

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

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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 x 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.

*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.

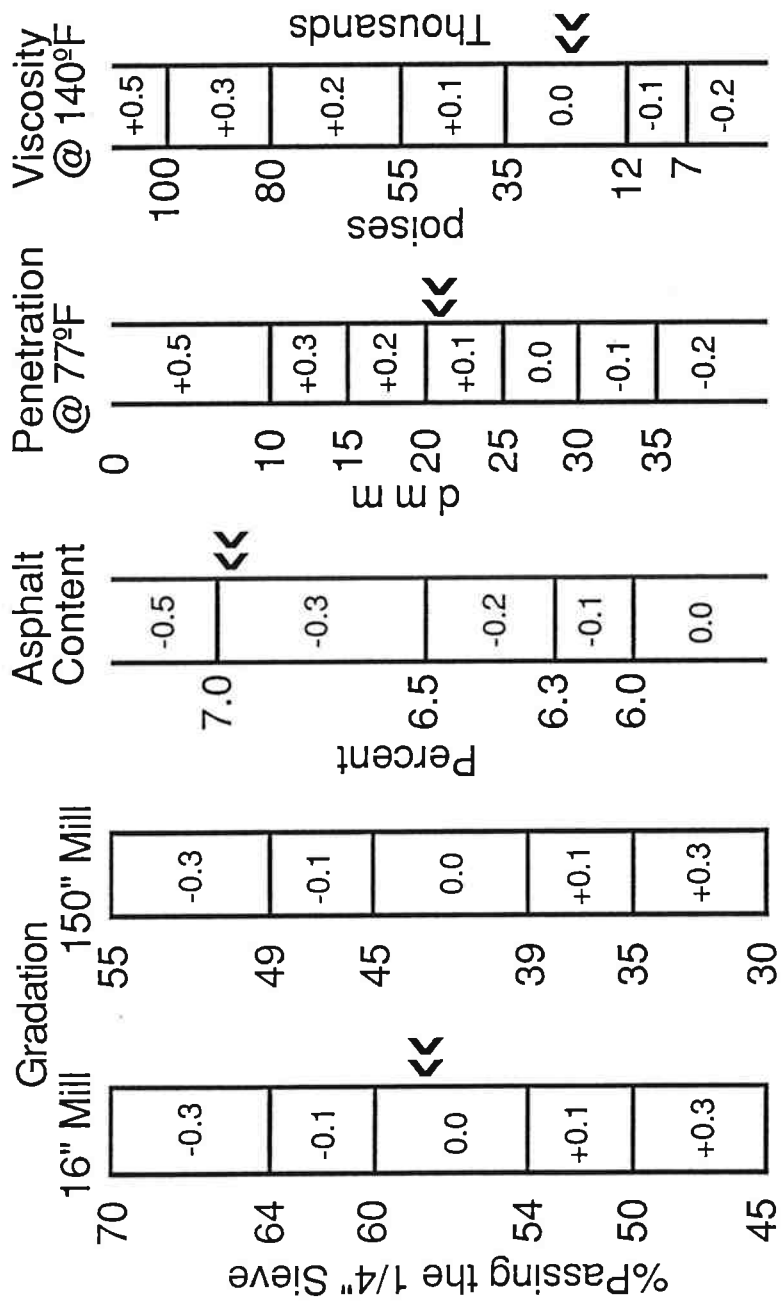
The penetration (ASTM D5) (4) and/or the absolute viscosity (ASTM D2171) (5) laboratory test results are used to determine the softness of the extracted asphalt and the RAP gradation is determined for only three screens -- 1/2-in., 1/4-in., and #10. The percent of recovered asphalt is determined via 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:

$$EC_{EST} = 1.2 + A_G + A_{AC} + A_{PV}$$

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 \pm 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:

