IN-DEPTH STUDY OF COLD IN-PLACE RECYCLED PAVEMENT PERFORMANCE

VOLUME II
CONSTRUCTION AND INSPECTION MANUAL

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16. Abstract

This manual presents an overview of important project selection, design, construction, and inspection considerations for cold in-place recycled (CIR) asphalt mixtures. The first section summarizes the historical use of CIR mixtures. The second summarizes the construction process. The third section presents some of the important preconstruction steps (project selection, field sampling, and mix design). The fourth section deals with field quality control of the CIR process. The fifth section deals with overall quality assurance and post-construction evaluation. The final section summarizes the procedures which are critical to a successful CIR process. This manual is based on CIR design and construction as practiced by the Oregon Department of Transportation (ODOT) in 1990 using CMS-2S or HFE-150 as recycling agents and depths of 2 to 4 inches. This manual is not intended for use on projects involving full-depth reclamation. This manual provides the reader with the necessary background to successfully manage and inspect CIR projects as the process is practiced by the Oregon Department of Transportation.

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DISCLAIMER

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GLOSSARY OF TERMS

Cold In-Place Recycling (CIR) -- The process of removing portions of existing asphalt pavement, adding water and emulsified recycling agent, and relaying the mixture. Class I and II refer to recycling only asphalt-bound materials normally to depths of 2 to 4 in. Class III refers to full-depth reclamation (including unbound base material and/or supplemental aggregate).

Milling -- The process of grinding off the top 2 to 4 in. of existing asphalt concrete pavement.

RAP (Recycled Asphalt Pavement) -- The material resulting from the milling of the existing asphalt pavement which when combined with recycling agent and water serves as the "black aggregate" for the recycled mat.

Recycling agent -- The bituminous material (normally an emulsified asphalt) added to the RAP to rejuvenate the existing asphalt or to facilitate placement of the recycled mix.

Recycling Train -- An assemblage of paving equipment with complete capability for cold in-place recycling of asphalt pavements. Included are a mill, screen deck, crusher, belt scale, pugmill and required water and emulsion storage.

Single Unit Train -- A single piece of construction equipment with capabilities for milling, measured addition of emulsion and water, and deposition of material in windrow. No capability for screening or crushing exists.

1.0 INTRODUCTION

1.1 Background

The national trend away from new construction to preservation of the highway system is requiring highway agencies to seek alternative approaches to rehabilitating distressed pavements. One promising and cost effective approach is cold in-place recycling (CIR).

Though cold in-place recycling of asphalt pavements has been used in the United States in some form since the 1920's, several methods have evolved since 1980. During this period, spurred by the development of milling and reclaiming equipment, CIR has evolved into one of the fastest-growing pavement rehabilitation procedures (Figure 1.1).

The term cold recycling is frequently misunderstood because it has been used to describe different processes used with substantially different design concepts and end results. These processes include, for purposes of this report, the following:

1) Class I. This recycling treatment is performed on a uniform pavement designed and built to specifications. It is expected that a rational CIR mix design can be prepared and produced. The treatment could handle low to medium traffic as a wearing course (with seal) and high traffic volumes as a base.

2) Class II. This recycling treatment is performed on a pavement with significant maintenance patches over a uniform pavement or a pavement with minimal design used in the original construction. It is not likely that Class II projects can be used as wearing courses.

3) Class III. This treatment is used on highways where considerable variation in pavement structure exists and additional aggregate or existing base is mixed in to strengthen the pavement structure. Normally the treatment is used as a base. Treatment usually varies from 4 to 12 ft in width and from 4 to 12 in. in depth.

All treatments produce significant cost savings compared with hot recycling or conventional mixes. Additionally, there are savings in energy, a conservation of materials, a reduced impact on the environment, and production rates as high as 6 lane miles per shift. Another significant advantage is the ability to limit the correction to the distressed lane.

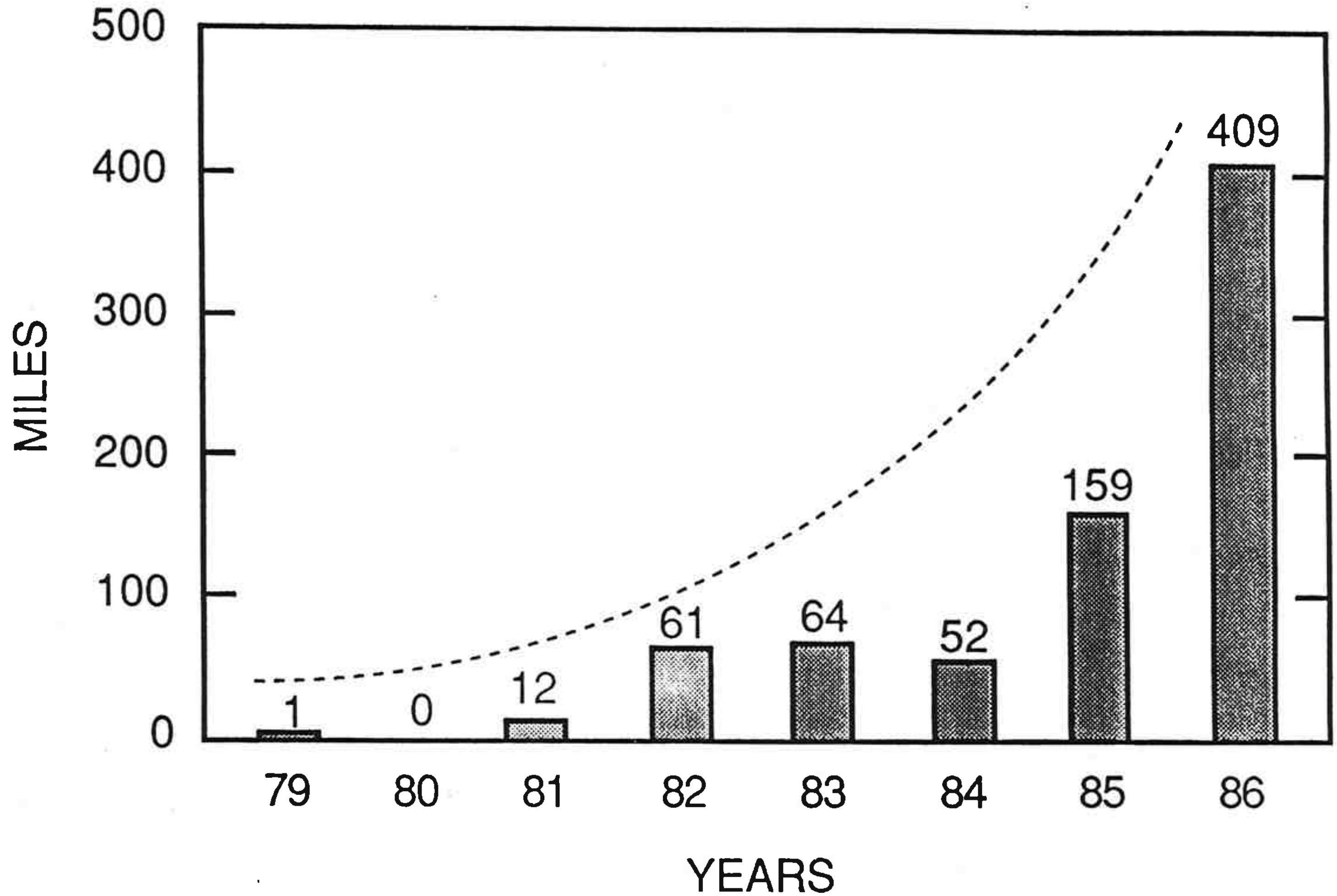


Figure 1.1. Growth in the Use of Cold Recycling (Class I and Class II Using Train on Single Mill Units).

1.2 Objective of Manual

The overall objective of this manual is to provide the user/contractor with a better understanding of the project selection, design, construction, and quality control considerations required to insure a successful cold in-place recycling project. Specifically, the objectives are to provide information on the following:

1) Guidelines for project selection, sampling, and mix design.
2) Information on equipment and procedures and specifications for CIR.
3) Quality Assurance guidelines for the engineer, contractor, and inspector.
4) Guidelines for post construction evaluation.

This manual is based on CIR design and construction as practiced by the Oregon Department of Transportation (ODOT) in 1990 using CMS-2S or HFE-150 as recycling agent and milling to depths of 2 to 4 inches. The 1990 ODOT specification is included in the appendix. This manual is not intended for use on projects involving full-depth reclamation.

2.0 PRECONSTRUCTION STEPS

A majority of the western states involved in cold in-place recycling are using partial depth recycling of the asphalt pavements (Class I or Class II). The reason for this is to avoid contamination with base materials. The recycle depth most commonly used is 2-in. with the exception of New Mexico and FHWA which recycles 2 to 4 in.

States such as California, Oregon, and New Mexico are using recycling on light to heavily traveled roadways. In California and New Mexico, most of the recycling is overlaid with a 0.15 ft minimum of hot mix. Oregon generally chip seals recycled pavements after a one month curing period on low volume roads and overlays with open graded cold or hot mix on medium or high volume roads.

Several types of recycling agents have been employed. For example, California uses almost exclusively emulsified recycling agents (ERA grades) with ERA 25 and ERA 75 being used most frequently. New Mexico uses the high float emulsions and in later projects has gone exclusively to the high float emulsions with polymer, HFE-150S. Nevada currently specifies the RAE (ERA) grades, and is exploring the possibility of using MC's and SC's in non-urban areas. Oregon has generally used CMS-2S and high float emulsions (HFE-150). FHWA has used both CMS-2S and CSS-1, with preference for CMS-2S.

