DEVELOPMENT OF IMPROVED MIX DESIGN
AND CONSTRUCTION PROCEDURES
FOR COLD IN-PLACE RECYCLED PAVEMENTS

1984-86 Construction Projects

Volume I

by

R. G. Hicks, Professor of Civil Engineering
Oregon State University

Dale Allen, Region Engineer
Oregon State Highway Division

Telimoye M. Oguara, Research Assistant
Oregon State University

Randy Davis, Assistant Region Geologist
Oregon State Highway Division

David Foster, Construction Inspector
Oregon State Highway Division

Prepared for

Oregon State Department of Transportation

Salem, Oregon

April 1987

Technical Report Documentation Page

1. Report No.
OR/RD-87-06

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Development of Improved Mix Design and Construction Procedures for Cold In-Place Recycled Pavements

5. Report Date
February 1987

6. Performing Organization Code

7. Author(s)
Hicks, R.G., Allen, D., et al.

8. Performing Organization Report No.
TRR 87-3

9. Performing Organization Name and Address
Transportation Research Institute
Oregon State University
Corvallis, OR 97331 and
Oregon DOT, Region 4, Bend, OR 97708

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
8793

12. Sponsoring Agency Name and Address
Research Section
Oregon Department of Transportation
Salem, OR 97310

13. Type of Report and Period Covered
Interim Report
May 1986-December 1986

14. Sponsoring Agency Code

15. Supplementary Notes
Oregon DOT Contracting Officer
Robert Blensly

16. Abstract

This is the first of a three-volume report prepared to document the results of the cold in-place recycling (CIR) effort in Oregon. The overall objectives of the project are to develop improved design and construction procedures for cold recycled pavements. Volume I of this report describes the efforts to accomplish this objective over the period 1984-86. Specific guidelines are given for design, construction, and field control.

Volume II contains the supporting data for the research effort. In particular, it contains a review of selected mix and thickness design procedures, mix design, and field data for the 1986 projects, and the proposed construction specifications for 1987 projects.

Volume III will be developed later and will include data documenting the performance of the 1986 projects over a three-year period (1986-89).

17. Key Words
Recycling, Cold Recycling, Asphalt Emulsion, Mix Design, Construction

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages

22. Price

Form DOT F 1700.7 (8-72)

ACKNOWLEDGEMENT

This is an interim report concerned with the Development of Improved Design and Construction Procedures for Cold In-Place Recycled (CIR) Pavements. The authors are grateful for the cooperation of the Oregon Highway Division field staff in Regions 4 and 5 and to personnel in the State Materials Laboratory in Salem, Oregon. Special appreciation is also extended to Dan Olson, Projects Manager, for collecting and summarizing much of the 1986 information contained in this report, and to Dick Nelson, District Maintenance Supervisor, for providing much of the 1984-85 information on CIR with the single unit mills.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy presented herein. The contents do not necessarily reflect the official views or policies of the Oregon Department of Transportation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 Problem Definition

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 of the most promising and cost effective approaches 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, the methods discussed in this report 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 (Fig. 1.1). Many agencies, however, remain skeptical of the use of CIR because of the lack of long-term performance data and adequately documented field engineering studies.

Further compounding the problem is that the term cold recycling is frequently misunderstood because of the 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 medium to high traffic volumes, either as a base or wearing coarse. The train recycle method would normally be used; however, depending on degree of distress, a single-unit train could also produce a Class I treatment. Treatment width is normally 12 ft.

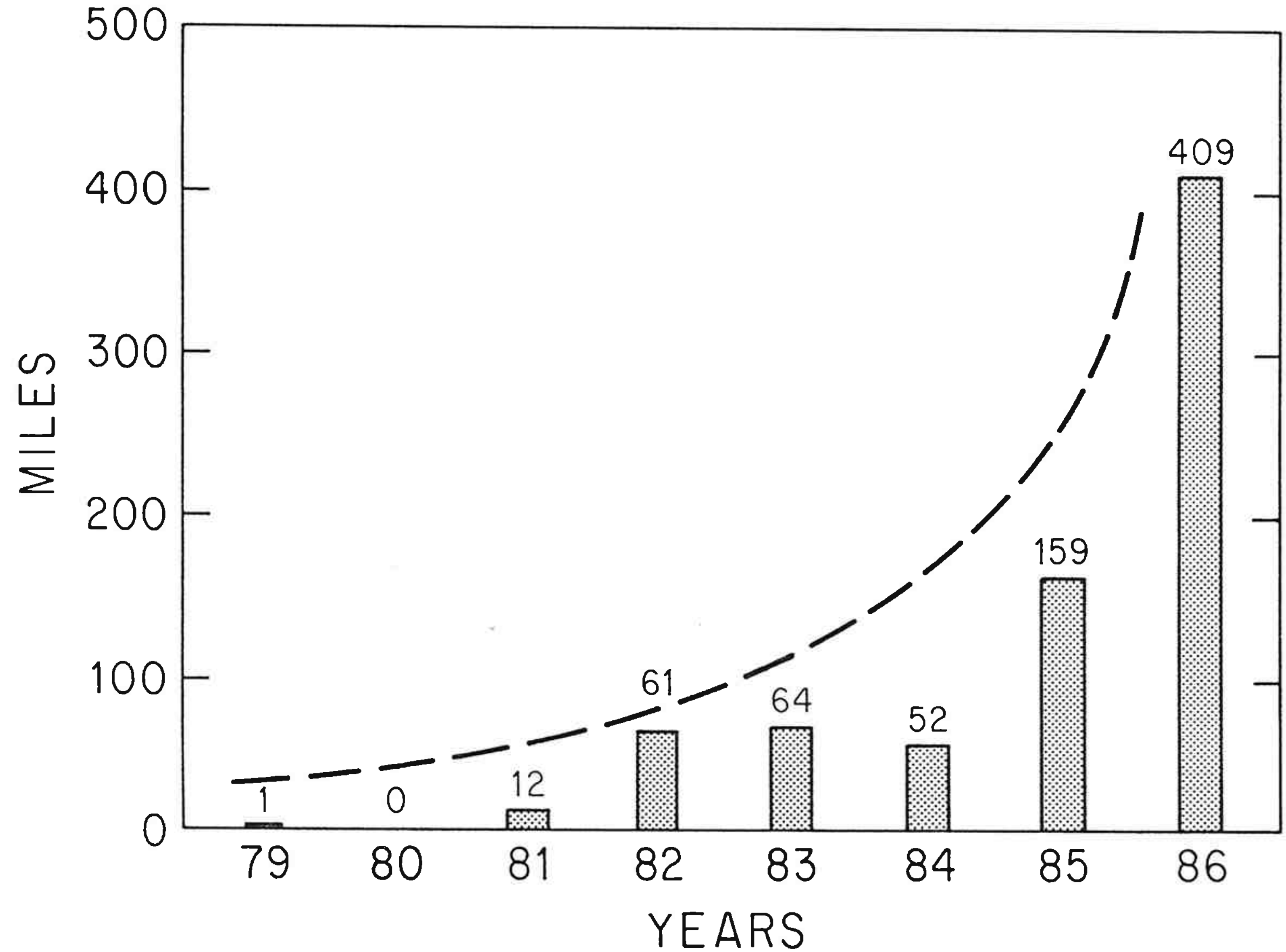


Figure 1.1 Growth in Cold Recycle (Class I and Class II Using Train on Single Mill Units)

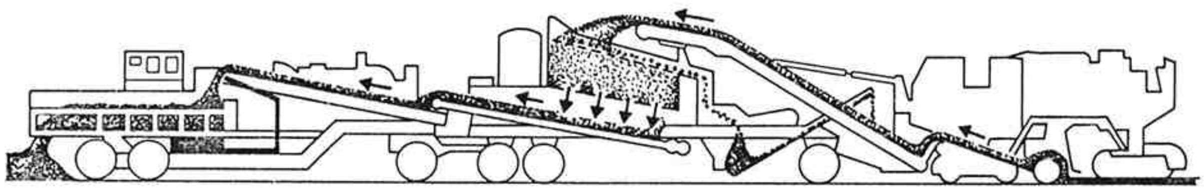
2) Class II. This recycling treatment is performed on a pavement with significant maintenance patches over a uniform pavement or a pavement with minimal design used in the original construction. Either the full train or single unit can produce millings of sufficient quality for reasonable mix designs. The finished mixture may be used as a base or wearing course. Treatment width is normally 12 ft.

3) Class III. This treatment is used on low volume highways where considerable variation in pavement structure exists and it may incorporate additional aggregate. The design of the mix is limited. Various milling and pulverizing units can be used to perform this operation. Normally the treatment is used as a base. Treatment width varies from 4 to 12 ft.

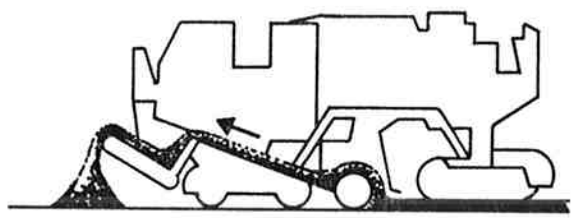
Figure 1.2 illustrates the equipment that would normally be used for each class of CIR.

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, reduced traffic exposure during construction, 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.

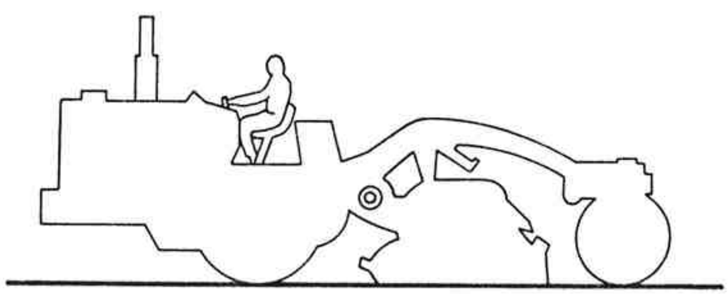
While CIR is widely acknowledged as a cost saving alternative, there is currently a lack of proven and simple mix and thickness design procedures and confidence in the durability of cold recycled mixes. In 1987 three major research efforts are underway to summarize and publish currently available technical data. These projects include:



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



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



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

Figure 1.2. Equipment Normally Used in Cold In-Place Recycling Treatments.

1) A National Cooperative Highway Research Program (NCHRP) synthesis on cold recycling design methods and practices.
2) An Asphalt Recycling and Reclaiming Association (ARRA) research study concerned with the "Evaluation of Design and Performance Criteria for CIR Asphalt Pavements."
3) This study, funded by Oregon Department of Transportation, concerned with the "Development of Improved Mix Design Procedures for CIR Asphalt Pavements."

It is expected that the above research efforts will address the need that exists for defensible and realistic procedures for the design and use of CIR asphalt pavements.

1.2 Objectives

The overall objective of this study was to develop simple and reliable mix design guidelines for cold in-place recycled asphalt pavements. Specifically, the study objectives were to:

1) develop a mix design procedure for cold in-place recycled asphalt pavement materials,
2) evaluate the structural contribution of the CIR asphalt pavement as well as the effects of environmental factors and traffic loads on the performance of these mixes,
3) develop improved guidelines and specifications for construction of CIR pavements, and
4) prepare an interim report for the 1987 construction season.

1.3 Study Approach

To accomplish the objectives the following steps were undertaken:

1) Literature Review. A thorough review of the current state of the knowledge regarding cold in-place recycling was undertaken. To make sure that all published information on cold recycling was included in the review, a HRIS/TRIS search of the literature was conducted. Agencies actively involved in recycling were then contacted to solicit information on their mix design procedures. Chapter 2 summarizes the use of CIR asphalt pavements in Oregon, while Appendix A summarizes current mix and thickness design procedures for the agencies contacted.

2) Preliminary Engineering. For each of the 1986 projects selected for cold in-place recycling, the preliminary engineering included:

   a) evaluation of the reclaimed asphalt pavement to determine gradation of millings, recovered asphalt penetration and viscosity, extracted gradation, and percent asphalt;

   b) determination of amounts of emulsion and water to be added to the mix;

   c) sample preparation and conditioning (mixing, curing, compaction);

   d) testing of mixes for laboratory-compacted Hveem stability, resilient modulus, voids, and specific gravity; and

e) establishment of criteria for mix design (stability, voids, modulus ratios).

From this study, percentages of reclaimed asphalt pavement, emulsified asphalt, and water for field operations were recommended. These results are presented in Chapter 3.

3) Field Investigation. The laboratory mix design recommendations were used as starting points for the field operations. Chapter 4 describes the construction processes, field control procedures, results, and cost data, while Appendix D contains selected field data.

4) Preliminary Evaluation. This step, described in Chapter 5, evaluates the 1986 program in terms of mix design procedures, construction operations, and job control. Specifications for 1987 projects are included in Appendix E.

5) Interim Report. This report involved the documentation of the preliminary design and construction operations for the 1986 program. Preliminary conclusions and recommendations for mix design and construction guidelines for CIR asphalt pavements are given in Chapter 6.

A followup report will document the performance of the 1986 projects over a 3-year period and will compare the results of tests on cores with similar tests on laboratory-prepared samples. The end result is expected to satisfy the project objectives.

2.0 COLD RECYCLING IN OREGON (1984-85)

Although cold in-place recycling (CIR) of existing pavements has been used as a base treatment in Oregon over the years (Class III treatment), CIR has been utilized as a surface course (Class I and II treatments) only since 1984.

In 1984, experimental partial depth work totaled about 12 miles (Table 2.1). This work was done with state forces and rented equipment. Because of the initial success, contracts were awarded to perform 89 miles of CIR in 1985 (Table 2.1). The general location of the 1985 projects is given in Fig. 2.1. The objectives of these initial projects were to determine costs on an actual major contract, observe the durability in various climates, and advance the state of the art of Class I and II CIR in the state of Oregon.

Encouraged by the substantial cost savings (Table 2.2), high production rates, and performance, 140 miles of highway were scheduled for cold in-place recycling in 1986. The results of the 1984-85 projects are described in this chapter, while the work associated with the 1986 projects will be discussed in Chapters 3 and 4 of this report.

2.1 Mix Design Methods-Oregon

Formal mix designs were not available for the 1984 projects. Emulsion and water contents were established in the field using trial-and-error procedures by experienced paving personnel. In general, the emulsion contents were about 1.5% while the water content varied from 2 to 4%.

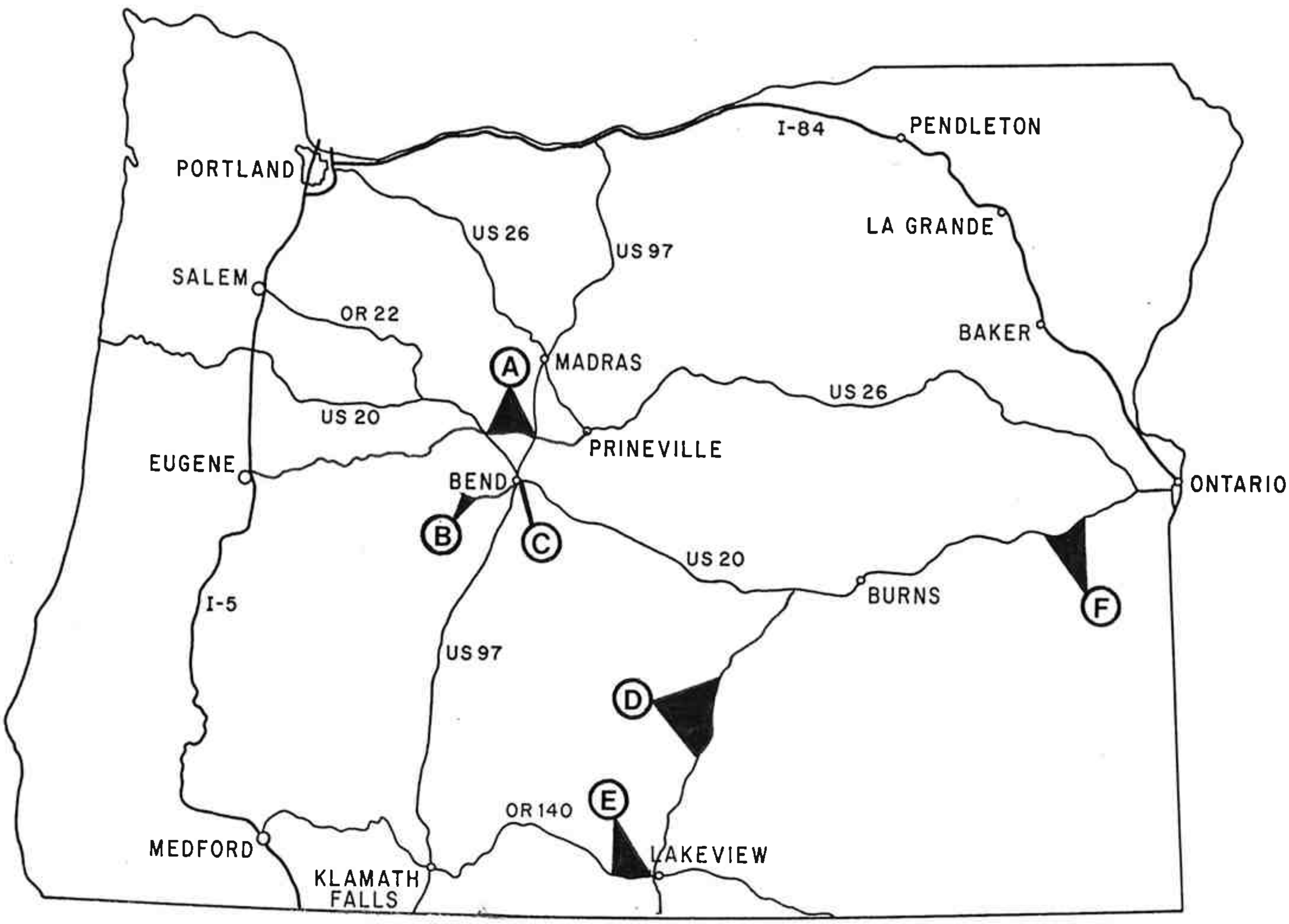
In 1985, Oregon first attempted to use a formal mix design procedure for CIR (Table 2.3). This procedure was the existing Oregon standard open-graded emulsion mix procedure which is basically a modification of the hot-mix procedure.

