? How?	Visual evaluation.	No.
Other Comments:	Very satisfied with HMA recycling. Qualities and tests usually equal or exceed virgin material. Consistency sometimes a problem if alternate recycle piles are incorporated.	

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Lac Qui Parle County	McLeod County
How much recycling have you done? *Years:*	4-5 Yrs	10 Yrs
Miles:		30± miles
Ttl. Budget/Percent of Const. Program:		
experience?		Good; **Pros:** use for salvaged bituminous; **Learned:** Do not use RAP is wear course-too many possible problems for the small amount used.
Types of recycling used?	Grind it and lay back down as a 1st lift of the sub base for the next years paving.	HMA: Some crushed and blended to make aggregate shouldering.
Costs for equipment, labor, materials? Contract or internal work?		All contract work: $22/ton
What project assessment and decision process are you using to determine your method of recycling?		We give the salvaged bituminous to the paving contractor and he decides what to use it for or to dispose of it.
Are you using a mix design?	N/A	Yes, 2350.
Are you following the Mn/DOT Specifications or using your own?		Mn/DOT 2350.
Type & percentage of oil/emulsion being used?		
assessment are you using prior to construction?	CIR someday. Capability of the remaining typical. Section to support loaded trucks moving the product	Subgrade strength to determine if the existing pavement can remain inplace or not.
What quality control/tests are being used during construction?		Gradation; stability; compaction.
Are you monitoring long-term performance? How?		

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Murray County	Olmsted County
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	We did a CIR project with overlay in 1992/93. The CE was not there at the time but stated the road has held up nicely.	8 Yrs 111 miles
In general, how would your rate your experience?	So far, so good. We would like to do more CIR or Hot-inplace recycle but need more information. We may contact SRF this winter for a specification.	**Pro:** Elimination of bituminous surface that is cracked and rutted. **Cons:** Need a minimum thickness if inplace bituminous subgrade failures that need to be repaired. Need more contractors to bid the projects.
Types of recycling used?		CIR.
Costs for equipment, labor, materials? Contract or internal work?	Unknown.	
What project assessment and decision process are you using to determine your method of recycling?	It is all new to us.	Depth of inplace bituminous, inplace shoulder width, subgrade structure and condition of inplace bituminous traffic ADT.
Are you using a mix design?	Again, we may need help writing a spec. to follow.	First 6 yrs., we used Mn/DOT design mix. We now use 3% for design and adjust in the field. Avg. is 2.5 – 3%.
Are you following the Mn/DOT Specifications or using your own?		Mn/DOT 2331: Cold Recycle Inplace Bituminous Material.
Type & percentage of oil/emulsion being used?		**Type:** CSS-1 **Percent:** 2.5 - 3%
What types of project evaluation/assessment are you using prior to construction?		Pavement thickness, subgrade, base, width, traffic, roadway condition and cost.
What quality control/tests are being used during construction?		**Gradations**; **Compaction**: rolling pattern, moisture content at 14 & 21 days; **Emulsion** check every 1,000 ft.
Are you monitoring long-term performance? How?		Yes, visual and strength testing.
Other Comments:		

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Pipestone County	Polk County
How much recycling have you done? *Years:* / *Miles:* / *Ttl. Budget/Percent of Const. Program:*	10 Yrs ≈40 miles	6 Yrs 10 mile Bituminous Reclamation $10.6 mil/yr / 49%
In general, how would your rate your experience?	Good.	We like the reclamation process and will keep doing it on roads. We are very interested in CIR.
Types of recycling used?	We crush old pavement and use as an aggregate base.	Hot Mix Asphalt, Bituminous Reclamation.
Costs for equipment, labor, materials? Contract or internal work?	**Crushing & Removing old pavement:** @ $4/CY; **Placing it as Aggregate Base:** @$1.75/ CY	Hot Mix Asphalt: $0.15 SY cheaper than virgin Bituminous Reclamation:$0.80/SY
What project assessment and decision process are you using to determine your method of recycling?	Historical Review.	Whether or not the existing pavement is adequate for an overlay. If not, the bituminous reclamation, the existing roadway will be aggregate base.
Are you using a mix design?	Cl 5M Aggregate Base	Mn/DOT
Are you following the Mn/DOT Specifications or using your own?	N/A	Mn/DOT
Type & percentage of oil/emulsion being used?	N/A	
What types of project evaluation/assessment are you using prior to construction?	N/A	Visual.
What quality control/tests are being used during construction?	Gradation	Gradation
Are you monitoring long-term performance? How?	Yes, visual Inspection.	Yes. Mn/DOT Pavetech Van, Braun Intertec Deflection Testing.
Other Comments:		