The determination to seal or overlay must be a decision predicated upon the structural design assumptions of the roadway. Minimal surface sealing such as a fog seal would be used on a pavement that is expected to perform satisfactorily for a short time or as part of a stage type reconstruction. The type and amount of traffic to use the recycled surface is also an influencing factor as to the necessity of a seal and the type of seal. Fog seals, chip seals, double chip seals, hot mix overlays, and open graded emulsion mix overlays have been used successfully.

Most agencies now recommended that all cold recycled mixes have a chip seal or better placed upon their surface. The final decision to seal or not should be engineered. If raveling or a dry recycled surface is apparent, this should enter into the decision process.

2.1 CIR Theories

Two theories have been proposed when designing cold recycled asphalt pavement (16). Briefly, the theories are:

1) Treat the millings as a black aggregate with some hardened asphalt coating and design an asphalt content to coat the milled particles. The assumption is that the millings will act as an aggregate.

2) Evaluate the physical and possibly chemical characteristics of the asphalt in the old pavement and add a rejuvenating or softening agent which would restore the asphalt to its original condition. The assumption is that 100% softening occurs and a "new asphalt" is created.

In recent years, California, Oregon, Nevada, and New Mexico have concluded that a combination of the above theories most likely occurs. This, if it could be given a name, is referred to as the "Effective Asphalt Theory" which is shown in Table 2.1.

Based on this theory, a percentage of the old asphalt softens and combines with the added binder to produce an asphalt content in the mixture known as the effective asphalt. The percent of asphalt that is softened is directly related to the softness of the old asphalt, the RAP gradation, and the percent of asphalt in the mix. Because these values can be readily measured, they have been incorporated into a procedure to estimate an initial design emulsion content which is described below.

2.2 Project Selection and Testing Plan

Project selection is probably the most important factor in determining the success of a CIR project. Not all projects are appropriate for CIR. Improper project selection can doom a project to failure. Table 2.2 summarizes where CIR is and is not recommended. Once it has been determined CIR is feasible, the preconstruction steps shown in Figure 2.1 are recommended.

Field Sampling. After a project has been identified as a recycle candidate, the first step in the preliminary engineering phase is to perform a paper search on the history of that highway. The principle information to be collected would be the type of asphalt used in the pavement, thickness of the

Table 2.1. A Design Theory for Cold In-Place Recycled Pavements

Effective Asphalt = % Emulsion + % of Softened Asphalt

Where:

1) % emulsion is the design emulsion added

2) % of softened asphalt is directly related to:

- Viscosity of old asphalt
- Gradation of rap
- Percent asphalt in old pavement

Table 2.2. Considerations for Project Selection

a) CIR Not Recommended
Pavements with obvious subgrade problems
Work area cannot accommodate traffic volume
Asphalt is stripping from aggregate*
Mixes exhibiting rutting due to unstable, fat mixtures
Cold and damp conditions, including heavily shaded areas
Late fall or early winter treatment
Asphalt pavement is less than 1-1/2-in. thick
Intent is to widen roadway by reducing thickness and incorporating unbound shoulder rock
b) CIR Recommended
Cracked and broken pavements
Pavements rutted due to age
Rough pavements
As leveling and base for overlays
ADT 5000 or less unless multilane
Where selective rehabilitation is needed (e.g., in truck lane of 4-lane roadway)
Native aggregate poor or in short supply

*Emulsions contain effective antistrip agents. While it is not recommended at this time that CIR be used to correct pavements with stripping problems, CIR may prove to be an effective treatment. Use of lime in CIR is also being evaluated.

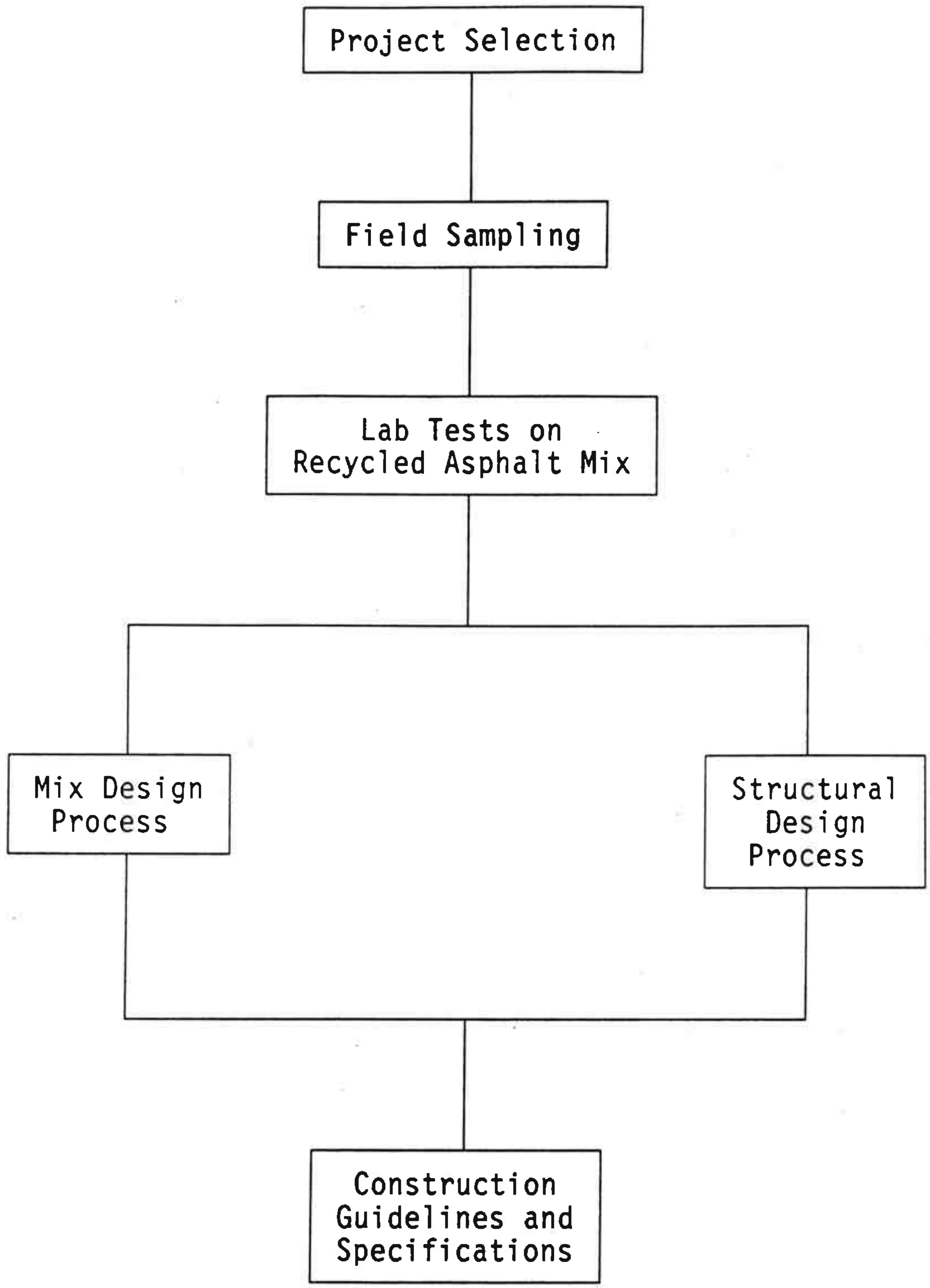


Figure 2.1. Preconstruction Steps for Cold In-Place Recycling.

pavement, and termini of previous jobs (Figure 2.2). The project is then divided into preliminary mix design areas shown as A, B, and C. Within each area milling samples should be obtained using a small 16-in. mill. The sample frequency in each design area would be a minimum of 1 sample plus 1 backup sample on each section. On longer sections, as many as 3 samples plus 3 backup samples would be obtained. The sample locations would be selected visually by identifying representative locations within the design area. Milling depth should correspond to the proposed recycle depth. Samples should be collected with the mill in forward motion. If visible maintenance patches or other intermittent treatments occur within the section, a sample would be taken from that section noting on the sample the fact that it came from a patching area. Samples are kept separate and submitted to the central laboratory for testing.

Laboratory Tests on RAP. The following tests should be performed on the RAP obtained from the field sampling:

1) Gradation of the RAP millings (16-in. mill).
2) Extracted asphalt content.
3) Penetration of extracted asphalt at 77°F.
4) Absolute viscosity of extracted asphalt at 140°F.

These values are then used to estimate the optimum design emulsion content using the following method.

2.3 Mix Design Considerations

Several procedures are available to determine the optimum emulsion and water content for CIR mixtures. The one described in this manual is based on the work performed in the state of Oregon (16).

