Hot Mix Recycling Evaluation in Washington

WA-RD 98.1

Final Report
December 1986

Washington State Department of Transportation
Planning, Research and Public Transportation Division
in cooperation with the
United States Department of Transportation
Federal Highway Administration

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
WA-RD-98.1		

4. Title and Subtitle	5. Report Date
Hot Mix Recycling Evaluation in Washington State	December, 1986
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
A.J. Peters, P.E., R.H. Gietz, P.E., J.P. Walter, P.E.	

9. Performing Organization Name and Address	10. Work Unit No.
Washington State Department of Transportation Materials Testing Lab P.O. Box 167 Olympia, WA 98504	11. Contract or Grant No.
	13. Type of Report and Period Covered

12. Sponsoring Agency Name and Address	14. Sponsoring Agency Code
Washington State Department of Transportation Transportation Building Olympia, WA 98504	

15. Supplementary Notes

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

The Washington State Department of Transportation (WSDOT) has completed construction of twenty-four hot-mix recycle projects as of January, 1985. At the beginning of this study there were sixteen completed projects that were to be examined. Evaluation of the laboratory and pavement performance data shows that WSDOT's initial two projects, Renslow to Ryegrass (1977) and Yakima River to West Ellensburg Interchange (1978), are still performing very well. Although the other fourteen projects have been constructed only within the last two and a half years, the early data indicates equally promising results. Because of the impressive pavement performance exhibited by the recycled pavements, together with hot-mix recycle benefits such as conservation of natural resources, feasibility of construction, and its cost advantage over new ACP, hot-mix recycling has become an attractive addition to the WSDOT paving program.

17. Key Words	18. Distribution Statement
Asphalt Concrete, Asphalt, Recycling, Rejuvenating Agents	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	38	

Form DOT F 1700.7 (8-69)
DOT FORM 341-004
6/72

HOT MIX RECYCLING EVALUATION IN WASHINGTON

by
A.J. PETERS, P.E.
R.H. GIETZ, P.E.
J.P. WALTER, P.E.

Final Report
Research Project HR-619

Prepared for
Washington State Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

December, 1986

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein.

ACKNOWLEDGEMENTS

The authors of this report are especially appreciative of the large effort expended by John Damitio who gathered the data and who helped write the report.

TABLE OF CONTENTS

	Page
Disclaimer Statement	i
Acknowledgements	i
Table of Contents	ii
List of Tables	iii
List of Figures	iiii
Abstract	iiiii
Conclusions and Recommendations	1
Introduction	2
-Literature Review	6
-Initial Project History	7
Project Reviews	13
Economic Feasibility	24
References	30
Appendix - Project Evaluations	*

*Project Evaluations in separate appendix

LIST OF TABLES

Table		Page
1	WSDOT Hot-Mix Recycling Projects	4
2	WSDOT Specifications for Paving Asphalt	11
3	WSDOT Specifications for Hot-Mix Recycling Agents	12
4	Recycled Asphalt Concrete-Mix Design Proportions	17
5	Recycled Asphalt Concrete - 140° F Viscosity (poise)	19
6	Bid Prices for WSDOT Hot-Mix Recycle Projects	25
7	1982 - ACP Bid Prices - Class B	26

LIST OF FIGURES

Figure		Page
1	WSDOT Hot-Mix Recycle Project Sites	5
2	Typical Recycled Roadway Section	14
3	Recovered 140F Viscosities of C-0758	22
4	Recovered 140F Viscosities of C-1012	23
5	Typical Performance of Washington Flexible Pavements	28
6	Projected Performance of C-0758	29
7	Projected Performance of C-1012	29

ABSTRACT

The Washington State Department of Transportation (WSDOT) has completed construction of twenty-four hot-mix recycle projects as of January, 1985. At the beginning of this study there were sixteen completed projects that were to be examined. Evaluation of the laboratory and pavement performance data shows that WSDOT's initial two projects, Renslow to Ryegrass (1977) and Yakima River to West Ellensburg Interchange (1978) are performing very well. Although the other fourteen projects have been constructed only within the last two and a half years, the early data indicates equally promising results. Because of the impressive pavement performance exhibited by the recycled pavements, together with hot-mix recycle benefits such as conservation of natural resources, feasibility of construction, and its cost advantage over new ACP, hot-mix recycling has become an attractive addition to the WSDOT paving program.

CONCLUSIONS AND RECOMMENDATIONS

The first two asphalt concrete recycling projects, which were construction in 1977 and 1978, seem to be very successful based on evaluation of test results and pavement performance records. The remaining fourteen projects reviewed also show promise of similar performance. Other conclusions that can be drawn:

- The mix design for recycling projects is much more critical than with routine asphalt concrete mix designs, however, the process is rational and consistent with standard procedures.
- The bid price of asphalt concrete where recycled planing materials were used, offers an average 34 percent cost advantage over new ACP based on 1982 production.
- Pavement performance data from Projects 1 and 2 indicates a pavement performance comparable with new ACP.
- Most projects containing recycled asphalt concrete had recovered viscosities comparable to those from new ACP. The first two projects are showing much lower recovered viscosities than would be expected with virgin ACP of comparable age which indicates less oxidation of the recycled asphalt cement.
- The Resilient Modulus values of the recycled asphalt concrete are comparable to non-recycled asphalt concrete of the same age.

The decision to allow the use of recycled asphalt concrete is supported by the data contained in this report. This decision has reduced cost without sacrificing performance, therefore the following recommendation can be made.

- The Department policy allowing the use of recycled asphalt concrete should be continued.

INTRODUCTION

Hot-mix recycling of Asphalt Concrete Pavement (ACP) has been an alternative method of rehabilitating ACP since the mid 1970's. To date a total of 24 projects utilizing hot-mix recycling have been constructed.

Background Statement

The concept of asphalt recycling is not new, but the implementation of hot-mix recycling was not considered practical on a large scale until the mid 1970's. Since that time, equipment manufacturers have developed machinery with better capability of recycling AC pavements which further encouraged such projects.

WSDOT constructed its first hot-mix recycling project in 1977, known as Renslow to Ryegrass (WSDOT Contract 0758). The project was 16 lane miles long and included 12,400 tons of recycled asphalt concrete. The second hot-mix recycling project, known as Yakima River to West Ellensburg Interchange (Contract 1012), was completed in 1978. This project was 15 lane miles long and included 11,165 tons of recycled asphalt concrete. Reports have been published describing the design and construction of both of the projects (10, 11). Additional studies were done in 1981 as part of the evaluation of the durability of each project. Subsequent to the first two projects, 22 additional projects have been completed.

