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

INTERIM REPORT

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16. Abstract

Oregon has developed a mix design procedure for cold in-place recycled (CIR) asphalt concrete pavements. The procedure involves estimation of an initial emulsion content based on gradation of recycled asphalt pavement (RAP), asphalt content of RAP, and penetration and viscosity of recovered asphalt. When an estimated emulsion content is determined, Marshall-sized specimens are prepared for a range of emulsion contents with the range centered on the estimated emulsion content. Hveem and Marshall stability, resilient modulus, and index of retained modulus (IRM) tests are performed on the specimens and a design emulsion content is selected based upon these results. Because of variations in RAP properties, continual need for field adjustments, and the difficulty of interpreting mix property test results, only the estimation part of this procedure is currently implemented.

This paper describes the mix design procedure and presents lab results demonstrating the difficulty of choosing emulsion content based on Hveem and Marshall stability, resilient modulus and IRM. Data comparing design emulsion content with actual emulsion contents used in the field are presented. Selection of water content is discussed. Test results of mix properties monitored over time are presented, demonstrating the curing of the emulsion. Performance data for CIR pavements constructed from 1984 through 1988 are presented as well as initial results of an attempt to use lime during recycling to correct a stripped pavement.

Significant findings as a result of this study include the following:

1) Field performance of CIR has been good, with a few exceptions. Proper project selection is extremely important.
2) Estimation procedures for determining emulsion content serve as a good starting point for field operations. Continual monitoring and adjustment of emulsion content is required in the field.
3) It is difficult to relate Hveem and Marshall stability, resilient modulus, fatigue and IRM laboratory testing to field construction conditions for CIR.
4) Mix property test results indicate that the stiffness and fatigue properties of recycled mixtures increase over a period of years.
5) Addition of 1% and 2% lime to RAP from badly stripped pavement produced better IRM results than the RAP without lime.

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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.

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1.0 INTRODUCTION

1.1 Background

Oregon has implemented cold in-place recycling (CIR) techniques for low volume roads as one alternative to conventional asphalt concrete pavement rehabilitation practices since 1984. The initial success of the early CIR projects (1984-85) prompted a joint research effort in 1986 between the Oregon State Highway Division (OSHD) and Oregon State University (OSU). This effort focused on developing improved mix design procedures and construction guidelines for cold in-place recycling. The work on this research effort was completed in June 1988 (1,2) and resulted in a workable but rudimentary mix design procedure.

Due to deficiencies* in the proposed mix design procedure, however, only part of the procedure has been implemented (3). The component of the procedure that has been implemented consists of estimating the emulsion and water contents. This procedure has been validated by the 1986 study as well as by extensive field experience. The component not implemented consists of fabricating standard 2-1/2 × 4 in. briquettes from recycled asphalt pavement (RAP) obtained with a 16-in. mill and subjecting these briquettes to mix property tests to determine the appropriate amount of emulsion to be added to the mix. Invariably, the results have predicted emulsion contents in excess of that actually used in the field.

Because the current practice for CIR mix design consists of emulsion and water content estimation as well as considerable judgement by field personnel during construction, additional work is needed to remove this judgement factor and replace it with sound criteria. That is, the initial emulsion and water contents should be based on the results of tests which evaluate the engineering properties of the recycled mixes.

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*Namely, the inability of mix property test results to accurately predict the emulsion content that is used in the field during actual construction.

1.2 Purpose

This current study was initiated in December 1988 to mitigate the deficiencies associated with the mix design procedure proposed by the 1986 CIR study. The specific objectives of this current study are to:

1) Verify and/or modify the procedure for selecting the content of recycle agent and water content for field projects. This will be based on projects constructed during the 1988 and 1989 construction seasons.
2) Verify and/or modify the mix design criteria for stability, resilient modulus, and moisture sensitivity.
3) Examine selected projects constructed during the 1984 through 1988 construction seasons and estimate the life expectancy of CIR treatments using standard and high float emulsions.
4) Investigate whether mixes which have previously exhibited stripping can successfully be corrected by recycling.
5) Verify the validity of the Total Liquids Test -- OSHD TM-126 (1) -- to establish the optimum total liquids content in the field.

It is the purpose of this interim report to provide detailed information regarding the progress made to date in achieving these objectives. In the final report for this project, the information presented in this report will be updated and expanded to reflect:

1) additional evaluation of laboratory mix design data for the 1989 construction season,
2) additional field performance surveys (spring 1990) and testing,
3) discussions with District Maintenance Supervisors and Project Managers in preparation of improved construction guidelines and an inspection manual, and
4) monitoring of construction mix designs and selected projects scheduled for the 1990 construction season using the developed guidelines in (3) above.

2.0 MIX DESIGN PROCEDURE

This chapter describes the current mix design procedure used by OSHD for CIR mixtures. Included is a description of the procedure (and its verification) used to select the amount of emulsion and water to be added to the mix, the sample preparation procedure, mix property test results, and field adjustments to be made to the emulsion and water prescribed by the mix design procedure.

2.1 Selection of Amount of Recycle Agent

The procedure to select the amount of emulsion (recycle agent) to be added to a recycled mixture evolved from the 1986 OSU/OSHD study (1,2). This procedure is essentially an estimation process which begins with a base emulsion content to which adjustments are made based on the results of laboratory tests conducted on a sample taken from the pavement to be recycled using a 16-in. mill. It has been found through experience with the CMS-2S and HFE-150 emulsions that a base emulsion content of 1.2% is a good starting point (3). Adjustments are then made to this base content according to the softness of the extracted asphalt, gradation of millings as produced by the 16-in. mill, and the percent of recovered asphalt from the sample.

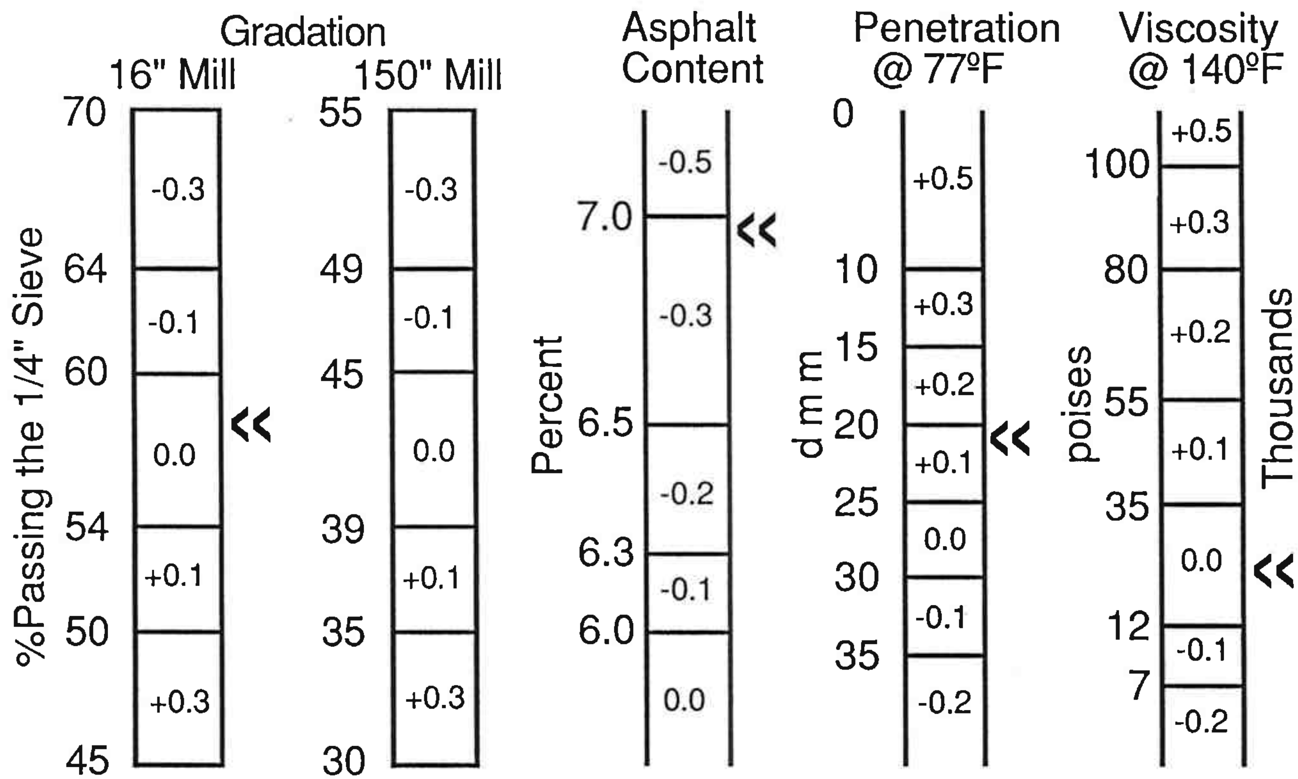
The penetration (ASTM D5) (4) and/or the absolute viscosity (ASTM D2171) (5) laboratory test results are used to determine the softness of the extracted asphalt and the RAP gradation is determined for only three screens -- 1/2-in., 1/4-in., and #10. The percent of recovered asphalt is determined via the Abson method (ASTM D1856) (4). From these laboratory test results, the added emulsion content (based on dry weight of millings) can be determined through the use of Figure 2.1 and the following equation:

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

where

EC_{EST} = estimated emulsion content, %

1.2 = base emulsion content, %



Example:

Given:

58% passing the 1/4" screen on the 16" mill, 7% residual asphalt, a penetration of 20 dmm, and a viscosity of 19,000 poises.

Adjustments (for borderline cases, use adjustment producing lower emulsion content):

0.0% for gradation, -0.5% for asphalt content, and 0.0% for penetration/viscosity

Estimated Emulsion Content:

1.2% + 0.0% - 0.5% + 0.0% = 0.7%

Figure 2.1. Emulsion Content Adjustments for Gradation, Asphalt Content, and Asphalt Softness.

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

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

It should be noted that for borderline cases (those that fall on a boundary) in Figure 2.1, the adjustment resulting in a lower estimated emulsion content (EC_{EST}) should be used. Also, where there exists a discrepancy between the adjustments for penetration and absolute viscosity, the adjustment resulting in a lower estimated emulsion content (EC_{EST}) should be used. The example in Figure 2.1 clarifies the use of the chart and the equation.

2.2 Verification of Selection of Emulsion Content

To accomplish one of the objectives of this study -- to verify and/or modify the procedure for selecting the content of recycle agent for field projects -- the above procedure was carried out on samples taken from three projects recycled during the 1989 construction season and compared to the actual emulsion content that was used in the field during construction. The three projects enlisted for this purpose were:

1) Stag Hollow Creek Road (Yamhill-Newberg Hwy): Region 2,
2) Umpqua Jct.-The Dalles-California Hwy (East Diamond Lake Hwy): Region 4, and
3) Horse Ridge-Crooked River Jct. (Central Oregon Hwy): Region 4.

Table 2.1 gives a comparison of the emulsion contents that were determined using the laboratory mix design procedure with those used during construction. As indicated, several designs were performed on samples taken from the Stag Hollow Creek Road project while fewer designs were performed for the Umpqua Jct.-The Dalles-California Hwy and Horse Ridge-Crooked River Jct. projects.

Comparing the design emulsion with those actually used in the field for the Stag Hollow Creek Road project, it is apparent that the emulsion contents predicted by the estimation process are close to the contents used in the field (generally within $\pm 0.4\%$ with a range extending from 0.8% lower than to 0.4% higher than that actually used in construction). For the Umpqua Jct.-The Dalles-California Hwy project, it is clear that the emulsion contents predicted by the estimation process correspond very closely to those used during construction. The predicted emulsion content for the Horse Ridge-

Table 2.1. Comparison of the Design and Actual Emulsion Contents on Three CIR Projects

Project	Mile Point	Emulsion Content, %		
		Design	Actual	Diff.*
Stag Hollow Creek Rd-Wapato Rd (Yamhill-Newberg Hwy)	1.03 WB	1.2	1.2	0.0
	2.57 WB	1.0	1.2	-0.2
	4.56 WB	1.4	1.3	0.1
	6.56 WB	1.7	1.3	0.4
	3.59 EB	1.6	1.3	0.3
	4.79 EB	0.5	1.3	-0.8
	5.55 EB	1.6	1.2	0.4
	7.13 EB	1.3	1.3	0.0
	8.20 EB	0.8	1.1	-0.3
	9.00 EB	0.6	1.2	-0.6
	9.82 EB	0.8	1.3	-0.5
Umpqua Jct-The Dalles-California Hwy (East Diamond Lake Hwy)	2.49 WB	1.0	1.2	-0.2
	14.24 WB	0.9	0.9	0.0
	1.64 EB	0.9	1.0	-0.1
	11.70 EB	1.0	0.9	0.1
Horse Ridge-Crooked River Jct. (Central Oregon Hwy)	23.00 WB	1.6	1.6	0.0
	34.70 WB	0.6	1.4	-0.8
	24.00 WB	1.4	1.6	-0.2
	33.70 EB	0.6	1.3	-0.7

*Diff. = Design - Actual

Crooked River Jct. project is the same as that used in the field for one sample location (MP 23.00) and is within 0.2% for another (MP 24.00), but design emulsion contents are 0.7-0.8% lower for the other two locations. The design emulsion contents at the east end of this project (near mile points 33.70 and 34.70) required considerable adjustment due to low temperatures during construction.