Estimating Design Emulsion Content. The procedure to select the amount of emulsion (recycle agent) to be added to a recycled mixture is essentially an estimation process which begins with a base emulsion content to which adjustments are made based on the results of laboratory tests conducted on a sample taken, using a 16-in. mill, from the pavement to be recycled. It has been found through experience with the CMS-2S and HFE-150 emulsions that a base emulsion content of 1.2% is a good

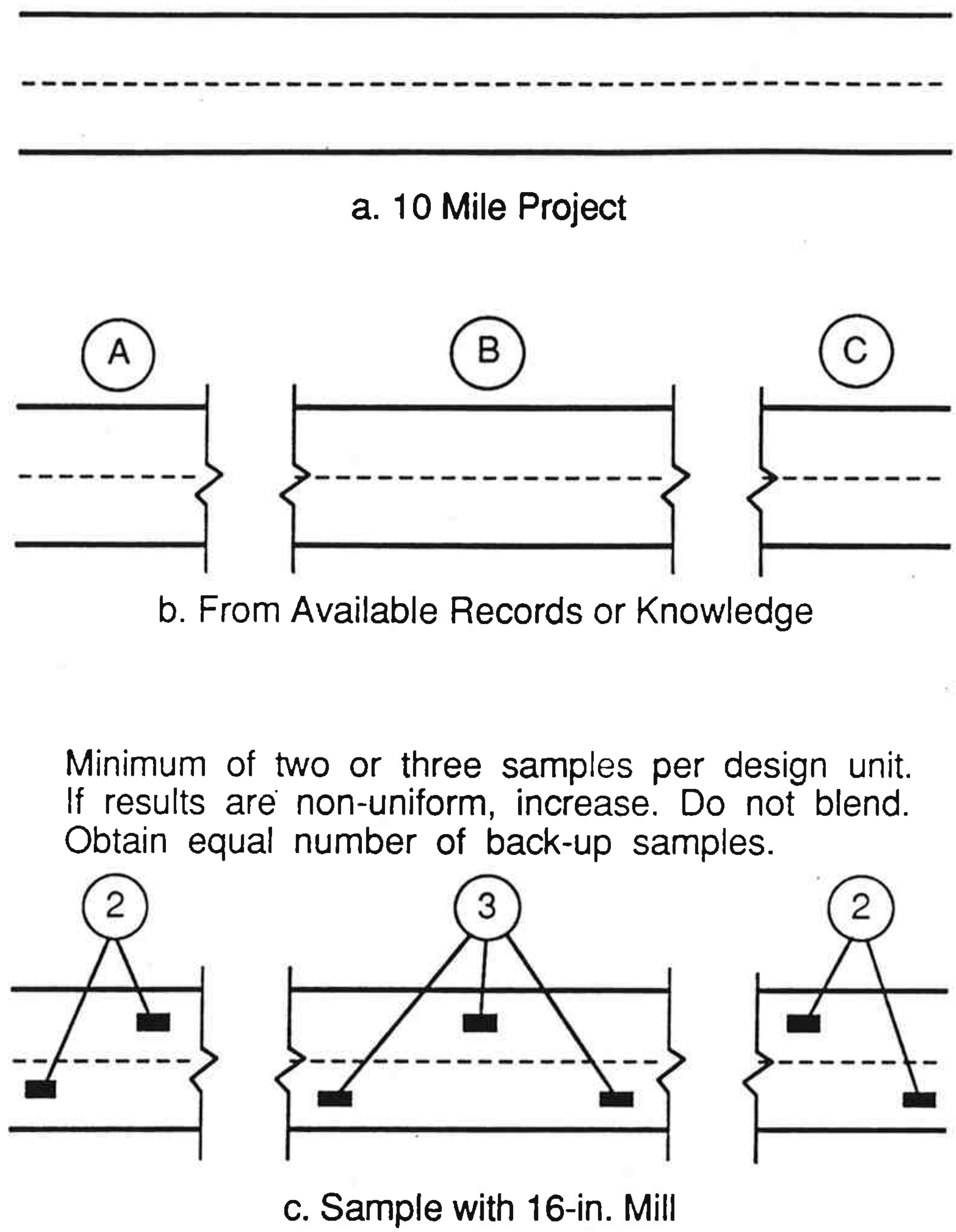


Figure 2.2. Suggested Field Sampling.

starting point (18). Adjustments are then made to this base content according to the softness of the extracted asphalt, gradation of millings as produced by the 16-in. mill, and the percent of recovered asphalt from the sample.

The penetration (ASTM D5) and/or the absolute viscosity (ASTM D2171) laboratory test results are used to determine the softness of the extracted asphalt and the RAP gradation is determined for only three screens -- 1/2-in., 1/4-in., and #10. The percent of recovered asphalt is determined via the Abson method (ASTM D1856). From these laboratory test results, the added emulsion content (based on dry weight of millings) can be determined through the use of Figure 2.3 and the following equation:

$$EC_{EST} = 1.2 + A_G + A_{A/C} + A_{P/V}$$

where

EC_{EST} = estimated emulsion content, %

1.2 = base emulsion content, %

A_G = adjustment for gradation, %

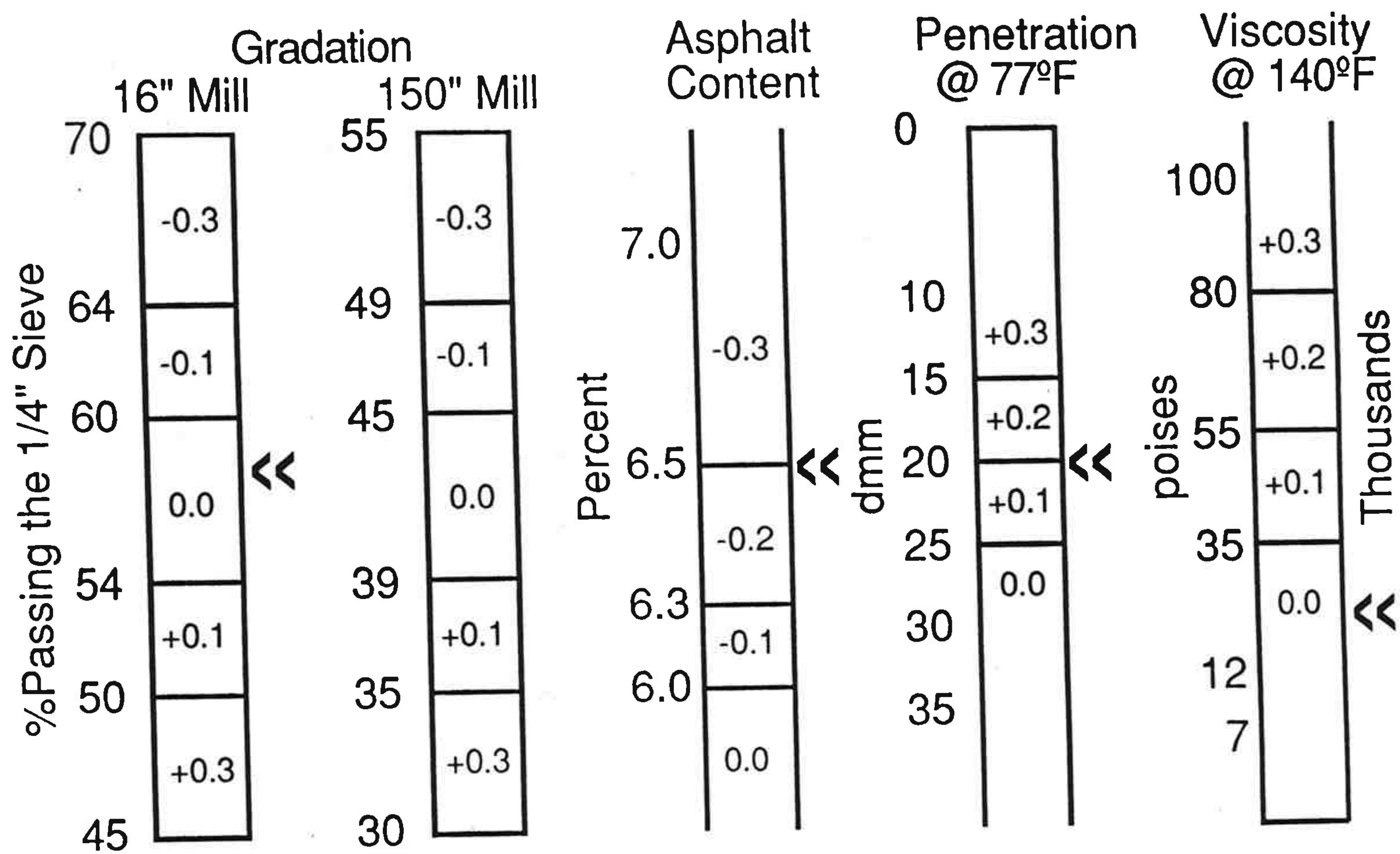
$A_{A/C}$ = adjustment for residual asphalt content, %

$A_{P/V}$ = adjustment for penetration <u>or</u> viscosity, %

It should be noted that for borderline cases (those that fall on a boundary) in Figure 2.3, the adjustment resulting in a lower estimated emulsion content (EC_{EST}) should be used. Also, where there exists a discrepancy between the adjustments for penetration and absolute viscosity, the adjustment resulting in a lower estimated emulsion content (EC_{EST}) should be used. The example in Figure 2.3 clarifies the use of the chart and the equation.

The significance of this procedure is that it provides a rapid and simple method to determine the design emulsion content. The laboratory tests used are widely accepted. The results appear to produce the optimum emulsion content within a fraction of one percent. For most recycle projects where preservation or restoration of an existing pavement is the primary objective, the estimated design emulsion content is adequate for the final recommended design.