Objective

The purpose of this report is to provide a detailed analysis of the first 16 projects (Table 1 and Figure 1), and, in addition, provide additional information relative to the performance of the Renslow to Ryegrass and the Yakima River

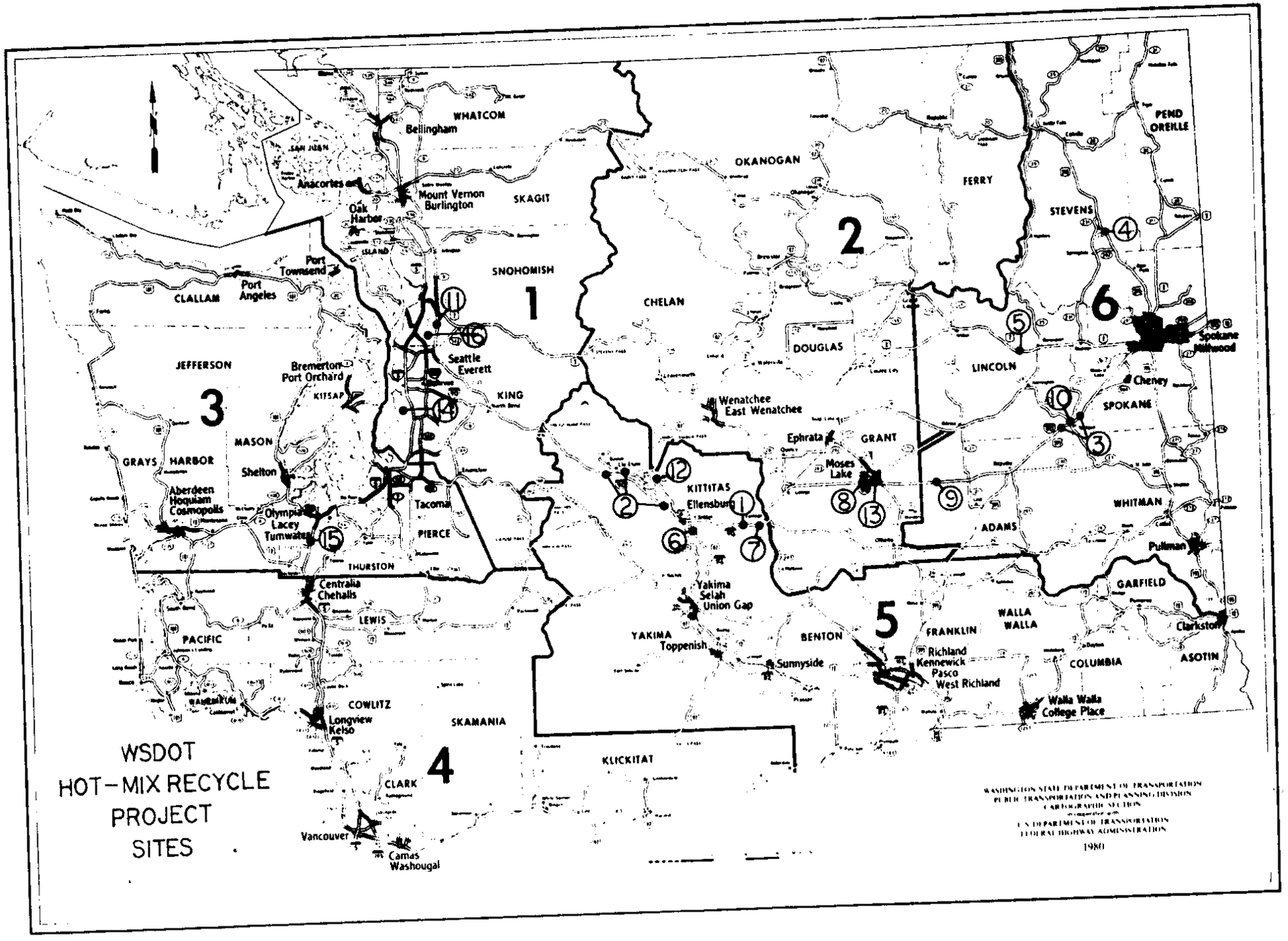
to West Ellensburg Interchange projects. As part of this study, a description of the hot-mix recycling methods and specifications used by WSDOT is presented.

TABLE 1

WSDOT ACP Hot-Mix Recycling Projects

Contract Number	Map Designation	Contract Name	Year Paved
0758	1	Renslow to Ryegrass	1977
1012	2	Yakima River to W. Ellensburg	1978
2058	3	Adams Co. Line to Tyler	1982
2116	4	Spokane Co. Line to Loon Lake	1982
2142	5	Rocklyn to M.P. 240.77	1982
2196	6	RS-90 to Thrall Road	1982
2231	7	Ryegrass to Vantage	1982
2246	8	Dodson Road to Mae Valley	1982
2279	9	Grant Co. Line to Schrag	1982
2293	10	Sprague to Fishtrap	1982
2319	11	Clearview to Lowell Road - Stage 1	1982
2360	12	B.P.A. Crossing to Swauk Creek	1982
2483	13	Mae Valley to SR-17 - Et. Al	1983
2551	14	S. 124th Street to S. Holden Street	1984
2571	15	SR-12 to Lathrop Rd. & Lathrop Rd. to Trosper Rd.	1983
2576	16	132nd St. S.E. to 112th St. S.E.	1984

FIGURE 1


WSDOT
HOT-MIX RECYCLE
PROJECT
SITES
WHATCOM
Bellingham
SAN JUAN
Anacortes
Mount Vernon
Burlington
SKAGIT
Oak Harbor
ISLAND
Port Townsend
Port Angeles
CLALLAM
SNOHOMISH
1
OKANOGAN
FERRY
PEND OREILLE
STEVENS
2
CHELAN
DOUGLAS
6
Spokane
Millwood
LINCOLN
Cheney
SPOKANE
JEFFERSON
Bremerton
Port Orchard
KITSAP
Seattle
Everett
KING
3
Wenatchee
East Wenatchee
Ephrata
GRANT
Moses Lake
MASON
GRAYS HARBOR
Shelton
Aberdeen
Hoquiam
Cosmopolis
Olympia
Lacey
Tumwater
Tacoma
PIERCE
KITTITAS
Ellensburg
WHITMAN
ADAMS
Pullman
THURSTON
Centralia
Chehalis
Yakima
Selah
Union Gap
GARFIELD
Clarkston
LEWIS
PACIFIC
YAKIMA
Toppenish
BENTON
5
FRANKLIN
WALLA WALLA
Sunnyside
Richland
Kennewick
Pasco
West Richland
COLUMBIA
ASOTIN
Walla Walla
College Place
COWLITZ
Longview
Kelso
SKAMANIA
KLICKITAT
CLARK
4
Vancouver
Camas
Washougal
WASHINGTON STATE DEPARTMENT OF TRANSPORTATION
PUBLIC TRANSPORTATION AND PLANNING DIVISION
CARTOGRAPHIC SECTION
in cooperation with
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
1980

LITERATURE REVIEW

A literature review on hot mix recycling of asphalt concrete was conducted and a general reference list of the reports reviewed is included in this report. Some of the information gathered that was common to most is as follows:

- Recycling is an acceptable method of reconstruction or rehabilitation of an asphalt concrete pavement.