2.3 Selection of Water Content

In the 1986 OSU/OSHD study, the amount of water to be added to a particular recycled mix was determined by subtracting the emulsion content from the total liquids content (the amount of moisture to provide a saturated surface damp condition). To better quantify the total liquids content, the modified Oregon State Highway Division test method OSHD TM-126 (1) was used in the current study -- a test to determine how much total liquids a particular recycle mix can tolerate. Thus, once the estimated emulsion content (EC_{EST}) is determined as described in Section 2.1, the modified OSHD TM-126 test is conducted on a mix to determine the total liquids content. Briefly, the Total Liquids Test is conducted as follows (see OSHD-TM-126 for complete details):

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

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

2.4 Verification of Selection of Water Content

The above procedure for selecting the amount of water to be added to the recycled mixture for the purposes of mix design was carried out on three projects to accomplish one of the objectives of the current study -- to verify and/or modify the procedure for selecting the water content for field projects. The three projects used for this purpose were as follows:

1) Stag Hollow Creek Road (Yamhill-Newberg Hwy): Region 2,

2) Umpqua Jct. - The Dalles-California Hwy (East Diamond Lake Hwy): Region 4, and

3) Horse Ridge - Crooked River Jct. (Central Oregon Hwy): Region 4.

Table 2.2 gives a comparison of the water contents that were determined in the laboratory using the Total Liquids Test to the range of water contents that were used in the field during construction. As indicated, the water contents predicted by the Total Liquids Test were much higher than those used for construction for one project, but quite close for the other two projects. For the Stag Hollow Creek Rd.-Wapato Rd. project, the water contents predicted by the Total Liquids Test were 1.0-2.2% higher than those used in the field. For the Umpqua Jct.-The Dalles-California Hwy project the maximum variation between design and actual was 0.2%. Actual field additions of water on the Horse Ridge-Crooked River Jct. project ranged from 0.7% less than to 0.1% more than the design.

The Stag Hollow Creek Rd.-Wapato Rd. project was not a successful CIR project. The majority of the project involved shaded areas and inadequate base. One result of these factors was a high moisture content in the RAP material in the field. It is suspected that the difference in actual water added and water predicted by the Total Liquids Test in the laboratory may be explained by the high in situ moisture content of the field materials. By the time the design millings were used in the laboratory test they may have lost much of their moisture content -- something which did not happen in the field. Consequently, less water had to be added in the field to result in the required total liquids content.

The other two projects were in more arid areas where water in the RAP was not as significant a factor. It is probably for this reason that agreement between design and actual water additions for these two projects was much better.

Table 2.2. Comparison of the Design and Actual Water Contents on Three CIR Projects

Project	Mile Point	Water Content, %		
		Design	Actual	Diff.*
Stag Hollow Creek Rd-Wapato Rd (Yamhill-Newberg Hwy)	1.03 WB	2.3	0.8	1.5
	2.57 WB	2.5	0.8	1.7
	4.56 WB	2.1	0.8	1.3
	6.56 WB	1.8	0.8	1.0
	3.59 EB	1.9	0.6	1.3
	4.79 EB	3.0	0.8	2.2
	5.55 EB	1.9	0.8	1.1
	7.13 EB	2.2	0.8	1.4
	8.20 EB	2.7	0.8	1.9
	9.00 EB	2.9	0.8	2.1
	9.82 EB	2.7	0.8	1.9
Umpqua Jct-The Dalles-California Hwy (East Diamond Lake Hwy)	2.49 WB	2.1	1.9	0.2
	14.24 WB	2.0	2.0	0.0
	1.64 EB	2.1	2.2	-0.1
	7.18 EB	2.1	2.0	0.1
	11.70 EB	2.0	2.0	0.0
Horse Ridge-Crooked River Jct. (Central Oregon Hwy)	23.00 WB	1.4	1.5	-0.1
	24.00 WB	1.6	1.5	0.1
	34.70 WB	2.4	2.1	0.3
	33.70 EB	2.4	1.8	0.7

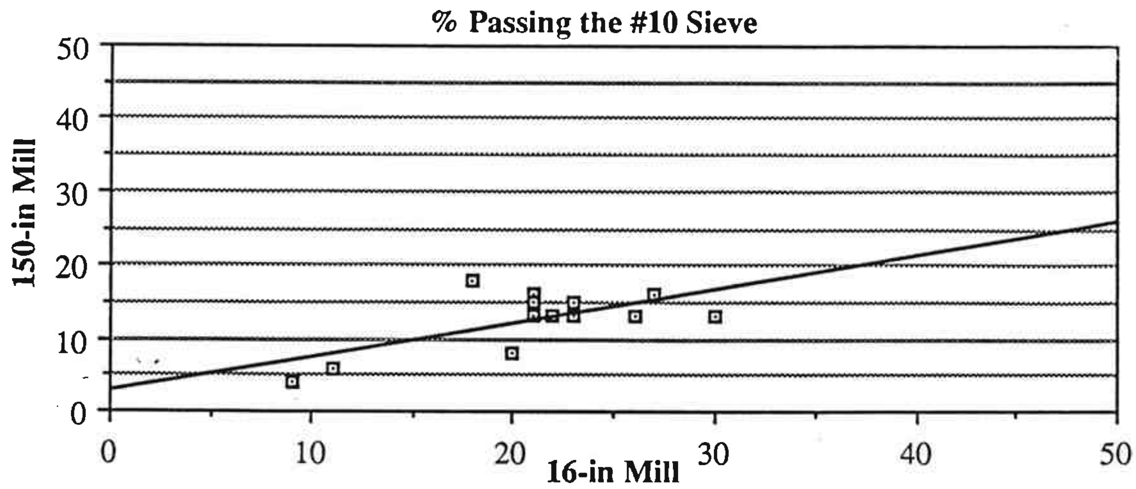
*Diff = Design - Actual

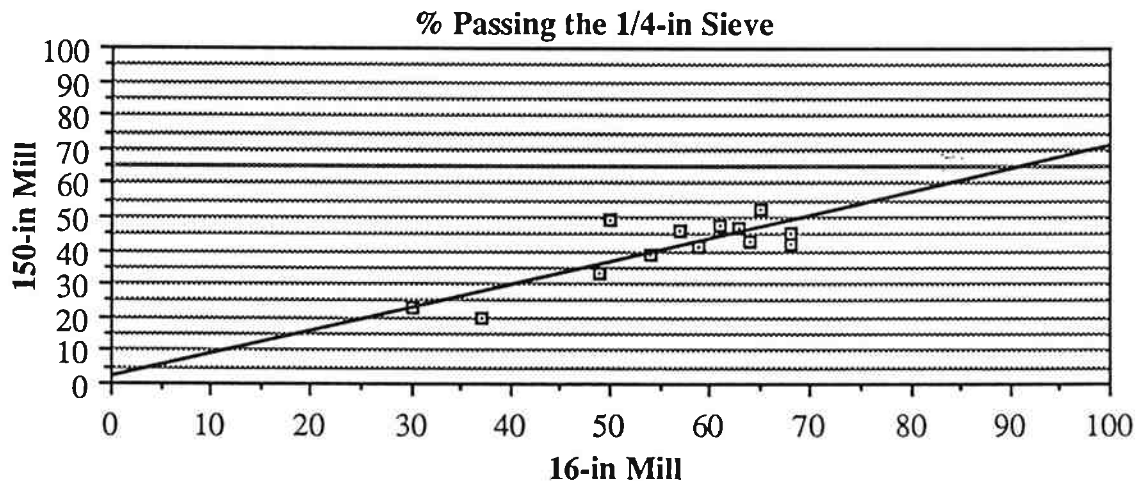
2.5 Sample Preparation

One of the purposes of the current study is to implement mix property tests to aid in establishing the proper amount of emulsion to be added to a particular recycle mix. Although this was also one of the purposes of the 1986 study, it was soon realized that the results of certain mix property tests gave estimates of the emulsion content that were too high (2). It is the intent of the current study to revisit the mix property tests used in the 1986 study to further investigate the possibility of using these tests as part of the mix design procedure for CIR mixtures.

To accomplish this, briquettes were prepared with RAP from two pavements that were recycled during the 1989 construction season (Stag Hollow Creek Rd.-Wapato Rd. and Umpqua Jct.-The Dalles-California Hwy.). The briquettes were then tested for Hveem and Marshall stability, modulus, and fatigue. The sample preparation procedures used to fabricate the specimens is as follows:

1. Split the millings into approximately 15,000 gram batches.
2. Screen the sample on the 1-in. sieve. Reduce all materials retained on the 1-in. sieve such that 100% of the sample passes the 1-in. sieve using a hammer or chisel.
3. Determine the gradation of the 15,000 gram sample using the 1/2-in., 1/4-in., and #10 sieves. This is the RAP gradation for the 16-in. mill.
4. Determine the adjusted gradation (for the 150-in. mill) through the use of Figure 2.2.
5. Batch five 1100 gram ± samples of the millings at the adjusted gradation for the 150-in. mill.
6. Using the remaining material, determine the optimum total liquids content using OSHD TM-126 with the modification that the optimum total liquids content occurs at a liquid loss of 1-4 ml (1-4 grams).
7. Calculate water contents (based on dry weight of millings) to be added to the samples for each emulsion content using the following equation:





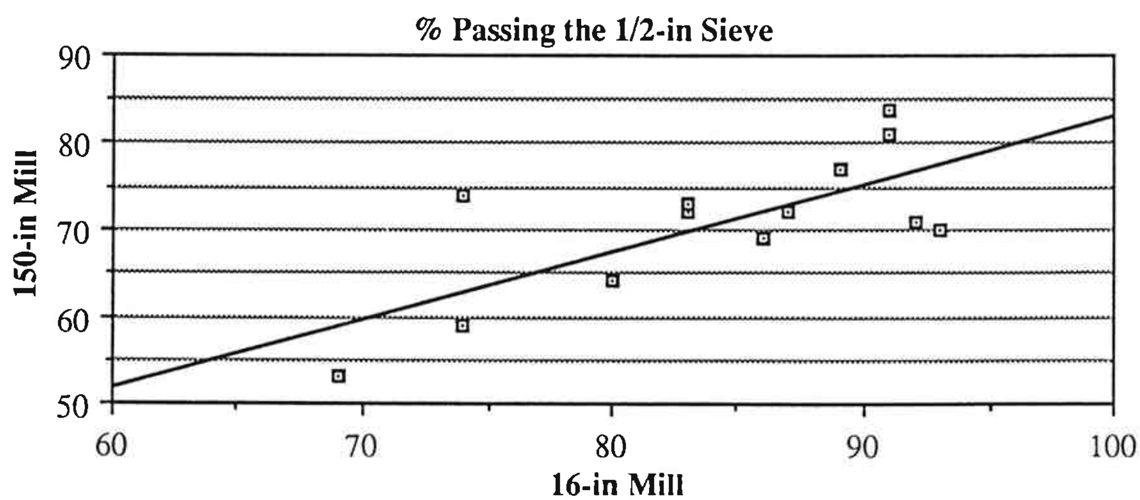


Figure 2.2. Determination of the Adjusted Gradation (for the 150-in. Mill) from the Gradation of the 16-in. Mill.

$$\%water = \%total\ liquids - \%emulsion$$

Briquettes are to be prepared with emulsion contents at the estimated emulsion content (EC_{EST}), at EC_{EST} - 0.3%, at EC_{EST} + 0.3%, at EC_{EST} + 0.6%, and at EC_{EST} + 0-.9%.

8. Heat the five 1100 gram samples to 140°F ± for 1 hour.
9. Add the water calculated above to the five samples and thoroughly mix by hand.
10. Add the emulsion contents to the premoistened millings. The emulsion is to be preheated to 140°F ± for 1 hour and mixed thoroughly into the batch by hand.
11. Dump the material into a 12-in. × 17-in. baking pan and allow to cure for 1 hour at 140°F ± to simulate the average time elapsed between the paver laydown and the initial compaction during actual construction.
12. Mold the samples using standard Hveem or Marshall procedures to produce 2.5-in. ± briquettes as described below:
    a) Preheat molds to 140°F ±.
    b) Compact the samples using 75 blows at 300 psi for the Hveem method or 50 blows per side for the Marshall method.
    c) Cure the briquettes overnight at 140°F ± and recompact 75 blows at 300 psi for the Hveem method or 25 blows per side for the Marshall method.
    d) Lay the molds on their side and cure the briquettes for 24 hours at 140°F ± prior to extrusion.
    e) Extrude the briquettes using a compression testing machine.
    f) Lay the briquettes on their side to maximize surface exposure and cure for 72 ± 24 hours at room temperature prior to testing.
    g) Determine bulk gravity.

This procedure is essentially the same as that used during the 1986 study except for:

1) the range of emulsion/water contents tested, and

2) the compactive effort used in the Hveem method for specimen fabrication.

In the 1986 study, specimens were prepared with three emulsion contents (namely, EC_{EST} and $EC_{EST} \pm 0.4\%$) while in the current study specimens were fabricating using five emulsion contents (EC_{EST}, EC_{EST} - 0.3%, EC_{EST} + 0.3%, EC_{EST} + 0.6%, and EC_{EST} + 0.9%). Thus, the range in emulsion content was increased in the current study relative to that used in the 1986 study. In addition, the compactive effort used in the Hveem method was refined (reduced) such that the resulting briquettes had voids contents in the range of 10-15% (similar to the voids contents of CIR pavements in the field). Reduction of the compactive effort used in the Marshall method was unnecessary since the compactive effort established by the 1986 study provided the appropriate voids contents (10-15%). Thus, the compactive effort for the Marshall method of compaction used in the 1986 study was also used in this study.