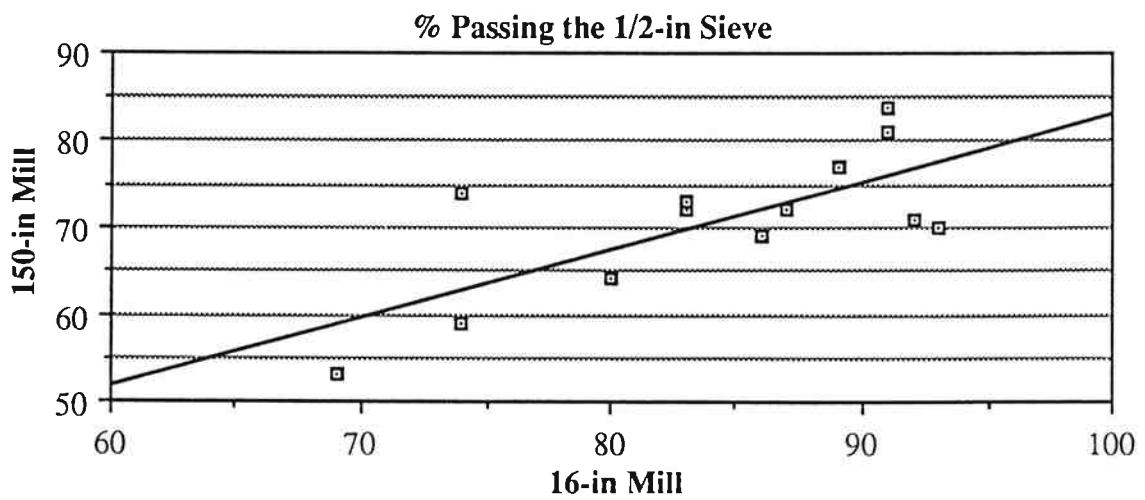
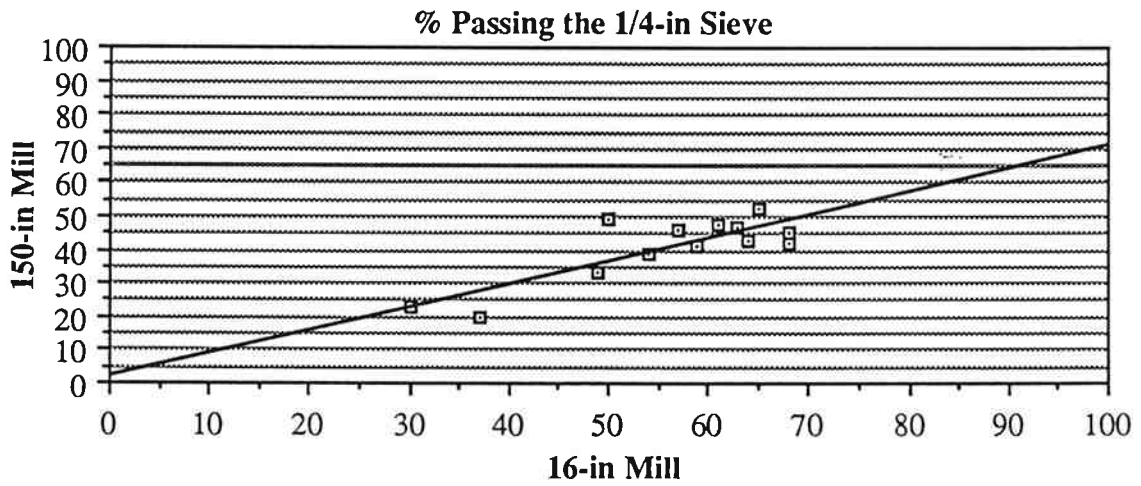
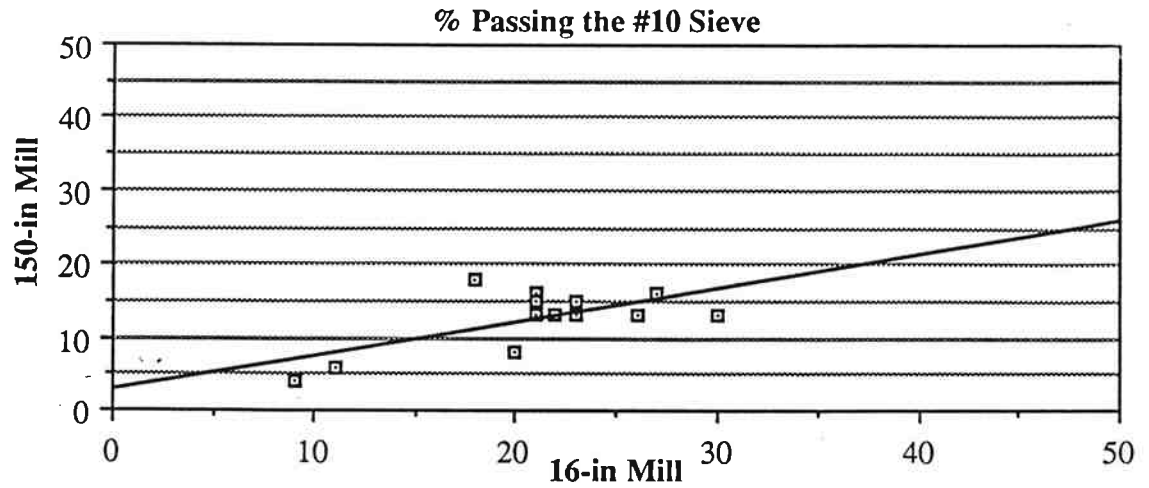