- Use and value of recycling agents in the recycling process to rejuvenate the old asphalt cement is still not widely accepted.

- Neither of the national materials standards developing agencies (AASHTO or ASTM) has adopted a set of specifications for recycling agents.

- Some controversy exists over the logic and ability to recycling the majority of the planings. Most specifications do not allow more than 60% planings in the recycled mix. Equipment problems and environmental problems are often cited as reasons.

- In lieu of using recycling agents, only softer asphalt cement is added to achieve the desired restored asphalt viscosity in the recycled mix. This technique limits the ability to recycle high percentages of planings.

INITIAL PROJECT HISTORY

The Washington State Department of Transportation, WSDOT, began experimenting with hot-mix recycling of asphalt concrete in the late 1970's. The initial projects were built with the intention that if the recycling process could be shown to be cost effective and satisfactory pavement performance realized, then additional projects would be considered. The first two projects, Renslow to Ryegrass (1977) and Yakima River to West Ellensburg Interchange (1978), consisted of recycling the top 0.15 feet of old pavement for a total of 32 lane miles. The top 0.15 feet of pavement was the wearing course of an asphalt concrete pavement that included a leveling and base course that totaled 0.80 feet thick. The wearing course had delaminated from the remainder of the pavement and was showing considerable fatigue in the wheel paths. Both of these initial projects were constructed under Federal Highway Administration programs; the first project under the FHWA Demonstration Projects Program and the second as a FHWA Implementation Project. The performance of the recycled asphalt concrete for both projects has been monitored by extensive lab testing and pavement performance evaluation that has extended over several years.

In late 1981, the conclusions from the evaluation of the initial projects were that the recycled pavements were performing satisfactorily and were cost effective. Specifications were then developed to allow the recycling of asphalt concrete on a permissive basis. During the process of developing and implementing these specifications, a couple of projects were constructed with recycled asphalt concrete under a combination

of mandatory and permissive specifications. This was a change from the mandatory specifications used for the initial two projects.

For the initial project (Renslow to Ryegrass), mandatory recycling was specified. The percent of planings and percent of new aggregate to be used, the type and amount of recycling agent to be used, and the amount of new asphalt cement were contract requirements. Specifications required the mixing operation to be performed in a batch plant, and allowed a variance from the State Department of Ecology air pollution requirements.

The second project (Yakima River to West Ellensburg Interchange) involved one significant change in specification. Instead of WSDOT requiring the use of a batch plant, mixing and heating were left up to the contractor. All other major design and construction requirements remained as they were in Project 1.

Based on the observed performance of the first two projects, a decision was made to proceed with three additional projects using various forms of alternate bids comparing the cost of new asphalt concrete to recycled asphalt concrete. In 1981, a permissive specification was developed and implemented. Currently when asphalt planing is specified to correct structural pavement deficiencies or for vertical clearance deficiencies, the planings become the property of the contractor with the provision that the planings may be used in the manufacture of the asphalt concrete pavement up to a predetermined maximum percentage. The contractor may also utilize up to 10% of previously acquired planings in asphalt concrete mix on any project where not specifically prohibited.

For those projects where planing was estimated to generate over 2000 tons of Recycled Asphalt Pavement, a preliminary mix design is performed to determine the amount of rejuvenator and new asphalt cement required for mix-incorporating 0, 30, 50 and 70% planings. The estimated new fluid content (rejuvenator plus asphalt cement) is to provide a reasonable basis to bid the asphalt concrete for recycling as a single bid item (including new fluids) on a per ton basis.

The specification developed in late 1981 is still being used. With use of the permissive specification, the need to determine if recycling is cost-effective for a particular situation does not exist. All that is required is a determination of the amount of the existing ACP to be removed. Under the specification each bidder can prepare his best bid and the economy of recycling should be reflected therein.

Asphalt and Recycling Agent Specifications

The specifications for asphalt cement used by WSDOT are a modified version of the Aged Residue (AR) specifications adopted by the West Coast Users and Producers of Asphalt. These specifications were adopted in the early 1970's and are shown in Table #2.

In the design of recycled AC pavements, it is the intent to restore the 140F viscosities of the reconstituted asphalt cement contained in the mixture to that of virgin AR 4000W asphalt cement. Recycling Agent (R.A.) series rejuvenators are utilized, using specifications adopted by the West Coast Users and Producers of Asphalt (Table 3). These specifications were adopted by WSDOT in the early 1980's and have been used on all of the ACP recycling projects except the first two.

The first two projects used a commercially available product known as Cyclogen "L" produced by Witco Chemical Company. This product is very similar to the RA-5, which is the lowest viscosity recycling agent.

Table 2

WSDOT Specifications for Paving Asphalt

Test	WSDOT Test Method	Viscosity Grade AR-4000W	AR-2000W
Residue Tests from RTFC (1)	208		
140F Viscosity, Poise	203	2500-5000	1500-2500
275F Viscosity, CST	202	275	200
77F Penetration, 100 g/5 sec., min	201	40	50
Percent of original penetration at 77F min.	(2)	45	40
45F Ductility (1 cm/min.), cm. min.	213	10	20
Test on Original Asphalt			
Flashpoint, F. min.	206	440	425
Solubility in Trichloroethylene, % min.	214	99.0	99.0

(1) TFO may be used, but RTF shall be the referee method

(2) Original penetration, as well as penetration after RTFC loss will be determined by WSDOT Test Method 201.

TABLE 3

WSDOT Specifications For Hot-Mix

Recycling Agents[1]

Test	ASTM Test Method	RA5 min	RA5 max	RA25 min	RA25 max	RA75 min	RA75 max	RA250 min	RA250 max	RA500 min	RA500 max
Tests On Original Asphalt											
140F Viscostiy, 10^{-3} CST	D2170 or D2171	0.2	0.8	1	4	5	10	15	35	40	60
Flashpoint COC, F	D92	400	-	425	-	450	-	450	-	450	-
Saturates, Wt. %	D2007	-	30	-	30	-	30	-	30	-	30
Specific Gravity	D70 or D1298	Report		Report		Report		Report		Report	
Residue Test From RTFC	D2872[2]										
Viscosity Ratio[3]	-	-	3	-	3	-	3	-	3	-	3
Weight Change, ±%	-	-	4	-	3	-	2	-	2	-	2

1 The final acceptance of recycling agents meeting this specification is subject to the compliance of the reconstituted asphalt blends with current asphalt specifications.

2 The use of ASTM C1754 has not been studied in the context of this specification; however, it may be applicable. In cases of dispute, the reference method shall be ASTM D2872.

3 Viscosity Ratio = $\frac{\text{RTFC Viscosity at 140F, CST}}{\text{Original Viscosity at 140F, CST}}$

PROJECT REVIEWS

Each of the sixteen hot-mix recycled projects has been reviewed and summarized in an appendix to this report. The review of each project includes background information and test data obtained during and after construction. The following is a summary of each of the items included in the review.