<u>Estimating Water Addition Required</u>. To assure adequate dispersion of the emulsion and complete coating of the RAP, addition of water to the mix is required. A saturated surface damp condition is desired. To better quantify the total liquids content, the modified Oregon State Highway Division test



Example:
Given:
58% passing the 1/4" screen on the 16" mill, 6.5% residual asphalt, a penetration of 20 dmm, and a viscosity of 19,000 poises.
Adjustments (for borderline cases, use adjustment producing lower emulsion content):
0.0% for gradation, -0.3% for asphalt content, and 0.0% for penetration/viscosity
Estimated Emulsion Content:
1.2% + 0.0% - 0.3% + 0.0% = 0.9%

Figure 2.3. Emulsion Content Adjustments for Gradation, Asphalt Content, and Asphalt Softness.

method OSHD TM-126 is used. This is a test to determine how much total liquids a particular recycle mix can tolerate. Thus, once the estimated emulsion content (EC_{EST}) is determined as described in Section 2.1, the modified OSHD TM-126 test is conducted on a mix to determine the total liquids content. Briefly, the Total Liquids Test is conducted as follows (see OSHD-TM-126 for complete details):

1) Samples are prepared at the final estimated design emulsion content and at incremental water contents (e.g., 0.5, 1.0, 1.5%) and each sample weight is recorded.
2) Each sample is placed and rodded in a split mold in two lifts.
3) Each sample is gradually compressed to a total load of 25 kips - one minute to achieve 20 kips plus one half minute to achieve the additional 5 kips. The 25 kip load is held for one minute.
4) The specimen weights are then determined. The difference between the initial sample weight and the weight of the compacted specimen is the liquid loss.

The total liquids content that results in a liquid loss of 1 to 4 ml (1 to 4 grams) is used as the design total liquids content. From this, the water content can be calculated (total liquids content minus estimated emulsion content). It should be pointed out that this test is used for determining total liquids and cannot directly determine the water content (i.e., the water must be calculated).

2.4 Quality Assurance Guidelines

Even if one develops the best mix design and construction specifications, the project may be "doomed to failure," if the engineer and contractor are not fully informed of the limitations of CIR mixtures. This section discusses some of the ways of minimizing problems with cold recycling which should be considered on all projects.

Engineer Orientation. When using cold recycle for the first time, it is important to alert the project engineer as to what is expected from the new procedures. In cold recycling there are different objectives or expectations from what may be accomplished with hot mix. Some of the areas that should be considered in use of cold recycling are as follows:

•

1) Is the CIR to be a stabilized base with a surface course?

2) Will the CIR be used instead of a leveling course?

3) Will the CIR be used, with a chip seal, as a wearing course?

The project engineer should be made aware of the importance of the procedures listed in Table 4.1 of this manual and what the results mean to the completion of a successful project. These procedures should also be stressed to the contractors at the prebid conference and to the contractor at the preconstruction conference.

A postconstruction debriefing with the project engineer provides a valuable source of information for modification of future contracts. Also, using a project engineer experienced in CIR to train other engineers helps to minimize problems on future CIR projects.

Contractor Qualifications. Although most agencies do not have specific provisions for contractor prequalification, the following contractor qualifications are desirable:

1) knowledge of paving materials,

2) experience in all types of bituminous paving,

3) ability to coordinate, manage, and supervise a multifaceted, high-production project, and

4) prior experience with cold recycling.

The contract specifications may preclude some of the contractors from bidding because of the lack of adequate equipment. Contractors that are not properly equipped will not be able to provide an acceptable product.

3.0 CONSTRUCTION GUIDELINES

Proper project selection, preconstruction investigation, and estimation of emulsion content will go a long way toward allowing the success of a CIR project. The project can still fail, however, if proper construction procedures are not followed. To assure success during the construction phase, a rigorous quality control program is required.

3.1 Equipment and Procedures

The following discussion is intended to provide a brief overview of the construction process in order that appropriate specifications, contracts, and quality control procedures may be developed.

The concept of CIR is rather simple, but there are several factors that are important to successful projects. Figure 3.1 illustrates the major steps in CIR for the various types of equipment which have been utilized. Figure 3.2 illustrates equipment that has been used for CIR.

The following discussion is keyed to the numbers across the bottom of Figure 3.1 and refers to the steps in the CIR process:

Step 1. The decision to cold recycle has been made, based upon factors discussed earlier.

Step 2. The physical evaluation of the project in terms of the existing roadway and the mixture and, if needed, the structural design is completed.

Steps 3 and 4. When the Paving Train or Single Unit Train (see Figure 3.2) is used the old asphalt surface is cold milled. The depth of milling and maximum size of milling must be specified. For example, it might be specified that the existing pavement be milled to a depth of 3 in. with a maximum size rap of 1-1/2 in. (Single Unit does not have sizing capability.) If the single unit train is being used, water and recycling agent are measured and added to the milling chamber at this time.

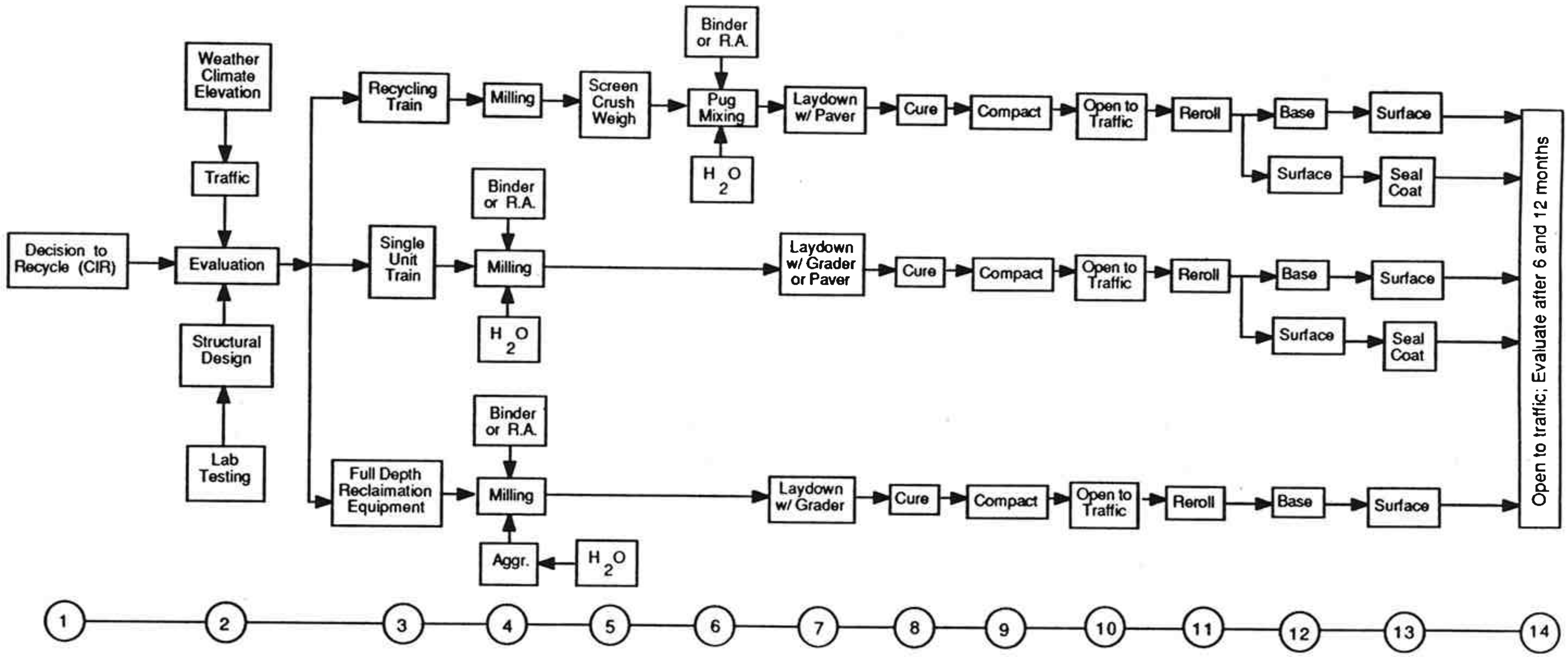
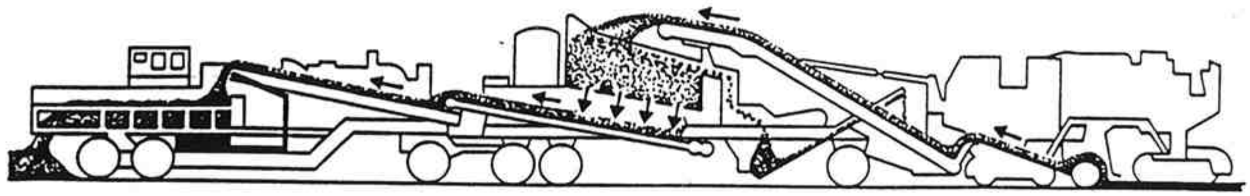
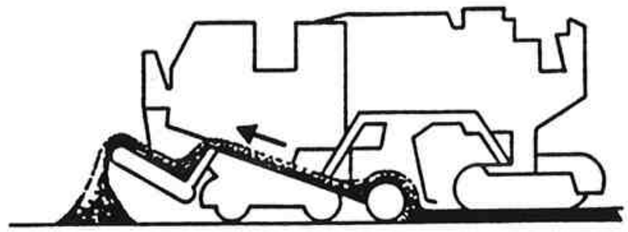


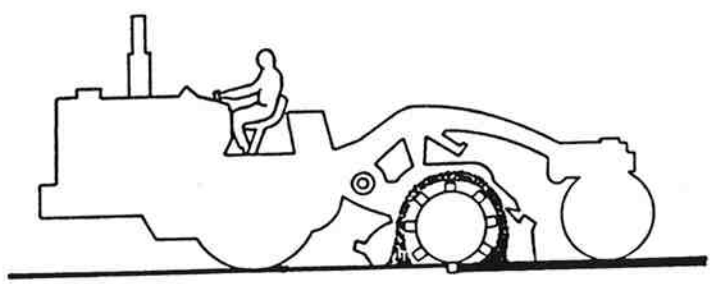
Figure 3.1. Flow Diagram for CIR Process.



a) Full train with mill, screen deck, crusher, belt scale, and pug. Laydown with a standard paving machine (Class I and II).



b) Single unit train with recycle agent sprayed into mill chamber (Class I and II).



c) Full depth operation which incorporates base or virgin aggregate with pulverizer (Class III).