Table 2.1. Projects Constructed in Oregon (1984-85)

Year	Highway	Project Name	Traffic Volume (ADT)	Length, Mi.	Depth of Cut, In.	Emulsion Type (Content)	Method of Construction	Chip Seal	Performance Spring 1987*
1984	OR 372	Sand Shed-Mt. Bachelor (Intermittent)	820	4.8	1-1/2	CMS-2S (1-2%)	State Forces, Class III treatment, Grader laid	Surface left open winter of 1984. Chip sealed in 1985	Fair to Good
	Misc.	Bend Area	up to 2000	8.0	1-1/2	CMS-2S (1-2%)	State Forces, Class III treatment, Grader laid	About 50% chip sealed	Fair to Good
1985	US 26	Sisters-Redmond	1450-8300	18.8	1-1/2	CMS-2S (1-2%)	Class II treatment	Chip seal placed on about 75% of work.	Fair to Good
	US 395	Harney Co. Line-Hogback Summit	220	30.7	1-1/2-2	CMS-2S** (1-2%)	Class I treatment	Entire section chip sealed	Fair to Good
	US 140	Drews Gap-Lakeview	1000	10.3	1-1/2-2	CMS-2S (1-2%)	Class I treatment	Entire section chip sealed	Good
	Misc.	Bend Area	up to 23,000	16.0	1-1/2-2	CMS-2S (1-2%)	Class I treatment	Surface left open	Good

*Pavements rated "Fair" after three years primarily exhibited thermal cracks. On those sections which were not sealed, cracking has reflected through the recycled mat. On sections which were sealed, map cracking has not appeared. It is estimated that 7% of the miles recycled will require some type of maintenance repair by 1988.

**HFE-150 and HFE-150s were also used, but only for test.



Unit	Unit Name	Year	Highway	Length (miles)	Mix Designs	Type of Work
A	Sisters-Redmond	1985	Mckenzie	18.8	3	Recycle-Partially Chip Sealed
B	Sand Shed-Mt. Bachelor	1984	Century Drive	4.8	0	Recycle-Chip Seal
C	Bend Area	1984	Varies	12.0	0	Recycle-Partially Chip Sealed
D	Harney Co. Line-Hogback Summit	1985	Lakeview-Burns	30.7	2	Recycle-Chip Seal
E	Drews Gap-Lakeview	1985	Klamath Falls-Lakeview	10.3	1	Recycle-Chip Seal
F	Harper Jct.-Vine Hill	1985	Central Oregon	15.8	1	Recycle-Overlay

Figure 2.1. Location Map for the 1984-85 Cold Recycling Projects.

Table 2.2. Cost Comparison with 2-Inch Overlay--1985 Contracts.

	Cold Recycle[1]	Overlay[2]	Difference
Cost per sq. yard	$1.20[3]	$4.00	330%
Cost/mile	$17,000	$94,000	550%
Tons processed/day	4,000	3,500	14%
Miles/day	4	2-1/2	160%
Cost/15 mile project	$255,000	$1,410,000	$1.15 million

[1]Based on 2-inch depth, 24-ft wide
[2]Based on 2-inch overlay, 40-ft roadway
[3]Cost without seal; $1.85 with chip seal, $1.40 with sand seal

Table 2.3. Mix Design Procedure Used for 1985 CIR Projects

1) Determine gradation of millings from reclaimed asphalt pavement (RAP).
2) Extract asphalt using hot reflux and recover asphalt using modified Abson procedure and determine penetration at 77°F, kinematic viscosity at 275°F, and absolute viscosity at 140°F.
3) Determine percent asphalt in the RAP and gradation of the aggregate after asphalt extraction.
4) Determine mix design moisture content that would provide saturated surface damp (SSD) millings.
5) Make 4 trial mixes by varying the emulsion content (1,2,3 and 4%) increments while holding the water content constant. Record the coating (film) thickness for each emulsion content.
6) Place mix in bread pan at 77°F for 24+ hours.
7) Place mix in compaction mold at 77°F and apply 20 tamping blows at 250 psi pressure and then compact with 150 blows at 500 psi pressure.
8) Cure compacted specimen at 140°F for 15 to 24 hours in mold.
9) Determine 1st Hveem stability at 77°F and bulk specific gravity.
10) Return specimen to mold and compact using 1000 psi static load and determine 2nd Hveem stability at 140°F and bulk specific gravity.
11) Return specimen to mold and cure at 240°F for 3 to 4 hours and continue compaction with 150 blows at 500 psi pressure.
12) Determine 3rd Hveem stability at 140°F and bulk specific gravity.
13) Determine Rice specific gravity and percent voids.
14) Determine dry and wet unconfined compressive strength by AASHTO T165 procedure and calculate Index of Retained Strength.

The design criteria used for the 1985 projects were:

Film thickness	sufficient-thick
Stability	
After 1st compaction at 77°F	> 20
After 2nd compaction at 140°F	> 10
Voids after 2nd compaction	5-8%
IRS 60% min	
Modulus Ratio	not used

Using the mix design criteria given above, the recommendations shown in Table 2.4 were given to the field personnel. However, these values were sometimes adjusted in the field to improve laydown and compaction, or reduce tenderness and/or flushing.

2.2 Comparison with other Mix Design Procedures

In reviewing Oregon's mix design procedure with those currently being used by other agencies (Appendix A), the preliminary evaluations on millings are found to be similar, but significant differences exist in the various methods used to: (1) determine the amount of recycling/reclaiming agents to be added, (2) cure the laboratory samples, (3) compact the sample, (4) evaluate the strength of the CIR mixes, and (5) evaluate the mixes for suitability. The significant differences are discussed in the following sections.

2.2.1 Estimating Amount of Recycling Agent

While the Chevron USA (6), Witco (7,8), NCHRP (9), and CALTRANS (10) procedures specify use of formulas to determine total asphalt demand in order to estimate needed amount of recycling/reclaiming agent, New Mexico (2), Pennsylvania (12), and Oregon simply use trial amounts of recycling agents to begin the mix design process.

Table 2.4. Summary of Mix Design Data (1985).

Project Name	Mix Design Recommendations		Actual Values Used	
	Water	Emulsion	Water	Emulsion
Sisters-Redmond	4.0	1.0	2-4	1-1/2
Klamath Falls-Lakeview #85-10209	3.0	1.0	2-4	1-1/2
Harney Co. Line-Hogback Summit 85-10210	3.0	1.0	2-4	1-1/2

Table 2.5. Summary of Curing Times and Test Temperatures Used by Selected Agencies.

Agency	Mix Design Method	Mixing Temperature	Curing Method & Temperature	Curing Time
California	Modified Hveem	Room Temp	Loose cure @140°F	16 hrs
Pennsylvania	Modified Marshall	140°F	Loose Cure @104°F	45 min
			Oven cure, @104°F compacted sample	3 days
New Mexico	Modified Marshall	Room Temp	Loose Cure @140°F	2 hrs
			Air Cure compacted sample	72 hrs
Oregon DOT (1985)	Modified Hveem	Room Temp	Loose Cure @77°F	48 hrs
			Oven Cure @140°F	15-24 hrs
			Oven Cure @240°F	15-24 hrs

2.2.2 Curing Time and Curing Temperatures

The differences in curing times and curing temperatures for laboratory-prepared samples have been a major cause of concern in cold recycling mix design (see Table 2.5). California cures at 140°F and 230°F* for 16±1 hours before determining stability values (10,11); Pennsylvania cures for 72 hours in a forced draft oven at 104°F before determining modulus and Marshall stability, while New Mexico warms the specimen in a 140°F oven for 2 hours, compacts, and air cures for 72 hours before conducting compression tests.

Oregon's initial design efforts used a 24-hour cure at 77°F before 1st stability and a second cure in the mold at 140°F for 15 to 24 hours, which is compatible with that of the California procedure. However, the third curing period of 240°F for 3 to 4 hours is probably unrealistic for the initial pavement strength because the recycled mixes are not subjected to these temperatures. The third cure is intended to represent ultimate strength for the mix after several months of pavement cure. When considering curing temperatures, Chevron researchers (13) have stated that "asphalt emulsion mixes should be made and tested at ambient rather than at elevated temperatures as most asphalt emulsion cold mixes do not encounter elevated temperatures during their construction or service life," and "only where the asphalt emulsion mix acts as a wearing surface should it be tested at 140°F." Therefore, curing at ambient temperatures or at a temperature that would more closely approximate the average temperature of a 2 to 3 inch recycled mixture during hot weather would seem best. Also, sufficient curing time, possibly 7 days at ambient temperature or about 4 days at the average hot weather pavement temperature, needs to be provided prior to measuring stability values. Values obtained

*Dropped to 140°F in 1986.

after this cure period will be significantly lower than values expected after six months to one year.

2.2.3 Compaction Effort (Laboratory Samples)

The compaction effort used to prepare laboratory samples also varies (Table 2.6). In 1985, Oregon used three stages of compaction, the first and third with 150 blows at 500 psi pressure, the second stage using a static leveling load of 1000 psi. California's procedure is similar to Oregon's, but uses a 1250 lb static leveling load. Pennsylvania changed from 50 to 75 Marshall blows because of indications in the field that the in-place densities were higher. New Mexico uses the 50 blow Marshall procedure.

2.2.4 Strength Tests

Table 2.7 summarizes the tests used to evaluate CIR mixtures. California relies on Hveem stability, and New Mexico on the compression test for strength evaluation. Pennsylvania combines Marshall stability and resilient modulus, while Oregon uses Hveem stability and compressive strength tests (IRS). For Oregon, the preliminary results of the Hveem stability test indicate a need to revise the test temperatures that would approximate initial field conditions. However, it has been observed that the index of retained strength (IRS) values derived from compressive strength ratios of saturated-to-dry samples of recycled mixtures are not as reliable as the resilient modulus ratios. In 1986, Oregon replaced IRS testing with resilient modulus ratio for freeze-thaw conditioned and unconditioned test results. It may, therefore, be more appropriate to use resilient modulus (M_R) tests rather than compressive strength tests in the design process.

Table 2.6. Compaction Procedures Used to Prepare Lab Samples.

Agency	Method of Compaction	Compaction Effort	Compaction Temperature
California	Hveem	150 blows @ 500 psi	140°F
Pennsylvania	Marshall	75 blows/side	77°F
New Mexico	Marshall	50 blows/side	140°F
Oregon DOT (1985)	Hveem	1st-150 blows @ 500 psi 2nd-1000 psi leveling 3rd-150 blows @ 500 psi	77°F 140°F 240°F

Table 2.7. Mix Design Tests and Criteria.

Agency	Strength/Stability	Voids	Moisture Sensitivity	Others
California	Hveem >30	4% min.	None	None
Pennsylvania	Initial modulus	None	Retained modulus	Optimum density
New Mexico	Compressive strength	None	None	Optimum density and moisture levels
Oregon (1985)	Hveem @ 77°F>20 Hveem @ 140°F>10	5-8%	IRS>60%	Film thickness

2.2.5 Mix Design Criteria

To date, most agencies have no definite design criteria for cold in-place recycling. However, a few agencies have established design guidelines. The Asphalt Emulsion Manufacturers Association (AEMA)-recommended guidelines (14) suggested Hveem stability values above 25 to 30 or Marshall stability values of 500+, voids between 2 and 8%, with 50% coating for cold mix designs. CALTRANS also specifies Hveem S-values of above 25 and 30, and minimum voids of 4%, while Chevron USA recommends a minimum value of 30. Since Oregon had no experience with recycled cold mix prior to 1985, their design criteria was somewhat arbitrary and only served as design guidelines. Definite design criteria need to be established so that mix designs would be based on satisfying requirements for stabilities, voids, and modulus ratios.

2.3 Evaluation of Thickness Design Methods

Numerous thickness design procedures have been developed that are capable of considering the load-carrying capability of cold in-place recycled pavements. Because of their widespread acceptability and use, either the AASHTO (15) or Asphalt Institute (16) methods can be adopted for cold recycling. A summary of the two methods and that of the Chevron USA procedure are in Appendix A. A summary of typical AASHTO structural layer coefficients obtained by Epps et al., (9) from a variety of recycled pavement test sections is also included in Appendix A.

It should be noted that the projects constructed in Oregon during the period 1984-85 did not involve a structural design. It was felt that the CIR was used primarily to preserve the existing pavement structure (e.g., trying to repair that currently in place to the highest strength possible). As a result, the need for structural coefficients in these applications is questionable. However, if cold recycled pavements were used in new construction or in reconstruction, the determination of a structural coefficient would be an appropriate task. The final report on the 1986 Oregon work will provide a better basis for determining the appropriate coefficient.

2.4 Significant Findings and Identified Research Needs

Oregon's experience on the projects completed during 1984-85 indicates that with the proper emulsion/water content and normal compactive effort, a durable recycled mixture can be achieved if the surface is sealed. However, a number of findings and research areas were identified in 1985 that led to the need for this research effort. These findings are discussed below.

2.4.1 Recycling Agents

A variety of materials have been used as recycling agents throughout the United States. These include:

1) conventional emulsions--normally slow setting or medium setting,
2) high float emulsions--with or without additives,
3) emulsified recycling agents identified by the West Coast User Producer Conference, and
4) rejuvenating agents.

The work performed in Oregon during the period 1984-85 utilized predominately conventional emulsions (CMS-2S) or high float emulsions (HFE 150). Typical specifications for these materials and the emulsified recycling agents are given in Table 2.8.

The work completed during the 1984-85 period definitely indicated a need to develop a better procedure to select the type and amount of recycling

Table 2.8. Typical Specifications for Recycling Agents.

Test	CMS-2S	HFE-150	ERA's
Viscosity, @ 77°F, SFS			15-85
Viscosity, @ 122°F, SFS	50-450	50 min	-
Settlement, 5 day %	5 max	-	-
Storage stability, 24 hr, %	1 max	1 max	-
Pumping stability			Pass
Coating ability			
Dry aggregate	Good	Good	-
Wet aggregate	Fair	-	-
Particle charge test	Positive	-	Positive
Sieve test, %	0.10 max	0.10 max	0.10 max
Oil distillate by volume, %	20 max	7 max	-
Residue, %	60 min	-	60 min
Tests on residue			
Pen @ 77°F, dm	100-250	150-300	-
Ductility @ 77°F, cm	40 min	-	-
Solubility in Trichlorethylene, %	97.5 min	-	-
Float test @ 140°F, seconds	-	1200	-

agent. For example, excess emulsion content contributed to tender mix and flushing problems. Too little emulsion often contributed to early raveling.

2.4.2 RAP Gradation (1985)

Findings indicate that many factors affect the gradation of the RAP millings. These factors and their effects are summarized in Table 2.9. The most important factors include type and amount of distress, type of mill, and type of aggregate in mixture.

2.4.3 Void Content (1985)

A significant finding from work completed was the high void content (8 to 15%) in the compacted recycled pavement. The effect of these high voids on long term mix performance is not yet clear. Additional research is needed to evaluate its potential effect on pavement performance.

2.4.4 Cure Time and Temperature for Laboratory-Prepared Samples (1985)

Additional study is required to evaluate the effect of time and temperature of cure on the stability and modulus of recycled asphalt mixes. This work is especially important in the development of an improved mix design procedure for cold recycled mixtures.

2.5 Summary

This chapter has reviewed Oregon's CIR program for the 1984 and 1985 constuction seasons. It also identified special research needs for the 1986 program which are addressed in the remaining chapters of this report.

Table 2.9. Factors Affecting Gradations of Millings.

Item	Effect
Type and amount of distress	• Badly distressed areas produce larger chunks which require crushing
Pavement temperature	• Distressed areas-coarser with increasing temperature • Non-distressed area-minimum effect
Milling spread	• Slower speeds produce finer millings
Type of mixture	• Macadam mixes produce open gradations • Dense mixes produce finer gradations
Type of mill	• Train (up cut)-coarser gradation • Single unit (down cut)-finer gradation • Number of teeth-closer spacing produces finer gradation
Type of aggregate in mix	• Sand and gravel mixes produce finer gradation than aggregate with 100% fracture

3.0 PRELIMINARY ENGINEERING PERFORMED ON 1986 PROJECTS

In order to develop an improved understanding of the relationship between mix design and field performance, an experimental program was initiated in the summer of 1986. The general objectives of the study program were to:

1) develop an improved mix design procedure and structural layer coefficients,
2) develop improved field control procedures and specifications, and
3) document unit costs.

This was to be accomplished during the construction of 12 projects in central Oregon.