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Ramsey County	Renville County
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	**Ramsey County has extensive history and documentation with respect to recycling. See pages C9 to C10 for their comments.**	Allow RAP in HMA
In general, how would your rate your experience?		
		HMA
Costs for equipment, labor, materials? Contract or internal work?		Unknown as we just bed HMA/ton replace and allow the use of RAP if the contractor wants to.
What project assessment and decision process are you using to determine your method of recycling?		
Are you using a mix design?		Yes, Mn/DOT district lab paving recommendation under the 2350 LV spec.
Are you following the Mn/DOT Specifications or using your own?		Mn/DOT Standard 2350 low volume.
Type & percentage of oil/emulsion being used?		**Type:** PG58/28
What types of project evaluation/ assessment are you using prior to construction?		Pavement thickness to measure GE requirements FWD Testing.
What quality control/tests are being used during construction?		Moisture, Marshall's, gradation, rice test core density.
Are you monitoring long-term performance? How?		Just getting started monitoring using a pavement management system.
Other Comments:		

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	St. Louis County	Stearns County
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	8+ Yrs 165 miles	10 Yrs Avg. 40 mi paving w/ RAP on LV3NW Only.
In general, how would your rate your experience?	Our experience level is high. Overall, very good results with our program, strongly supported by the County Board of Commissioners. Able to improve roads to acceptable level of service without the expense of a complete grading project. Reclaimed bituminous strengthens the base and new bituminous driving surface provides additional strength and a smooth driving surface.	If less than 30% RAP is used, we don't notice as much of a problem. We've noticed less reflective cracking since we eliminated RAP in our wear courses and held the RAP to 30% or less in non-wear courses.
Types of recycling used?	Mostly, FDR with our own maintenance forces.	CIR.
Costs for equipment, labor, materials? Contract or internal work?	Equipment: $ 2,850/mi; Labor: $ 340/mi Materials $ 3,300/mi (Gravel); $ 58,000/mi (Bit. Overlay)	
What project assessment and decision process are you using to determine your method of recycling?	Mostly look at pavement condition. Roads are typically low volume (up to 200 ADT) and do not justify the large regrading expense but need more than an overlay. Existing pavement is reclaimed to add strength to road base and new bituminous pavement is placed. In most cases, additional gravel is placed.	2350 Specifications modified to no RAP allowed in wear courses.
Are you using a mix design?	Not for reclamation. For bituminous using Mn/DOT 2350 Specs.	Contractor submits mix design.
Are you following the Mn/DOT Specifications or using your own?	Utilizing our own maintenance forces for reclamation and Mn/DOT 2350 for the bituminous pavement.	2350
Type & percentage of oil/emulsion being used?	None	**Type:** 58-28 For LV3WE/52-34 for LV3NW **Percent:** Contractor determines % oil with mix design.
What types of project evaluation/ assessment are you using prior to construction?	Pavement surface condition, pavement thickness, subgrade type (soil conditions) and strength. ADT.	9 Ton design with bituminous pavement design chart based on N-18; R-Values.
What quality control/tests are being used during construction?	Visual observation of roller and subgrade deflection. Standard Mn/DOT Spec. for the bituminous pavement.	Standard 2350 Testing rates with Mn/DOT performing companion testing.
Are you monitoring long-term performance? How?	Visual	Visual Inspection.
Other Comments:	Changing to contract projects rather than in-house as a result of the need to refocus summer maintenance forces. Will result in higher per mile costs for our program. Also looking at other options of road rehabilitation projects.	