Figure 3.2. Equipment Normally Used in Cold In-Place Recycling Treatments.

Where full-depth reclamation equipment is used old materials are pulverized and new materials are added in the same operation. The equipment required to do this operation could be one of several types, including:

- motor grader or scarifier
- cold planer
- rotary mixer (single or double shaft)
- travel plant

Step 5. With a full-scale recycling train, high quality and uniform blends are obtained with a screening deck, crusher, and weigh belts to meet size and gradation requirements for the desired mixture design.

Step 6. When the full train is used, thorough mixing with a traveling pug mill or continuous mixer is provided. At this point, emulsion or recycling agent and water are added as required by the mixture design.

Step 7. A paving machine is the preferred method of laydown.

Step 8. Because water is usually required for mixing and coating with emulsion, there is often more water present than needed for compaction. Therefore, a drying or curing period is often required to evaporate excess water. Specifications may require heating the water to facilitate the evaporation of excess water and to aid in the breaking and curing of emulsion, particularly in cool weather conditions. It is recommended that a minimum of one hour be allowed for drying and curing prior to compaction. Mix should set firmly under breakdown roller. If mixture "waves" in front of roller or cracks, allow further drying.

Step 9. Compaction using steel rollers is generally appropriate. Because compaction of cold mixes is somewhat more difficult than hot mixes, some agencies have found that vibratory steel rollers work well. Pneumatic rollers, if used on fine mixes, can seal the surface and prevent the CIR mixture from curing.

Step 10. The pavement is opened to traffic and compacts under traffic for a period of 3 to 15 days. Initially, speeds may need to be restricted to prevent excess raveling.

Step 11. When the CIR mat has dried and cured adequately, it is re-rolled with steel wheeled and pneumatic rollers to eliminate any rutting that may have occurred.

Steps 12 and 13. During the design process, a determination is made as to whether the CIR pavement will serve as a surface wearing course or base course. The final construction step will be to apply a final wearing course, or seal coat. Again, the choice will be determined by the design, but because of the open nature of the CIR surface, it is important to apply a seal coat (chip seal) before winter. A seal coat must not be applied before pavement moisture content has been allowed to drop to 1% or less. Leaving "total liquids" briquettes at the job site and weighing prior to sealing or applying a surface course is a good way to check moisture content.

Step 14. In order to provide feedback about the performance, regular evaluations should be made and the results used to improve future projects.

3.2 Field Testing and Quality Control

Cold in-place recycling may still be considered more of an art than a science. Experience is still the best teacher in determining what to do. In addition to required testing and measurements, continual visual examination during and after construction is required for successful CIR projects.

Most of the construction operations shown in Figure 3.1 are somewhat routine and can be readily covered in the specifications. However, special provision should be made to assure adequate proportioning, mixing, curing, and compaction of the recycled asphalt pavement. Several factors will influence the behavior and performance, including:

- Size gradation
- Pavement temperature
- Air temperature
- Solar heating
- Amount of emulsion added
- Amount of mixing water added
- Temperature of emulsion and mixing water
- Curing
- Compaction

The control of these factors through regular testing and evaluation will reduce the potential for problems. Observations have shown the following factors to be important:

1) Using too much asphalt emulsion and/or recycling agent will result in an unstable mix that is subject to rutting and shoving.
2) Too little asphalt emulsion may cause the mixture to ravel. Minor ravelling is acceptable.
3) Excessive mix water may cause the asphalt to flush to the surface and will retard curing.
4) Too little mix water results in mix segregation, raveling under traffic, and/or high void contents.
5) Coarse gradation of the processed RAP may cause problems with laydown, segregation, dragging, and excess voids.
6) Fine gradation tends to reduce the mix's tolerance for water and emulsion deviations.
7) Water required for mixing is generally in excess of that required for compaction. Curing and/or removal of excess water will generally be required before adequate compaction can be achieved.

This last item has been shown to be a critical factor in constructing a successful CIR project. Depending upon the weather, curing may take place in a matter of hours or it may be many days. Rules of thumb might be developed for a particular agency and/or location. For example, an Oregon DOT project (3) found that:

1) Two to three hours of cure with pavement surface temperature greater than 90°F are required prior to permitting uncontrolled traffic.

2) The mix density was increased upon rolling after three to fourteen days of curing.

In an effort to minimize problems associated with curing of the emulsion, ODOT has introduced the practice of heating the mix water and the emulsion into the 120° to 140°F range. Although this process does not significantly increase the mixture temperature due to the relatively small proportion of liquids in the mix, it is the opinion of field personnel experienced in CIR construction that the practice minimizes curing problems in cool, or damp conditions. One experienced inspector believes that heating the water reduces the need to increase the emulsion content when conditions are cool. The practice of heating water may cause problems of breaking and curing too fast, however, where windrow temperatures would be in excess of 120°F anyway.

3.3 Controlling Construction Operations to Achieve Optimum Results

Table 3.1 summarizes ODOT's recommendations for field quality control. It's implementation is discussed below. Most of the items presented in Table 3.1 are straightforward and not prone to error. The challenges of field control are in two major areas; verification and adjustment of emulsion and water content, and proper compaction and traffic control procedures.

"If Things Aren't Going Well, Key on the Water or Emulsion." These are the words of an ODOT project manager with extensive experience in CIR. They stress the criticality and uncertainty of maintaining proper mix proportions in the variable conditions of the field.

The central laboratory should have provided estimated emulsion requirements for areas where milling samples were taken. Visual observation of the entire project referenced to milling locations should give an indication if patching has been done subsequent to the millings or if the pavement is

Table 3.1. Recommended Field Quality Control Programs

Tests	Frequency	Purpose
RAP gradation	1/2 mile	Identify changes in pavement material
Emulsion content and water content	Continuous meter reading	Verify design content
Emulsion content and water content	Daily tank sticking	Verify meter reading
Total liquids	1/2 mile	Used to adjust water
Liquid loss color	1/2 mile	Used to adjust emulsion content
Emulsion and mix water temperature (when heating is required)	1/2 mile	Assure proper temperature
Mix temperature	1/2 mile	Verify minimum laydown temperature
Emulsion quality	Every 50 tons	Check product consistency
Depth and width	Random	Establish pay items
Smoothness	Random	
Optional Tests		
Extracted gradation	Random	Information only (after recycle)
Extracted asphalt content	Random	Information only (after recycle)
Viscosity/penetration	Random	Information only (after recycle)

more variable than the design would indicate. Either of these occurrences can serve as a warning to expect changes in emulsion content or other problems. If the milling locations are representative of the pavements to be recycled, design emulsion contents should be reliable.

If visual observation of the project indicates poor drainage and/or heavily shaded areas, expect RAP to have higher moisture content than the milling samples tested in the lab, and therefore anticipate that the amount of water to be added will be less than that called for in design. Heavily shaded areas will also serve as a warning that emulsion curing will be slow, and that 24-hr traffic control may be required.

Equipment generally approved by CIR specifications has the capability to meter emulsion and water (including water directed to the milling machine cutter head) into the RAP material. Usually, digital readouts of the rates of application are available which give a continuous reading of the liquids being added.

The normal procedure is to start construction with the water and emulsion contents designed for the pavement at the starting point. Experienced CIR inspectors and construction supervisors then generally verify or adjust the quantities of liquids added through several procedures. They generally conclude that the mix is too wet or too dry based on holding and squeezing the windrowed material in their hands, standing on the windrow and noting the way they sink, observing the nurse tank track imprint in the edge of the windrow, or observing the way the windrow "slumps" as it is deposited. What they're really looking for is thorough coating of the RAP material and workability. Based on these observations, liquid addition may be increased, decreased, or remain the same.

The use of the Kelly Ball (ASTM C-360) to replace these subjective "tests" has been investigated, but with inconclusive results. It is known that constructible pavements resulted when Kelly Ball displacements 30 seconds after placement on a leveled section of windrow ranged between 1 3/4 and 2 1/2 in. (mean of 2 in. for readings taken) and sunk an additional 3/16 in. during the next 30 seconds. It is not known if mixtures with improper emulsion and water contents would have similar displacements and rate of displacement.

Checking gradation is an objective method of adjusting emulsion content. Based on percent of RAP passing the 1/4-in. sieve, variations from the design basis may be noted and adjustments made based on Figure 2.3. Significant variations from the gradation upon which the design is based will be apparent to the experienced observer simply by visual observation.

The Total Liquids Test (OSHD-TM 126) provides a rational way of checking emulsion and water contents, but since the test takes 45 minutes, the information is not available for immediate adjustment. Liquids loss from this test should target a range of 1 to 4 grams with losses up to 10 grams being acceptable. If loss is greater, cut back on water added. If loss is less, add additional water. The liquid lost should be only slightly discolored. Dark liquid lost indicates too much emulsion. Clear liquid loss indicates possibly insufficient emulsion. When in doubt, error on the side of too little emulsion.

The paving ahead of the mill should be examined for the presence of "fat" spots or unstable mixes. The emulsion content should be dropped 0.2% in areas that appear slightly fat and dropped 0.4% in areas that are obviously unstable and rutted. These adjustments are made only if field samples are not taken at the exact locations of the distress.

Adjustments to emulsion content should also be made based on the visual appearance of the mat after initial compaction, assuming that the pavement is reasonably uniform. Additional emulsion should be added (up to +0.2%) if the mat remains brown or is prone to raveling. On the other extreme, the emulsion content should be reduced 0.2% if the mat is very black and shiny and no raveling is apparent, if pushing or rutting occur under traffic, or if bleeding or flushing occur. The recycled pavement should have a brown appearance for at least 24 hours.