3.1 Location of 1986 Projects

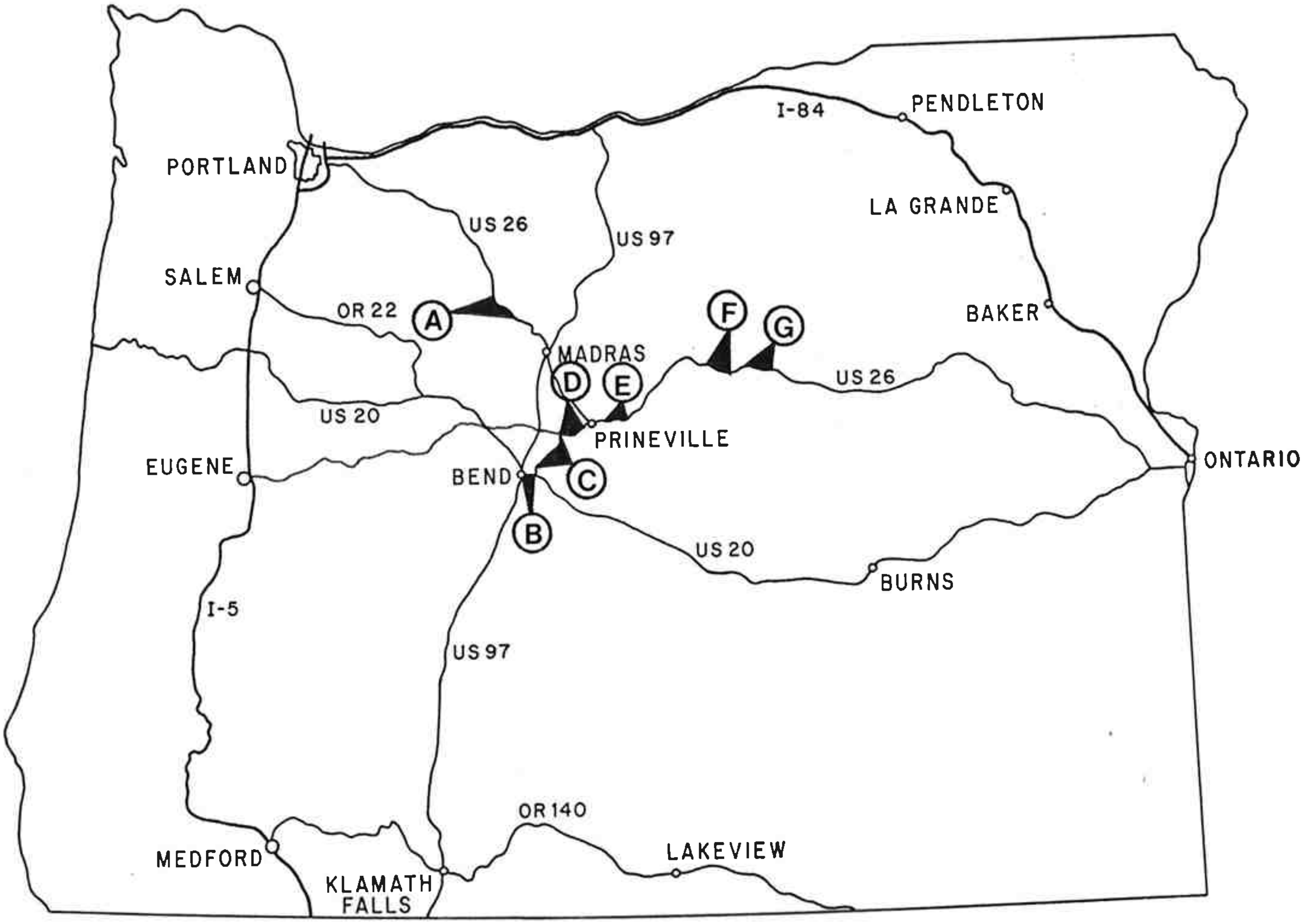
The cold recycling program for 1986 was comprised of two separate contracts:

1) Region 4 projects involving 7 units--The location of these projects is shown in Fig. 3.1.
2) Districts 10 and 11 projects involving 6 units--The location of these projects is shown in Fig. 3.2.

Special studies were conducted on the Warm Springs Highway project (Unit A, Fig. 3.1), and the Lake of the Woods project (Unit B, Fig. 3.2). Tables 3.1 and 3.2 summarize the variables considered.

3.2 Existing Pavement Condition and Traffic Data

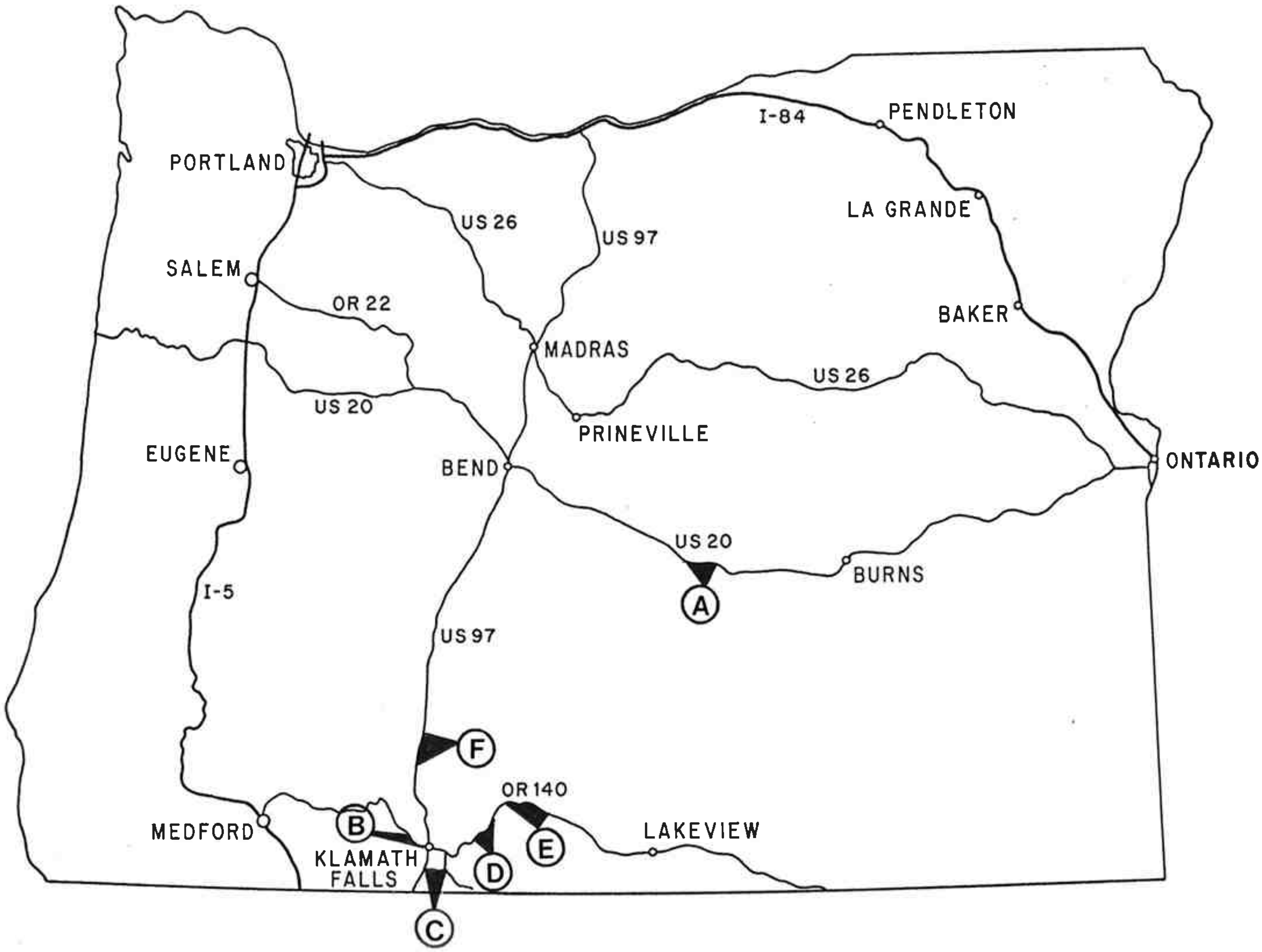
Prior to construction, each of the units was carefully evaluated using ODOT's standard pavement condition rating method (Appendix B). Table 3.3 summarizes the ratings for each project while Figs. 3.3 and 3.4 give typical photos of each unit.



Unit	Unit Name	Highway Name	Length (Miles)	Number[1] of Mix Designs	Type of Work
A[2]	MP 79.2-Wasco Co. Line	Warm Springs	17.3	4	Recycle-Chip Seal
B	Bend 12th St.-Powell Butte	Central Oregon	3.2	2	Recycle-Sand Seal
C	MP 18.00-Powell Butte	Powell Butte	18.0	2	Recycle-Chip Seal
D	Powell Butte-Prineville	Ochoco	9.8	3	Recycle-Sand Seal
E	Ochoco Dam-MP 35.0	Ochoco	10.6	4	Recycle-Chip Seal
F	MP 73.4-MP 81.6	Ochoco	8.2	2	Recycle-3" Overlay
G	MP 89.6-Jct. Ore. 19	Ochoco	8.7	1	Recycle-Chip Seal

[1]Based on file search and field investigation prior to contract.
2Unit with special test section

Figure 3.1. Location Map and Description of Region 4 (District 10) Recycle Projects--1986.



Unit	Unit Name	Highway Name	Length (Miles)	Number[1] of Mix Designs	Type of Work
A	MP 75.0-MP 84.0	Central Oregon	9.00	2	Recycle and 3/4" Oil Mat
B[2]	Lakeshore Dr.-Greensprings Jct.	Lake of the Woods	6.36	4	Recycle-Chip Seal
C	US 97-Ore. 39	Lower Klamath	7.00	1	Recycle-Chip Seal
D	Dairy-Ritter Rd.	Klamath Falls-Lakeview	6.00	2	Recycle-Chip Seal
E	Sprague River Rd.-Bly	Klamath Falls-Lakeview	17.78	1	Recycle-Chip Seal
F	MP 235.3-Spring Cr.	US 97	6.00	1	Recycle-Chip Seal

[1]Based on file search and field investigation prior to contract.
[2]Unit with special test section.

Figure 3.2. Location Map and Descriptions of Districts 10 and 11 Recycle Projects--1986.

Table 3.1. Variations of Recycled Depth and Emulsion Content on the Warm Springs Highway Test Section (Total Unit Length = 17.3 miles).

Recycled Depth (in.)	Emulsion Content %	Length of Section (ft)
2	1.0	500
2	1.6	400
2	1.9	500
3	1.0	1,000
3	1.3	400
4	1.0	1,000
	Total	3,800

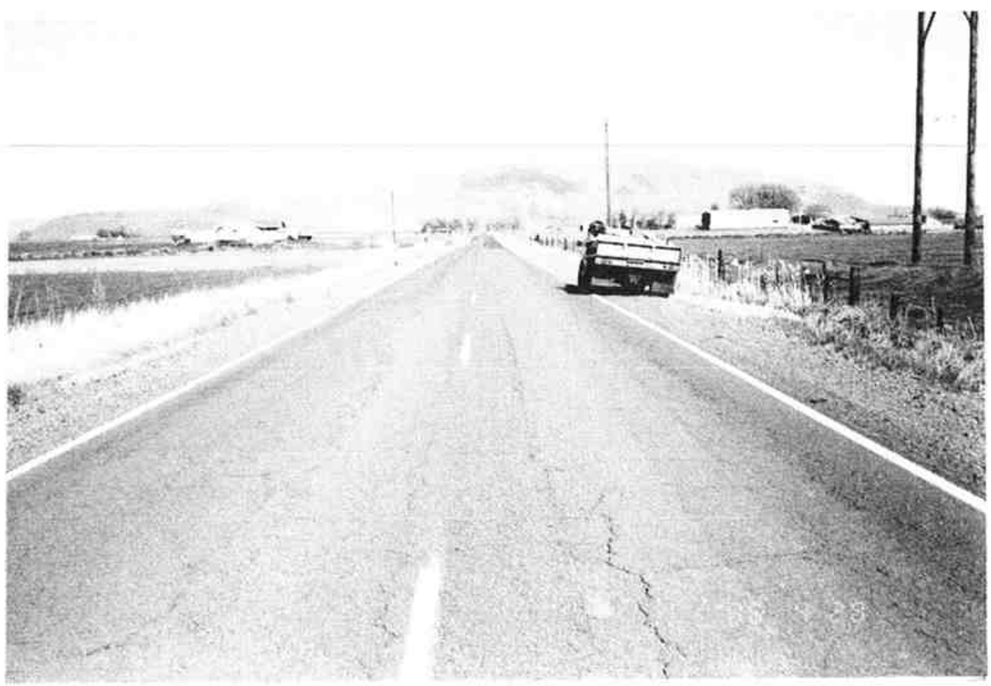
Table 3.2. Variation of Recycled Depth on Lake of the Woods Highway Test Section (Total Unit Length = 6.36 miles).

Recycled Depth (in.)	Length of Test Section (ft.)
2-1/4	1,000
3	1,000
4	1,000
Total	3,000

Table 3.3. Summary of Pavement Evaluation -- 1986 Projects.

Unit	Name of Section	Lower Rating	Higher Rating	Average Rating	General Information
		a) Region 4 Recycle Projects			
A	MP 79.2- Wasco Co. Line	Very Poor	Poor	Poor	Thermal cracks spaced 20-30 ft
B	Bend 12th St.- Powell Butte	Very Poor	Poor	Poor	Poor ride quality
C	MP 18.0- Powell Butte	Very Poor	Poor	Very Poor	Thermal cracks spaced 10 ft
D	Powell Butte- Prineville	Very Poor	Fair	Poor	Alligator cracks
E	Ochoco Dam- MP 35.0	Poor	Fair	Poor	Thermal cracks spaced 20-50 ft
F	MP 73.4- MP 81.6	Poor	Fair	Poor	Delamination between lifts
G	MP 89.6- Jct. Ore. 19	Poor	Fair	Poor	Thermal Cracks spaced 20-30 ft
		b) Districts 10 and 11 Recycle Projects			
A	MP 75.0- MP 84.0	Poor	Poor	Poor	Delaminated with ruts, flushed pavement
B	Lakeshore Dr.- Greensprings Jct.	Very Poor	Very Poor	Very Poor	Alligator cracks, potholes
C	US 97-Ore. 39	Poor	Poor	Poor	Alligator cracks, thermal cracks
D	Dairy - Ritter Rd.	Poor	Poor	Poor	Thermal and alligator cracks
E	Sprague River Rd.- Bly	Poor	Poor	Poor	Thermal cracks spaced 15-30 ft
F	MP 235.3- Spring Creek	Very Poor	Poor	Very Poor	Flushed with stripping asphalt

a) Warm Springs Highway, Unit A (Rated "Poor")



b) Ochoco Highway, Unit E (Rated "Very Poor")

Figure 3.3. Typical Photos of Region 4 Projects Before Construction.

a) Central Oregon Highway, Unit A (Rated "Very Poor")

b) Lower Klamath Highway, Unit C (Rated "Poor")

Figure 3.4. Typical Photos of Districts 10 and 11 Projects Before Construction.

Traffic data for each of the units are summarized in Table 3.4. It is interesting to note that the ADT on the projects varied from around 600 to 5000, while the traffic coefficient varied from about 7.0 to 10.0.

3.3 Deflection and Ride Data (Before Construction)

Prior to construction, several of the units were tested for surface deflection and ride. Surface deflection measurements were measured using the OSHD research Dynaflect. For each section within a unit, a minimum of 11 measurements were taken every 50 ft in each direction. Table 3.5 summarizes these deflection values.

Before ride data were recorded using the Mays trailer. For each unit, the Mays roughness was measured throughout the project length. Table 3.5 summarizes these results.

3.4 Existing Materials

During April and early May, 1986, samples of reclaimed asphalt pavement (RAP) were obtained using a small 16-in. mill (see Fig. 3.5). Three hundred-lb samples from each mix design section within a project were submitted to the Materials Laboratory for evaluation prior to the award of the recycle contract. The laboratory combined samples* for each mix design section. Using hot reflux extraction and a modified Abson recovery procedure, the asphalt content and asphalt properties (kinematic viscosity @ 275°F, absolute viscosity @ 140°F, and penetration @ 77°F) were determined for each mix design area and test section. The as-received and extracted RAP gradations were also determined for each sample.

---

*Combining samples proved to be a mistake as it eliminated the opportunity to determine the degree of uniformity, or nonuniformity, to be expected within a unit.

Table 3.4. Traffic Data -- 1986 Projects.