COMPILATION OF MINNESOTA EXPERIENCE - COUNTY

QUESTION	Watonwan County	Yellow Medicine
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	Any bituminous base work over the last 12 years	10 Yrs 60 miles $7 mil/yr / 17%
In general, how would your rate your experience?	Performs well	Using reclaimed bituminous with aggregate base, sometimes leave porosity too high and water soaks in softened subgrade.
Types of recycling used?	HMA – base course only	Mill or reclaim and used as an interim surface.
Costs for equipment, labor, materials? Contract or internal work?	Contract work. Cost for mix with recycle about same as all virgin aggregate.	The cost in included in grading.
What project assessment and decision process are you using to determine your method of recycling?	All base courses can have 50% recycle. All material removed in a project is recycled.	We need temporary surface from year of grading to year of surfacing.
Are you using a mix design?	Mn/DOT mix design.	N/A
Are you following the Mn/DOT Specifications or using your own?	Mn/DOT 2331	N/A
Type & percentage of oil/emulsion being used?	**Type:** PG 52-34; **Percent:** Usually about 4-5% depending on Trial mix.	N/A
What types of project evaluation/ assessment are you using prior to construction?	Overlay of 3" or more. Level course with recycle or new surface of 6" or more. Base courses with recycle.	N/A
What quality control/tests are being used during construction?	Gradation on virgin aggregate in field. Samples taken to Mn/DOT lab for testing.	N/A
Are you monitoring long-term performance? How?	Strength testing, visual Inspection.	Used as a temporary surface, no long-term use.
Other Comments:		

COMPILATION OF MINNESOTA EXPERIENCE - CITY

QUESTION	City of Farmington	City of Fridley
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	We do not use recycled asphalt in the City of Farmington. Our spec calls for *virgin materials only*.	3Yrs 3 miles (1 mile per yr) $500,000±; 5%±
In general, how would your rate your experience?		We use the milling of ex-pavement as a supplement to the proposed CLS aggregate base. **CON:** Reclaiming machine may mix the oil-treated sand base with the millings (becomes to sandy). **PRO:** Save money exporting and importing. * *Handling and stockpiling care is very important.*
Types of recycling used?		
Costs for equipment, labor, materials? Contract or internal work?		Reclaim and Respread (full depth): $3/SY
What project assessment and decision process are you using to determine your method of recycling?		Recycling/reclaiming the existing pavement is standard practice on our yearly street project (recon). Aggregate base is comprised of Class 5 Recycled Crushed concrete supplemented with reclaimed bituminous.
Are you using a mix design?		RAP is not used for HMA. **HMA:** Wear is 41A, 58-28; **Base:** is 31, 58-28.
Are you following the Mn/DOT Specifications or using your own?		Cl 5 Aggregate Specs 2350 Bit.
Type & percentage of oil/emulsion being used?		
assessment are you using prior to construction?		▪ Soil Testing/Exportation with Recommendations ▪ Pavement Rating ▪ Coordination with Utility work: Gas, water, sewer
What quality control/tests are being used during construction?		▪ Gradation ▪ Density ▪ Roll test
Are you monitoring long-term performance? How?		Keep updated street segment history with date constructed, section thickness, maintenance. Also, have a pavement rating system.
Other Comments:		RAP maybe allowed with HMA if the contractor request to use it. Then quality assurance and costs play a significant roll in determining if allowed.

COMPILATION OF MINNESOTA EXPERIENCE - CITY

QUESTION	City of Mankato	City of North Branch
How much recycling have you done? *Years:* / *Miles:* / *Ttl. Budget/Percent of Const. Program:*	20+Yrs 75 +miles	1 Yr 1 mile
experience?	Good. We do not allow RAP in the wear course.	Our experience was good. We used bituminous reclamation to incorporate the existing bituminous into the base.
Types of recycling used?	Bituminous is privately stockpiled and recycled in HMA.	We may have not used recycled material for bituminous base or wear.
Costs for equipment, labor, materials? Contract or internal work?	None. Bid incidental to common excavation in streets.	
What project assessment and decision process are you using to determine your method of recycling?	Contractors remove existing bituminous pavement and stockpile at private HMA plants for use on later projects.	
Are you using a mix design?	2350	
Are you following the Mn/DOT Specifications or using your own?	Mn/DOT 2350	
Type & percentage of oil/emulsion being used?	PG 58-28; varies by each mix design.	
What types of project evaluation/ assessment are you using prior to construction?	Mn/DOT GE Design Index	
What quality control/tests are being used during construction?	Gradation; % Oil; voids	
Are you monitoring long-term performance? How?	Rating via paver program	
Other Comments:		