Vicinity Map and Roadway Section

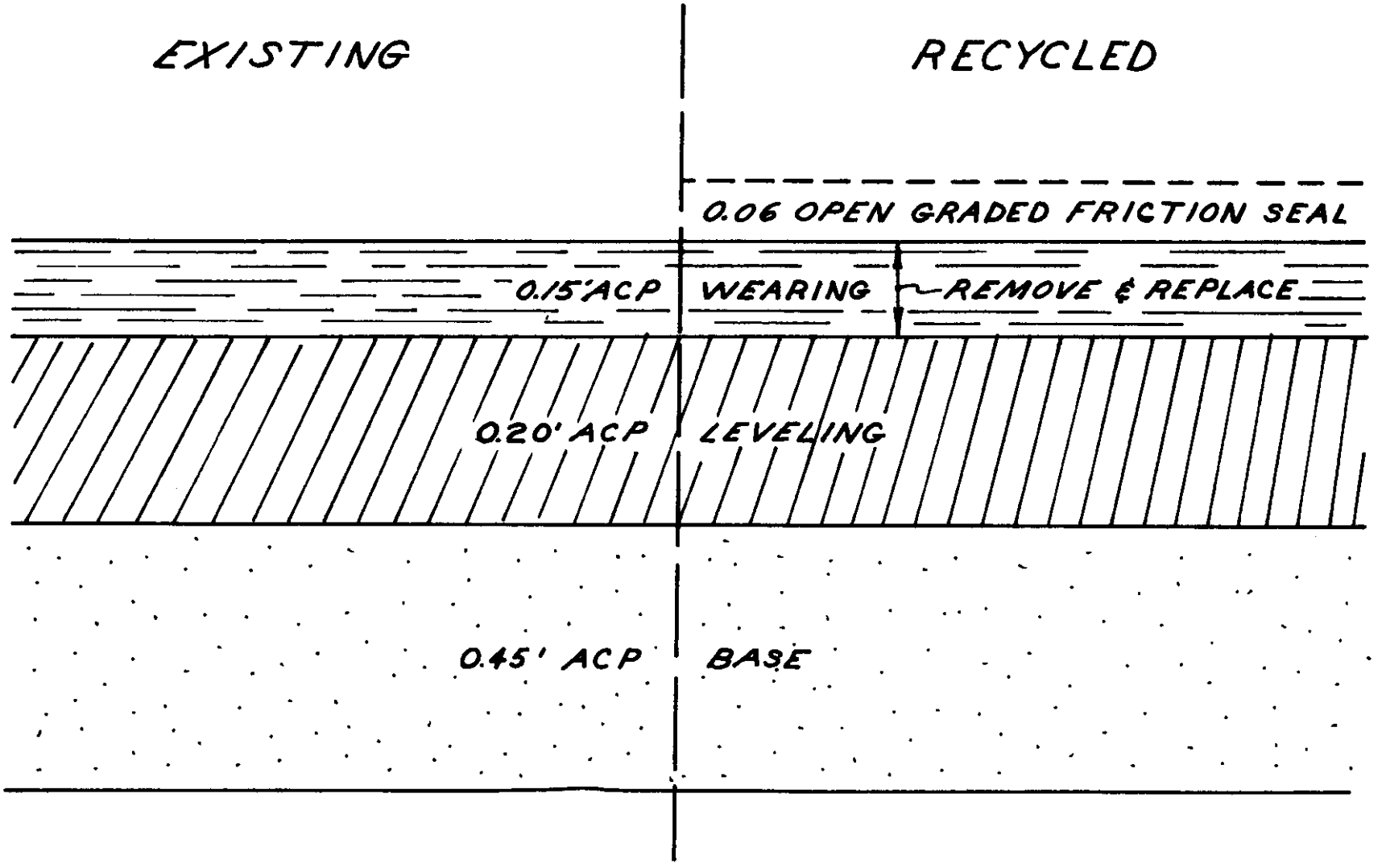
The vicinity maps and roadway sections are included to show the project location, and the pavement structural section. A typical roadway section is shown in Figure 2 which includes the use of an open graded hot-mixed friction seal. Friction seals have been used on a number of the recycled pavements due to concerns over ravelling and the stability of the recycled mix.

Preliminary Laboratory Pavement Evaluation - Pre Contract

On most of the projects, a preliminary laboratory analysis of the existing pavement was done. A summary of the laboratory analysis for each project is included in the appendix. Those projects that utilized contractor stockpiled planings do not have a preliminary evaluation. The summary includes an average and range value for particle size, asphalt content, 77F penetration and 140F viscosities. In the case of some of the more recent projects, those constructed under the new specification, a recommended asphalt and rejuvenator content for various ratios of planings to new aggregate is shown. The purpose was to provide the contractor with some realistic quantities of these materials so that they could be included in the bid price for Asphalt Concrete. The bidding process allows

Figure 2

TYPICAL RECYCLED ROADWAY SECTION



the contractor the option of bidding 0% planings to some fixed maximum which is usually about 70%.

Project Mix Design

The job mix design recommendations are shown in the appendix and are based on the Hveem procedure in accordance with standard WSDOT test procedures. These recommendations were based on WSDOT standard acceptance values for asphalt concrete including stability, percent voids, stripping and gradation as shown in the standard specifications. The WSDOT specifications for hot recycled ACP allow for up to a five point reduction in stability from a 35 minimum and allow up to a 2% increase in the % passing #200 from 7% maximum at various percentages of planings exceeding 50%. These allowances were intended to encourage recycling and were based on the performance of the initial projects.

If planing of the roadway was called for in the contract, and the quantity of planings generated exceeded 2000 tons, a substantial amount of preliminary work was done in the laboratory to establish the condition of the materials in the roadway. This information was incorporated into applicable job mix design and included Abson recovered 140F viscosities and asphalt content.

The basic goals of the mix design for recycled asphalt concrete are: (1) to rejuvenate the asphalt cement by addition of rejuvenator, (2) to satisfy the stability requirements by the addition of new (virgin) aggregate which compensates for aggregate degradation that occurs during removal, and/or crushing, and (3) to add sufficient new asphalt to give low percent voids and a stable mixture. Information provided in the project mix

design included average gradation of the virgin aggregate, average gradation of the aggregate in the planings, the percentage of asphalt cement in the planings, the percentage of new asphalt cement to be added to the mixture and grade and the percentage of recycling agent that should be used.

A summary of the mix design proportions for all the projects is included in this report (Table 4).