Unit	Unit Name	Highway	1985 ADT	% Heavy Trucks	10 Year Traffic Coefficient	Annual ESAL
		a) Region 4 Projects				
A	MP 79.2-Wasco Co. Line	Warm Springs	2850	14.5	9.1	98,300
B	Bend 12th St.-Powell Butte	Central Oregon	4800	6.1	8.4	50,100
C	MP 18.0-Powell Butte	Powell Butte	2200	5.2	7.2	13,400
D	Powell Butte-Prineville	Ochoco	3600	16.9	8.7	68,600
E	Ochoco Dam-MP 35.0	Ochoco	1100	21.4	8.5	55,600
F	MP 73.4-MP 81.6	Ochoco	600	37.0	8.5	54,900
G	MP 89.6-Jct. Ore. 19	Ochoco	600	37.0	8.5	54,900
		b) Districts 10 and 11 Projects				
A	MP 75.0-MP 84.0	Central Oregon	1000	14.0	8.0	33,300
B	Lakeshore Dr.-Green Springs Jct.	Lake of the Woods	1750	18.9	8.5	59,300
C	US 97-Ore. 39	Lower Klamath	800	9.2	6.8	9,400
D	Dairy-Ritter Rd.	Klamath Falls-Lakeview	2000	13.4	8.4	51,800
E	Sprague River Rd.-Bly	Klamath Falls-Lakeview	2700	2.7	7.2	14,000
F	MP 235.3-Spring Cr.	U.S. 97	3400	30.8	10.3	291,300

Table 3.5. Summary of Before Deflection and Ride Data -- 1986 Projects.

Unit	Name	Hwy	Average Deflection (mils)	Overall Rating Pavement	Overall Rating Subgrade	Avg. Ride m/Mile*	Ride Rating*
	a) Region 4 Projects						
A	MP 79.2-Wasco Co. Line	53	0.56-0.74	ok to weak	good	72	smooth
C	MP 18.0-Powell Butte	371	1.60	weak	good	164	rough
D	Powell Butte-Prineville	41	1.76	weak	good	162	rough
E	Ochoco Dam-MP 35.0	41	1.75	weak	poor	-	-
F	MP 73.4-MP 81.6	41	-	-	-	162	rough
G	MP 89.6-Jct. Ore. 19	41	1.79	weak	poor	116	slightly rough
	b) Districts 10 and 11 Projects						
A	MP 75.0-MP 84.0	7	1.80	weak	good	184	rough
B	Lakeshore Dr.-Greensprings Jct.	270	1.27	weak	good	68	smooth
C	US 97-Ore. 39	423	1.64	weak	good	91	average
D	Dairy-Ritter Rd.	20	2.09	weak	good	130	slightly rough
E	Sprague River Rd.-Bly	20	2.25	weak	good	137	slightly rough

*Both directions

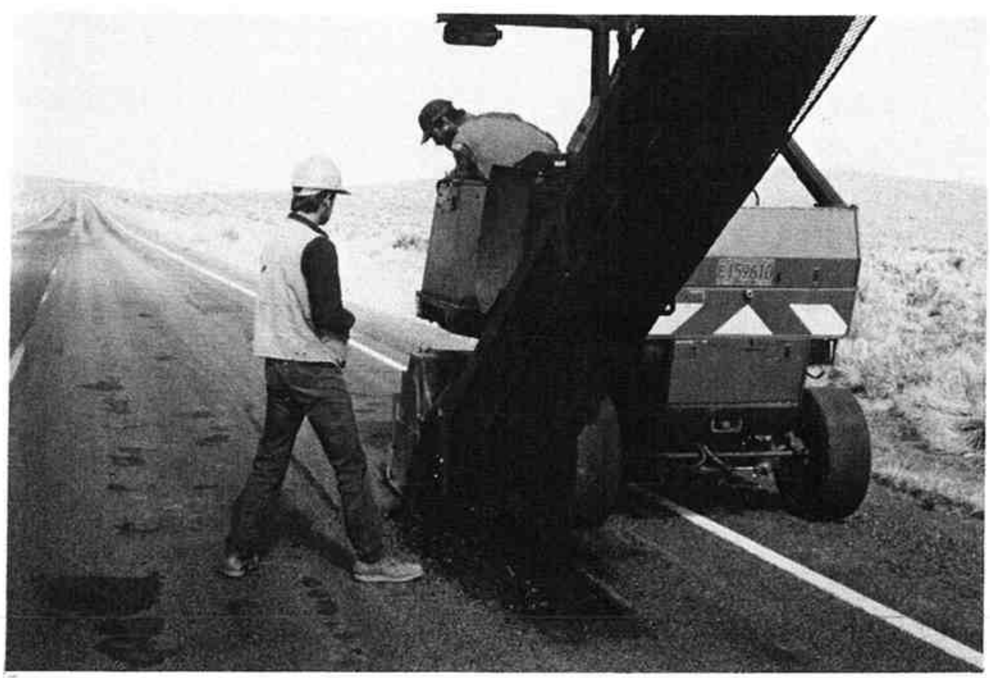


Figure 3.5. Sampling Existing Pavements.

Table 3.6 summarizes the properties of the millings. Items of interest are as follows:

1) There was considerable variation in asphalt content and gradation between mix design sections for most projects. This demonstrates the need to predetermine mix design sections within a project.

2) The kinematic viscosity of the recovered asphalt ranged from around 500 to 3000 cs.

3) The absolute viscosity of the asphalt (in poises) varied from a low of 2693 to a high in excess of 100,000. Values less than 10,000 poises would be considered to be typical of a new pavement, while values in excess of 100,000 would be considered to be typical of a highly oxidized material.

4) Penetration values varied from a low of 2 to a high of 90, with the majority falling in the 10 to 30 range.

3.5 Mix Design Guidelines (1986)

Because of the concerns discussed in Chapter 2 regarding the 1985 mix design procedure for cold in-place recycling, revised mix design guidelines were developed for the 1986 projects. A summary of the guidelines is given in Table 3.7.

The Materials Section prepared preliminary mix designs for each project unit, with most units requiring more than one mix design. The initial mix design criteria recommended for the projects are included in Table 3.8. These criteria were employed in all projects during the first half of the summer of 1986 (all projects in Districts 10 and 11 and Units F and G of Region 4). As the work progressed, experience on several 500 to 1000 ft. test sections indi-

Table 3.6 Properties of Existing Pavement Materials (1986 Projects).

(a) Region 4 Projects

Unit	A						B		C		D			E			
Mix Design Area	1	2	3	4	1*	2*	1	2	1	2	1	2	3	1	2	3	4
Extracted Asphalt Properties:																	
Asphalt Content %	5.5	5.8	6.3	5.3	5.4	5.7	6.9	5.3	7.2	7.8	5.8	6.4	6.7	4.8	5.2	5.8	5.1
Kinematic Viscosity (cs)	907	736	681	1600	852	374	480	1030	689	628	727	874	1287	784	1524	849	1979
Absolute Viscosity (p)	25,828	11,469	11,694	83,437	18,067	2,693	5,109	31,633	17,884	14,325	18,763	28,678	39,227	18,284	16,151	26,811	100,000+
Penetration @ 77°F,dmm	14	25	26	7	15	90	34	14	27	16	15	12	13	23	15	21	12

Unit	A											
Mix Design Area	1		2		3		4		1*		2*	
Gradation: % Passing:	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	89	100	99	100	98	100	95	100	96	100	94	100
3/4-inch	85	100	96	100	96	100	91	100	88	100	90	100
1/2-inch	76	94	85	97	89	96	79	98	75	91	77	92
3/8-inch	66	85	73	91	82	88	69	90	61	80	62	82
1/4-inch	47	70	53	81	71	78	55	77	44	69	46	69
#4	37	60	42	72	62	70	46	67	33	60	36	61
#10	18	37	18	46	34	48	23	43	11	37	13	39
#40	5	20	5	24	8	24	6	20	1.7	19	2.2	20
#200	1.4	8.1	1.6	13.3	0.3	10.4	1.9	10.1	0.4	9.0	0.6	8.7

Unit	B				C				D					
Mix Design Area	1		2		1		2		1		2		3	
Gradation: % Passing:	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	99	100	98	100	98	100	100	100	95	100	97	100	94	100
3/4-inch	98	100	93	100	96	100	99	97	93	100	95	100	91	100
1/2-inch	91	99	83	98	80	87	83	89	89	97	89	98	82	96
3/8-inch	83	94	73	88	66	75	67	75	81	91	80	92	70	85
1/4-inch	65	85	56	75	53	63	50	60	68	77	61	79	51	69
#4	54	77	46	66	45	55	41	52	58	65	49	69	41	59
#10	24	54	22	44	28	40	24	36	30	40	21	44	19	36
#40	5	25	6	20	11	21	10	21	9	20	4	21	5	18
#200	0.9	11.3	1.5	7.6	1.6	5.0	1.8	6.7	1.5	8.2	0.9	9.2	1.2	6.7

Unit	E							
Mix Design Area	1		2		3		4	
Gradation: % Passing:	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	97	100	94	100	96	100	86	100
3/4-inch	95	97	92	100	92	100	84	100
1/2-inch	86	94	79	93	74	93	80	98
3/8-inch	71	83	65	79	57	76	67	84
1/4-inch	52	69	48	63	39	57	48	68
#4	42	58	38	52	30	47	39	57
#10	21	36	18	32	13	28	19	35
#40	6	16	5	14	3	12	4	16
#200	1.2	5.4	0.9	5.4	0.4	4.7	0.6	6.5

(a) Region 4 Projects (Cont'd) / (b) Districts 10 and 11 Projects

Unit	(a) F		(a) G	(b) A		(b) B				(b) C	(b) D		(b) E	(b) F
Mix Design Area	1	2	1	1	1*	1	1*	2*	3*	1	1	2	1	
Extracted Asphalt Properties:														
Asphalt Content %	6.3	6.1	4.2	6.5	6.3	5.1	4.6	4.4	5.1	5.4	6.7	5.5	5.1	No Data Available (Emergency Repair)
Kinematic Viscosity (cs)	1069	486	1490	1089	1117	2379	2572	2920	1987	1756	596	1002	738	
Absolute Viscosity (p)	43,605	5,812	78,137	22,969	24,366	100,000+	100,000+	100,000+	100,000+	100,000+	11,953	69,133	22,925	
Penetration @ 77°F,dmm	10	37	15	27	26	2	4	4	5	6	16	5	13	

Unit	(a) F				(a) G		(b) A			
Mix Design Area	1		2		1		1		1*	
Gradation: % Passing	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	87	100	99	100	97	100	99	100	99	100
3/4-inch	81	98	92	96	92	100	98	100	98	100
1/2-inch	69	91	74	82	80	95	91	95	91	96
3/8-inch	54	80	49	56	67	84	81	89	83	88
1/4-inch	37	65	30	39	49	70	65	73	68	71
#4	28	54	22	31	40	59	54	62	57	62
#10	11	34	9	18	20	36	27	38	30	38
#40	3	17	2	10	6	17	7	20	10	20
#200	0.5	7.6	0.4	4.6	1.1	7.1	0.7	4.9	1.2	3.8

Unit	(b) B								(b) C	
Mix Design Area	1		1*		2*		3*		1	
Gradation: % Passing	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	100	100	98	100	84	100	93	100	98	100
3/4-inch	98	100	96	100	81	100	90	99	94	100
1/2-inch	93	97	89	95	74	93	83	93	83	96
3/8-inch	84	91	79	87	65	83	74	84	72	87
1/4-inch	68	79	61	71	50	68	57	70	54	70
#4	56	69	48	60	40	59	46	60	43	60
#10	26	42	21	35	18	35	21	36	21	38
#40	8	20	6	17	6	18	7	18	7	20
#200	2.3	4.7	2.0	4.4	2.0	4.9	1.8	5.1	1.8	4.0

Unit	(b) D				(b) E	
Mix Design Area	1		2		1	
Gradation: % Passing	RAP	EXT	RAP	EXT	RAP	EXT
1-inch	98	100	94	100	96	100
3/4-inch	96	100	92	100	94	100
1/2-inch	92	100	86	100	87	97
3/8-inch	83	97	75	93	78	90
1/4-inch	64	87	59	80	63	78
#4	51	77	47	68	51	67
#10	23	51	22	42	23	43
#40	6	25	7	22	6	20
#200	1.4	10.5	2.0	8.8	1.8	9.7

*Special Test Sections

Table 3.7. Initial 1986 Oregon Mix Design Guidelines for CIR (Revised Mid-Summer 1986).

1. Determine gradation of reclaimed asphalt pavement (RAP) millings.
2. Extract asphalt using hot reflux and recover asphalt using modified Abson recovery to determine penetration at 77°F, kinematic viscosity at 275°F, and absolute viscosity at 140°F.
3. Determine percent asphalt content in the RAP and gradation of aggregate after asphalt extraction.
4. Determine mix design moisture content to provide saturated surface damp condition.
5. Prepare trial mixes @ 1.0, 2.0, 3.0, and 4.0% CMS-2S emulsion based on dry weight while holding the moisture content obtained in (4) constant.
6. After mixing for 2 minutes, place mix is bread pan and cure in the oven for 15 hours @ 140°F.
7. Place mix in compactor and apply 20 tamping blows at 250 psi and then compact with 150 blows at 500 psi.
8. Cure compacted specimen at 140°F for 24 hours in the mold.
9. Determine 1st Hveem stability @ 77°F and bulk specific gravity.
10. Return specimen to mold and compact specimen using 1000 psi static load and determine 2nd Hveem stability at 140°F and bulk specific gravity.
11. Return sample to mold and cure sample at 240°F for 3 hours and continue compaction with 150 blows at 500 psi.
12. Determine 3rd Hveem stability at 140°F and bulk specific gravity.
13. Determine Rice specific gravity and percent voids.
14. After 1st compaction of resilient modulus specimens, put samples in air bath at 77°F for 24 hours and determine unconditioned resilient modulus.
15. Vacuum saturate samples for 30 minutes at 27 inches of Hg, rest samples for 30 minutes, and place in 77°F water bath for 3 hours, and then determine saturated resilient modulus.
16. Vacuum saturate for 30 minutes, double wrap sample, and place in freezer for 15 hours; remove and place in 140°F. bath for 30 minutes, remove wrapping, and re-place sample in 140°F bath for 24 hours; place in 77°F bath for 3 hours, and then determine freeze-thaw resilient modulus.
17. Determine index of retained modulus after vacuum saturation and after one freeze-thaw cycle.

Table 3.8. Mix Design Criteria for 1986 Projects.

Item	Criteria
a) Initial Criteria	
1) Film thickness	Sufficient
2) Coating	70% min
3) Moisture	Surface Damp
4) Void content after:	
1st stability	6-10%
2nd stability	5-8%
3rd stability	1-3%
5) Unconditioned Resilient Modulus (M_R)	150,000 psi min
6) M_R Ratio (vac. sat.)	.70 min
7) M_R Ratio (freeze-thaw)	.50 min
b) Revised Mix Design Criteria	
1) 2nd stability	10 minimum
2) Void content after 3rd stability	4-6%
3) Film thickness	Dry-sufficient (60% coating)
4) Minimum emulsion content	1%

Table 3.9. Recommended Emulsion and Water Contents (1986 Projects).

Unit	Number of Mix Designs	Emulsion Content %	Water Content %
a) Region 4 Projects			
A	6	1 to 2.5	2 to 4
B	2	1 to 1.5	3 to 4
C	2	1	3 to 5
D	3	1 to 2	4 to 5
E	4	1.5 to 2.5	3 to 5
F	2	2 to 3	2.5
G	1	3	2.5
b) Districts 10 and 11 Projects			
A	2	2 to 2.5	3
B	4	2.5 to 3.5	4
C	1	3.5	5
D	2	2 to 3	3
E	1	3	4
F*	-	-	-

*Emergency repair. No mix design performed.

cated that the emulsion contents and/or water content used in construction or recommended from the mix designs were higher than desirable and resulted in unstable mixtures. This necessitated a review of the preliminary 1986 mix design criteria. The revised criteria are also included in Table 3.8. Units F and G of Region 4 and all the projects in Districts 10 and 11 were completed before the revised criteria were established. Units A through E of Region 4 were constructed using the revised criteria.

Table 3.9 is a summary of the preliminary mix design results. The recommended emulsion contents varied from project to project. For Region 4, Units A through D, the emulsion content varied from 1.0 to 2.5% with an average of 1.45%, while for Units E through G of Region 4 and the Districts 10 and 11 projects the emulsion contents recommended varied from 1.5 to 3.5% with an average of 2.53%. The water content ranged from 2.5 to 5.0%, with an average of 3.76% required on these projects. In a few cases, the voids were slightly higher than those specified in the design criteria. The unconditioned resilient modulus values were higher than the minimum 150,000 psi. Most of the mixes also met the minimum 70% modulus/vacuum-saturated modulus ratio criterion, but few of the mixes satisfied the minimum 50% modulus/freeze-thaw modulus ratio. Appendix C in Volume II of this report provides the detailed mix design data.

3.6 Problems with Mix Design Process

Considerable information about mix design was obtained from the cold recycling projects of 1986. In some cases, initial mix design effort resulted in emulsion contents which were too high. Mid-summer adjustments in mix design criteria corrected these problems. Recommendations for mix design guidelines for the 1987 program are developed in Chapter 5 of this report.

4.0 CONSTRUCTION PROCESS--1986 PROJECTS

In 1986, 155 centerline miles of pavements were recycled in Region 4. Of this amount, 135 miles were accomplished using the train process under contract with J.C. Compton, Portland, Oregon; the remainder was completed using state forces and the single unit mill. This chapter describes the construction processes used to accomplish this work, the field quality control test procedures and results, and actual cost data. The last section of the chapter evaluates the 1986 construction program.