2.6 Development of Mix Design Criteria

To accomplish one of the objectives of the study a laboratory study was undertaken to verify and/or modify the mix design criteria for stability and resilient modulus (that evolved from the 1986 study). This section describes the progress made to date in accomplishing this objective. In the laboratory study, test specimens were fabricated with RAP, as described in the previous section, from two projects constructed during the 1989 construction season. These projects were:

1) Stag Hollow Creek Rd.-Wapato Rd. (Yamhill-Newberg Hwy), and

2) Umpqua Jct.-The Dalles-California Hwy (East Diamond Lake Hwy).

The specimens fabricated from samples from these projects were then subjected to laboratory tests to evaluate their mix properties (resilient modulus, fatigue, Marshall stability, and Hveem stability) over time in order to determine mix design criteria for the recycled mixtures. It is the intent that these design criteria will aid in establishing the appropriate emulsion content for field projects.

2.6.1 Resilient Modulus

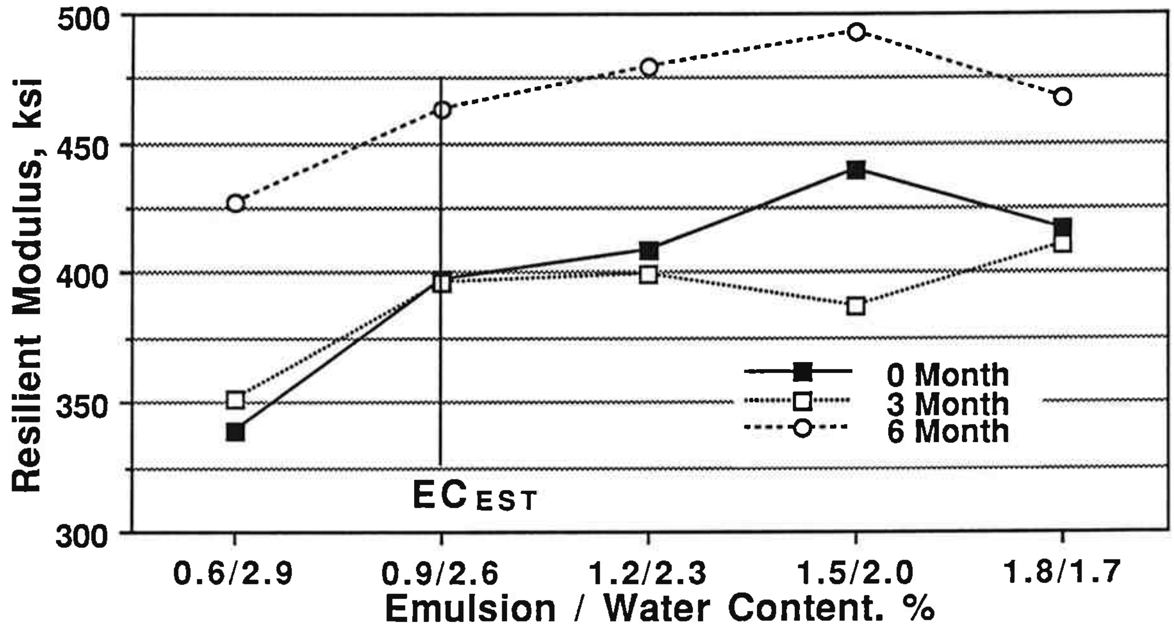
Diametral resilient modulus tests (ASTM D4123) were conducted on laboratory-fabricated specimens at periods of 0 (shortly after compaction), 3, and 6 months at the OSHD laboratory where the specimens were cured in the ambient temperature of the laboratory (~25°C) between test periods. The modulus tests were conducted at a test temperature of 25°C using a pulse load duration and frequency of 0.25 s and 1/3 Hz, respectively and a pulse load magnitude to induce a tensile strain of 100 micro-strain ($\mu\epsilon$). The results of these tests are summarized in Table 2.3 and shown graphically in Figure 2.3. As indicated in Figure 2.3a, the peak modulus for the Umpqua Jct.-The Dalles-California Hwy project occurs at an emulsion content of 1.5% for the 0 month test results -- 0.6% higher than that of the estimated emulsion content (EC_{EST}) as determined by the estimation procedure (Section 2.1). The 3 month test results essentially duplicate the 0 month test results while the 6 month test results show an increase in modulus across all emulsion/water contents. It was expected that the modulus would increase over time and that the peak modulus would shift to the left in Figure 2.3 (i.e., over time, the peak modulus was expected to increase as well as correspond to a lower emulsion content). However, it is clear that the peak modulus only showed an increase over time and that it corresponded to the same emulsion content.

For the Stag Hollow Creek Rd.-Wapato Rd. project, the peak modulus (see Figure 2.3b) occurred at an emulsion content of 1.7% -- again, 0.6% higher than that predicted by the estimation process described in Section 2.1. The 3 month test results, although somewhat lower than the 0 month test results, also show that the peak modulus occurs at the 1.7% emulsion content. The results of the 6 month tests indicate both an increase in modulus for all emulsion/water contents and a reduction in the emulsion content corresponding to the peak modulus. That is, the peak modulus occurs at the 1.4% emulsion content -- a reduction of 0.3% relative to the 0 and 3 month test results.

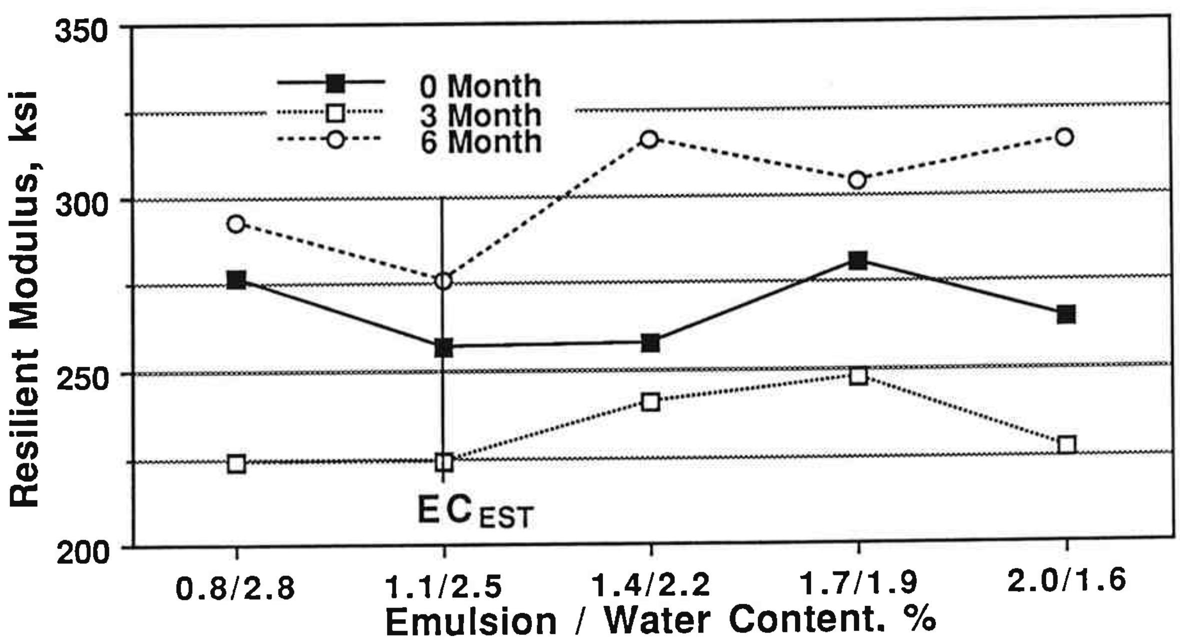
Although the above results do not conclusively confirm what was expected (that the peak modulus should correspond to lower emulsion contents over time), it can be said that for both projects the peak modulus at the 0 month test period corresponded to an emulsion content that was a constant value greater (about 0.6%) than that predicted by the estimation procedure described in Section 2.1. This is

Table 2.3. Summary of Resilient Modulus of Mix Design Samples

Project	Emulsion/Water Content (%)	Resilient Modulus, ksi		
		0 Month	3 Month	6 Month
Umpqua Jct-The Dalles-California Hwy (East Diamond Lake Hwy)	0.6/2.9	339	351	427
	0.9/2.6	397	396	463
	1.2/2.3	409	399	479
	1.5/2.0	440	387	493
	1.8/1.7	417	411	467
Stag Hollow Creek Rd-Wapato Rd (Yamhill-Newberg Hwy)	0.8/2.8	277	224	293
	1.1/2.5	257	224	276
	1.4/2.2	258	241	316
	1.7/1.9	281	248	304
	2.0/1.6	265	227	315



a) East Diamond Lake Hwy



b) Stag Hollow Creek Rd

Figure 2.3. Resilient Modulus of Mix Design Samples.

potentially useful information in that it was desired to establish a shift factor to be applied to the emulsion content corresponding to the peak modulus of the 0 month test period since it was previously known and expected that the peak modulus obtained shortly after compaction (0 month) would predict an emulsion content that was too high. Hence, the above results would indicate that a shift factor of minus 0.6% should be applied to the emulsion content corresponding to the peak modulus as obtained shortly after specimen fabrication. However, since the relative change in modulus between emulsion contents is small, use of a peak modulus to predict an emulsion content may be difficult (i.e., definitive trends showing a peak modulus may be nonexistent).

2.6.2 Fatigue

Fatigue tests have been conducted at the 0 and 3 month test periods. The fatigue tests were conducted as described in Reference 6 using a test temperature of 25°C, a pulse load frequency of 1 Hz, a pulse load duration of 0.1 s, and a pulse load magnitude to induce an initial tensile strain of 100 $\mu\epsilon$. The results of these tests are given in Table 2.4 and shown graphically in Figure 2.4. As indicated in Table 2.4, several tests during the 3 month test period were terminated due to excessive fatigue lives (greater than 150,000 repetitions). It was decided to terminate the tests after 150,000 repetitions to prevent excessive wear and tear on the test equipment. Thus, 5 of the 6 fatigue tests for the 3 month test period were terminated since they did not fail after 150,000 load repetitions. Because of this, the fatigue tests for the 6 month test period were not conducted since little information would be gained from the results.

2.6.3 Hveem Stability

Hveem stability tests, conducted in accordance with ASTM D1560 (5), were performed at periods of 0, 3, and 6 months on laboratory-fabricated test specimens that were cured, between test periods, in the ambient conditions of the laboratory. The results of these tests are presented in Table 2.5 and shown graphically in Figure 2.5. The results generally indicate, for both projects, an overall decrease in stability with increased emulsion content (see Figure 2.5). However, a minimum Hveem stability value of

Table 2.4. Summary of the Fatigue Results for Mix Design Samples

Project	Test Period (Months)	Sample ID	Bulk Gravity	Rice Gravity	% Voids	Modulus (ksi)	Average Modulus (ksi)	Fatigue (reps)	Average Fatigue (reps)
Umpqua Jct-The Dalles-CA Hwy	0	1	2.358			621	560	35974	40787
		2	2.355			542		39479	
1.1% Emulsion		3	2.356			518		46909	
2.5% Water	3	4	2.335			435	504	164230*	137000+
		9	2.359			507		78900	
		10	2.350			571		168000*	
	6	11							
		12							
		26							
Stag Hollow Creek Rd-Wapato Rd	0	27	2.381			447	406	239080*	110000+
		28	2.410			354		58136	
0.9% Emulsion		29	2.404			416		33258	
2.6% Water	3	35	2.289			350	373	167000*	162000*
		36	2.285			370		165120*	
		37	2.268			399		154320*	
	6	38							
		39							
		40							