Table 4

RECYCLED ASPHALT CONCRETE

Mix Design Proportions
(As Constructed)

Contract	% Planings	% Asphalt From Planings	% Asphalt New AR-4000W	Recycling Agent %	Recycling Agent Type
0758	72-74	4.7	0	0.75	RA-5*
1012	79	5.2	0	1.6	RA-5*
2058	75	3.8	0.5	1.1	RA-5
2116	70	4.1	0	1.0	RA-5
2142	40	2.0	0	3.1	RA-250
2196	52	2.7	2.3	0.6	RA-5
2231	75	4.4	0	1.3	RA-5
2246	75	3.9	0.6	0.6	RA-5
2279	65	3.6	0	1.6	RA-75
2293	77	3.7	1.8	0.6	RA-5
2319	8	0.5	4.9	0	--
2360	9	0.5	5.1	0	--
2483	35	1.8	0	3.4	RA-500
2551	33	1.7	0	3.8	RA-500
2571	70	4.0	0	0.8	RA-75
2576	35	1.9	0	3.4	RA-500

* The product actually used was Cyclogen L which is basically RA-5.

Control Samples of Asphalt Concrete

During construction, samples of the recycled asphalt concrete were periodically taken at the mix plant. These samples were tested in the field and in the Headquarters Materials Laboratory. The samples were tested in the field to determine gradation and asphalt content for specification compliance. One sample of each day's production was sent to the Headquarters Laboratory for checking stability, % voids of lab compacted samples, and recovered viscosity. The recovered viscosities are summarized in Table 5. The stabilities, void content and recovered viscosities were used in a number of cases to adjust the percentage of recycling agent or to change the grade of the recycling agent.

Additional data was collected from the first two projects which included 39.2F penetrations, 77F penetrations, 60F viscosities, 45F ductilities, 77F ductilities, the Rostler Sternberg chemical analysis, and resilient modulus on lab compacted asphalt concrete samples. The information is included in the appendix as part of the project summary.

Compaction Data

Density of the asphalt concrete pavement was determined by nuclear gauge after completion of finish rolling. The average and range of percent voids is included in the appendix under each project.

The specification requirements for density have ranged from air flow requirements on the 1977 project to 92 percent of Rice density on all projects built since 1982. The density specifications were met on all projects except for a few control lots.

Table 5

RECYCLED ASPHALT CONCRETE

(Construction Mix Samples)

Contract	%Planings	140 F Viscosities (Poise) ** Average	Range
0758	72-74	3,894	2,466-7,408
1012	79	2,227	2,123-2,367
2058*	75	31,479	1,950-163,464
2116	70	2,848	1,909-3,946
2142	40	1,981	1,382-3,094
2196	52	5,258	2,044-10,919
2231	75	4,067	1,826-9,238
3346	75	3,825	2,273-7,020
2279	65	4,279	3,061-6,409
2293	77	9,229	5,472-24,534
2319	8	2,854	2,344-3,278
2360	9	4,527	3,328-8,052
2483	35	2,574	1,859-4,053
2551	33	6,949	--
2571	70	3,215	1,259-6,481
2576	35	2,770	2,234-3,326

* Recycling Agent feed pump broke during part of production.

** The desired 140 F viscosity is 2500-5000 poise.

Construction Cores

Cores were taken after construction as part of a routine record coring operation. The density of the cores was determined and then the asphalt extracted so that aggregate gradation and asphalt content could be determined. Percent of voids was calculated using Rice densities obtained on control samples of mix. The information is included in the appendix as part of the project summary.

Post Construction Cores

In preparation for this report cores were taken from each of the sixteen projects. Testing included aggregate gradation, asphalt content, density, percent voids, Abson recovered 77F penetration, 140F viscosity and 45F ductility and 77F Resilient Modulus. This information is included in the appendix.

On projects #1 and #2 the friction seal overlay was intentionally omitted from a short pavement section on both projects. The performance of these sections is good and is documented in the appendix. The recovered viscosities of both projects are shown in figures 3 and 4. The increased hardening of the asphalt due to oxidation is not occurring nearly as rapidly as conventional ACP. The non overlaid sections seem to be oxidizing slightly faster than the overlaid ones, although not nearly as rapidly as those conventional asphalt concrete pavements that were monitored in years past. Similar conclusions can be reached by reviewing the penetration data shown in the appendix (pages 1.22 and 2.26).

Pavement Condition

A pavement condition survey (13) is conducted on all Washington State routes every two years. In 1983 WSDOT implemented a policy changing the survey to even numbered years which resulted in a one time survey in consecutive years. All the hot-mix recycle projects are included in the most recent survey (1986). The pavement condition survey data includes an Average Daily Traffic count, a measured roadway roughness (converted to a ride score), a structural rating (based on occurrence of cracking and patching), and an overall pavement rating. The pavement rating is the product of the "ride score" and the structural rating. A rating of 100 would be a pavement having no defects. As an example, the Yakima River to West Ellensburg Interchange project when originally constructed in 1969 had a rating of 100 and had deteriorated to a rating of 53 when it was recycled in 1978. At that time it had experienced extensive hairline cracking in the wheel path with some longitudinal and transverse less than 1/4 inch wide. The resurfacing investigation and subsequent milling indicated that all but the transverse cracking defect was confined to the wearing course. The underlying ACP layers had only experienced a moderate amount of thermal cracking. Data from the pavement condition survey, summarized in the appendix includes the Average Daily Traffic (1986), and the structural ratings.