4.1 Construction Procedures Used

Two methods of construction were employed. Valentine Construction Company was the subcontractor and used a specially designed "recycling train." This work would be classified as Class I or II treatments. The state maintenance crew, on the other hand, relied on the use of a "single unit" machine (Class I and II treatments). Each construction method is discussed below.*

4.1.1. Recycling Train

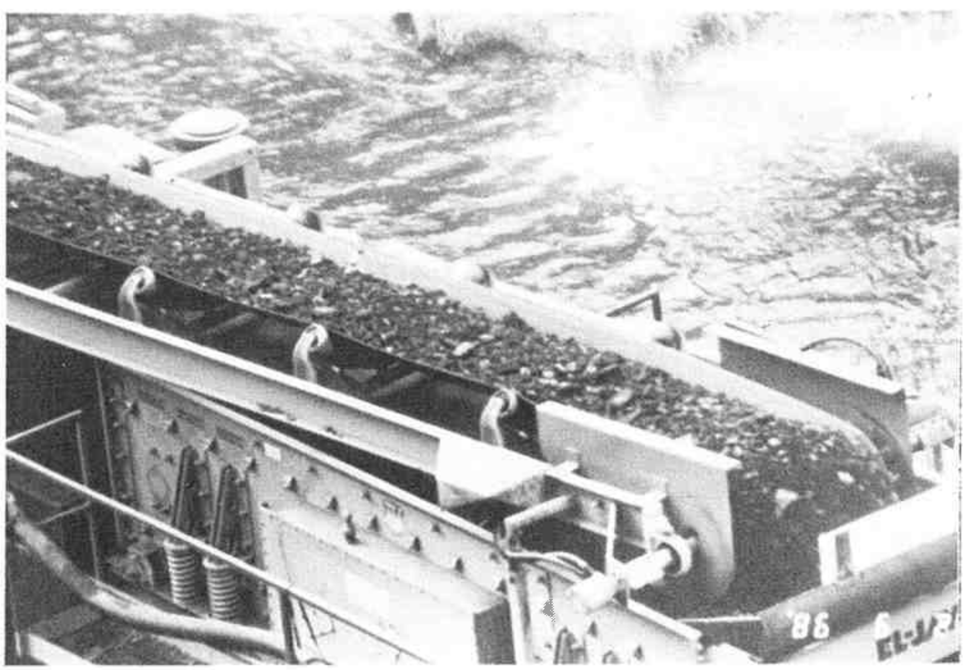
The train consisted of a water tank followed by a CMI 1000 upcut rotomill having a 12 ft-6-in. milling head. The mill pulled a trailer-mounted screen deck, roll crusher, and pug mill followed by a nurse tanker for the emulsion. Figure 4.1 shows an overview of this process.

The existing pavements were milled to depths of between 1-1/2 and 2-1/4 in. (normally 2 in.) and, for the special tests sections, to depths of up to 4 in. The millings were screened on a 1-1/2 in. screen and the oversized millings were crushed. A CMS-2S emulsion was added and mixed in the pug

---

*A 40-minute video of the construction process is available from the Research Section, Oregon DOT.

a) Overview of Process



b) RAP on Conveyor

Figure 4.1. Construction Process Using the Train Method.

mill. The mixture was deposited in a windrow on the roadway about 110 ft from where it was removed (Fig. 4.2). Tack was applied to the milled surface using a spray bar attached to the rear of the train. Laydown was accomplished with standard paving equipment (Fig. 4.3).

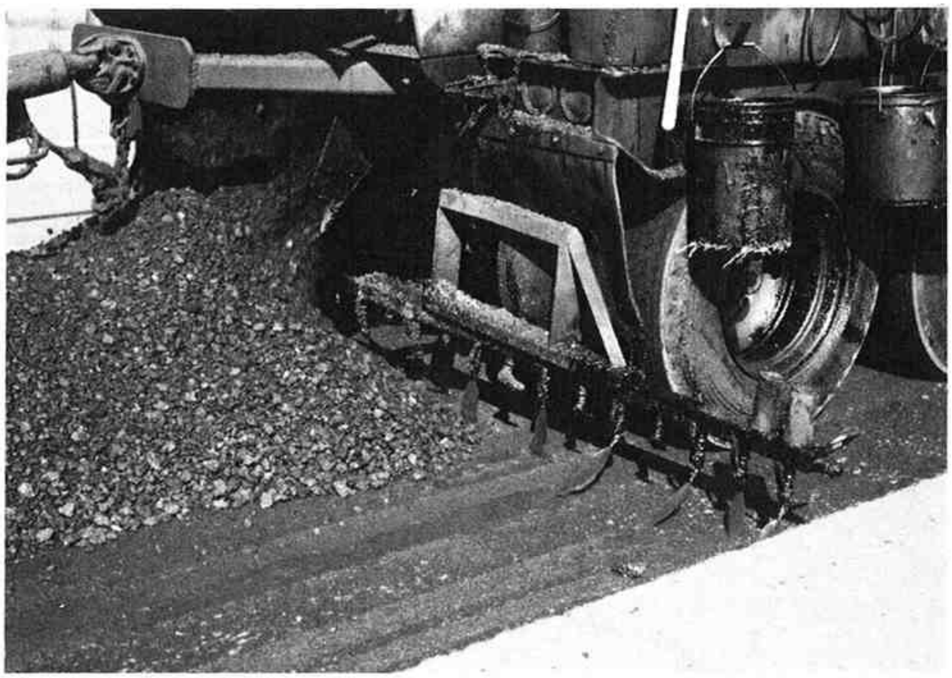
The train has controls to monitor the quantity of emulsion and water. To avoid difficulties in handling of the mixture, the paving machine was normally operated within 100 ft. of the train. After laydown, a two stage compaction was specified. The initial compaction was accomplished using a rolling pattern of one pass vibratory and one pass static with an Ingersoll Rand model DA-50 double drum vibratory roller, and one pass static using a Hyster model 15-7 tandem steel wheel roller. The mat was opened to traffic immediately following initial compaction. The second compaction followed within 3 to 7 days. This consisted of three passes of a RAYGO model C2A double drum roller in static mode and three passes of a Brothers 40,000 pneumatic roller (Fig. 4.4). The typical appearance of the compacted surface is shown in Fig. 4.5.

Following final compaction, the recycled pavement was normally covered with a 3/8-in. single chip seal using a CRS-2 or a polymer modified (HFE-150) emulsion. Three units were sealed with a sand seal. Fig. 4.6 illustrates the different types of seals.

Tables 4.1 and 4.2 summarize the water and emulsion contents used for each project as well as pertinent information on the construction process.

4.1.2 Single Train Unit

The single unit process involved the use of a downcut RAYGO Barco Mill 800. This unit has a 12-1/2 ft. milling head and was serviced by a water and emulsion tanker (Fig. 4.7). A modification was made to the unit to include a



a) Tack Application

b) Entering Pickup Machine

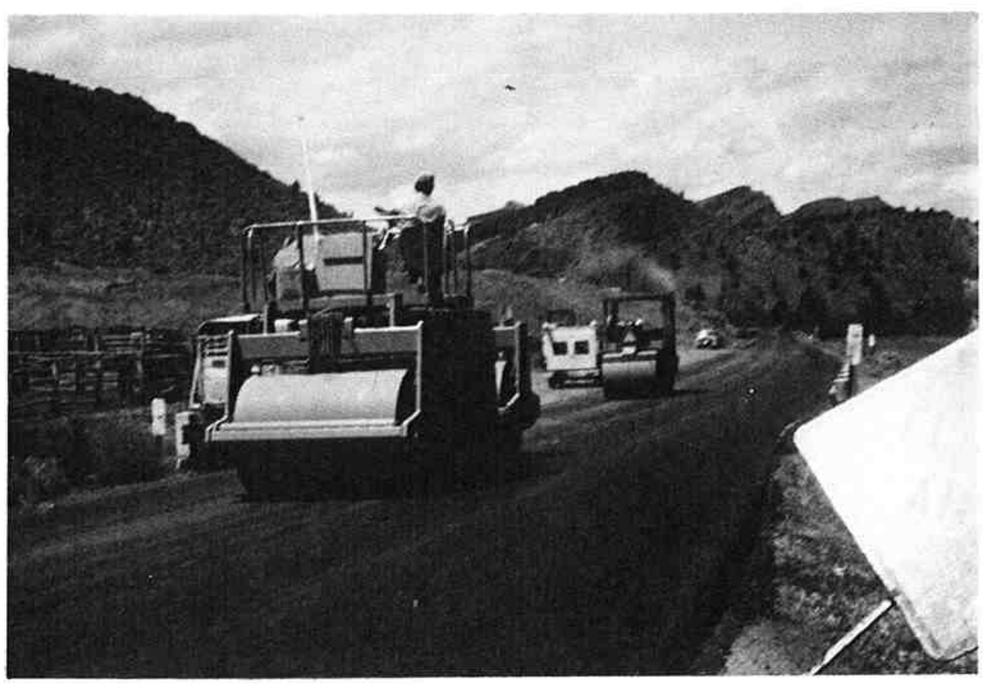
Figure 4.2. Cold Recycled Mix Prior to Laydown.

a) Laydown with Paving Machine

b) Mix Prior to Compaction

Figure 4.3. Placement of Cold Recycled Mix.

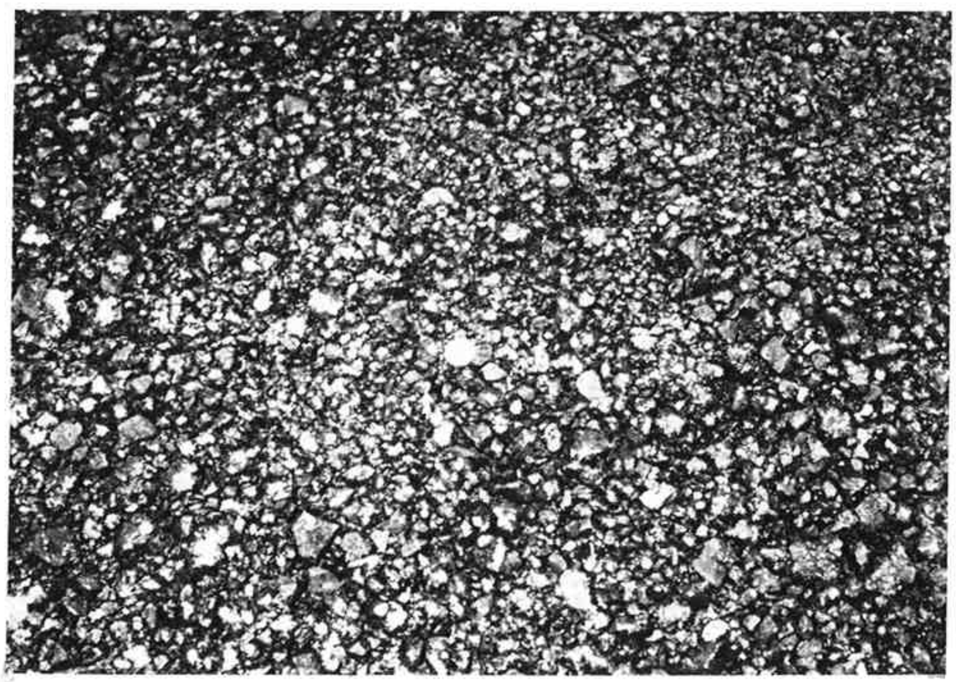
a) Initial Compaction



b) Final Compaction

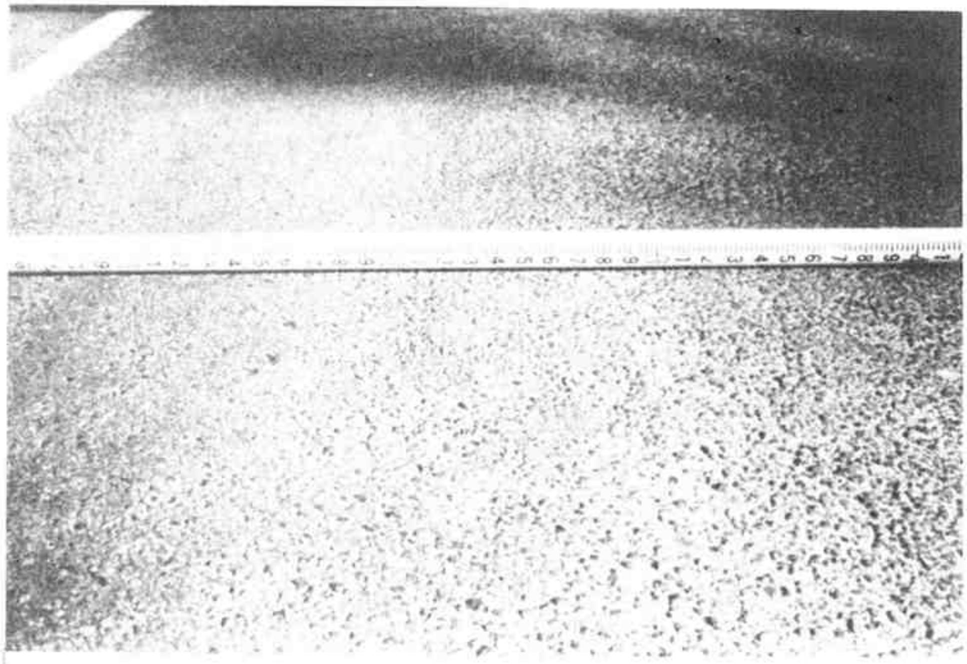
Figure 4.4. Compaction of Cold Recycled Mix.

a) After Initial Compaction

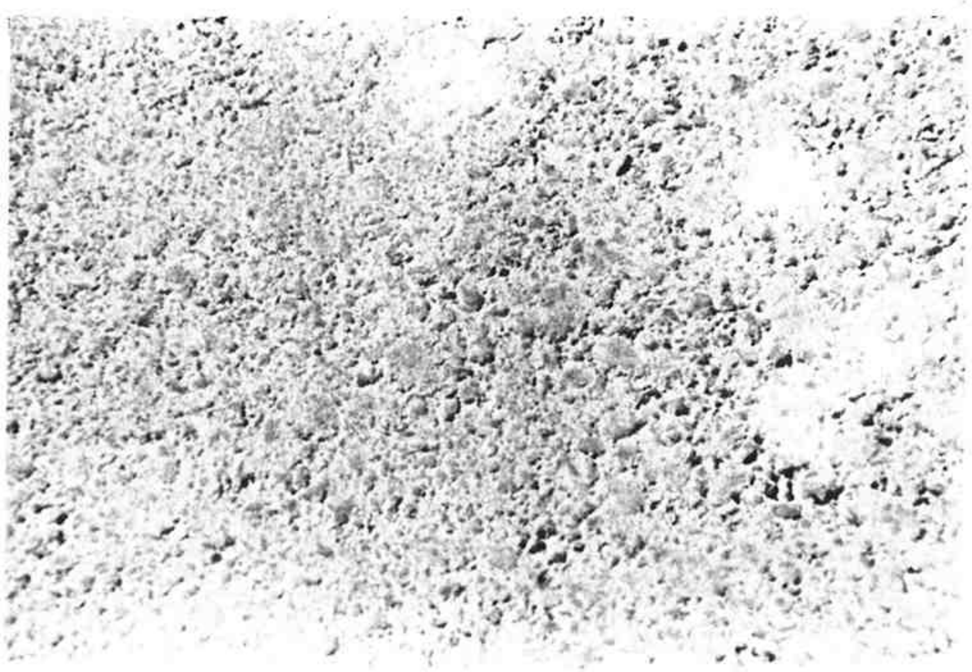


b) After Final Compaction

Figure 4.5. Appearance of Cold Recycled Mixes.



a) Chip Seal



b) Sand Seal

Figure 4.6. Finished Seal on Cold Recycled Mix.

Table 4.1. Comparison of Emulsion/Water Contents, Region 4 Recycle Projects.

Unit	Name	Initial Recommended %		Mid-Season Recommended %		Actual % Used		Construction Problems
		Emulsion	Water**	Emulsion	Water***	Emulsion	Water	
A-1	MP 79.2-	1.5	4.0	1.0	2.5	1.2	2.4	The mid-season mix design
2	Wasco Co. Line	1.5	4.0	1.0	2.5	1.3	2.4	criteria appeared to work
3		2.0	4.0	1.0	2.5	1.0	2.3	well. Project looks good.
4		2.5	4.0	1.5	2.5	1.9	3.0	
B-1	Bend 12th St.-	None	None	None	None	1.5	3.0	No problem.
2	Powell Butte	None	None	None	None	1.5	3.0	Looks good.
C-1	MP 18.0-	1.0	3.0	1.0	2.5	1.1	2.4	Thin section, no major pro-
	Powell Butte	1.0	5.0	1.0	2.5	1.3	2.7	blems. Paver sticking to mix due to hot weather. Increased emulsifier and cutter. Improved laydown.
D-1	Powell Butte-	1.0	4.0	1.0	2.5	1.1	2.3-3.0	Few areas of rough texture due
2	Prineville	1.0	5.0	1.0	2.5	1.1	2.3-3.0	to worn mill, cold weather and
3		2.0	5.0	1.0	2.5	1.1	2.3-3.0	rain. Surface not sealed prior to winter.
E-1	Ochoco Dam-	2.5	3.0	1.0	2.5	1.4	2.2	Macadam pavement found to be
2	MP 35.0	1.5	5.0	1.0	2.5	1.3	2.2	less than 1-inch thick in
3		2.0	3.0	1.0	2.5	1.1	2.2	several areas.
4		1.5	5.0	1.0	2.5	1.6	1.7	Few Problems.
F-1	MP 73.4-	3.0	2.5	*	*	2.6	2.8	Pavement flushed at initial
2	MP 81.6	2.0	2.5	*	*	1.8	2.8	mix design contents. No problem at 1.8%. Base failures required dig out and new base rock.
G-1	MP 89.6- Jct. Ore. 19	3.0	2.5	*	*	1.4-1.5	3.0	Minor ravelling occurred within the limits of sharp curves on this unit. Project looks good.