In general, when there is too much water in the mixture, the material looks wet and can not be compacted. It "shoves" and has the appearance of an over-rolled hot mix. If there is too little water, the mixture looks dry, the RAP material will not show uniform coating, and the compacted mat will ravel.

When making adjustments to what has been a satisfactory operation, total liquids is generally kept at the same level. In other words, if emulsion content is reduced 0.2%, water addition is increased by the same amount, and if emulsion content is increased, water addition is decreased accordingly.

Balling of fines is another problem which may occur. The problem usually results from improper mixing of emulsion.

A problem which may occur which is more related to the paver than to liquids content is the problem of segregation of the mat. Segregation at the center of the panel is usual, resulting in a very open appearance. The paver may require modification to minimize this segregation.

Compaction, Traffic Control, and Re-rolling Specifications will provide guidelines for compaction. However, it is important to remember that the purpose of initial rolling is simply to get the material set. It is not desired to seal the surface initially. Moisture must get out so that the material may cure. Consequently, rubber-tired rollers should not be used for breakdown rolling, except on coarse RAP. Both static and vibratory steel-wheeled rollers have been successfully used. It is important not to over-roll, which may be manifested by the flushing of emulsion and/or fines to the surface.

Although the paving machine should stay close to the recycling train or single unit train, there are times when the breakdown roller should stay well back. These times would be in cold temperatures, or when compacting fine materials.

Generally, recycling operations should not be undertaken or continue unless weather conditions and forecasts indicate that at least 3 hours of 90° windrow temperatures are likely. If this guideline is followed, traffic may be allowed (with speed limitations) on the mat at the conclusion of rolling operations. If shaded areas or weather conditions inhibit curing, 24-hour traffic control may be required. If areas will not set up and continue to ravel, a fog seal may be required.

About 7 to 14 days after traffic has been allowed on the mat, the mat is once again rolled to remove any wheeltrack rutting and to seal the surface. Re-rolling should not be allowed until excess moisture has evaporated from the mat. One way to determine that adequate drying has taken place is to leave total liquids (OSHD TM-126) briquettes along the roadway to experience curing conditions identical to those experienced by the mat. When the briquettes no longer lose weight, moisture content has reached equilibrium.

Sealing. A well-constructed CIR mat can still be lost if sealed too soon, or if not sealed before winter conditions. Specifications should specify a minimum moisture content before sealing, and some type of seal should always be installed prior to the onset of winter weather.

3.4 Lime

CIR projects may require the addition of lime to the RAP. To-date, the most efficient method for introduction of lime is to spread granulated lime uniformly ahead of the milling machine, introduce water to slake the lime, roll the granules to allow dispersion of the lime into the mix, and use the milling machine to disperse the lime into the mix. From a process control point, critical items to note are the following:

1) Proper amount of lime to achieve the desired concentration in the mixture.
2) Proper breakdown of the lime granules in order that the lime is completely dispersed into the mix in a fashion that will allow coating of RAP/aggregate particles.
3) Mix and milling head water addition should be reduced to compensate for addition of water to slake the lime.

4.0 POSTCONSTRUCTION EVALUATION

Work performed during the period from 1984-90 by Oregon DOT indicates the most common problems encountered include rutting, raveling, cracking, and local failures. Causes of and solutions to these problems are summarized in Table 4.1. It should be noted that rutting is considered to be the most serious problem. However, it can be corrected by re-recycling as follows:

1) In cases with excess emulsion, re-recycle the distressed area and increase the depth of cut to pick up additional material.

2) In cases of flushing, re-recycle (without going any deeper and without adding recycling agent or emulsion) and delay the initial compaction period.

Table 4.1. Pavement Problems in CIR Mixes - Causes and Solutions

Type	Causes	Solutions	Comments
Rutting	• Too much emulsion • Sealing surface during laydown • Early application of chip seal	• Proper mix design • Limited vibratory compaction and prohibit pneumatic rollers until mix is stable • Allow cure period to reduce moisture to 1-1/2% (usually 2 weeks of good weather)	Occurs within the first few days after construction or during hot weather the season following recycling
Raveling	• Cool weather/shaded areas • Slow setting recycling agent • Inadequate traffic control • Insufficient recycle agent	• Preheat mixing water • Fog seal areas experiencing raveling • Use pilot cars	Occurs within first few hours after opening surface to high speed traffic
Cracking	• Open-graded nature of mix • Freeze-thaw action if not sealed • Insufficient structural section • Improper recycle agent • Rolling too soon • Other unknown factors	• Require a sand or fine chip seal on all low to medium trafficked roads • Use an open-graded emulsion mix or hot mix on heavily travelled roads • Allow drying prior to compaction	Can occur during first winter if surface is not sealed and mix is subject to numerous freeze-thaw cycles
Local Failures	• Inadequate base • Wet subgrades	• Identify these areas prior to recycling • Dig out, rebase, and patch prior to recycling	These frequently occur on low volume highways with little or no base rock. Since CIR has little strength during the first 24 hrs, truck traffic will break up new CIR surfaces

5.0 SUMMARY OF FACTORS CRITICAL TO SUCCESSFUL CIR PROJECTS

The following list presents a summary of the factors most critical to the selection, design, administration, construction, and inspection of CIR projects:

1) Project selection is the most important factor for successful CIR. Trying to recycle pavements with inadequate base, inadequate width, inadequate depth of AC pavement, or extremely variable RAP properties, for example, is futile. See Table 2.2 for a list of projects to avoid.

2) Maintaining proper proportions of emulsion and mix water during recycling is the biggest challenge in the field. Design of proper emulsion content and water content, and procedures for verifying and adjusting in the field have been discussed at length in this manual.

3) Initial compaction (rolling) of the recycled mat is intended to set rather than seal the surface. Trapping moisture in the mat would be detrimental to performance.

4) Sealing the CIR mat before winter conditions is essential to prevent moisture and freeze/thaw damage to a pavement with high voids content (10-15%).

5) The pavement must not be sealed too soon, trapping excess moisture in the mat. Specifications should preclude sealing the CIR mat if moisture exceeds 1 1/2%.

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APPENDIX

1990 ODOT Specifications for CIR

(Warning: SP420 has its own version of SP407-Asphalt Tack Coat printed after 420.91. If the regular version of SP407 is not required for this project, put SP420 version of SP407 in the proper numerical order for Part 400 Special Provisions. If the regular version of SP407 is required for this project, combine the two versions into one SP407.)

SECTION 420 - COLD IN-PLACE RECYCLED (CIR) ASPHALT CONCRETE PAVEMENT

Section 420, which is not in the Standard Specifications, is included for this project by special provision.

Description

420.01 Scope - This work shall consist of constructing cold in-place recycled (CIR) asphalt concrete pavement using Class I and Class II recycling treatments in accordance with these specifications, and in reasonably close conformity to the lines, grades, thicknesses and cross sections shown on the plans or established by the Engineer.

420.02 Definitions and Abbreviations - The following definitions and abbreviations are used in this Section:

(a) Definitions:

Emulsified Asphalt - Emulsified asphalt cement.

Course - See Typical Section on plans.

Coverage - One pass over the entire surface designated.

CIR Asphalt Concrete Pavement - CIR asphalt concrete pavement is a mixture of pulverized existing asphalt pavement (RAP), which has been removed and mixed with recycling agent and water; then relaid; and compacted in a continuous operation.

5-90

Class I Recycling Treatment - Class I recycling treatment is performed on a uniform pavement, previously designed and built to specifications. The CIR mixture produced under Class I is based on a rational mix design method.

Class II Recycling Treatment - Class II recycling treatment is performed on either a pavement with significant maintenance patches over a uniform pavement or a pavement with minimal design used in the original construction. The CIR mixture produced under Class II is less uniform than for Class I and is based on either a rational mix design method or mix design guidelines.

Equipment Option A - Performing CIR work using a recycling train.

Equipment Option B - Performing CIR work using a single processing unit.

Mixture - Cold in-place recycled asphalt concrete after all materials are combined and mixed.

Pass - The passing of a roller over a given spot.

Panel - The width of CIR material being removed and placed by the recycling train or single processing unit in a single pass.

Recycling Agent - Material added to RAP to soften and rejuvenate existing asphalt material.

(b) Abbreviations:

CIR - Cold in-place recycled asphalt concrete pavement.

JMF - Job mix formula.

RAP - Reclaimed asphalt pavement.

420.05 Prepaving Conference - Any supervisory personnel of the Contractor and any subcontractor who are to be involved in the recycle and paving work shall meet with the Project Manager, at a time mutually agreed upon, to disucss methods of accomplishing all phases of the recycle and paving work.

Materials

5-90 420.11 Recycling Agent and Water - The Contractor shall provide:

5-90 (a) Recycling agent - Either CMS-2RA or HFE-200RA that has been manufactured from new materials and meets the following requirements:

Test on Emulsion (AASHTO T 59)	CMS-2RA Min.	CMS-2RA Max.	HFE-200RA Min.	HFE-200RA Max
Viscosity @ 122°F., sec.	50	450	50	-
Sieve Test (%)	-	0.1	-	0.1
5-90 One Day Storage Stability (%)	-	1.0	-	1.0
Residue @ 500°F (%)	60	-	65	-
Oil Distillate (%)	5	15	0	7
Charge	+ Pass		- Pass	
Test on Residue				
Penetration @ 77°F, cm/100 (AASHTO T 49)	100	250	200	350
5-90 Float Test @ 140°F, sec. (AASHTO T 50)	-	-	1,200	-
Solubility (%) (AASHTO T 44)	97.5	-	97.5	-

(b) Water - Water that conforms to the requirements of 233.11.