*Test intentionally stopped

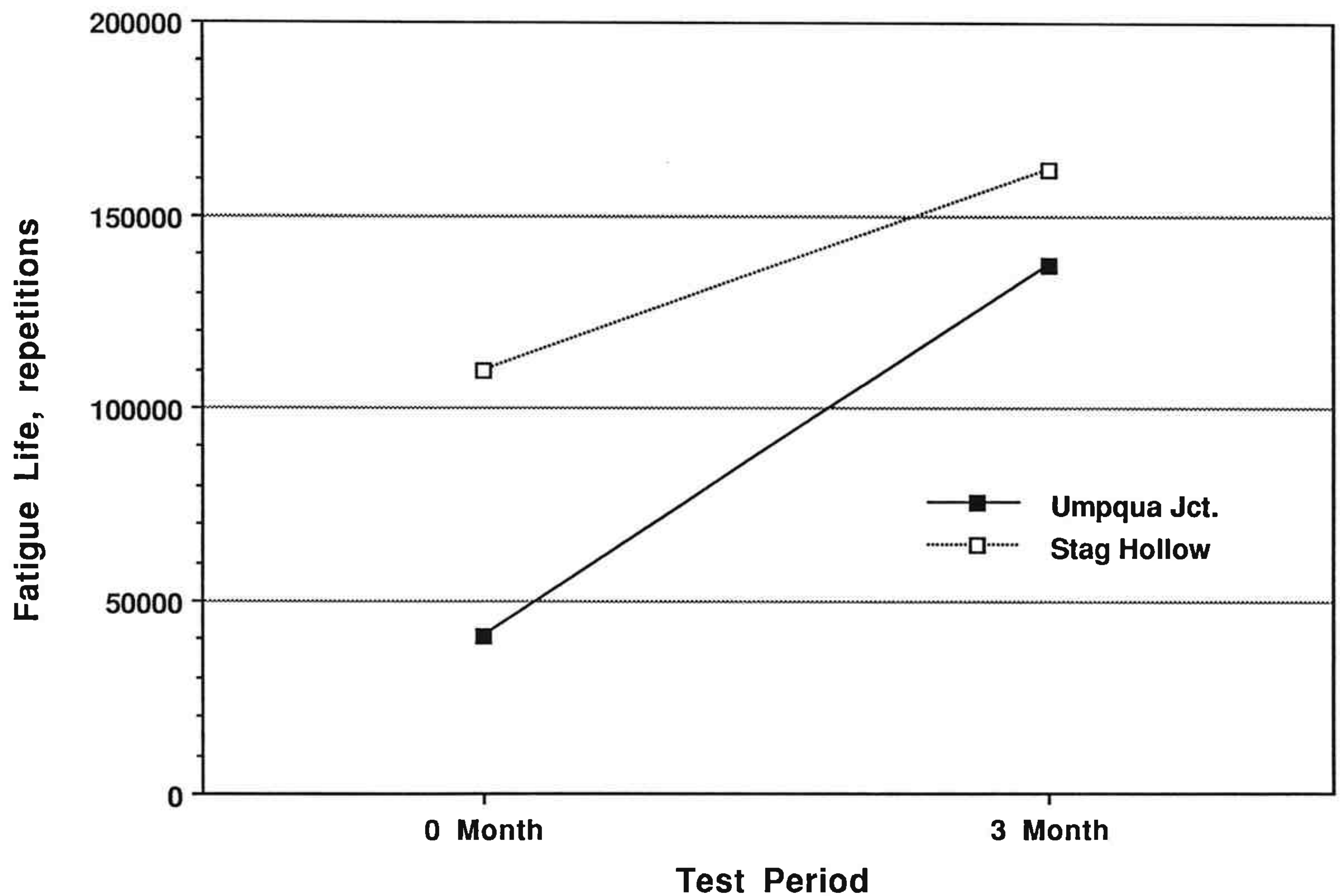
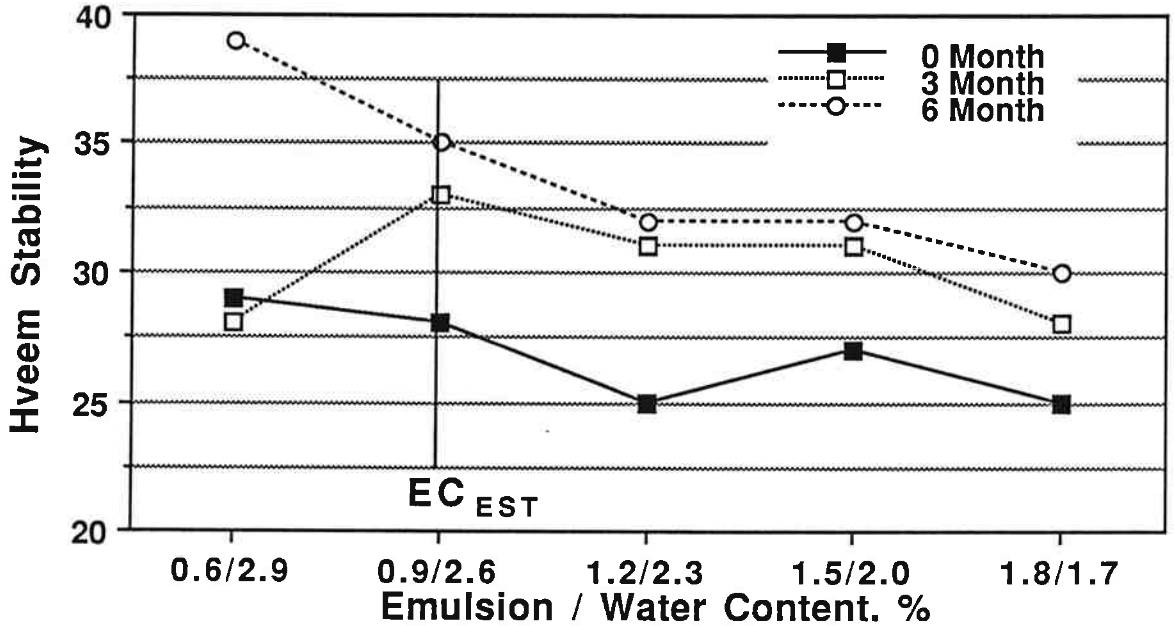


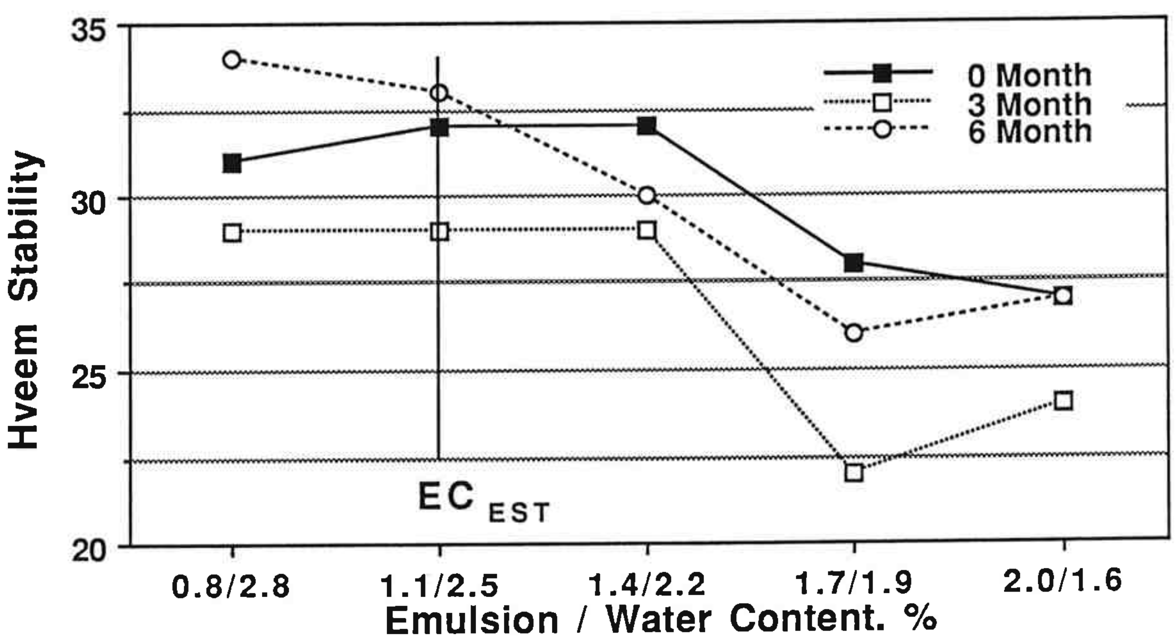
Figure 2.4. Fatigue of Mix Design Samples.

Table 2.5. Summary of Hveem Stability Results for Mix Design Samples

Project	Emulsion/Water Content (%)	Hveem Stability		
		0 Month	3 Month	6 Month
Umpqua Jct-The Dalles-California Hwy (East Diamond Lake Hwy)	0.6/2.9	29	28	39
	0.9/2.6	28	33	35
	1.2/2.3	25	31	32
	1.5/2.0	27	31	32
	1.8/1.7	25	28	30
Stag Hollow Creek Rd-Wapato Rd (Yamhill-Newberg Hwy)	0.8/2.8	31	29	34
	1.1/2.5	32	29	33
	1.4/2.2	32	29	30
	1.7/1.9	28	22	26
	2.0/1.6	27	24	27



a) East Diamond Lake Hwy



b) Stag Hollow Creek Road

Figure 2.5. Hveem Stability of Mix Design Samples.

30, as indicated by the data obtained during the 0 month test period would predict an emulsion content that is within ±0.3% of that determined by the estimation procedure described in Section 2.1.

2.6.4 Marshall Stability

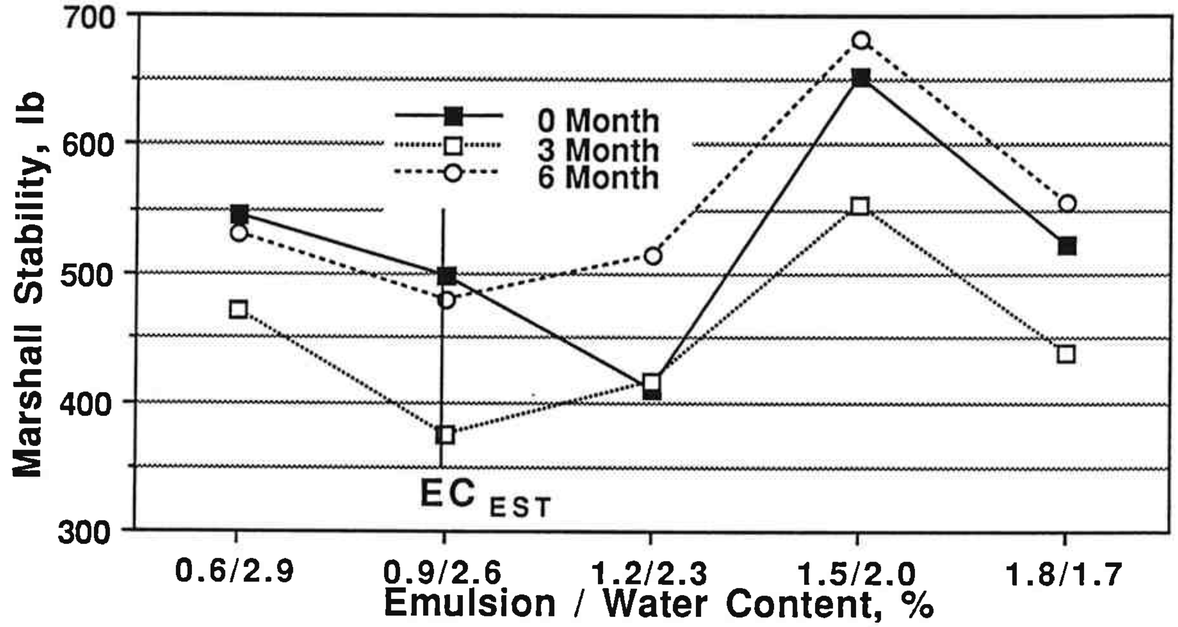
Tests for Marshall stability, conducted in accordance with ASTM D1559 (5), have been completed for the 0, 3, and 6 month test periods. The specimens were cured in the ambient temperature of the laboratory (~ 25°C) between test periods. Table 2.6 summarizes the test results while Figures 2.6 and 2.7 depict these graphically. As indicated in Figure 2.6, the Umpqua Jct.-The Dalles-California Hwy specimen results show a general initial decrease in stability with increased emulsion content followed by a distinctive peak for all test periods. The flow values for this project show a general increase with increased emulsion content for all test periods.

The stability results for the Stag Hollow Creek Rd.-Wapato Rd. project show a dual peak situation for the 0 and 3 month test periods with the first peak corresponding to the emulsion content predicted by the estimation procedure described in Section 2.1 (see Figure 2.7). The second peak for the 0 month test results corresponds to an emulsion content 0.9% higher than that predicted by the estimation procedure while that for the 3 month test period corresponds to an emulsion content that is 0.6% higher. The 6 month test results show a single peak which is 0.3% higher than that predicted by the estimation procedure. The flow values for this project for all test periods show a general overall increase with increased emulsion content.

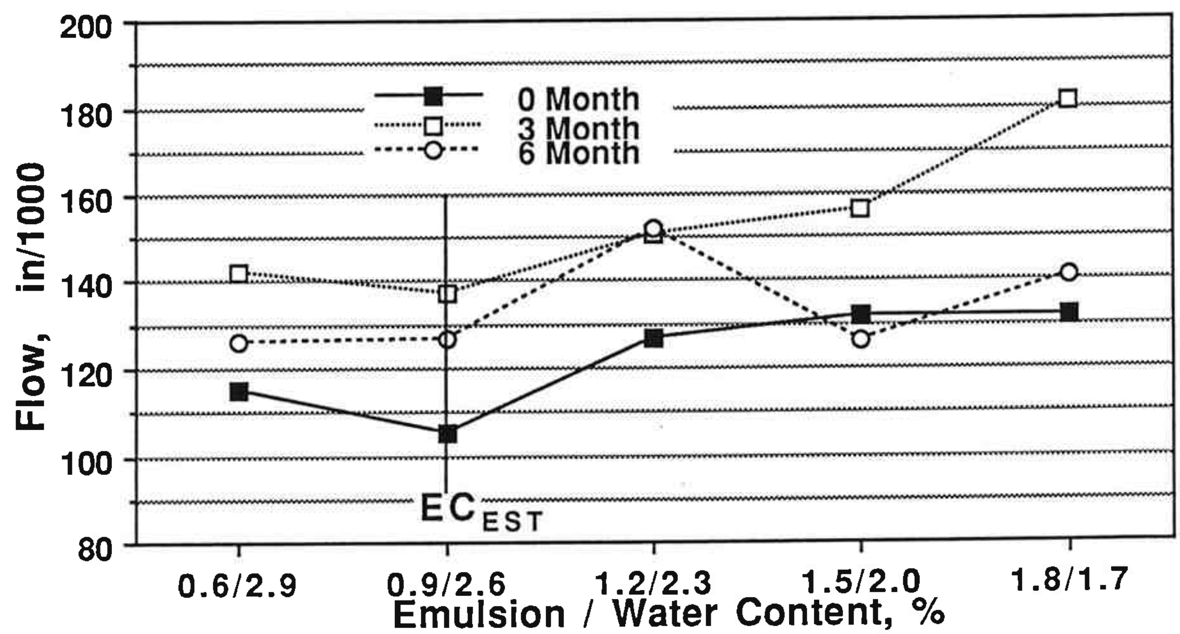
From the stability results, it is apparent that prediction of the emulsion content to be used in the field would be a difficult task since definitive trends in the data are, at best, fair. Also specifying a minimum stability appears unwarranted since the maximum stabilities between the two projects differ significantly (i.e., 652 lb for the Umpqua Jct.-The Dalles-California Hwy. project and 362 lb for the Stag Hollow Creek Rd.-Wapato Rd. project obtained during the 0 month test period). It should be pointed out, however, that the actual field installation of the Stag Hollow Creek Rd.-Wapato Rd. project has not performed well.