*Project completed before mid-season adjustment.
**Total water based on oven dry weights.
***Added water only. Does not include water already in RAP.

Table 4.2. Comparison of Emulsion/Water Contents, Districts 10 and 11 Recycle Projects.

Unit	Name	Initial Recommended %		Mid-Season Recommended %		Actual % Used		Construction Problems
		Emulsion	Water**	Emulsion	Water***	Emulsion	Water	
A-1	MP 75.0-	2.0	3.0	None	None	1.5	2.0-3.0	Severe flushing and rutting in test sections (500 ft) where 2.0, 2.5, and 3.0 emulsions used. Mix stable with no problems @ 1.5%.
3	MP 84.0	2.5	3.0	None	None	1.6	2.0-3.0	
B-1	Lakeshore Dr.-	3.0	4.0	1.4	2.0	1.4	2.4	Brittle asphalt with pen <5 caused surface ravelling for first 24 hrs. Required re-rolling. Follow-up tests after completion indicate emulsion content used was low.
2	Greensprings Jct.	3.5	4.0	1.0	2.5	1.5	2.3	
3		2.5	4.0	1.3	2.5	1.8	2.8	
4		2.5	4.0	1.5	2.5	1.9	2.6	
C-1	US 97-Ore. 39	3.5	5.8	*	*	1.5	2.2	Extraction results indicate emulsion content to be 2.2% No problems.
D-1	Dairy-	2.0	3.0	*	*	1.2	2.2	No problems.
	Ritter Rd.	3.0	3.0	*	*	1.9	2.2	
E-1	Sprague River Rd.-Bly	3.0	4.0	*	*	1.5	2.3	Changed crusher opening to allow coarser RAP. In 1/2 mile test section the 3% initial design emulsion was tried and resulted in severe rutting.
F	MP 235.3- Spring Cr.			No tests				

*Project completed before mid-season adjustment.
**Total water based on oven dry weights.
***Added water only. Does not include water already in RAP.

a) Milling and Mixing Operation

b) Processed Material

Figure 4.7. Single Unit Process.

spray bar for applying tack immediately ahead of the windrow. The unit was used on approximately 20 centerline miles of recycling projects with good results.

The only problem observed when using this unit occurred if the pavement was heavily alligator cracked which resulted in oversized pieces of RAP. On a majority of the work, the number and amount of oversize pieces of millings were no problem. A safety concern developed when the cutter "flashed" in the milling chamber due to the naphtha in CMS-2S. This was eliminated by allowing more air flow or using the high float emulsions such as HFE-150.

Laydown, rolling, and traffic control were no different than when using the train method. Emulsion and water are sprayed directly into the cutting chamber when using this process. Typical production rates were 2 lane-miles per day.

4.2 Field Control Procedures and Results

For the 1986 projects, field control was limited to the key areas of emulsion quantity and quality, added water, millings gradation, and compaction. The control procedures used for each of these properties are discussed below.

4.2.1 Emulsion Content and Quality

Three methods were used to monitor the quantity of emulsion added:

1) Field Inspection Reports (FIR). Throughout the day, the emulsion content was recorded (a minimum of three times) from gauge readings, and the quantity of reclaimed asphalt pavement (RAP) in tons was recorded from the belt scale. (These readings were actually monitored continuously.) The tons of RAP

and % emulsion were also estimated by calculating average spread as follows:

$$\text{Tons of RAP} = \frac{\text{Length x Treated Width x Treated Depth}}{2000}$$

$$\text{\% Emulsion} = \frac{\text{Tons of Emulsion Used x 100\%}}{\text{Tons of RAP}}$$

2) Equipment Controls. The daily % emulsion programmed into the train from the gallon meters on the recycle equipment vs. total tons of RAP processed was checked periodically.

3) Field Extraction of the Mixture. The % emulsion added was determined at least twice per day using this procedure. This proved to be the least desirable and accurate.

The emulsion used for recycling was sampled from each delivery and tested in the Salem laboratory to check its compliance with specifications.

4.2.2 Water Content

The water added to the mix was monitored by reading and recording the gallon meters on the train a minimum of three times per day. Meters were actually monitored continuously.

4.2.3 RAP Millings

The gradation of the millings was monitored daily during the recycling process by FIR. Specifications required that 98% of the millings pass the 1-1/2-in. screen. In the train method, 100% pass or the RAP is returned to the crusher. Laboratory tests were also performed on the millings to determine residual asphalt content (by extraction) and moisture content (convection oven) at least twice per day. Milling samples were tested for Rice gravity (AASHTO T-209). The mix, surface, and air temperatures were recorded whenever milling or mix samples were taken.

4.2.4 Compaction

Nuclear density tests were conducted once per lane-mile during the initial compaction and once per 0.3 lane-mile during the second compaction. The procedure used conformed to AASHTO T-238.

4.2.5 Field Control Results

Tables 4.3 and 4.4 summarize the results of the significant field control measures. Items of particular interest include:

1) The emulsion content from the meter reading indicated the added emulsion ranged from 1 to 2%.
2) Based on meter readings, the added water ranged from 1 to 3%; however, when oven dried, the moisture content ranged from less than 1 to about 5%. This difference could be attributed to the fact that the water in the emulsion was included in the latter measurement.
3) Initial compaction generally resulted in relative densities of 80 to 90% and voids ranging from 10 to above 20%. Final compaction increased the relative densities to 82 to 95% and decreased the voids to about 5 to 18%.
4) The millings obtained from the 150-in. mill were always coarser than those from the 16-in. mill used for laboratory mix designs.

4.3 Cost Data

Table 4.5 summarizes cost data for all the 1986 cold recycling projects. The unit cost of recycling without seal is about $1.29 per sq. yd. for a recycled depth of between 1-1/2-in. and 2-in. For a 24-ft wide roadway (2

Table 4.3 Summary of Field Control Results--1986 Projects.

Unit	Emulsion Content % Meter Reading	Water Added %		Initial Compaction				Second Compaction			
		Programmed	Oven dry	Bulk Density, pcf	Max Density, pcf	Mean Compaction %	Mean Voids %	Bulk Density pcf	Mean Rice Gravity	Mean Compaction %	Mean Voids %
				a) Region 4 Projects							
A	1.0-1.5	2.3-2.4	-	118-134	156.4	80.0	20.0	123.3-144	150.9	89.1	10.9
B	-	-	-	-	-	-	-	-	-	-	-
C	1.0-1.2	1.0-2.8	0.8-2.8	120.8	-	82.7	17.3	117.2	-	82.6	17.5
D	1.1-1.3	2.3-3.0	-	126.3	-	83.4	16.6	127.6	-	84.3	15.7
E	1.0-1.4	1.8-2.4	-	126.4	-	88.3	11.7	125.4	-	-	-
F	-	2.5-3.2	2.4-3.5	110-136	140.0	87.8	12.2	114.8-141	140	91.3	8.7
G	1.3-1.5	3.0	2.0-4.1	121.3	145.2	83.0	17.0	125.6	145.2	86.5	13.5
				b) Districts 10 and 11 Projects							
A	1.5-2.0	2.0-3.1	3.4-5.4	109-117	125.5	90.0	10.0	-	-	-	-
B	1.5-2.0	1.0-2.5	-	95-116	144.8	72.7	27.3	115-121	144.1	82.0	18.0
C	1.4-1.5	1.9-2.1	1.8-4.0	115	140.6	81.8	18.2	121.5	141.9	85.6	14.4
D	-	-	-	113.5-120.0	142.7	81.8	18.2	117.4-124	142.7	84.6	15.4
E	1.4-1.5	1.9-2.3	2.9-3.8	121.8-125.0	145.0	85.1	14.9	125.7-130.6	145.0	88.3	11.7
F	1.1-1.4	2.1-3.0	2.6-4.8	113-116	138.5	83.2	16.8	127.7-135.0	138.0	95.2	4.8

Table 4.4. Milling Gradations--1986 Projects.

a) Region 4 Projects

Unit No.	A				B		C		D			E			F		G
Unit Name	MP 79.2-Wasco Co. Line				Bend 12th St.-Powell Butte		MP 18.0-Powell Butte		Powell Butte-Prineville			Ochoco Dam-MP 35.0			MP 73.4-MP 81.6		MP 89.6-Jct. Ore. 19
Highway	Warm Springs				Central Oregon		Powell Butte		Ochoco			Ochoco			Ochoco		Ochoco
Design Area #	1	2	3	4	1	2	1	2	1	2	3	1	2	3	1	2	1
RAP Gradation:																	
% Passing w/16-inch mill																	
1/2-inch	76	85	89	79	91	83	80	83	89	89	82	86	79	74	69	74	80
1/4-inch	47	53	71	55	65	56	53	50	68	61	51	52	48	39	37	30	49
#10	18	18	34	23	24	22	28	24	30	21	19	21	18	13	11	9	20
w/150-inch mill																	
1/2-inch															53	59	64
1/4-inch															20	23	33
#10															6	4	8

b) Districts 10 and 11 Projects

Unit No.	A		B				C		D		E		F	
Unit Name	MP 75.0-MP 84.0		Lakeshore Dr.-Greensprings Jct.				US 97-Ore. 39		Dairy-Ritter Rd.		Sprague River Rd.-Bly		MP 235.3-Spring Cr.	
Highway	Central Oregon		Lake of the Woods				Lower Klamath		Klamath Falls-Lakeview		Klamath Falls-Lakeview		US 97	
Design Area #	1	2	1	1*	2*	3*	1	2	1	2	1	2	1	2
RAP Gradation:														
% Passing: w/16-inch mill														
1/2-inch	91	91	93	89	74	83	83		92	86	87			
1/4-inch	65	68	68	61	50	57	54		64	59	63			
#10	27	30	26	21	18	21	21		23	22	23			
w/150-inch mill														
1/2-inch	84	81	70	77	74	72	73	72	71	69	72	76	80	74
1/4-inch	52	45	42	48	49	46	39	46	43	41	47	45	47	42
#10	16	13	13	16	18	15	13	15	15	13	13	13	9	9

*Special Test Sections

Table 4.5. Project Cost Data--1986.

	Recycle		Chip Seal		Total	
	Sq.Yd	Per Mile[1]	Sq.Yd.	Per Mile[1]	Sq.Yd.	Per Mile[1]
Mob., TP&D	$0.12	$ 1,755	$0.06	$ 819	$0.18	$ 2,574
Recycle: Labor/Equip.	0.74	10,422	-	-	0.74	10,442
Emulsion (CMS-2S)	0.31	4,308	0.24	3,356	0.54	7,663
Water (M-Gal)	0.01	104	-	-	0.01	104
Emulsion in Tack (CRS-2)	0.11	1,535	-	-	0.11	1,535
Seal Agg.	-	-	0.26	3.642	0.26	3,642
Totals[2]	$1.29	$18,144	$0.55	$7,817	$1.84	$25,961

[1]Per mile costs based on 2-in. depth, 24-ft wide.

[2]All costs without engineering and contingencies.

the first roller (refer to Appendix E for details). Recompaction or second stage compaction is done 3 to 12 days after laydown. The equipment used for this operation consists of one pneumatic and one steel-wheeled roller. A total of 3 to 5 passes with these compactors is normally required.

5.4.2 Process Control

Unlike conventional field control for hot mix paving, much of the field testing for CIR should be performed prior to the actual construction. The process and acceptance tests recommended during construction include those shown in Table 5.7.

Most of these tests are self explanatory, with exception of the test for total liquids. This test is designed to verify the total liquids in the mix. The test procedure together with an evaluation of it is given in Appendix G of Volume II.

Table 5.7. Recommended Field Quality Control.

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
Mix temperature	1/2 mile	Verify minimum laydown temperature
Emulsion quality	Every 50 ton	Check product consistency
Depth and width	Random	Establish pay item
Smoothness	Random	Check ride quality
<u>Optional Tests</u>:		
Extracted Gradation	Random	Information only (after recycle)
Extracted asphalt content	Random	Information only (after recycle)
Viscosity/penetration	Random	Information only (after recycle)

6.0 SUMMARY AND RECOMMENDATIONS

6.1 Summary

This section summarizes the significant findings resulting from this study. The findings include:

1) General

a) CIR use is rapidly growing and is expected to become a major rehabilitation process.

b) Classes of CIR - The terms cold recycle and cold recycling research have previously attempted to include a wide range of different treatments with different results under a single generic description. This report provides a distinction between three different classes of CIR: Class I, Class II, and Class III.

c) Initial savings from CIR are substantially greater than hot recycling or conventional asphaltic concrete.

2) Mix Design

a) A procedure was developed to determine both the estimated emulsion and water contents. The procedure uses widely accepted tests which do not require fabrication of laboratory briquets. For preservation and rehabilitation of existing pavements, these estimated design contents would normally satisfy the final design requirements.

b) Recommended laboratory procedures were developed for sample preparation (briquets) when it is necessary to include the CIR pavement design as part of a structural design.

c) Tests recommended for use in determining the final design content and predicted strength are modulus, fatigue, and Hveem or Marshall stability. These tests would normally be used on projects where the CIR is to become part of a structurally designed overlay.

d) When preparing trial mixes using the recommended procedure, emulsion contents should be varied in increments of 0.3% to 0.4%.

e) Because of the slow cure process (three months or more), it is important to recognize that the laboratory-cured samples will exhibit significantly lower strength values than the fully cured pavement.

f) A gradation correlation has been made between millings obtained from the small portable 16-in. mills and the RAP obtained from the 12-ft mills. This allows fabrication of laboratory samples to gradations produced by large mills.

g) Void contents from 10 to 14% can be expected with CIR mixes.

h) CMS-2S, HFE-150, HFE-150S, ERA-25, and ERA-75 are the most frequently used emulsions.

3) Construction Process

a) The optimum recycle depth to obtain the moist suitable handling properties and high quality ride is 2 in. to 2.5 in.

b) A rapid (15 minute) field process control test has been developed. This test measures total liquid and provides indication of proper emulsion content.

c) Recycle mixes <u>must</u> be sealed to avoid freeze/thaw and water damage during the extended cure time. The minimum recommended seal would use 1/4-in. aggregate and approximately 0.30 gallon/sq.yd. of rapid-set emulsion.

d) Overlays and seals have been placed after two weeks of warm weather with no adverse problems. The need to obtain in-place moisture levels of 1.5% has not been verified.

e) Initial compaction results in densities from 80 to 85%. Two-stage compaction 3 to 12 days after laydown will increase the values from 2 to 5%.

f) Total liquid (emulsion plus milling water) in CIR mixtures should be 4 to 4.5% to provide satisfactory laydown and compaction.

g) Curing time for CIR mixes can range to 3 months or more, depending on mix gradation and temperature.

h) Primary properties in the old pavement which effect CIR mixes are softness of asphalt (viscosity or pen), gradation of RAP, and percent asphalt.

i) Both the single unit and train methods can produce acceptable CIR pavements.

j) Cool temperatures (mix below 90°F) will prevent mixture from setting up and raveling may result.

k) Detailed contract specifications have been developed for both the single unit and train process for Class I and Class II CIR.

l) Typical production rate for the train method is 5 lane-miles per shift and for the single unit, 2 lane-miles per shift.

6.2 Recommendations

Based on the findings in this study, the following recommendations are offered for the 1987 program in Oregon:

1) Mix Design

   a) Follow the guidelines developed in this report.

   b) Evaluate the effects of changing the water content.

   c) Evaluate other recycling agents (ERA 25) and emulsions (HFE-150S).

2) Construction Procedures

   a) Implement and evaluate the new specifications.

   b) Develop roller pattern specifications to replace relative densities.

   c) Specify a chip seal on all CIR.

3) Field Control

   a) Implement and evaluate the recommended field control program for total liquids, emulsion, and water content.

   b) Resolve the density issue (Rice gravities and % compaction vs rolling pattern).

7.0 REFERENCES

1. Windisch, Richard, "Pennsylvania Recycling Urge Prompts 10-Mile Project," Rural and Urban Roads, Nov. 1980, pp. 34-36.

2. Hanson, Douglas I., "In-Situ Cold Recycling," New Mexico Highway Department, 1985.

3. "Cold Recycle Projects on Oregon's High Desert," Process Report Prepared by Region 4, Oregon State Highway Department, Bend, Oregon, December 1985.

4. Allen, Dale D., et al., "Technical Report on Cold Recycling in Oregon," Oregon State Highway Division, January 1986.

5. Allen, Dale, et al., "Oregon DOT Region's Rules for Recycling," Asphalt Recycling and Reclaiming '85, Road and Bridges, October 1985.

6. "Cold-Mix Recycling Manual," Chevron USA Inc. Asphalt Division, August 1982.

7. Davidson, D.D., Canessa, W., and Escobar, S.J., "Practical Aspects of Reconstituting Deteriorated Bituminous Pavements," ASTM Special Technical Publication 662, pp. 16-34, 1977.