COMPILATION OF MINNESOTA EXPERIENCE - CITY

QUESTION	City of Winona
How much recycling have you done? *Years:* *Miles:* *Ttl. Budget/Percent of Const. Program:*	
In general, how would your rate your experience?	
Types of recycling used?	HMA.
Costs for equipment, labor, materials? Contract or internal work?	
What project assessment and decision process are you using to determine your method of recycling?	
Are you using a mix design?	Standard Mn/DOT mix design.
Are you following the Mn/DOT Specifications or using your own?	Mn/DOT 2000 Standard
Type & percentage of oil/emulsion being used?	
What types of project evaluation/ assessment are you using prior to construction?	
What quality control/tests are being used during construction?	Standard Mn/DOT testing
Are you monitoring long-term performance? How?	
Other Comments:	All recycling is done with standard Mn/DOT mix and allowed recycled materials added.

LOCAL ROAD RESEARCH BOARD
RECYCLED ASPHALT PAVEMENT (T2)

Questionnaire response from Ramsey County Public Works
Prepared by Daniel Schacht. November 13, 2001.

How much recycling done?

2001 is the 16th year we have done cold inplace (CIR) recycling. Total mileage recycled: 53 miles, all except for one mile was internal work. During that same period, we reconstructed 55 miles of roads. So, CIR has represented about 49 percent of our total program in terms of mileage. The budget is more difficult to estimate. Assuming CIR project cost of $200,000 per mile and reconstruction at $2,000,000 per mile, we have spent $10,600,000 on CIR and $110,000,000 on reconstruction. Percents in terms of costs are then nine percent (9%) for CIR and 91 percent for reconstruction.

How we would rate our experience.

Our experience has been excellent. Biggest pro has been quality of product. We have recycled deteriorated asphalt pavement that also have needed reshaping. That means road sections with too much, not enough, or irregular crowns, and/or with settled utility crossings. On many roads that had gravel shoulders, we have removed the gravel, replaced with it with pulverized bituminous, and paved the shoulder as part of the recycling work.

There have been very few cons. One lesson we learned is that for a single unit recycler, CIR must be done in two passes, initial pulverizing in the first pass and addition of asphalt emulsion in the second. We had tried one project where the pulverizing and addition of emulsion was all done in one pass, but that process was extremely slow and the final product quality was unsatisfactory.

Type of recycling.

We have done CIR, using CSS1H or HFMS-2S emulsions, and one project used fly ash.

Costs for labor, equipment and materials.

The last projects we costed out were two in 1998. The cost sheets are attached (pages C9 to C10). Total projects costs were $10.36 and $12.14 per square yard, but only about 24 percent of that were strictly for CIR (pulverizing, adding emulsion, and regrading and compacting.)

Project assessment and decision process.

We use our pavement management system to identify candidates for recycling. The system identifies pavements for overlaying, replacement of pavement, or reconstruction. CIR is not a separate category in our PMS, but is considered an alternative to any of the three categories. CIR is more likely to be selected if a crown correction is needed.

Mix design.

For the first several years of our work, we used a mix design. First, we worked with the Koch Pavement Solutions using their designs, later we used the Oregon method which established an emulsion addition percentage based on the existing mix gradation and the percent and penetration of the residual asphalt. The last several years, we simply add a standard two percent (2%) of emulsion, and may adjust that slightly up or down based on observation of the material. This has worked well.

Specifications used.

None, since the work is not contracted. Our personnel who do the work use their long experience with the process.

Type and percentage of emulsion used.

Mostly HFMS-2s, although we occasionally use some CSS1H when the other is not available. Two percent (2%) is our standard addition rate.

Quality control tests.

We occasionally do moisture testing or check densities. We do compaction with a vibratory padfoot roller, and the operators roll until the pads "walk out" of the material, which indicates adequate compaction. Measured densities have been consistently around 128 lbs/cubic foot.

Monitoring of long-term performance.

Yes, we do this with our pavement management system. All our pavements are rated every two years. There are 12 different condition indicators that are rated. All the data is on an Excel spreadsheet, so we can easily analyze and graph the data, and compare the CIR road performance with overlay and reconstruction.

Comments.

Performance data has been provided on pages C9 to C10.