Table 2.6. Summary of Marshall Stability Results for Mix Design Samples

Project	Emulsion/Water Content (%)	Marshall Stability, lb			Flow, in/1000		
		0 Month	3 Month	6 Month	0 Month	3 Month	6 Month
Umpqua Jct-The Dalles-California Hwy (East Diamond Lake Hwy)	0.6/2.9	546	472	530	105	142	126
	0.9/2.6	498	375	480	105	137	127
	1.2/2.3	409	415	515	127	151	152
	1.5/2.0	652	554	681	132	156	126
	1.8/1.7	522	438	555	132	181	141
Stag Hollow Creek Rd (Yamhill-Newberg Hwy)	0.8/2.8	269	334	475	119	162	178
	1.1/2.5	301	364	512	130	169	222
	1.4/2.2	291	352	536	139	151	221
	1.7/1.9	303	384	527	120	192	194
	2.0/1.6	362	345	482	188	169	270

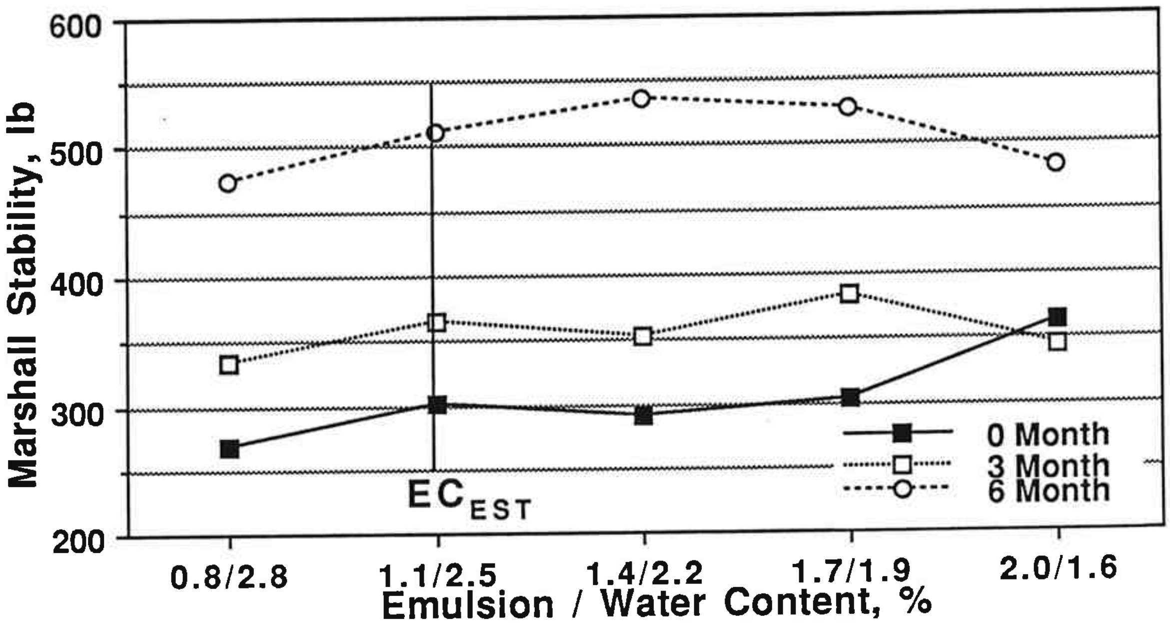


a) Stability

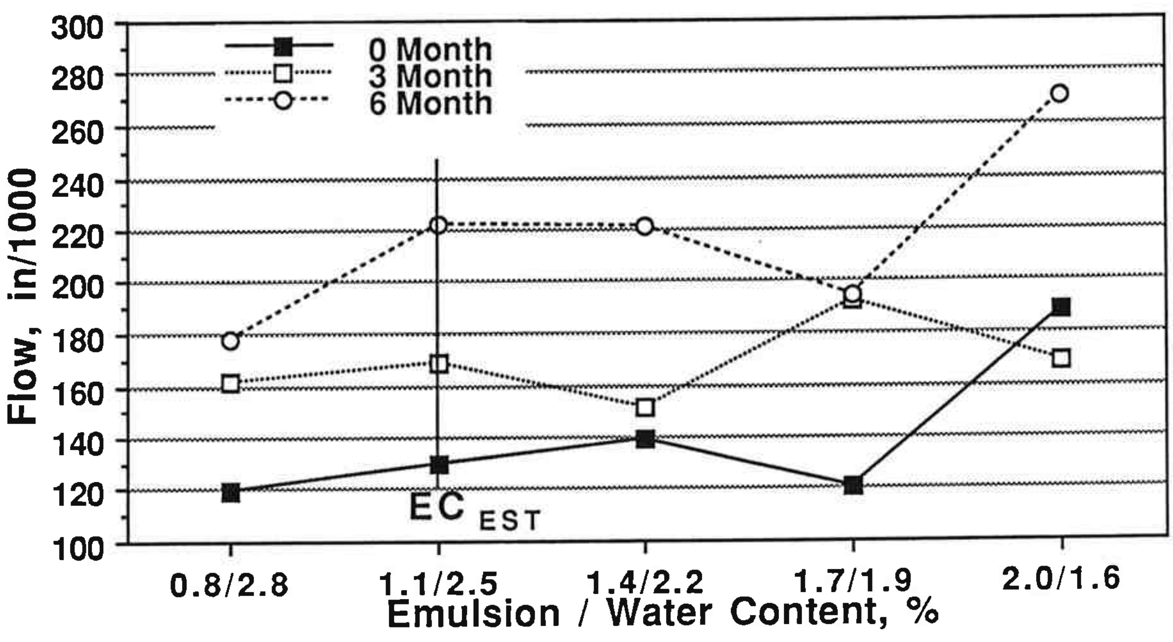


b) Flow

Figure 2.6. Marshall Stability for Mix Design Samples - East Diamond Lake Hwy



a) Stability



b) Flow

Figure 2.7. Marshall Stability for Mix Design Samples - Stag Hollow Creek Road

2.6.5 Summary

It is apparent from the above results that use of mix property test results, for the purpose of predicting an emulsion content for field projects, is a difficult task. That is, none of the above mix property test results can, by themselves, or taken together, accurately predict the same emulsion content that is predicted by the estimation procedure (described in Section 2.1) which has been shown to be a good indicator of a starting point in the construction of recycled mixtures.

2.7 Field Adjustments

In addition to the calculated adjustments to the base design emulsion content (described above) field adjustments are often made to recognize: (1) differences in RAP gradation, (2) isolated fat spots or unstable mixtures, and (3) visual appearance of the mat 2 to 3 hours after rolling. The field adjustments to the final estimated design emulsion content developed by ODOT are described in detail below:

1) RAP Gradation. RAP gradation is checked frequently during construction. If differences from the RAP gradation used to estimate the emulsion content occur, the emulsion content is changed as described above (i.e., using Figure 2.1).

2) Isolated Fat Spots and Unstable Mixes. Isolated fat spots and unstable mixes are noted ahead of the mill. The emulsion content is dropped 0.2% in areas that appear slightly fat and dropped 0.4% in areas that are obviously unstable and rutted. These adjustments are made only if field samples are not taken at the exact locations of the distress.

3) Visual Appearance. Minor adjustments of ±0.1% to ±0.2% are made by visual appearance of the mat 2 to 3 hours after initial compaction. Additional emulsion is added (up to +0.2%) if the mat remains brown or is prone to raveling. On the other extreme, the emulsion content is reduced 0.2% if the mat is very black and shiny and no raveling is apparent.

3.0 PERFORMANCE DATA

This chapter describes the progress made to date on one of the objectives of this study -- to examine selected projects constructed during the 1984 through 1988 construction seasons for the purpose of estimating the life expectancy of CIR treatments using standard and high float emulsions. Included in the following sections are descriptions of the projects evaluated, the results of condition surveys, deflection measurements, and mix property tests as well as an evaluation of these results.

3.1 Project Descriptions

A total of 10 projects recycled during the 1984 through 1988 construction seasons are being intensely evaluated for the purpose of estimating the life expectancy of CIR treatments. These projects are listed in Table 3.1 which also includes construction information (i.e., project length, class of recycle, type of emulsion used, etc.). Note that the Sand Shed-Mt. Bachelor project (1984) is a Class III treatment while the remaining projects are Class I treatments (1). Note also that all projects were constructed using either the CMS-2S or the HFE-150 emulsions. The CMS-2S is a cationic medium set emulsion with a soft base asphalt while the HFE-150 is a high float emulsion.

It should be pointed out that the Sand Shed-Mt. Bachelor project was one of the first surface recycling jobs constructed in Oregon. Since formal mix designs were unavailable in 1984, emulsion and water contents were established in the field using trial-and-error techniques by experienced paving personnel. The remaining projects (1985-1988) were constructed based on the results of formal mix designs which have evolved over time. (Reference 3 details the evolution of the mix design practices used in Oregon for CIR.)

3.2 Visual Inspection

To aid in establishing the life expectancy of cold in-place recycled pavements, a visual inspection of all recycled pavements (1984-1988) was conducted in the spring of 1989. The purpose of this inspection was to obtain the type and amount of distress including rut depth, thermal and fatigue

Table 3.1. CIR Projects (1984-1988) Evaluated for Life Expectancy

Year	Highway	Project Name	Length (mi.)	Recycle Depth (in.)	Emulsion Type (Content)	Class of Treatment	Surface Treatment
1984	OR 372	Sand Shed-Mt. Bachelor	5.0	1.5	CMS-2S (1-2%)	Class III	Surface left open winter of 1984, chip sealed in 1985
1985	OR 20	Drews Gap-Lakeview	11.0	1.5-2	CMS-2S (1-2%)	Class I	Polymer chip seal
	OR 49	Harney Co. Line-Hogback Summit	30.7	1.5-2	CMS-2S (1-2%)	Class I	Chip seal
1986	OR 53	MP 79.2-Wasco Co. Line	17.3	2-4	CMS-2S (1%)	Class I	Polymer chip seal
	OR 41	MP 89.6-Jct. OR 19	8.7	1.5-2	CMS-2S (1.4-1.5%)	Class I	Chip seal
	OR 270	Lakeshore Dr.-Greensprings Jct.	6.4	2.5-4	CMS-2S (1.4%)	Class I	Chip seal
	OR 372	Lava Springs-Sand Shed	5.7	2	CMS-2S (1%)	Class I	Chip seal
1988	OR 426	Jct. Klamath Falls-Malin Hwy-CA Line	2.8	2	CMS-2S (0.5%)	Class I	None
	OR 42	MP 13.27-Moro	4.8	2	HFE-150 (1.0%)	Class I	Polymer chip seal
	OR 22	Fort Klamath-Crooked Creek	5.7	2	HFE-150 (1.1%)	Class I	Sand seal

cracking, and flushing. The amount of maintenance work and the condition rating were also determined for all projects. The inspections, carried out by Oregon DOT personnel, are summarized in Table 3.2. Further comment is given to the 10 projects being intensively evaluated as follows.

Sand Shed-Mt. Bachelor. Although this project was a Class III recycle job, the visual inspection indicates that it has a fair overall condition rating. The project has signs of some fatigue (alligator) cracking and potholes, minor rutting and flushing, and has had some patching.

Drews Gap-Lakeview. This project has a fair-to-good condition rating with minor distress, mainly thermal cracking with spacings as small as 30 ft and some flushing in the wheel tracks. The project has had minor maintenance work.

Harney Co. Line-Hogback Summit. This project was divided into three sections for inspection purposes as follows:

1) Harney Co. Line-Bacon Camp Rd.,
2) Bacon Camp Rd.-MP 57, and
3) MP 57-Hogback Summit.

The first section (Harney Co. Line-Bacon Camp Rd.) has a fair condition rating with minor distress (minor rutting, flushing, and fatigue cracking). However, between mile posts 39 and 41, sections of the pavement are gone and some areas show bare gravel while others are fat with asphalt. Between mile posts 44 and 47 the pavement looks okay with no potholes but has slight bleeding problems.

The second section (Beacon Camp Rd.-MP 57) has a fair condition rating, but looks dry, with some of the pavement falling apart in large potholes. Consequently, major maintenance work has been required on this section.