FIGURE 3

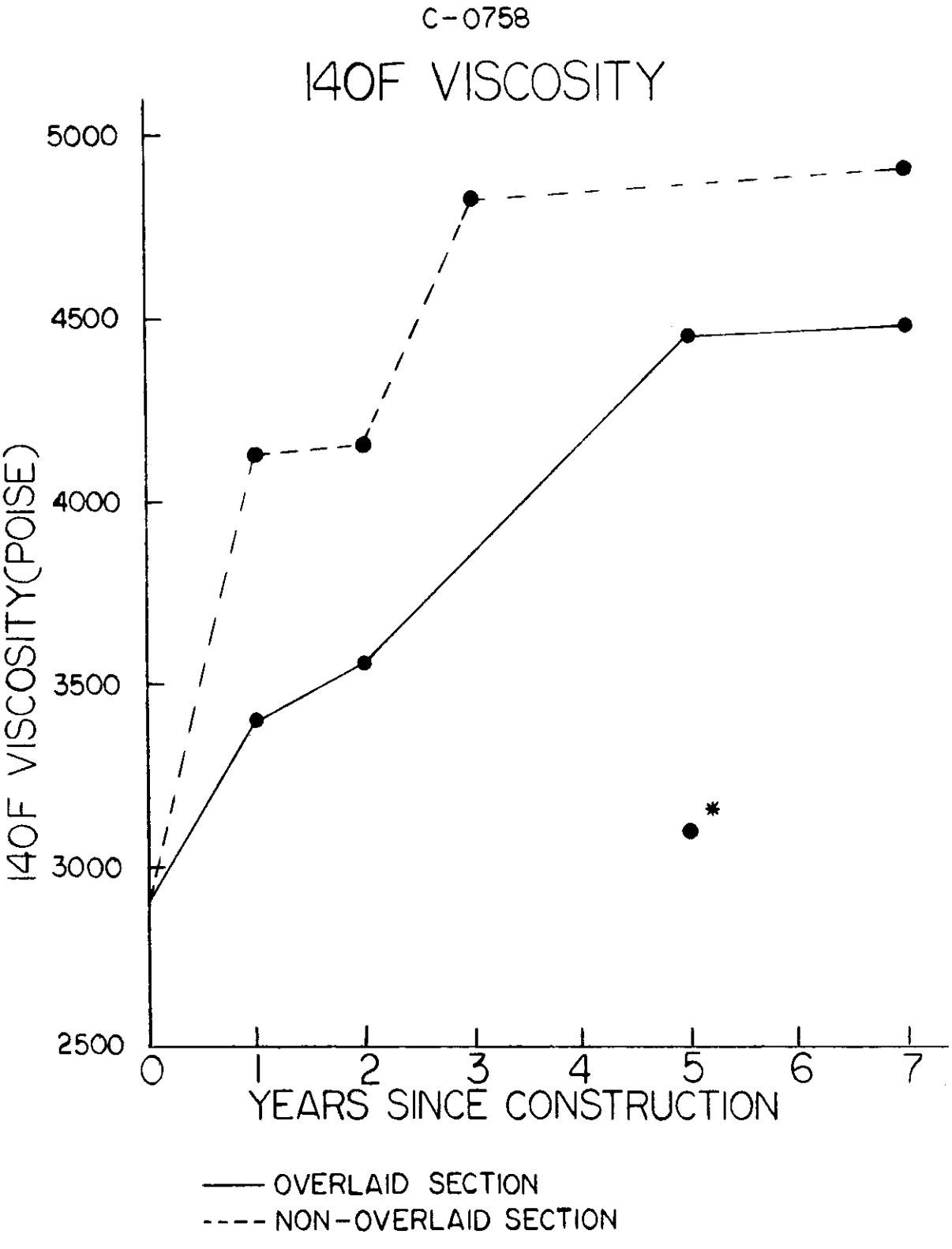
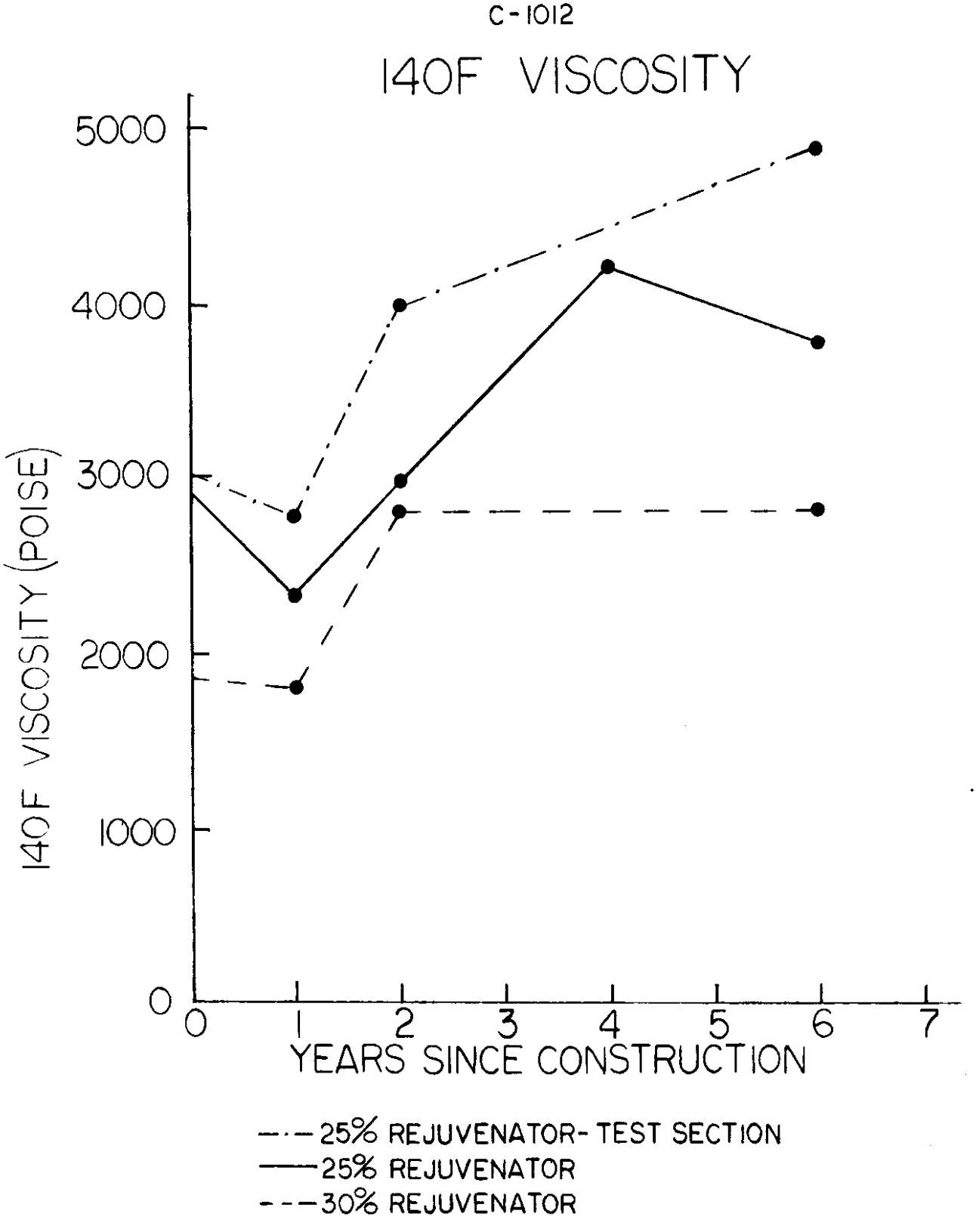

C-0758
140F VISCOSITY
5000
4500
4000
3500
3000
2500
140F VISCOSITY(POISE)
0
1
2
3
4
5
6
7
YEARS SINCE CONSTRUCTION
OVERLAID SECTION
NON-OVERLAID SECTION
*ONLY 1 SAMPLE (NON-OVERLAID SECTION)

FIGURE 4


C-1012
140F VISCOSITY
5000
4000
3000
2000
1000
0
140F VISCOSITY (POISE)
0
1
2
3
4
5
6
7
YEARS SINCE CONSTRUCTION
25% REJUVENATOR- TEST SECTION
25% REJUVENATOR
30% REJUVENATOR

ECONOMIC FEASIBILITY

Two major factors were considered in the assessment of the economic feasibility of hot-mix recycling in Washington State. The first factor is initial cost. If hot-mix recycling is to be considered a permanent fixture in the WSDOT pavement rehabilitation program, then its price must be competitive with that of new asphalt-concrete. The second factor is performance. In order for hot-mix recycling to be cost-effective, the recycled pavement must demonstrate performance equivalent to that of new ACP.