(Use the following paragraph when the Contractor will produce choke aggregate.)

(c) Choke aggregate - The material to be used as choke aggregate shall be either clean sand, crushed gravel or quarry rock free of clay, loam or other harmful substances and shall conform to the following:

Sieve Size	Percent Passing
3/8"	100
1/4"	95-100
10	20-40
40	6-18
100	0-5

If approved by the Engineer, crusher rejects may be used provided they do not create any excessive dust conditions.

(Use the following paragraph with Division-furnished material.)

(c) Choke aggregate - Choke aggregate will be furnished by the Division. Material to be used on this project is stockpiled on Division-controlled property located on Highway _____ at M.P. _____.

3/17

(Use bracketed item when Equipment Option A is allowed.)

420.12 Recycled Asphalt Pavement (RAP):

(a) Option A - Recycled material removed from the existing asphalt pavement (using Equipment Option A) shall have a maximum size of 1-1/2 inches prior to entering the mixer unless otherwise directed by the Engineer. Any recycled material larger than 1-1/2 inches shall be separated by screening or other means, broken down by mechanical means to pass a 1-1/2-inch sieve and uniformly reincorporated with the balance of the recycled material.

4-89 **(Use following paragraph when Equipment Option B is allowed.)**

(b) Option B - Recycled material removed from the existing asphalt pavement using Equipment Option B shall have a maximum size of two inches. Incidental oversize may be allowed by the Engineer if it is not detrimental to the mixture or wearing surface. If the gradation is determined to be detrimental, the Contractor shall take such action necessary to correct the oversize problem. These actions may include reducing the milling speed, adjusting the crusher, changing screen size (when screens are used) or other such measures as may be necessary. Failure of the Contractor to be able to provide an acceptable product will cause a rejection of any unsuitable equipment.

5-90 420.13 Job Mix Formula (JMF) - The CIR asphalt concrete mixture shall consist of RAP from the existing pavement, recycling agent and water combined in the proportions designated by the Engineer. Variability in the composition of the RAP material may require changes in the proportions of the constituents, as directed by the Engineer. Normally, the recycling agent content will be between 0.1 and 1.8 percent, by weight, and water between 1.0 and 3.0 percent by weight.

5-89 420.15 Process Control Testing - Process control sampling and testing will be performed by the Engineer.

420.16 Acceptance of Mixture - The mixture will be accepted visually on the roadway following initial rolling subject to 420.39(c) Recompaction. Any mixture not acceptably mixed or that ravels shall be corrected by the Contractor as follows:

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- Any area showing an excess or a deficiency of recycling agent shall be reprocessed or replaced.

- If raveling occurs, immediate traffic control and additional rolling shall be provided.

Traffic control for rolling, reprocessing, or replacement shall be as directed by the Engineer. This work will be paid for at contract item prices as specified in 109.04A. Items of work not covered by contract items will be paid for as Extra Work. If the Engineer determines the excesses, deficiencies, or raveling are due to the Contractor's operations, the corrective work shall be done at the Contractor's expense.

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Equipment

420.23 Asphalt Concrete Pavers - Pavers shall be:

(a) Self-contained, power-propelled units, supported on tracks or wheels, none of which contact the mixture being placed.

(b) Equipped with augers and an activated screed or strike-off assembly, heated if necessary, which:

- Provides the same augering, screeding, and heating equipment to extensions used on travel lanes as to the rest of the paver.
- Can spread and finish AC in specified widths, thicknesses, lines, grades, and cross section.
- Will not segregate, tear, shove, or gouge the AC.
- Produces a finished surface to specified evenness and textures.

(c) Equipped with a paver control system which:

- Automatically controls AC placement to specified slope and grade.
- Automatically maintains the paver screed in proper position.
- Provides specified results through a system of mechanical sensors and sensor-directed devices that are actuated from independent line and grade control references.

420.24 Compactors - The Contractor shall provide either steel-wheeled, pneumatic-tired, or vibratory rollers capable of reversing without backlash, as specified.

5/17

(a) Steel-wheeled rollers - Steel-wheeled rollers shall have:

- A gross static weight of at least 8 tons.
- A static weight on the drive wheel of at least 250 pounds per inch of width.

If used for finish rolling:

- A gross static weight of at least 6 tons.
- No drivewheel static weight requirement.

(b) Vibratory rollers - Vibratory rollers shall:

- Be equipped with amplitude and frequency controls.
- Be specifically designed to compact AC.
- Be capable of at least 2,000 vibrations per minute.

5-90 If used for finish rolling:

- Have a gross static weight of at least 6 tons.
- 5-90 Not be operated in the vibratory mode.

(c) Pneumatic-tired rollers - Pneumatic-tired rollers shall:

- Be self-propelled, tandem, or multiple axle, multiple wheel type.
- Have smooth-tread, pneumatic tires of equal size.
- Have tires staggered on the axles, spaced and overlapped so uniform compacting pressure is provided for the full compacting width.
- Be capable of exerting ground pressure of at least 80 pounds per square inch of tire contact area with a minimum total load of 2800 pounds per tire.

(Use bracketed item when single unit option is allowed.)

420.26 Equipment Options A and B:

Equipment Option A-Recycling Train - (Under this option the) existing pavement shall be recycled using a recycling train consisting of the following major components: (a) Planing machine or grinder, (b) crusher and (c) pugmill mixer.

(a) Planing machine or grinder - The existing pavement shall be removed by a self-propelled planing machine having a minimum 144-inch wide rotary cutter and capable of removing the existing pavement to a depth of four inches in a single pass.

The unit, also, shall be capable of accurately establishing profile grades within a tolerance of 0.02 foot by reference from either the existing pavement or from independent grade control and shall have a positive means for controlling cross slope elevations. The equipment shall incorporate a totally enclosed cutting drum with replaceable cutting teeth and shall have an effective means for removing excess material from the surface and for preventing dust from escaping into the air. The use of a heating device to soften the pavement will not be permitted.

The unit shall be equipped to discharge water into the mixing chamber, with fully variable control and meter capable of measuring the rate of feed within five gallons per minute.

(b) Crusher - The crusher shall be of the portable type capable of reducing the oversized RAP materials to the specified size.

(c) Pug mill mixer - The CIR asphalt concrete mixture shall be mixed in a pug mill type plant capable of providing a mix of RAP, recycling agent and water to uniform proportions as designated by the Engineer.

The pug mill shall be equipped with a liner to prevent build-up of materials during the mixing operation.

Mixing plants shall be equipped with a positive control linking the RAP, recycling agent and water feed in a manner that will maintain a constant ratio of each constituent. The plant shall be equipped with facilities so that the Contractor can verify and calibrate the RAP, recycling agent and water quantities by a method acceptable to the Engineer.

The RAP shall be measured by weight and the recycling agent and water may be proportioned by either weight or volume. The equipment shall be capable of feeding and maintaining a constant rate of RAP feed within a tolerance of plus or minus 5 percent (by weight) or the designated amount and a constant rate of recycling agent and water feeds within plus or minus 0.2 percent (by weight) of the designated amounts.

The mixing plant shall be equipped with positive displacement pumps and a computerized metering system which can accurately meter the amount of recycling agent and water. The pumps shall be interlocked belt weighing system that measures the quantity of RAP material entering the mixing plant. The interlock shall be designed so that recycling agent and water cannot be added until RAP material enters the mixer. Overrides of the interlock system shall be equipped with short duration timers to prevent their continuous use. Overrides shall be used only during start-up periods.

The belt weighing device and computerized-metering system shall have readouts that indicate the quantity in tons of RAP, water and recycling agent being fed into the mixer at any given time. Totalizer readouts shall also be provided to allow determination of accumulative quantities of each constituent.

(Use following four paragraphs when single unit option is allowed.)

Equipment Option B - Single Processing Unit:

Under this option the existing pavement shall be processed using a planing machine meeting all of the requirements of a planing machine under "Equipment Option A".

In addition, the planing machine shall be capable of adding recycling agent and water to the RAP in amounts directed by the Engineer to produce a uniform mixture.

Positive displacement pumps which can accurately meter the planned amount of recycling agent and water into the pulverized asphalt concrete shall be used. The pumps shall be interlocked to the movement of the machinery used to apply the recycling agent and water to provide that no recycling agent or water can be added when the machinery is not moving.

The recycling agent and water feeds shall have positive readout capabilities so that the amount of recycling agent and water in tons incorporated into at any given time can be read directly. Totalizer readouts shall also be provided to allow determination of accumulative quantities of water and recycling agent used in the mixture.

(d) Recycling agent, storage and heating tanks - Storage tanks shall be equipped with accurate volume measuring devices or manufactures calibration charts for each storage tank and a thermometer for measuring the temperature of tank's contents.

Between the storage tanks and the liquid asphalt mixing device or recycling equipment, a parallel piping filter system with at least one filter per line shall be used. Filters shall be capable of eliminating solid or semisolid particles from the recycling agent liquid.

Each filtering line shall be equipped with on-off valves and changeable filter elements.

5-90 The recycling agent shall be routed alternately through each filter line for a period of two to four hours, and alternate filters changed on the same frequency unless otherwise directed by the Engineer.

5-90 Loads of recycling agent which break prematurely in the storage tanks or haul vehicles or which cause frequent plugging of the filters as determined by the Engineer will be rejected for use.