The third section (MP 57-Hogback Summit) has a poor condition rating with more pronounced rutting and thermal cracking relative to the other two sections. Although the pavement looks acceptable visually, the surface has a rough texture resulting in poor ride characteristics.

MP 79.2-Wasco Co. Line. This project was divided into two sections for inspection purposes with both sections showing distress. One section had a fair condition rating while the other had a poor rating. Significant maintenance work has been required to maintain these ratings. Because this project

Table 3.2. Performance Evaluation - Spring 1989

Year Built	Section	Hwy No.	M.P.	M.P.	Length (mi.)	Depth of CIR (in.)	Emulsion Used	Original Pavement	Rut Depth (in.) Lt.	Rut Depth (in.) Rt.	Thermal Crack Spacing (ft)	Flushing	Fatigue Cracks	Maint. Work	Rating	Notes
1984	Fremont Hwy-(N. Lane)	19	8.0	8.6	0.6	1.5	CMS-2S	C		1/16	20-60	–	minor	minor	fair	Delete from study.
	Fremont Hwy-(N. Lane)	19	16.8	18.3	1.5	1.5	CMS-2S	C	3/16	5/16	20-60	heavy	minor	major	poor	Delete from study.
	Sand Shed-Mt. Bachelor	372	16.6	21.6	5.0	1.5	CMS-2S	C	1/16	3/16	occasional	minor	minor	minor	fair	Intermittent CIR between mile points.
1985	Sisters-Dry Creek	15	93.2	99.0	5.8	2	CMS-2S	C	1/8	1/16	30-50	heavy	minor	--	poor-fair	
	Dry Creek-Warrin Rd	15	99.0	105.0	6.0	2	CMS-2S	0-11	1/8	3/16	30	--	minor	–	fair	
	Warrin Rd.-Redmond	15	105.0	111.9	6.9	2	CMS-2S	B	1/8	1/8	15-30	--	minor	--	fair-good	
	Summit Drews Gap-Lakeview	20	81.8	92.8	11.0	1.5	CMS-2S		1/16	1/8	30-100	minor	minor	minor	fair-good	
	Harney Co. Line-Bacon Camp Rd	49	35.1	49.0	13.9	1	CMS-2S	variable	1/8	3/16	130	minor	minor	major	fair	Maintenance due to delamination.
	Bacon Camp Rd-M.P 57	49	49.0	57.0	8.0	1	CMS-2S	variable	3/16	1/8	--	--	minor	major	fair	
	M.P. 57-Hogback Summit	49	57.0	65.8	8.8	1	CMS-2S	variable	3/16	3/16	100	–	minor	major	poor	
	O'Neil-Prineville*	370	9.5	17.7	8.2	1	CMS-2S	0-9?	3/16	1/8	70-30	minor	minor	minor	poor	Grader laid.
1986	Pilot Butte-Powell Butte Jct	7	1.1	4.3	3.2	2	CMS-2S	B	1/16	1/16	--	--	--	--	good	Overlaid w/1.5 in. AC; condition before overlay.
	Horse Ridge-Fort Rock Rd	7	18.1	21.0	2.9	3	CMS-2S	B	1/8	3/16	20	minor	minor	--	fair-good	
	G.I. Ranch-Harney Co. Line	7	75.0	84.0	9.0	1.5	CMS-2S	C	3/16	3/16	30-120	minor	–	minor	fair-good	US 20 test section.
	Dairy-Wild Horse Cr	20	19.0	25.0	6.0	1.5	CMS-2S	C	5/16	1/8	--	heavy	–	major	poor	Maintenance due to base failure; polymer seal.
	Sprague R. Rd-Sycan Marsh Rd	20	35.9	42.2	6.3	1.5	CMS-2S	C	1/8	3/16	60	minor	–	minor	fair	Polymer seal.
	Sycan Marsh-Bly	20	42.2	54.0	11.8	1.5	CMS-2S	C	1/8	3/16	--	minor	–	minor	fair	
	Powell Butte-Houston Lake Rd	41	6.8	16.5	9.7	1.5	CMS-2S HFE-150	variable	3/16	1/4	100	–	minor	major	poor	No seal initially; pavement flushed when sealed; overlaid w/OGEM in 1989.
	Ochoco Dam-Ranger Station	41	249.9	35.5	10.6	1.25	CMS-2S	oil mat	1/16	3/16	--	minor	–	minor	fair	Overlaid w/OGEM in 1989.
	Keys Cr Summit-Whiskey Cr	41	73.4	81.6	8.2	2	CMS-2S	C?	1/16	1/16	--	–	–	--	good	Overlaid w/OGEM in 1989.
	M.P. 89.6-Jct John Day Hwy	41	89.6	98.4	8.8	1.5	CMS-2S	oil mat	3/16	1/16	--	minor	–	minor	good	Chip sealed in 1986.
	M.P. 79.2-Bridge Cr	53	79.2	86.9	7.7	1.5	CMS-2S	B	3/16	1/8	occasional	minor	–	signif.	fair	Early polymer seal; recycled w/too much emulsion.
	Bridge Cr-County Line	53	86.9	96.5	9.6	1.5	CMS-2S	C	1/8	3/16	60	minor	–	signif.	poor	Early polymer seal; recycled w/too much emulsion.
	Lake Shore Dr-Gr. Spgs. Hwy	270	62.4	68.8	6.4	1.5	CMS-2S	B	3/16	1/8	--	minor	minor	–	good	
	Tub Springs Rd-Antelope*	293	9.0	13.5	4.5	1-1.5	CMS-2S	oil mat	1/16	1/8	--	minor	–	--	good	
	McKay Cr-Prineville*	360	23.7	26.3	2.6	1.5	CMS-2S	B2-oil mat	1/8	1/4	--	minor	minor		fair-good	Partially (1 mi.) overlaid in 1986.
	Jct Ochoco Hwy-Desch. Co. Line	371	0.0	7.6	7.6	.75-1.5	HFE-150 CMS-2S	C & B & oil mat	1/4	3/16	--	heavy	minor	minor	fair-good	
	Desch. Co. Line-Jct Cent. Ore.	371	7.6	18.0	10.4	.75-1.5	CMS-2S	oil mat	1/8	3/16	30-80	–	minor	minor	fair-good	

*CIR done by State forces

Table 3.2. Performance Evaluation - Spring 1989 (continued).

Year Built	Section	Hwy No.	M.P.	M.P.	Length (mi.)	Depth of CIR (in.)	Emulsion Used	Original Pavement	Rut Depth (in.) Lt.	Rut Depth (in.) Rt.	Thermal Crack Spacing (ft)	Flushing	Fatigue Cracks	Maint. Work	Rating	Notes
1987	For Rock Rd-Crooked R. Hwy*	7	21.0	30.2	9.2	2	several	B	N/A	1/8	60-90	--	minor	--	poor-good	East lane only; overlaid w/OGEM in 1989.
	Whiskey Cr-M.P. 89.6*	41	81.6	89.6	8.0	1-2.5	CMS-2S	variable	1/8	1/8	--	heavy	--	minor	good	
	Jct Hwy 97-Tub Springs Rd*	293	0.0	9.0	9.0	1.25-2	CMS-2 EB HFE-150 WB	oil mat	1/16	1/8	--	minor	--	--	good	
	Jct Hwy 97-Rammes Rd*	360	0.0	9.0	9.0	1.75-2	CMS-2S NB HFE-150 SB	oil mat	3/16	1/8	--	minor	minor	--	fair	No base.; recycled w/too much emulsion.
	Kiwa Springs-Sand Shed*	372	11.0	16.6	5.6	2	HFE150	B	1/6	3/16	60-100	--	minor	--	good	
	Conant Basin Rd-Shotgun Rd*	380	20.7	29.8	9.1	1.5-2	CMS-2S	variable	1/8	1/8	--	minor	--	--	good	Overlaid w/0-9 in 1987.
1988	Shaniko Jct-Quaale Rd	4	67.2	75.6	8.4	1.5	HFE-150	B	1/8	3/16	--	--	--	--	poor-fair	M.P. 67.2-69.2 (SB) failed due high asphalt - 2 in. ruts.
	Shaniko Jct-Qualle Rd	4	75.6	78.6	3.0	1.5	HFE-150	0-11	1/16	1/8	--	--	minor	--	good	
	Shaniko Jct-Qualle Rd	4	78.6	80.0	1.4	1.5	HFE-150	0-11	0	0	--	--	--	--	good	
	M.P. 152-CA Line*	19	152.0	157.7	5.7	2	CMS-2S	B?	3/16	3/16	--	minor	minor	major	poor	Unstable.
	Houston Lake Rd-Prineville*	41	16.5	18.0	1.5	2	HFE-150 HFE-150S	B & C	1/16	1/16	--	--	--	--	good	Scheduled to be overlaid w/AC.
	Prineville-Ochoco Dam*	41	19.4	24.9	5.5	2	HFE-150	B & C & oil mat	1/16	1/8	--	minor	--	minor	fair-good	Overlaid w/OGEM in 1989.
	Ochoco Ranger St-Rich Cr*	41	35.5	45.0	9.5	2	CMS-2S HFE-150	variable	0	1/16	--	--	--	--	good	
	Wheeler Co. Line-W. Brand Cr*	41	50.1	60.3	10.2	2	HFE-150	variable	1/8	0	--	--	--	--	good	
	Lake Abert-Valley Falls*	49	87.0	89.9	2.9	1-1.5	CMS-2S	oil mat	3/16	1/4	--	minor	minor	major	poor	Fat oil mat.
	Merrill-Jct Hatfield Hwy*	50	13.7	16.3	2.6	2	CMS-2S	B	1/8	1/16	100-200	minor	--	--	good	
	Jct Ochoco Hwy-Burma Rd	380	0.0	11.8	11.8	2	HFE-150	C?	1/8	1/16	--		minor	--	fair	No seal - raveled.
	Burma Rd-Conant Basin Rd	380	11.8	20.7	8.9	2	HFE-150	C?	1/16	1/16	--		--	--	good	Sealed in 1989.
	Malin Hwy-CA Line	426	0.0	2.4	2.4	2	CMS-2S	Mod-B w/seal	1/8	1/8	--		minor	--	good	Stripped.
	Crater Lake Hwy (Ft. Klamath-Crooked Cr)	22	90.07	95.4	5.3	2	HFE-100S	E							good	

*CIR done by State forces

was intensively studied in the 1986 study, substantial effort was given to the investigation of the cause or causes of the failure of this project. It was determined that the pavement was recycled with too high of an emulsion content and that a polymer chip seal was placed too soon.

MP 89.6-Jct. OR 19. This project has a good condition rating. Only minor distress (some rutting and flushing) is apparent and the pavement has had only minor maintenance work.

Lakeshore Dr.-Greensprings Jct. This project has a good condition rating and has minor distress. However, some fat spots are apparent and cracks in the shoulders are beginning to spread into the recycled pavement. Also, some signs of raveling have appeared in the eastbound lane.

Jct. Klamath Falls-Malin Hwy.-CA Line. This project has a good condition rating after having been in service through one winter. No maintenance work has been performed and only minor distress (fatigue cracking) is apparent on this recycled mix. It should be noted that the original pavement was stripped.

MP 13.27-Moro. Although this project is not included in Table 3.2, it was inspected independently and showed the pavement had a consistent gradation and asphalt content throughout the project. However, areas in the wheel paths have started to show signs of wear and have a somewhat smooth appearance.

Fort Klamath-Crooked Creek. This project, which was recycled with a polymer-modified emulsion (HFE-100S), has a good condition rating. However, the pavement has some segregation problems as well as some raveling, bleeding, and cracking.