The bid prices of the sixteen hot-mix recycle projects under review are shown in Table 6. The next to the last column shows the price per ton of mix, including new aggregate, new asphalt (AR-4000W), recycling agent, and the removal cost of the planings. The last column represents the bid price per ton of the mix excluding planing.

The quantities of recycled asphalt-concrete produced in 1982 and the average bid prices, are shown in Table 7, accumulated by Districts. The average bid price for all new ACP (Class B) produced in Washington in 1982 is also shown. A comparison indicates a pronounced cost advantage, that averages 34 percent statewide, for hot-mix recycling.

Pavement Performance

Since pavement performance is a very important criteria in the appraisal of hot-mix recycling, the pavement condition survey data collected every two years was used to evaluate the present condition of each of the projects. Pavement ratings can theoretically range from 0 (very poor)

Table 6

Bid Prices for WSDOT Hot-Mix Recycle Projects

Contract	Year	District	Quantity	% Planings	$/Ton*	$/Ton**
0758	1977	5	12,400	72-74	19.04	10.00
1012	1978	5	11,165	79	22.53	11.24
2058	1981	6	28,700	75	17.88	11.20
2116	1982	6	18,200	70	21.46	15.10
2142	1982	6	11,300	40	19.03	14.86
2196	1982	5	7,994	52	30.48	22.50
2231	1982	5	35,931	75	19.85	14.50
2246	1982	2	46,290	75	19.04	12.00
2279	1982	6	31,430	65	21.16	15.90
2293	1982	6	15,965	77	18.96	13.30
2319	1982	1	15,330	8	22.00	22.00***
2360	1982	2	12,496	9	27.00	27.00***
2483	1983	2	17,260	35	23.88	18.00
2551	1983	1	14,270	33	22.30	18.90
2571	1983	3	26,860	70	19.42	15.11
2576	1983	1	12,577	35	20.50	20.50***

*Includes planing

**Excludes planing

***No planing

Table 7

1982 ACP BID PRICES

Class B

District	Recycled Quantity	Recycled Ave. Bid Price*	Non-Recycled Quantity	Non-Recycled Ave. Bid Price
1	15,330	22.00	157,999	24.80
2	58,786	15.19	103,939	18.07
3	0	--	114,499	26.48
4	0	--	140,554	28.61
5	43,925	15.96	197,369	22.56
6	76,895	15.02	57,335	19.72
Statewide	194,936	15.83	771,695	23.89

*Bid price does not include planing.

to 100 (perfect). By means of the past data, projections can be made as to when major pavement rehabilitation will need to be scheduled for that particular section of road. This normally occurs when the pavement rating drops below 62 for the Interstate routes and 35 to 45 for all other state routes.

A plot of the Average Pavement Rating vs Age of Flexible Pavements in Washington is depicted in Figure 5. The graph illustrates the varying trends of asphalt-concrete deterioration as a function of AC thickness and time. The graph is based on condition surveys of non-recycled ACP pavements. Typically, asphalt-concrete pavement is expected to last 12 to 13 years (with normal use and maintenance) before the pavement rating drops to a point where rehabilitation is necessary. In order to be considered as a reasonable alternate, recycled ACP must perform similarly to new ACP and demonstrate some cost savings.

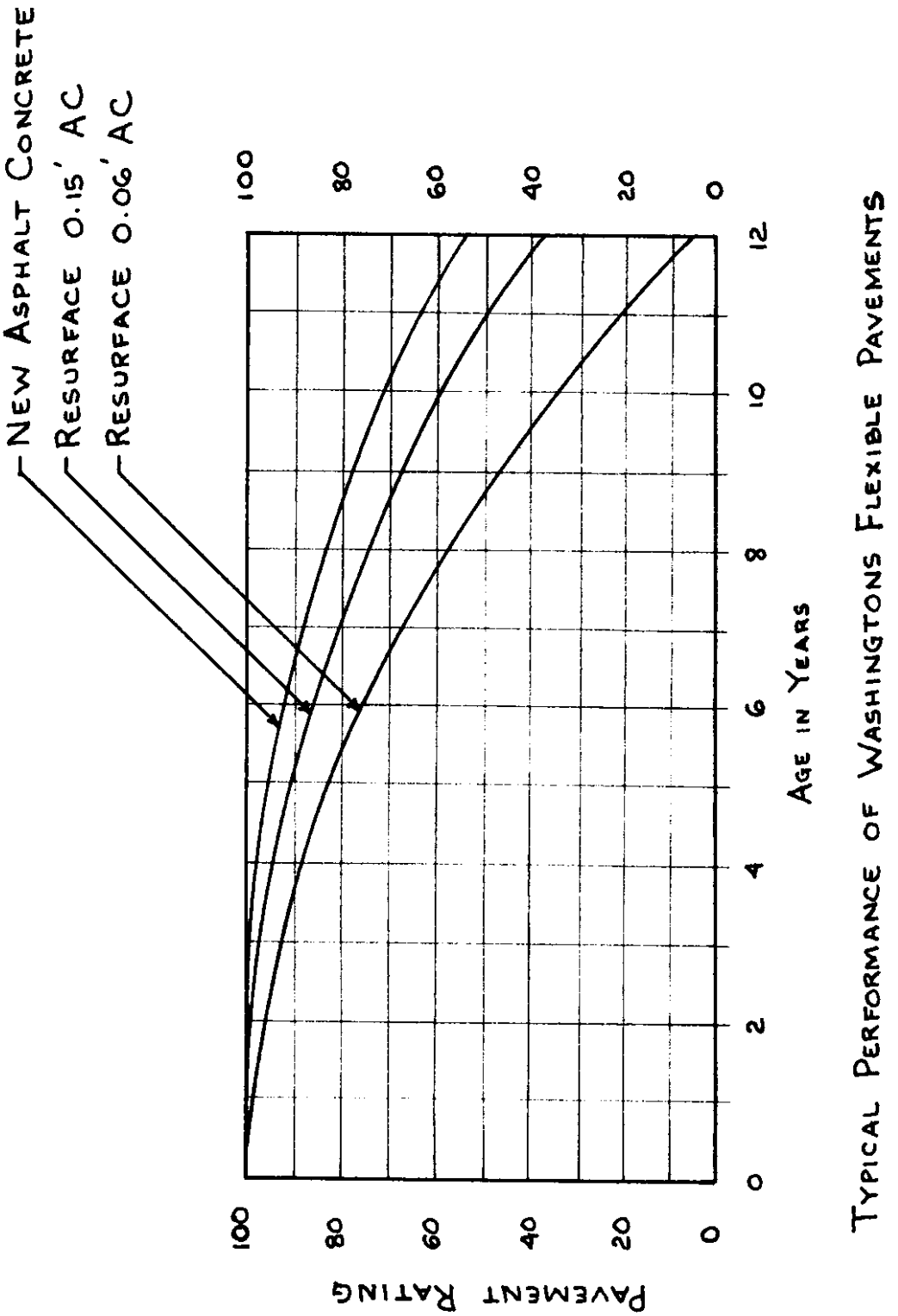
Only Projects 1 and 2 provide enough data points to give a reasonably reliable forecast of pavement performance. The Pavement Rating vs Age Plots for both Contract 0758 and 1012 are shown in Figures 6 and 7. Based on the projected performance, pavement rehabilitation would theoretically be necessary after 10 to 15 years. This compares very well with the performance of new asphalt-concrete.