8. Davidson, D.D., Canessa, W., and Escoabar, S.J., "Reclaimite Manual for Asphalt Pavement Rejuvenation," Proceedings, Association of Asphalt Paving Technologists, Vol. 46, 1977.

9. Epps, J.A., Little, D.N., Holmgreen, R.J., and Terrel, R.L., "Guidelines for Recyling Pavement Materials," NCHRP Report 224, Transportation Research Board, Washington, D.C., Sept. 1980.

10. Method of Test for Determining the Percent and Grade of Recycling Agent to Use for Cold Recycling of Asphalt Concrete," California Department of Transportation, Division of Construction, Sacramento, November 1983.

11. Personal communication from Robert N. Doty to R.G. Hicks, May 1, 1986.

12. Kandhal, P.S., "Cold Recycling of Asphalt Pavements: Pennsylvania Experience," Paper presented at the 65th Annual Meeting of the Transportation Research Board, Washington, D.C., Jan. 13-17, 1986.

13. Coyne, Lloyd D., "Asphalt Emulsion Cold Mix Design," Proceedings, 13th Annual Meeting of the Asphalt Emulsion Manufacturers Association, San Antonio, Texas, March 1986.

14. "A Basic Asphalt Emulsion Manual," Asphalt Emulsion Manufacturers Association Publication, September 1984.

15. "AASHTO Guide for Design of Pavement Structures," American Association of State Highway and Transportation Officials, Washington, D.C., 1986.

16. The Asphalt Institute, "Thickness Design Asphalt Pavements for Highways and Streets," Manual MS-1, 9th Edition, September 1981.

travel lanes), the recycling cost is about $18,144 per mile. With application of chip seal on the recycled surface, the additional cost is $0.55 per sq. yd. or $7,817 per mile. If the surface were sand sealed, the additional cost would be approximately $2,000/centerline mile.

4.4 Initial Performance

An initial performance survey of all the projects was made in the fall of 1986 and all were performing well. Fig. 4.8 shows the appearance of two of the projects. Both of the projects had been chip sealed within two weeks after construction. Table 4.6 summarizes the performance of all projects as of spring 1987.

4.5 Evaluation of the Construction Process

The results of the 1986 construction process would indicate the following:

1) RAP Gradation. The RAP gradation from the 16-in. mill was always finer than that from the 150-in. mill. This must be considered in the development of any mix design method. Further, mixes with fine RAP gradations were more difficult to recycle.

2) Water Content. It was important to control the water content to equal approximately 4% minus the emulsion content. Too much water flushed emulsion to the surface during compaction, particularly in fine mixtures, while too little water resulted in laydown and compaction problems. Coarse RAP allows greater variation in the total liquid content.

a) MP 79.2-Wasco Co. Line (Unit A, Region 4)
MP 88.45, with Chip Seal

b) Lakeshore Drive-Greensprings Jct. (Unit B, Dists. 10 and 11)
MP 63.36 with Chip Seal

Figure 4.8. Initial Performance of Selected Projects, Fall 1986.

Table 4.6. Performance of 1986 Work (Spring, 1987).

Unit	Highway Name	Condition	Comments
	a) Region 4 (District 10 Projects)		
A	Warm Springs	Very Good	--
B	Central Oregon (Powell Butte)	Fair	Areas where sand seal did not seal surface have cracked.
C	Powell Butte	Good	Ride rough on 20% of job.
D	Ochoco (Prineville)	Poor	Areas with inadequate seal have cracked.
E	Ochoco (Ochoco Dam)	Good	--
F	Ochoco (Mitchell)	Good	--
G	Ochoco (Jct. OR 19)	Very Good	--
	b) Districts 10 and 11 Projects		
A	Central OR (MP 75-84)	Very Good	--
B	Lake of the Woods	Good	--
C	Lower Klamath	Very Good	--
D	Klamath Falls-Lakeview (Dairy)	Very Good	--
E	Klamath Falls-Lakeview (Bly)	Very Good	
F	US 97	Poor	Rutting occuring SB lane where emulsion content too high. NB lane, fair.

3) Emulsion Content. The recommended design emulsion content was higher than that used. The initial performance of the mix was very sensitive to excess water addition and added emulsion content. Too much emulsion resulted in bleeding and instability problems.

4) Compaction. Initial compaction resulted in densities of about 80 to 85%. Final compaction increased the densities to 85 to 90%. The resulting voids after construction are on the order of 10 to 15%. It is expected this will decrease slightly over time with traffic.

5.0 SUGGESTED GUIDELINES FOR 1987 PROJECTS

Prior to establishing final design criteria, a "Discussion Paper" describing Oregon's practices was circulated to selected states for comment. The states included California (Scrimsher), Nevada (Pradre), New Mexico (Hanson), Pennsylvania (Kandahl), Washington (Jackson), and FHWA. As a result of the replies and Oregon's experience, several initial conclusions and preliminary design guidelines were formulated. This chapter presents the results of these discussions in the following areas: (1) general design considerations, (2) design theories, (3) project selection, and (4) construction considerations.

5.1 General Design Considerations

5.1.1. Depth of Recycling

The majority of the states contacted 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 which recycles 2 to 3-1/2 in. and Pennsylvania which uses full depth recycling on thin asphalt maps plus incorporating base aggregate.

5.1.2. Traffic Volume

California, Oregon, and New Mexico are using recycling on light to heavily traveled roadways. California indicated that projects were done with traffic coefficients ranging from 9 to 12. In California, all of the recycling was overlaid with a 0.15 ft minimum of hot mix. Oregon, generally, chip seals recycled pavements after a one month curing period.

5.1.3. Laboratory Mix and Test Temperatures

There is general agreement from all agencies that design procedures should not use laboratory tests which subject the mixture to temperatures above 140°F. The density and mix changes at these temperatures do not relate to those found in field pavements. Temperatures of 140°F or lower were recommended.

5.1.4. Recycle Agents

California uses almost exclusively 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 increasingly to the high float emulsions with polymer, HFE-150S. Pennsylvania uses both the medium- and slow-set emulsions and frequently incorporates base rock into the recycling. Nevada uses CMS-2S and the ERA grades. Oregon has generally used CMS-2S and has made trial use of high float emulsions.

5.1.5 Density

Oregon and California found that uncured, uncompacted field samples containing the field emulsion and moisture content could not be compacted in the laboratory to the density of the field cores. Compaction in the laboratory to the field density requires drying or curing the mix @ 140°F. This promotes softening of the old asphalts similar to field conditions. CALTRANS found that a density slightly higher than the field density could be obtained by curing the mix for 16 hours at 140°F, then compacting at 140°F. Because this method produced a higher target density than could be obtained in the field, a requirement was set to obtain 92% of this relative compaction. Values as high as 97% were obtained in California, but this did not occur on the day the recycle mix was compacted. On the day recycling was done, the highest density that could be attained was 90% relative compaction. After 2 to 3 days of traffic or re-rolling, the values would increase 2 to 4%. Because of this, a 2-density requirement was established: a minimum value of 87% initially, and a minimum of 92% prior to placing the overlay. Oregon requires a two-stage compaction with the second stage being done 5 to 15 days after laydown. The recompaction typically increases the density 2 to 5%.

5.1.6 Void Content

All states that have checked the void content report a very high void content immediately after placement. California provided the information shown below that demonstrates the high voids expected in cold recycle mixes:

(1) Lab Compaction Temp.	(2) Sp. Gr. *	(3) % Rel. Hot**	(4) Comp. Cold Recy**	(5) Voids
230°F	2.38	100.0	---	4.0%
140°F	2.31	97.0	100.0	6.9%
140°F	2.12	89.1	92.0	14.5%
140°F	2.00	84.0	87.0	19.4%

* Theoretical maximum specific gravity for the mix is 2.48.
** Target density for hot mix is 2.38 at 4.0% voids. Target density for cold recycled mix is 2.31 at 6.9% voids.

Note the large void content at both 87 and 92% relative compaction for the cold recycled mix (columns 4 and 5). Also note that for a hot mix with a relative compaction of 97% (column 3), which is considered excellent in the field, the void content is still 6.9% (column 5). At 100% relative compaction for a cold recycled mix, 6.9% voids is realized. California has yet to obtain over 97% for CIR mixes, and considers voids around 10.0% as a best condition. Oregon's experience indicates the voids range from 8 to 15%. Despite the high voids, most states report that the cold recycled pavements to date are performing well. This is comparable to Oregon's experiences with open-graded cold mixes which have a high void content and perform exceptionally well.

5.1.7. Ride

While ride is normally not considered a design consideration, it has been found that several states are cautious about using CIR because of the fear of creating an undesirable ride. Through the use of the Mays Ride Meter, a large number of "before" and "after" ratings were taken on cold recycle projects in Oregon. Typical findings for the 1986 projects (Figure 5.1) show that significant improvements in ride can be expected. Based on the Mays Ride Meter, an "average ride" ranges between 75 and 100 in. per mile. On CIR projects completed, the typical ride score will be in the average or smooth range.

5.2 Design Theories

Initially, two theories were considered when designing cold recycled asphalt pavement. Briefly, the theories were:

1) Treat the millings as a black aggregate with some hardened asphalt coating and design an asphalt content to coat the milling particles. The assumption was that the millings would 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 was that 100% softening would occur and a "new asphalt" would be created.

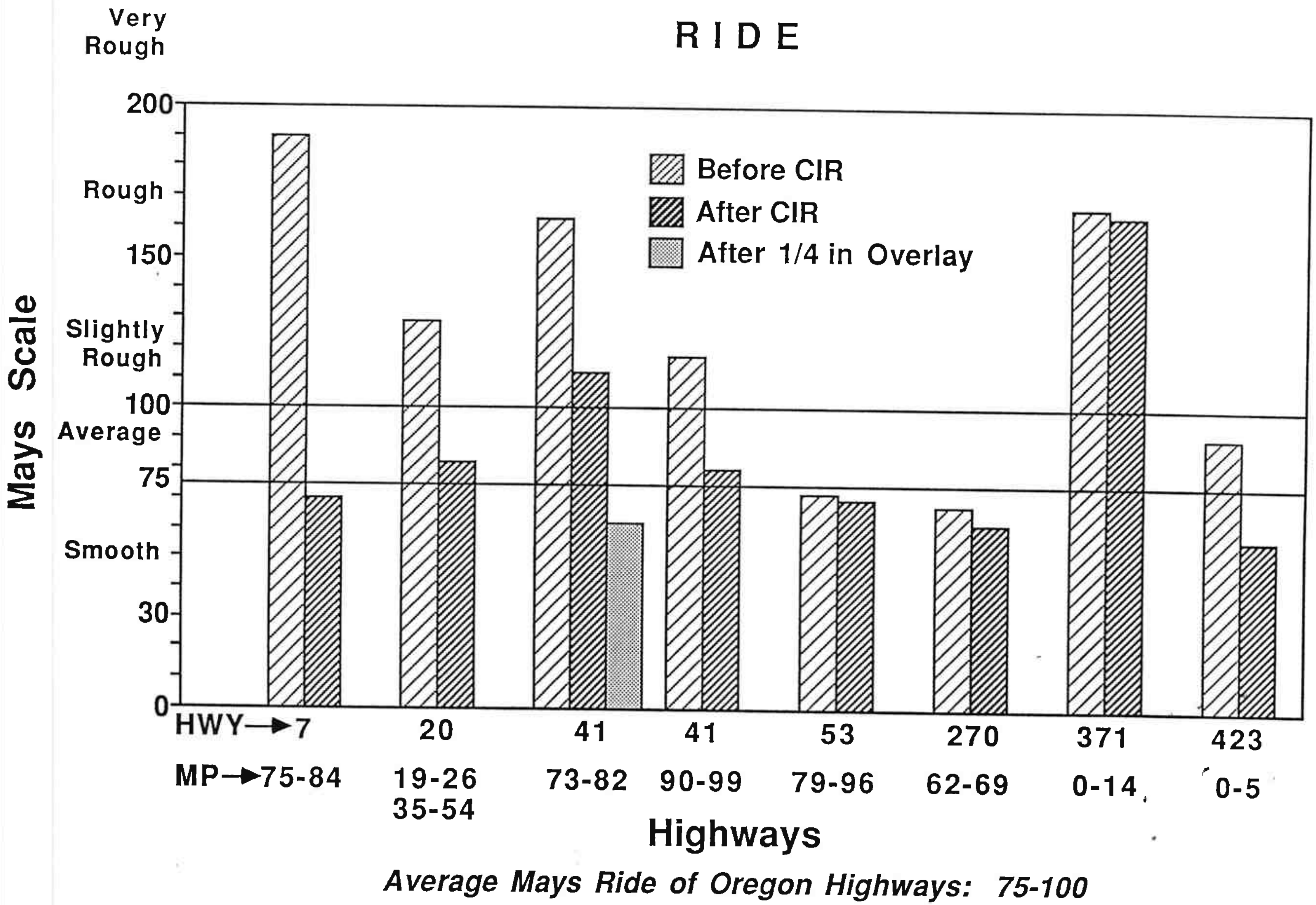


Figure 5.1 Before and After Ride Data, 1986 Central Oregon Projects.

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 5.1.

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, this method allows for the procedure described to estimate an intial design emulsion content.

5.3 Project Selection and Testing Plan

Where cold recycling should and should not be used has been the source of some concern. Table 5.2 summarizes where CIR is and is not recommended. Once it has been determined CIR is feasible, the following evaluations are recommended.

5.3.1 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 being sought would be the type of asphalt used in the pavement, thickness of the pavement, and termini of previous job (Fig. 5.2). 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 2 samples plus 2 backup samples on each section. On

Table 5.1. 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 5.2. Considerations for Project Selection.

a) CIR Not Recommended

- Work area cannot accommodate traffic volume
- Asphalt is stripping from aggregate*
- Mixes exhibiting rutting due to unstable fat mixture
- Cold and damp conditions
- Late fall or early winter treatment

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 travelled lane of 4-lane roadway)

*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.

longer sections, a minimum of 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 would correspond to the proposed recycle depth. 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 laboratory for testing.

5.3.2 Laboratory Tests on RAP

The following tests are performed on the RAP obtained from the field sampling:

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

These values are then used in the following procedure to estimate the optimum design emulsion content.

5.3.3. Estimating Design Emulsion Content

From experience in using CMS-2S on approximately 300 miles of CIR, Oregon has found that a base design emulsion content of 1.5% is a good starting point. Adjustments are made on this base design from the laboratory values which indicate the softness of the old asphalt, the gradation of the millings, and the percent of asphalt in the old pavement. The calculations from these adjustments are shown in Table 5.3. The limits for the final estimated design emulsion content can range from a low of 0.4% to a high of 2.6%. The adjustments are discussed below:

Table 5.3. Proposed Adjustments from Base Design of 1.5%.

Base Design	1.5%
Adjustment for Softness	±0.5%
Adjustment for Gradation	±0.3%
Adjustment for % Asphalt	±0.3%
Final Estimated Design	____ %

Lowest Design..... 0.4%
Highest Design ... 2.6%

1) Softness of Asphalt. The softness of the asphalt is measured by the absolute viscosity at 140°F and the penetration value of 77°F. Figure 5.3 indicates the ranges for these values that have been found in the CIR completed to date. By using these ranges, an adjustment up to ± 0.5% can be selected for any particular pavement. If there is a discrepancy between what the penetration and viscosity are showing, the viscosity value should be used.

2) Gradation Adjustment. By plotting the RAP gradations, a range of values was obtained for the percent passing the 1/2-in., 1/4-in., and #10 screens. Figure 5.4 shows the range of test values when the sampling is performed with a 16-in. mill and the RAP gradation that can be expected when using the 150-in. mill. By using this graph, a maximum adjustment of ±0.3% can be made to the base design emulsion content. Findings to date indicate that if a RAP gradation is fine on the 1/2-in. screen, it will also indicate a fine gradation on the 1/4-in. and #10 screen. The same holds true for a coarse or average gradation.

3) Asphalt Adjustment. The final adjustment from the base design is for the percent of asphalt extracted from the RAP. Figure 5.5 indicates the expected range of asphalt content and the adjustment range of ±0.3%.