Construction

420.31 Season and Weather Limitations - In-place recycling of existing asphalt concrete pavement shall not begin until the pavement surface temperature is 70°F and rising. The construction of CIR asphalt concrete pavement will not be allowed before May 15 or after August 1, except the Engineer may approve a start-up prior to the pavement surface temperature reaching 70°F under the following conditions:

- The Contractor requests such an early start in writing;
- The Contractor assumes all financial responsibility for correction of raveling problems with the CIR mixture during the early start period. This includes, but is not limited to, the cost of complete recycling, additional choke, rollers, pilot cars and flaggers, etc. as determined by the Engineer.

The Contractor shall stop milling work at the end of each day when the temperature of the mixture behind the paver drops below 90°F or three hours before sunset, whichever occurs first.

Pavement damaged by rain after placement shall be reprocessed, or repaired by other methods approved by the Engineer, at the Contractor's expense.

If recycling and placement operations are not completed by August 1, the Contractor will not be allowed to resume operations until May 15 of the following year.

420.32 Rate of Progress and Scheduling - The Contractor shall plan and schedule the recycle operation in such a manner that the materials are removed, mixed, replaced and the area open to traffic immediately after initial compaction is completed.

All recycled areas shall be completely backfilled with reprocessed and compacted asphalt concrete materials so the area is open to two-way traffic during all hours of darkness.

420.33 Preparation of Underlying Surfaces - The Contractor shall:

(a) Panel recycling (less than 12' wide) with aggregate shoulders - Blade existing aggregates in shoulder areas away from milling operation so that shoulder aggregates are not mixed with pavement millings.

(b) All projects:

(b-1) Minimize the amount of fines on the milled surface that can be detrimental to a proper bond of the tack coat. If excess fines are on the milled surface, remove by brooming or other method acceptable to the Engineer.

(b-2) Just prior to windrowing the recycled pavement mixture, apply tack coat conforming to Section 407 of these special provisions to the entire profiled area including the vertical edges. Rates of application shall be as directed by the Engineer.

No separate measurement or payment will be made for blading or brooming work required for CIR work.

5-90 420.34 Heating Recycling Agent and Water - The temperature of the recycling agent prior to entry into the mixture shall be not less than 125°F nor more than 185°F.

5-90 The temperature of the water just prior to entry into the mixture shall be not less than 100°F.

420.35 Mixing - All the various required components of the asphalt concrete mixer shall be utilized and operated in a manner to assure compliance with this section.

5-90 The RAP, recycling agent and water shall be measured and introduced into the mixer in the amounts specified in the JMF and as designated by the Engineer.

5-90 Mixing shall continue until the recycling agent and water have been distributed throughout the RAP to form a uniformly coated mixture.

420.37 Control of Line, Grade and Milling Depth - The line and grade reference control shall be a floating beam device of adequate length and sensitivity to provide adequate control on either or both sides of the paver.

Manual control of line and grade for the paver will be permitted when approved by the Engineer.

5-90

Milling shall be performed at the depth shown on the plans unless otherwise directed by the Engineer. Any area of pavement with deficient asphalt coating caused by excessive milling depth shall be replaced at the expense of the Contractor.

420.38 Spreading and Placing - Except for unavoidable delay or breakdown, recycling and placing recycled pavement by the paving machine shall be at a rate sufficient to provide continuous operation of the paving machine. If paving operations result in excessive stopping of the paving machine, as determined by the Engineer, recycling and paving operations shall be suspended until the Contractor can synchronize the rate of recycle with the capacity of the paving machines.

(a) General - The mixture shall be laid on an approved surface, spread and struck off to established grade and elevation. Specified asphalt pavers shall be used to distribute the mixture.

The asphalt mixture shall be deposited in a windrow, then picked up and placed in the asphalt paver.

The loading equipment shall be self-supporting and shall not exert any vertical load on the paving machine nor cause vibrations or other motions which could have a detrimental effect on the riding quality of the completed pavement. The loading equipment shall pick up substantially all of the material deposited on the roadbed and place it directly into the receiving hopper of the paving machine.

In areas where patching, irregularities or unavoidable obstacles make the use of specified equipment impracticable, the mixture may be spread with special hopper equipment with adjustable strike-off or by other equipment and means approved by the Engineer, provided the surface finish is within a tolerance of 0.01-foot of that hereinafter set forth.

420.39 Compaction:

(a) General - Immediately after the CIR asphalt concrete mixture has been spread, struck off and surface irregularities and other defects remedied, it shall be thoroughly and uniformly rolled until the mixture is compacted as specified.

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(a-1) Rolling - The CIR asphalt concrete mixture shall be compacted with rollers conforming to the requirements of 420.24. The type, number and weight of rollers shall be sufficient to compact the mixture.

Rollers shall move at a slow but uniform speed recommended by the manufacturer with the drive rolls or wheels nearest the paver. Vibratory rollers, when used in the vibratory mode, shall be operated at frequencies of at least 2,000 vibrations per minute. The maximum operating speed of pneumatic rollers shall be 5 MPH.

Normal rolling shall begin at the sides and proceed longitudinally parallel to the road centerline, each pass overlapping one-half the roller width, gradually progressing to the center. On superelevated curves the rolling shall begin at the low side and progress to the high side, each pass overlapping one-half the roller width. When paving is in echelon or when abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure. Rollers shall not make sharp turns on the course being compacted and they shall not be parked on the fresh CIR mixture. Alternate passes of a roller shall terminate in stops at least five feet distant longitudinally from adjacent preceding stops.

(a-2) Surface repair - Any displacement of the mat regardless of thickness occurring as a result of the reversing of the direction of a roller, or from other causes, shall be corrected. Steel roller wheels shall be moistened with water or other approved material to the least extent necessary to prevent pickup of mixture.

When the rolling causes undue tearing, displacement, cracking or shoving the Contractor shall make changes in compaction equipment and/or rolling procedures necessary to alleviate the problem.

(b) Initial compaction - Compaction of the fresh CIR asphalt concrete mixture shall be performed with a minimum of two vibratory rollers. Rollers shall be operated in either vibratory or static mode as directed by the Engineer. The mixture shall be compacted with at least two passes by each roller and such additional passes as the Engineer may direct.

(c) Recompaction - After initial compaction and prior to recompaction, the CIR asphalt concrete pavement shall be opened to public traffic and allowed to cure. Recompaction shall be performed between 3 and 15 days after laydown when directed by the Engineer. Rolling shall not be performed when the surface temperature is less than 90°F.

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The entire recycled pavement area shall be recompacted with at least one steel wheeled roller and one pneumatic roller. Each roller shall make at least three passes and such additional passes as the Engineer may direct.

420.42 Joints:

(a) Drop-offs - Prior to any suspension of operations at the end of each shift, the full width of the area to be paved, including outside shoulders, shall be completed to the same elevation with no longitudinal drop-offs.

If unable to complete the pavement without longitudinal drop-offs as specified above, the Contractor shall, within the specified time constraints, construct and maintain a wedge of asphalt concrete at a slope of 10:1 or flatter along the exposed longitudinal joint located within the area to be paved. Longitudinal joints one inch or less will not require a wedge. The wedge shall be removed and disposed of prior to continuing paving operations. Construction, material, maintenance, removal and disposal of the temporary wedge shall be at the Contractor's expense.

Where allowable abrupt or sloped drop-offs occur within or at the edge of the paved surface the Contractor shall provide, at his expense, suitable warning signs as required under Section 111 of the Supplemental Standard Specifications.

(b) Finishing and details - Special care shall be taken at longitudinal joints to provide positive bond and to provide density and finish to new mixture equal in all respects to the mixture against which it is placed.

420.43 Pavement Smoothness:

(a) General - The top surface of CIR asphalt concrete pavement shall be tested with a 12-foot straightedge parallel to or perpendicular to the centerline, and shall not vary by more than 0.02 foot. The Contractor shall furnish the straightedge and operate it under the direction of the Engineer.

When utility appurtenances such as manhole covers and valve boxes are located in the traveled way and they are not required to be adjusted or are required to be adjusted before paving, this tolerance will not apply.

(b) Corrective action - When tests show the pavement is not within the specified tolerance, the Contractor shall take immediate action to correct equipment or procedures in his paving operation to eliminate the unacceptable pavement roughness.

Any surface irregularities exceeding the specified tolerances shall be corrected by the Contractor within the period of 2 to 5 days following initial compaction using one of the following methods:

- Remove, replace or reprocess the surface course.

- Grind the pavement surface utilizing the planing machine or grinder as hereinbefore set forth to a maximum depth of 0.3 inch.

The cost of all corrective work, including traffic control and furnishing of materials, shall be performed at the Contractor's expense and no adjustment in contract time will be made for corrective work.

420.45 Choke Aggregate Placement - Immediately prior to the last roller coverage during initial compaction as hereinafter specified and before opening to traffic, the Contractor shall place choke aggregate at a rate of approximately 0.001 to 0.003 cubic yard per square yard. Choke aggregate shall be spread by a method that provides uniform coverage across the CIR mat. Any piles, ridges or uneven distribution of choke aggregate shall be eliminated by spreading and/or removing with hand tools or mechanical means as the Contractor elects prior to the final roll or coverage.

420.55 Shoulder Restoration - The Contractor shall restore the aggregate shoulder areas to their original condition in all areas where the aggregate was dislodged, moved, rutted, etc., due to milling and recycle work. Restoration shall include blading and leveling existing aggregate materials as directed by the Engineer.

No separate measurement or payment will be made for shoulder restoration work.

Measurement

5-90 420.81 Measurement - The number of square yards of CIR asphalt mixture shall be based on the paved widths and milled depths shown on the plans and the horizontal measurement along the centerline of the actual length of the pavement recycled.

No allowance will be made for pavement recycled in excess of the paved width and milled depth shown on the plans unless directed by the Engineer.