Figure 2.2. Determination of the Adjusted Gradation (for the 150-in. Mill) from the Gradation of the 16-in. Mill.

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

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 $140^{\circ}F \pm$ 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 $140^{\circ}F \pm$ for 1 hour and mixed thoroughly into the batch by hand.
11. Dump the material into a 12-in. \times 17-in. baking pan and allow to cure for 1 hour at $140^{\circ}F \pm$ 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. \pm briquettes as described below:
 - a) Preheat molds to $140^{\circ}F \pm$.
 - 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 $140^{\circ}F \pm$ 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 $140^{\circ}F \pm$ 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 fabricated 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

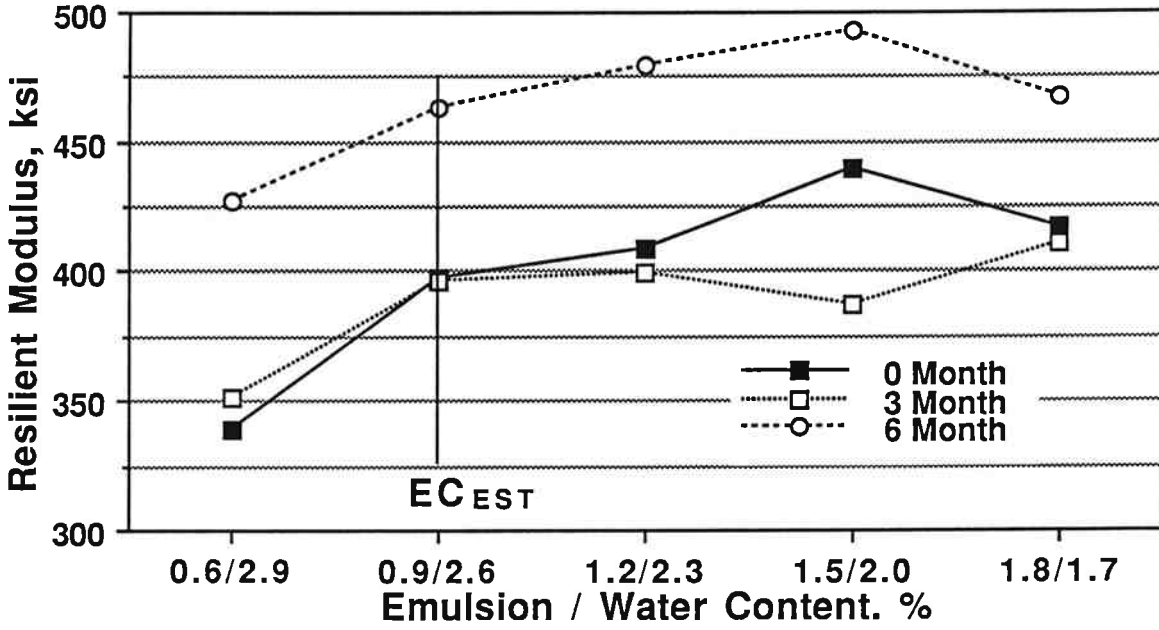
Diametral resilient modulus tests (ASTM D4123) were conducted on laboratory-fabricated specimens at periods of 0 (shortly after compaction), 3, and 6 months at the OSHD laboratory where the specimens were cured in the ambient temperature of the laboratory ($\sim 25^{\circ}\text{C}$) between test periods. 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.