3.3 Deflection Data

Deflection data has been obtained over time on 9 of the 10 projects being intensively evaluated for life expectancy of cold recycled pavements -- the data for the Lava Springs-Sand Shed project was unavailable for this study. These deflections are summarized in Table 3.3. In all cases the deflections are the average of 11 readings obtained via the Dynaflect deflectometer. It can be seen from these data that in some cases CIR slightly improves the structural integrity of pavement. However, for the majority

Table 3.3. Deflection Data for Selected Projects

Project	Year Recycled	M.P.	Date Deflected	Deflection* (mils)	Equiv. Benkleman Beam	Before or After CIR
Sand Shed-Mt. Bachelor (Century Drive)	1984	17.49 SB	8/84	1.43	34.13	Before
			8/85	1.53	37.19	After
			7/86	1.75	44.11	After
			6/89	1.86	47.59	After
		17.58 NB	8/84	1.53	37.05	Before
			8/85	1.64	40.33	After
			7/86	1.80	45.61	After
			6/89	1.95	50.47	After
Harney Co. Line-Hogback Summit (Lakeview-Burns Hwy)	1985	36.00 SB	5/85	1.29	30.02	Before
			8/85	1.36	32.02	After
			7/86	1.30	30.28	After
			8/87	1.40	33.24	After
			5/89	2.12	56.46	After
		36.09 NB	5/85	1.39	32.83	Before
			8/85	1.46	34.85	After
			7/86	1.39	32.77	After
			8/87	1.47	35.19	After
			5/89	2.27	61.71	After
		60.00 NB	8/84	2.43	67.88	Before
			8/85	2.40	66.81	After
			7/86	3.03	91.81	After
			8/87	2.68	77.20	After
			5/89	2.08	54.76	After
		60.33 SB	7/84	1.35	31.71	Before
			8/85	1.35	31.67	After
			7/86	1.33	31.07	After
			8/87	1.36	31.81	After
			5/89	1.95	50.31	After
		64.26 SB	5/89	1.72	43.16	After
Drews Gap-Lakeview (Klamath Falls-Lakeview Hwy)	1985	86.02 EB	7/84	0.93	20.00	Before
			4/85	1.39	33.14	Before
			8/85	1.17	26.81	After
			7/86	1.09	24.31	After
			5/89	1.12	25.19	After
		86.11 WB	7/84	0.82	17.27	Before
			4/85	1.22	28.13	Before
			8/85	1.05	23.32	After
			7/86	0.86	18.38	After
			5/89	0.95	20.55	After
		87.40 WB	5/89	1.14	25.67	After
		93.50 EB	7/84	1.46	35.05	Before
			7/86	1.46	35.12	After
			5/89	1.51	36.64	After
		94.00 WB	7/84	1.63	40.13	Before
			6/85	1.28	29.63	Before
			7/86	1.72	42.86	After
			5/89	1.81	45.88	After

*Average of 11 readings

Table 3.3. Deflection Data for Selected Projects (continued)

Project	Year Recycled	M.P.	Date Deflected	Deflection* (mils)	Equiv. Benkleman Beam	Before or After CIR
M.P. 79.2-Wasco Co. Line (Warm Springs)	1986	88.00 SB	4/86	0.66	13.27	Before
			10/86	0.65	13.19	After
			9/87	0.71	14.45	After
			5/89	0.76	15.91	After
		88.19 NB	4/86	0.71	14.63	Before
			10/86	0.77	16.11	After
			9/87	0.72	14.93	After
			5/89	0.80	16.82	After
		88.28 SB	4/86	0.74	15.27	Before
			10/86	0.71	14.51	After
			9/87	0.67	13.61	After
		88.47 NB	4/86	0.62	12.54	Before
			10/86	0.63	12.74	After
			9/87	0.63	12.60	After
		88.56 SB	4/86	0.56	11.07	Before
			10/86	0.55	10.67	After
			9/87	0.52	9.99	After
			5/89	0.57	11.15	After
		88.75 NB	4/86	0.57	11.31	Before
			10/86	0.67	13.65	After
			9/87	0.68	13.97	After
			5/89	0.79	16.51	After
		89.90 NB	5/89	0.81	17.04	After
Lakeshore Dr-Greensprings Jct (Lake of the Woods)	1986	63.28 EB	4/86	1.29	29.90	Before
			10/86	1.33	31.06	After
			9/87	1.19	27.09	After
			5/89	1.46	34.75	After
		63.36 WB	5/89	1.18	26.83	After
		63.47 WB	4/86	1.40	33.02	Before
			10/86	1.33	30.92	After
			9/87	1.12	25.22	After
			5/89	1.42	33.59	After
		63.56 EB	4/86	1.21	27.60	Before
			10/86	1.28	29.52	After
			9/87	1.08	24.02	After
			5/89	1.41	33.48	After
		63.75 WB	4/86	1.13	25.50	Before
			10/86	1.18	26.84	After
			9/87	1.03	22.60	After
			5/89	1.27	29.33	After

*Average of 11 readings

Table 3.3. Deflection Data for Selected Projects (continued)

Project	Year Recycled	M.P.	Date Deflected	Deflection* (mils)	Equiv. Benkleman Beam	Before or After CIR
M.P. 89.6-Jct OR 19 (Ochoco Hwy)	1986	96.40 WB	6/89	2.50	70.02	After
		96.91 EB	6/84 6/86 10/86 6/89	1.30 1.81 1.34 2.42	30.39 46.25 31.60 67.01	Before Before After After
		97.00 WB	6/84 6/86 10/86 6/89	1.41 1.52 1.26 2.69	33.75 37.26 39.07 77.36	Before Before After After
Jct Klamath Falls-Malin Hwy-CA State Line (Hatfield Hwy)	1988	0.75 SB	5/89	2.51	70.85	After
		0.75 NB	5/89	2.41	66.99	After
		1.00 SB	5/89	2.43	68.08	After
		1.25 SB	5/89	2.74	79.62	After
		1.25 NB	5/89	2.80	81.97	After
Fort Klamath-Crooked Creek (Crater Lake Hwy)	1988	90.50 WB	5/89	2.29	62.50	After
		90.50 EB	5/89	2.37	65.15	After
		91.00 WB	5/89	2.67	77.06	After
		91.00 EB	5/89	2.57	72.69	After
		94.00 EB	5/89	2.37	65.50	After
MP 13.27-Moro (Sherman Hwy)	1988	17.30 SB	7/85 7/87 4/89	0.55 0.74 0.91	10.80 15.32 19.56	Before Before After
		17.39 NB	7/85 7/87 4/89	0.50 0.70 1.06	9.58 14.40 23.39	Before Before After
Horse Ridge-Crooked River Jct (Central Oregon Hwy)	1989	23.00 EB	5/89	1.29	27.78	Before
		23.00 WB	5/89	1.16	26.36	Before
		29.91 EB	6/85 6/87 5/89	1.14 1.50 1.54	25.57 36.31 37.41	Before Before Before
		30.00 WB	6/85 6/87 5/89	1.03 1.18 1.22	22.68 26.92 27.96	Before Before Before
Umpqua Jct-US 97 (East Diamond Lake Hwy)	1989	5.00 WB	5/89	2.05	54.08	Before
		5.00 EB	5/89	2.09	55.44	Before
		5.50 WB	5/89	2.01	52.62	Before
		5.50 EB	5/89	2.21	59.34	Before

*Average of 11 readings

Table 3.3. Deflection Data for Selected Projects (continued)

Project	Year Recycled	M.P.	Date Deflected	Deflection* (mils)	Equiv. Benkleman Beam	Before or After CIR
Hackett Dr-Crescent (The Dalles-CA Hwy)	1989	185.00 SB	6/89	2.73	79.27	Before
		185.08 NB	6/89	2.97	89.06	Before
		185.82 SB	6/87	2.13	56.08	Before
		185.91 NB	6/87	2.46	68.77	Before
Stag Hollow Creek Rd-Wapato Rd (Yamhill-Newberg Hwy)	1989	1.26 EB	4/84 8/86 5/89	2.22 2.04 1.28	61.70 54.76 29.54	Before Before Before
		1.35 WB	4/84 8/86 5/89	2.31 2.12 1.33	64.17 57.20 31.13	Before Before Before

*Average of 11 readings

of projects CIR merely retains or prolongs the stiffness of the pavement as indicated by little or no change in deflection before and after recycling (see Table 3.3).

3.4 Mix Properties

To aid in the evaluation of cold recycled pavement performance, mix properties have been investigated over time. Mix property tests have been (or currently are being) conducted on cores taken in fall 1988 and fall 1989 from the 10 projects being intensively evaluated for life expectancy of recycled pavements. Table 3.4 shows the mile points and locations (relative to centerline of the pavements) that the cores were taken from each project. The tests performed on these cores included:

1) gravities,
2) asphalt coating,
3) modulus, fatigue, and permanent deformation, and
4) Marshall stability and flow.

This section summarizes the results of these tests obtained thus far.

The density (gravity) and asphalt coating results are summarized in Table 3.5. The results generally indicate:

1) Voids are between about 5 and 13% with several of the older (pre-1987) projects showing voids contents of 10% or less.
2) Asphalt coating ranges between 30 and 100% (from dry or uncoated to sufficiently coated). Five of the 10 projects have asphalt coating of 50% or less.

The modulus and fatigue test results for the 1988 field cores are summarized in Table 3.6. Resilient modulus tests were conducted in accordance with ASTM D4123 (5). The tests were conducted at 23°C, at a pulse load frequency of 1 Hz, with a pulse load duration of 0.1 sec, and at a pulse load magnitude to induce a tensile strain of 100 microstrain ($\mu\epsilon$). The fatigue tests were conducted according to the procedure described in Reference 6 and under the same loading conditions and temperatures as that of the modulus tests. The results of these tests generally indicate:

Table 3.4. Project Coring Locations

Project Name	Highway	Year Constructed	M.P. & Location	
			Fall 1988	Fall 1989
Sand Shed-Mt Bachelor	OR 372	1984	not cored	22.00 7'L
Drews Gap-Lakeview	OR 20	1985	87.40 9'L	87.40 9'L
Harney Co. Line-Hogback Summit	OR 49	1985	64.50 8'R	64.20 9.5'R
MP 79.2-Wasco Co. Line	OR 53	1986	89.90 7'L	89.90 8'L
MP 89.6-Jct OR 19	OR 41	1986	96.40 8.5'L	96.40 7'L
Lakeshore Dr-Greensprings Jct	OR 270	1986	63.36 9'R	63.36 9'R
Lava Springs-Sand Shed	OR 372	1986	14.60 8.5'L	14.60 7'L
Jct Klamath Falls-Malin Hwy-CA Line	OR 426	1988	1.00 10'R	1.00 10'R
MP 13.27-Moro	OR 42	1988	16.00 9.5'R	16.00 9'R
Fort Klamath-Crooked Creek	OR 22	1988	94.00 9'R	94.00 8'R

Table 3.5. Gravities and Asphalt Coating

Project	Test Period	Bulk Gravity	Rice Gravity	% Voids	Asphalt Coating	
					%	Notes
Sand Shed-Mt. Bachelor	Fall 88	Not cored in Fall 1988				
	Fall 89	2.273	2.462	7.7	100	Sufficient
Drews Gap-Lakeview	Fall 88	2.116				
	Fall 89	2.152	2.270	5.2	90	Sufficient
Harney Co. Line-Hogback Summit	Fall 88	2.030				
	Fall 89	2.005	2.230	10.1	30-45	Dry
M.P. 79.2-Wasco Co. Line	Fall 88	2.273				
	Fall 89	2.381	2.571	7.4	50	Dry
M.P. 89.6-Jct OR 19	Fall 88	2.241				
	Fall 89	2.338	2.502	6.6	30-45	Dry
Lakeshore Dr-Greensprings Jct	Fall 88	2.132				
	Fall 89	2.141	2.461	13.0	75-80	Dry-sufficient
Lava Springs-Sand Shed	Fall 88	2.134				
	Fall 89	2.088	2.409	13.3	65-70	Dry-sufficient
Jct Klamath Falls-Malin Hwy-CA Line	Fall 88	2.159				
	Fall 89	2.190	2.410	9.1	40	1.4-in.+ uncoated
MP 13.27-Moro	Fall 88	2.235				
	Fall 89	2.283	2.585	11.7	95-100	Sufficient
Fort Klamath-Crooked Creek	Fall 88	2.002				
	Fall 89	2.034	2.335	12.9	40	Dull

Table 3.6. Modulus and Fatigue Results (1988 Field Cores)

Project	Sample ID	Resilient Modulus (ksi)	Average Modulus (ksi)	Fatigue Life (reps)	Average Fatigue (reps)
Sand Shed-Mt. Bachelor (Century Dr Hwy)	Not cored in fall 1988				
Drews Gap-Lakeview (Klamath Falls-Lakeview Hwy)	E1 E2 E3	467 535 494	499	51046 72798 61571	61805
Harney Co. Line-Hogback Summit (Lakeview-Burns Hwy)	F1 F2 F3	453 558 514	508	111276 108712 106608	108865
MP 79.2-Wasco Co. Line (Warm Springs Hwy)	A1 A2 A3	371 351 410	377	45929 68725 47240	53965
MP 89.6-Jct OR 19 (Ochoco Hwy)	B1 B2 B3	588 586 646	607	31536 69347 40360	47081
Lakeshore Dr-Greensprings Jct (Lake of the Woods Hwy)	D1 D2 D3	545 513 533	530	69519 94655 72018	78731
Lava Springs-Sand Shed (Century Drive Hwy)	H1 H2 H3	433 467 452	451	72099 67633 38015	59249
Jct Klamath Falls-Malin Hwy CA State Line (Hatfield Hwy)	C1 C2 C3	628 563 617	603	30885 24767 28909	28187
MP 13.27-Moro (Sherman Hwy)	G1 G2 G3	187 246 326	253	23416 22523 8499	18146
Ft. Klamath-Crooked River (Crater Lake Hwy)	J1 J2 J3	495 520 456	490	14110 8096 10267	10824

1) Moduli range between about 250 and 600 ksi.

2) The fatigue lives range between about 10,000 and 110,000 repetitions.

Table 3.7 summarizes the Marshall stability test results performed on the 1988 field cores. These tests were conducted in accordance with ASTM D1559 (5) at 60°C. The results generally indicate:

1) Stabilities range between about 600 and 1400 lb.

2) Flow values range between 21 and 33 mils.

The results of the modulus and fatigue tests for the 1989 field cores are summarized in Table 3.8. The results generally indicate:

1) Moduli range between about 500 and 800 ksi with some sections showing little or insignificant change relative to the 1988 test results while others have shown significant increases or decreases.

2) Fatigue lives are at a minimum of about 24,000 repetitions. Three projects show fatigue lives in excess of 150,000 repetitions.

The Marshall stability test results for the 1989 field cores are presented in Table 3.9. These results generally indicate:

1) Stabilities range between about 1000 and 2400 lbs with all sections showing significant increases over the previous year's results.

2) Flow values range between 17 and 20 mils with all sections showing decreases in flow value relative to the 1988 results.