4) Use of Estimated Design Emulsion Content. The significance of this procedure is that it provides a rapid and simple method to calculate emulsion content. The laboratory tests used are

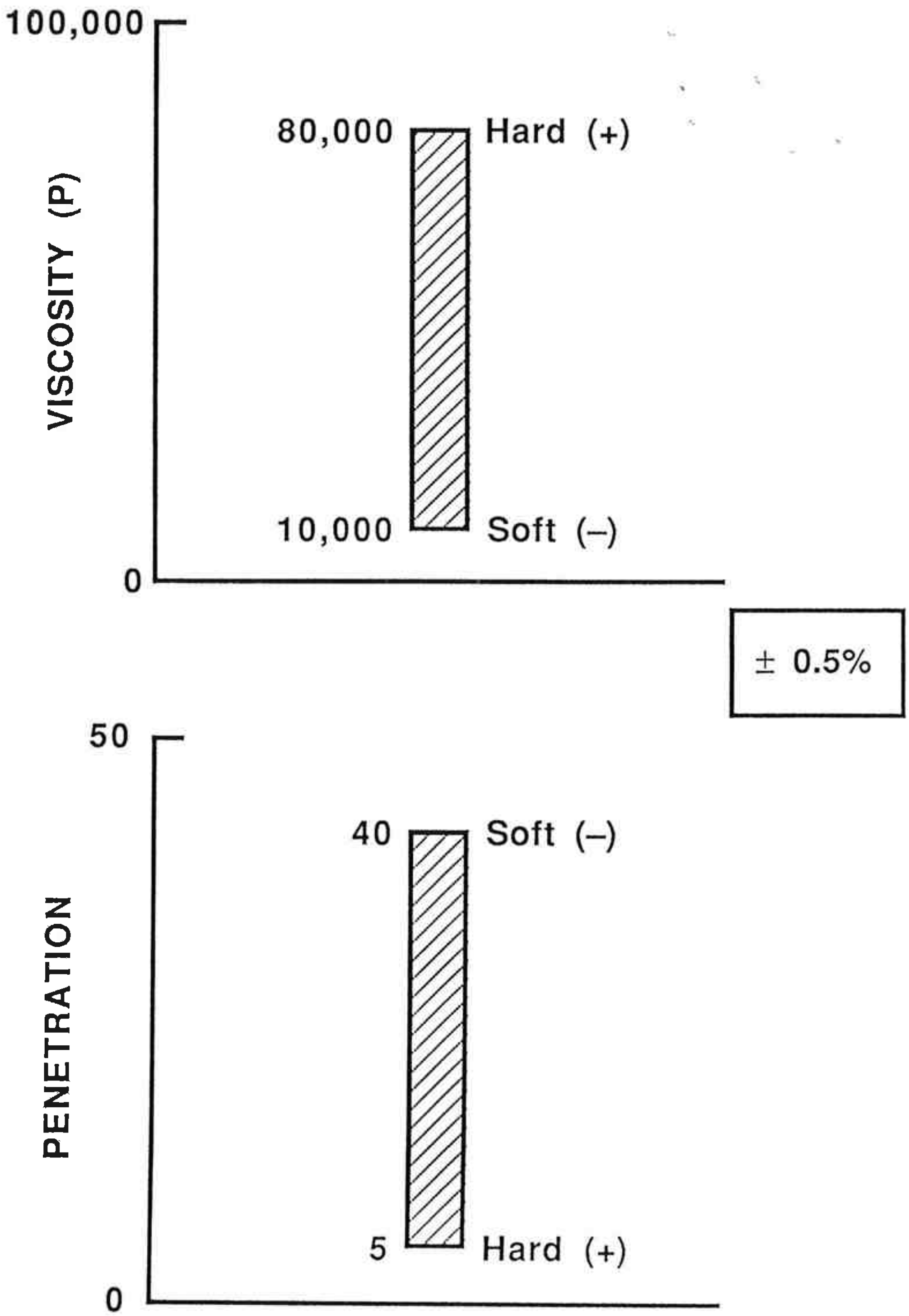


Figure 5.3. Softness of Asphalt in Old Pavement.

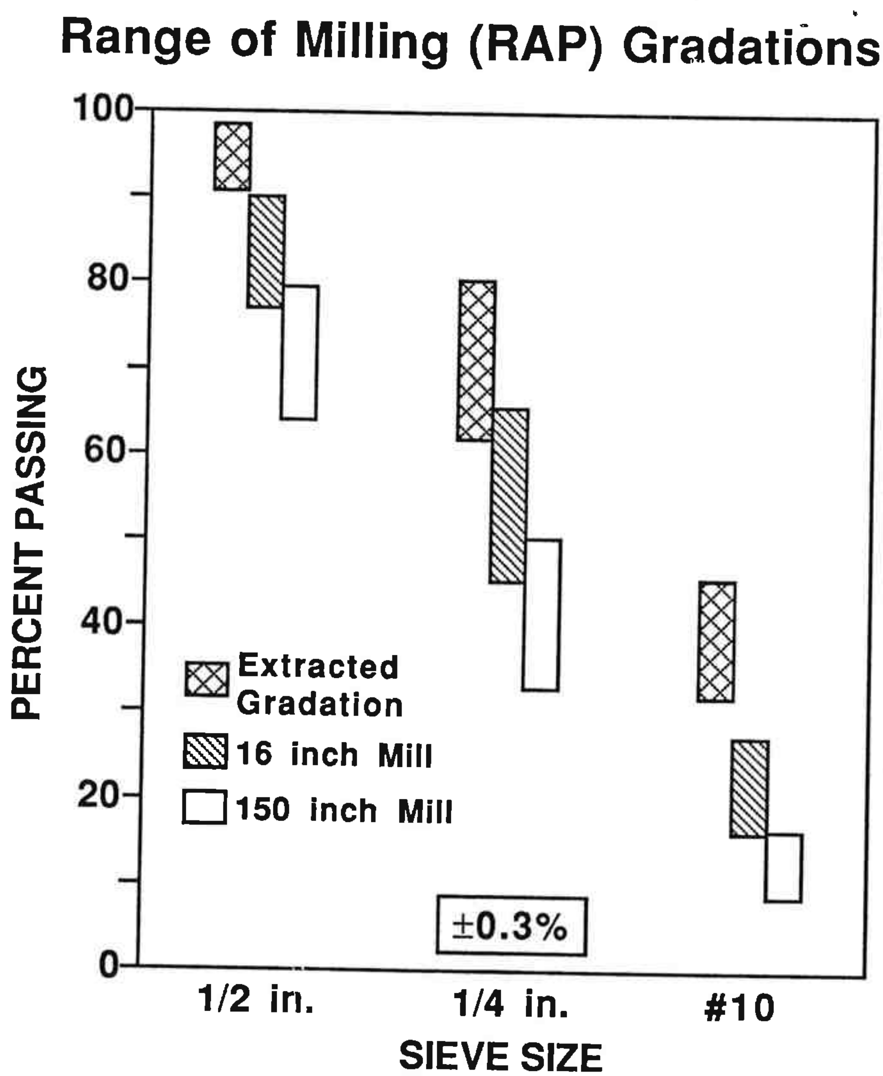


Figure 5.4. Range of Milling (RAP) Gradations from 16-In. Mill and 150-In. Mill on Train.

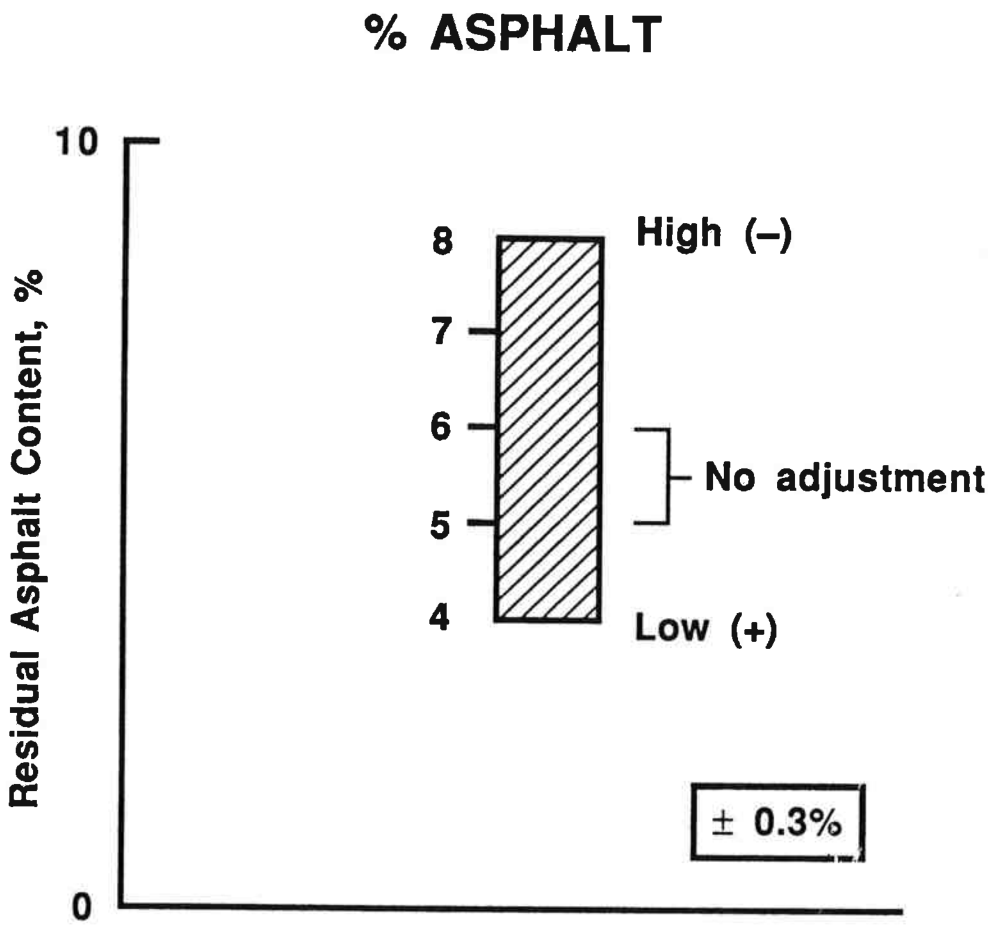


Figure 5.5. Adjusted for Residual Asphalt Content.

widely accepted. One of the more controversial design issues for CIR is eliminated: the lack of a widely accepted procedure to fabricate, compact, and cure test briquets in the laboratory which reflect actual field conditions. The results appear to produce the optimum emulsion content within a fraction of one percent (see Table 5.4). Last, for most recycle projects where preservation or restoration of an existing pavement is the primary objective, the estimated design emulsion content would be adequate for the final recommended design.

5.3.4. Final Design

Figure 5.6 summarizes the steps to select a final design content where the CIR pavement will become part of the structural design to upgrade the surface. Once the estimated emulsion content is determined, samples can be prepared using either the Hveem or Marshall compaction method. A suggested sample preparation procedure using the Marshall and/or Hveem methods is given in Table 5.5. After compaction and preliminary curing, the samples are then tested for stability, resilient modulus, and fatigue. The final emulsion content would be selected using criteria such as given in Table 5.6.

5.4 Construction Considerations

5.4.1 Compaction

Initial compaction is accomplished using two coverages with a vibratory breakdown roller approximately one-half hour behind the paver. The first pass is in the vibratory mode while the second pass is in the static mode. The second roller is static steel-wheel roller operating at least 2000 ft behind

Table 5.4. Comparison of Emulsion/Water Content Region 4 Projects.

Unit	Mix Design Area	Actual Used, %		Recommended Procedure	
		Emulsion	Water	Emulsion	Water
A	1	1.2	2.4	1.0	2.5
	2	1.3	2.4	1.4	2.5
	3	1.0	2.3	0.9	2.5
	4	1.9	3.0	2.0	2.5
B	1	1.5	3.0	-	-
	2	1.5	3.0	-	-
C	1	1.1	2.4	1.2	2.5
	2	1.3	2.7	1.3	2.5
D	1	1.1	2.3-3.0	1.1	2.5
	2	1.1	2.3-3.0	1.1	2.5
	3	1.1	2.3-3.0	1.4	2.5
E	1	1.4	2.2	1.5	2.5
	2	1.3	2.2	1.6	2.5
	3	1.1	2.2	1.8	2.5
	4	1.6	1.7	1.7	2.5
F	1	2.6	2.8	1.7	2.5
	2	1.8	2.8	1.3	2.5
G	1	1.4-1.5	3.0	1.9	2.5

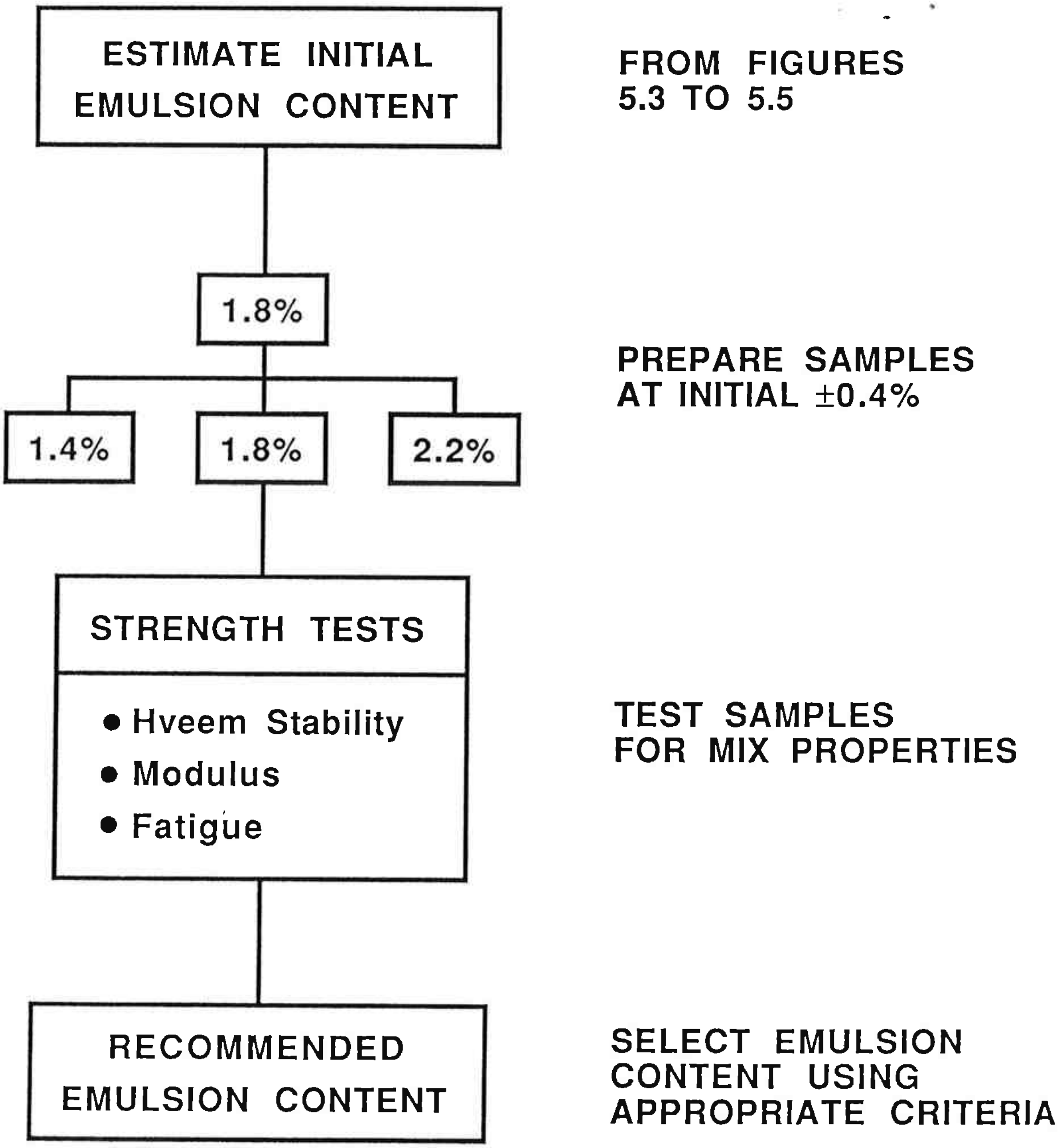


Figure 5.6. Suggested Mix Design Process - Future Projects.

Table 5.5. Suggested Sample Preparation Procedure for CIR.

1) Millings are split into approximately 5500 g batches; this size sample provides sufficient material for four 2.5-in. high specimens with an 1100 gm sample for moisture determination.
2) Sample is screened on the 1-in. sieve. The material retained on the 1-in. sieve is reduced in size to 100% passing 1-in. sieve using 3-lb hammer. This is because the retained 1-in. is too large for 4-in. molds.
3) Batch five 1100 gm samples of millings at the average gradation.
4) Determine moisture content of one batch by drying 24 hrs at 230°F.
5) Samples are heated to ±140°F prior to mixing (1-2 hrs).
6) Water is added to the millings in the appropriate proportion based on the dry weight of the millings: % water = 4.5% total liquid - % added emulsion. Water is mixed into millings thoroughly by hand.
7) Emulsion is added to the premoistened millings after water addition using the recommended content. The added emulsion is based upon the dry weight of the millings. The emulsion is preheated to ±140°F (1 hr) and mixed thoroughly into the batch by hand or using a mechanized mixer.
8) The material is spread into a 12-in. x 17-in. baking pan and allowed to cure for 1 hr at ±140°F to simulate average time elapsed between paver laydown and initial compaction during actual construction.
9) Samples are molded using standard Marshall or Hveem procedures to produce ±2.5-in. high briquets as described below:
   a) Molds are preheated to ±140°F.
   b) Compact samples using standard 50 blow compactive effort for Marshall procedure or 150 blows at 450 psi for the Hveem procedure.
   c) Cure overnight at 140°F and recompact using 25 blows per side for the Marshall procedure and 75 blows at 450 psi for the Hveem procedure.
   d) The molds are laid on their side and the briquets are cured for 24 hrs @ ±140°F prior to extrusion.
   e) Briquets are extruded with the compression testing machine.
   f) Briquets are laid on their side to maximize surface exposure and cured for 72 hrs. @ ± room temperature prior to testing.
10) Specimens are tested for stability, modulus, and fatigue at 77°F.

Table 5.6. Suggested Mix Design Criteria.

Property	Recommended Value
Hveem stability	> 10 after 2nd compaction
Resilient modulus @ 77°F	150,000-300,000 psi
Modulus ratio @ 77°F after saturation	> 0.60
Fatigue life @ 100 $\mu\varepsilon$ @ 77°F	> 5,000