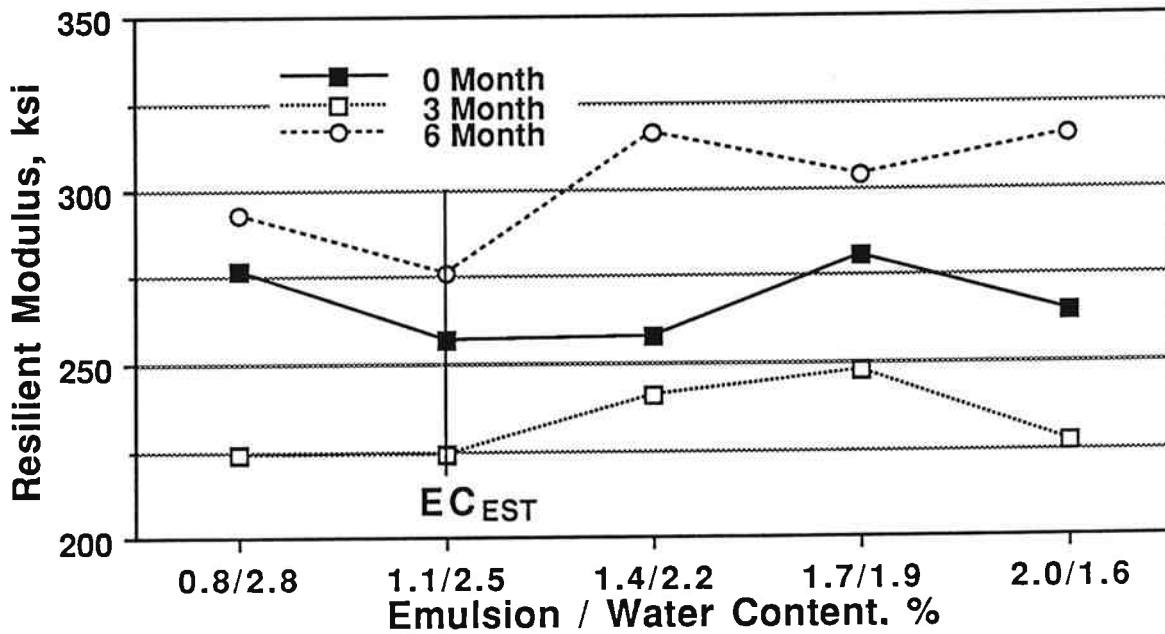
Although the above results do not conclusively confirm what was expected (that the peak modulus should correspond to lower emulsion contents over time), it can be said that for both projects the peak modulus at the 0 month test period corresponded to an emulsion content that was a constant value greater (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 1.1% Emulsion 2.5% Water | 0 | 1 | 2.358 | | | 621 | 560 | 35974 | 40787 |
| | | 2 | 2.355 | | | 542 | | 39479 | |
| | | 3 | 2.356 | | | 518 | | 46909 | |
| | 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 0.9% Emulsion 2.6% Water | 0 | 27 | 2.381 | | | 447 | 406 | 239080* |
| 28 | | | 2.410 | | | 354 | | 58136 | |
| 29 | | | 2.404 | | | 416 | | 33258 | |
| 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