Table 3.7. Marshall Stability Results (1988 Field Cores)

Project	Sample ID	Marshall Stability	Average Stability	Flow (in./100)	Average Flow (in/100)
Sand Shed-Mt. Bachelor (Century Dr. Hwy)	Not cored in fall 1988				
Drews Gap-Lakeview (Klamath Falls-Lakeview Hwy)	E4 E5 E6	1251 1142 *	1196	22 23 *	22
Harney Co. Line-Hogback Summit (Lakeview-Burns Hwy)	F4 F5 F6	774 859 731	788	30 37 31	33
M.P. 79.2-Wasco Co. Line (Warm Springs Hwy)	A4 A5 A6	1127 1107 1084	1106	22 19 21	21
M.P. 89.6-Jct OR 19 (Ochoco Hwy)	B4 B5 B6	1007 934 844	928	20 23 22	22
Lakeshore Dr-Greensprings Jct (Lake of the Woods Hwy)	D4 D5 D6	1167 1131 1216	1171	21 28 22	24
Lava Springs-Sand Shed (Century Drive Hwy)	H4 H5 H6	1762 1219 1194	1392	34 23 31	29
Jct. Klamath Falls-Malin Hwy CA State Line (Hatfield Hwy)	C4 C5 C6	897 1104 1084	1028	22 23 18	21
M.P. 13.27-Moro (Sherman Hwy)	G4 G5 G6	663 760 625	683	25 35 18	26
Ft. Klamath-Crooked River (Crater Lake Hwy)	J4 J5 J6	563 602 620	595	24 25 24	24

*No test results

Table 3.8. Modulus and Fatigue Results (1989 Field Cores)

Project	Sample ID	Resilient Modulus (ksi)	Average Modulus (ksi)	Fatigue Life (reps)	Average Fatigue (reps)
Sand Shed-Mt. Bachelor	L1 L2 L3	757 501 882	713	**** 138184 85983*	138184
Drews Gap-Lakeview	M1 M2 M3	550 562 481	531	** 73860 122291	98076
Harney Co. Line-Hogback Summit	K1 K2 K3	395 530 529	485	192473* 159821 ***	176147+
M.P. 79.2-Wasco Co. Line	A1 A2 A3	518 527 535	526	150100* ** **	150000+
M.P. 89.6-Jct OR 19	D1 D2 D3	399 492 546	479	73030 61343 39355	57909
Lakeshore Dr-Greensprings Jct	B1 B2 B3	749 771 661	727	46034 542379* 160561	250000+
Lava Springs-Sand Shed	N1 N2 N3	520 506 436	487	151231 94114 111563	118969
Jct Klamath Falls-Malin Hwy-CA Line	H1 H2 H3	815 821 704	780	38444 24209 58803	40485
M.P. 13.27-Moro	C1 C2 C3	462 466 409	445	41553 14600 22344	26166
Fort Klamath-Crooked Creek	F1 F2 F3	475 522 506	501	28026 22800 20219	23682

*Test intentionally terminated due to excessive fatigue life.
**Test equipment failure.
***Purposely did not test due to excessive fatigue life of other cores.
****Localized failure near the loading strip.

Table 3.9. Marshall Stability Results (1989 Field Cores)

Project	Sample ID	Marshall Stability (lb)	Average Stability (lb)	Flow (in/100)	Average Flow (in/100)
Sand Shed-Mt. Bachelor (Century Drive Hwy)	L4 L5 L6	2454 2365 2412	2410	17 17 16	17
Drews Gap-Lakeview (Klamath Falls -Lakeview Hwy)	M4 M5 M6	2274 1693 2180	2049	18 21 19	20
Harney Co. Line-Hogback Summit (Lakeview Burns Hwy)	K4 K5 K6	1542 1771 1508	1607	20 20 16	19
M.P. 79.2-Wasco Co. Line (Warm Springs Hwy)	A4 A5 A6	1240 1102 1202	1181	19 18 15	18
M.P. 89.6-Jct OR 19	D4 D5 D6	1214 1429 1473	1372	16 18 17	17
Lakeshore Dr-Greensprings Jct (Lake of the Woods Hwy)	B4 B5 B6	1722 1456 1614	1597	16 18 16	17
Lava Springs-Sand Shed (Century Drive Hwy)	N4 N5 N6	1396 1714 1764	1625	18 20 17	18
Jct Klamath Falls-Malin Hwy-CA State Line (Hatfield Hwy)	H4 H5	1553 2079	1816	21 17	19
M.P. 13.27-Moro (Sherman Hwy)	C4 C5 C6	1467 1641 1589	1566	17 18 16	17
Ft. Klamath-Crooked Creek (Crater Lake Hwy)	F4 F5 F6	1085 1062 921	1023	18 17 17	17

4.0 RECYCLING OF PAVEMENTS EXHIBITING STRIPPING

This chapter describes the efforts afforded to the accomplishment of one of the objectives of this study -- to establish whether mixes which have previously exhibited stripping can successfully be corrected by recycling. More specifically, presented below is a description of the project selected for evaluation and why it was selected, the results of the mix design moisture sensitivity tests, the method of introduction of anti-strip agent, and the performance of the recycled pavement.

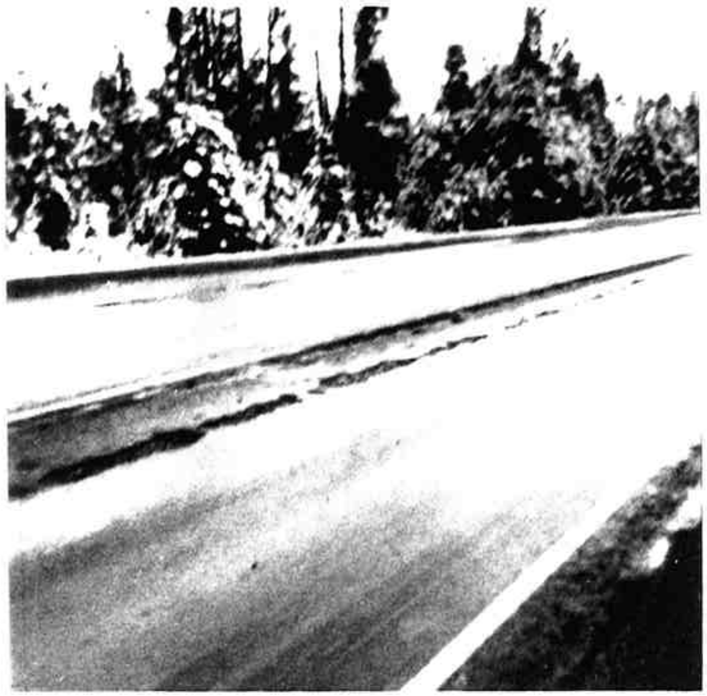
4.1 Project Selection and Description

The project selected for the purpose of determining whether or not stripped pavements can be corrected by CIR is just north of the town of Gilchrist on US 97 (The Dalles-California Hwy.). The project was selected in an area that consists of about five miles of extensive stripping within two successive overlays (a B- or C-mix overlay placed around 1982 followed by an E-mix overlay in 1985 and a chip seal in 1986). Milling and plug patching work indicated extensive stripping in both overlay lifts (see Figure 4.1).

Originally, the entire section from Hackett Dr. to Crescent on US 97 was scheduled to be recycled. It was subsequently decided to mill out the stripped material and inlay with a Class F hot mix. However, a short (1/2-mile) section of the stripped pavement was reserved for recycling. In this short section of the Hackett Dr.-Crescent project the pavement was recycled with 1% lime anti-strip additive in the northbound lane and 2% lime in the southbound lane. Thus, the recycled portion of the Hackett Dr.-Crescent project consisted of about a 1/2 lane-mile section of 1% lime additive and a 1/2 lane-mile section of 2% lime additive.

4.2 Mix Design with Moisture Sensitivity Tests

The mix design procedure described in Section 2.1 was carried out on millings from the Hackett Dr.-Crescent project and laboratory fabricated specimens were prepared at the estimated design emulsion content (EC_{EST}) and at $EC_{EST} \pm 0.3\%$. The water content for the specimens having the



a) Stripping in the Inner Wheel Track

b) Stripping in Both Wheel Tracks

Figure 4.1. Photographs Showing the Typical Severity of Stripping on the Hackett Dr.-Crescent Project.

estimated design emulsion content (EC_{EST}) was determined via the procedure described in Section 2.3. The total liquids content for the specimens prepared at $EC_{EST} \pm 0.3\%$ was held constant to correspond to the total liquids content established for EC_{EST}. For example, the total liquids content for EC_{EST} was determined to be 3.7%. Thus, the total liquids for EC_{EST} - 0.3% was also 3.7% with an increase in water content of 0.3% (corresponding to the decrease in emulsion content of 0.3%).

Four sets of specimens were prepared for evaluation. Three of the sets were prepared from millings obtained before lime was added in the field while the fourth set was prepared from millings as received which contained 2% lime. For the millings obtained before lime was added in the field one set of specimens was fabricated without adding lime, one set was fabricated with 1% lime additive, and the third set was fabricated with 2% lime additive.

After fabrication the test specimens were subjected to Oregon's standard test procedure (OSHD TM-315) for moisture susceptibility. The results of these tests are summarized in Table 4.1. The results generally indicate:

1) For all emulsion contents, the addition of 1% lime results in an improvement in the freeze-thaw modulus ratio relative to the mix without lime.

2) For all emulsion contents, the addition of 2% lime results in an improvement in the freeze-thaw modulus ratio relative to the mix with 1% lime.

3) The results of the specimens fabricated in the laboratory with 2% lime correspond well with the results of tests performed on the mix having 2% lime as received.

4.3 Method of Introducing Anti-Strip Agent

The method chosen to introduce the anti-stripping agent (lime) was that of belly-dumping quicklime (CaO). See Figure 4.2. Thus, during the recycling process, quicklime was belly-dumped immediately ahead of the milling machine (a single unit process was used for recycling on this project). Initially the quicklime was left dry which resulted in insufficient breakdown during the milling process. To mitigate this, water was added to the quicklime creating a semi-slurry before the mill processed the lime and pavement. This resulted in improved dispersion of the lime during the milling process. One

Table 4.1. Summary of Moisture Sensitivity Test Results for the Hackett Dr-Crescent Section

Treatment	Emul/Water Content (%)	% Voids	Modulus, ksi			Ratios, %	
			Uncond	Vac Sat	Frz-Thaw	Vac Sat/ Uncond	Frz-Thaw Uncond
No Lime	0.6/2.9 0.9/2.6 1.2/2.3	5.4	171 175 177	145 150 178	59 81 99	85 86 101	35 46 56
1% Lime Added	0.6/4.4 0.9/4.1 1.2/3.8	5.6	199 189 196	149 154 159	112 128 136	75 82 81	56 68 69
2% Lime Added	0.6/5.9 0.9/5.6 1.2/5.3	8.0	198 180 204	156 132 190	133 121 171	79 73 93	67 67 84
2% Lime As Rec'd	0.6/4.4 0.9/4.1 1.2/3.8	3.1	280 229 216	264 223 235	175 161 153	94 97 109	63 70 71

5.0 PRELIMINARY CONCLUSIONS

Preliminary conclusions as of April 1990 include:

1) Field performance of CIR has been good, with a few exceptions. Proper project selection is extremely important.

2) Estimation procedures for determining emulsion content serve as a good starting point for field operations. Continual monitoring and adjustment of emulsion content is required in the field.

3) It is difficult to relate Hveem and Marshall stability, resilient modulus, fatigue and IRM laboratory testing to field construction conditions for CIR.

4) Mix property test results indicate that the stiffness and fatigue properties of recycled mixtures increase over a period of years.

5) There is some indication that peak values of modulus and Marshall stability at time 0 occur at emulsion contents about 0.6% greater than the emulsion content indicated by the estimation procedure.

6) Addition of 1% and 2% lime to RAP from badly stripped pavement produced better IRM results than the RAP without lime.

6.0 REFERENCES

1. HICKS RG, et al. Development of improved mix design procedures and construction guidelines for cold in-place recycled pavements. Interim Report, Vols. I and II, FHWA-OR/RD-87-6. February 1987.

2. SCHOLZ T, et al. Development of improved mix design and construction procedures for cold in-place recycled pavements. Final Report, Vols. III and IV, FHWA-OR/RD-89-01. June 1988.

3. SCHOLZ T, et al. Mix design practices for cold in-place recycled pavements. Symposium on Asphalt Emulsions, ASTM STP 1074. December 1988.

4. ANNUAL BOOK OF ASTM STANDARDS. Roofing, waterproofing, and bituminous materials. Vol 04.04. 1989.

5. ANNUAL BOOK OF ASTM STANDARDS. Road and paving materials; traveled surface characteristics. Vol. 04.03. 1989.

6. SCHOLZ T. Evaluation of cold in-place recycling of asphalt concrete pavements in Oregon. MS Thesis. Oregon State University. June 1989.

a) Overview of Lime Addition Process

b) Closeup of Lime on Surface Prior to Milling

Figure 4.2. Method of Lime Addition - Hackett Dr to Crescent.

drawback noted during the recycling process was that the lime created problems with the paving equipment.

4.4 Performance

At the time of this writing, the lane with 2% lime appears to be performing better than the lane with 1% lime. An area on the low side of a superelevated curve, in the 1% lime lane shows significant stripping and raveling. The remainder of the test section is still performing reasonably well. More complete results will appear in the final report.