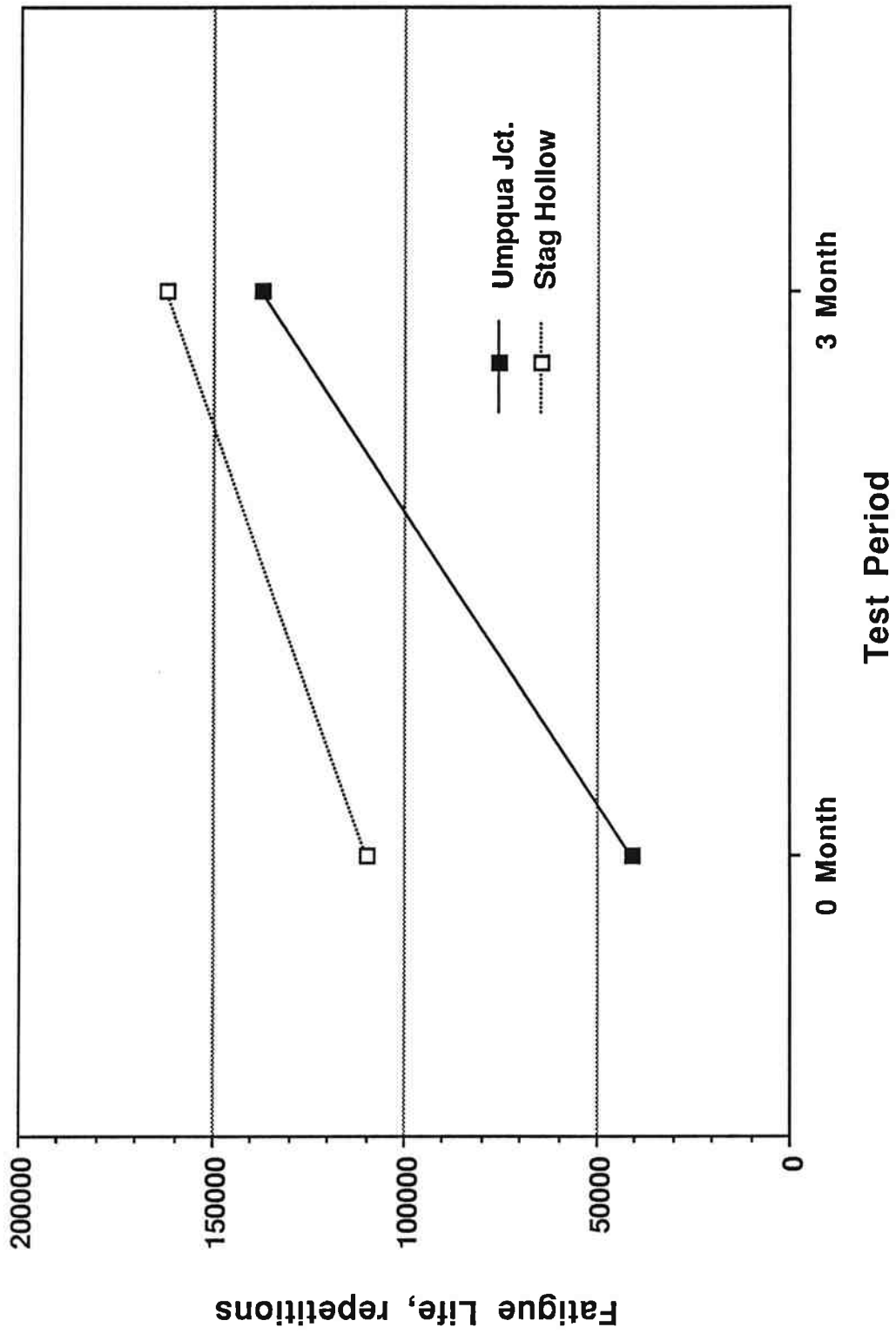


Figure 2.4. Fatigue of Mix Design Samples.

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 |