Based on the performance of these two projects, combined with the 34 percent cost savings, hot-mix recycling appears to be very cost effective.

---

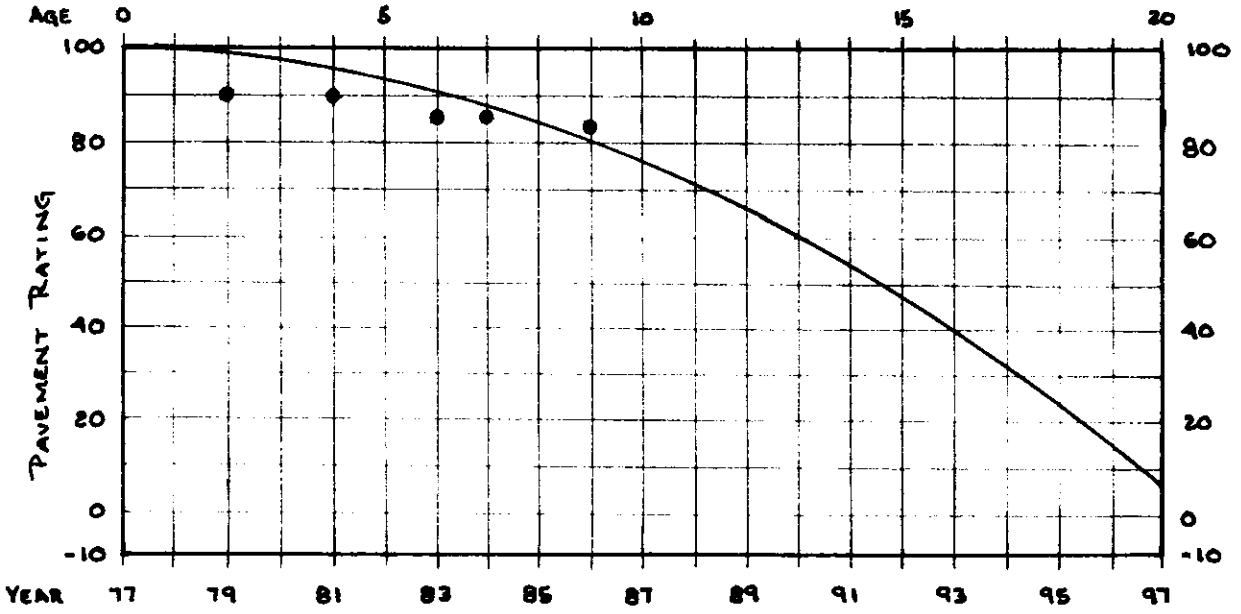
*Both C-0758 and C-1012 are Interstate projects.

Figure 5



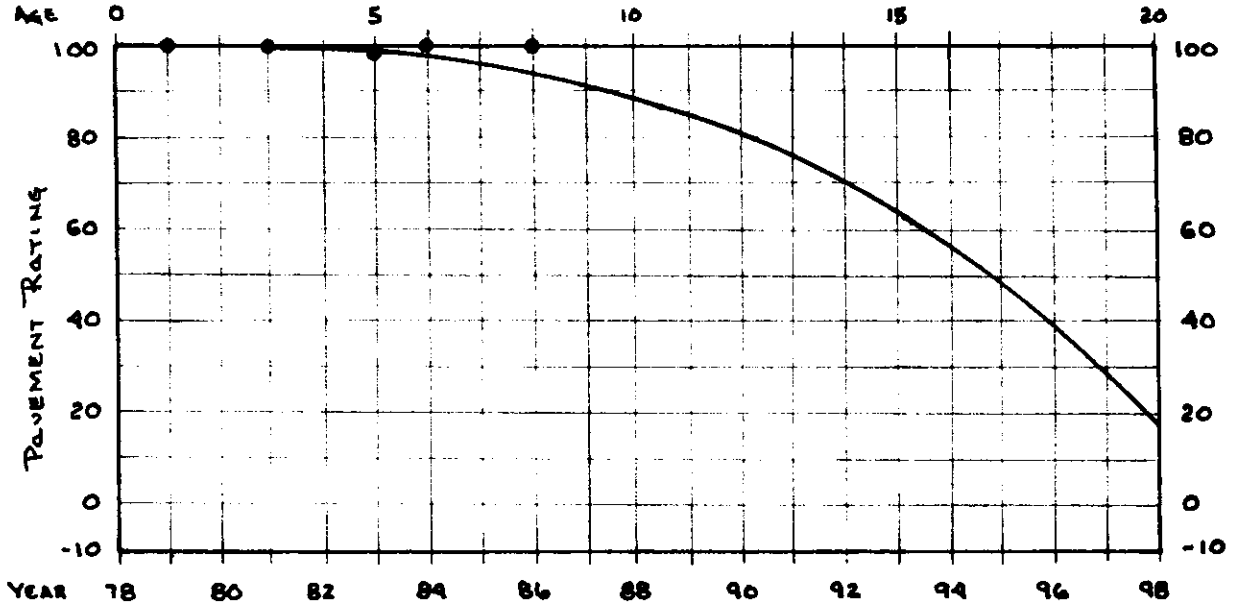
TYPICAL PERFORMANCE OF WASHINGTONS FLEXIBLE PAVEMENTS

FIGURE 6



PROJECTED PERFORMANCE OF C-0758

FIGURE 7



PROJECTED PERFORMANCE OF C-1012

REFERENCES

1. Recycling Asphalt Pavements: Palm Beach County, Florida,
by Charles F. Potts,
FHWA Demonstration Project No. 39,
FHWA-DP-39-19, March 1980

2. Hot Mix Recycling: Gray County, Kansas,
by Rodney G. Maag and William H. Parcells, Jr.
FHWA Demonstration Project No. 39,
FHWA-KS-82/3, January 1983

3. Recycling Asphalt Pavements: Springfield, Missouri,
by Anderson Engineering Inc.,
FWWA Project No. 39,
FHWA-DP-39-32, April 1981

4. Recycling Asphalt Pavements: Durango, Colorado,
by Robert F. LaForce,
FHWA Demonstration Project No. 39,
FHWA-DP-39-28, November 1980

5. Recycling Asphalt Pavements: Blewett Pass, Washington,
by Materials Section,
FHWA Demonstration Project No. 39,
FHWA-DP-39-6, March 1980

6. Recycling Asphalt Pavements: North Brunswick, New Jersey,
by Edgar J. Hellriegel,
FHWA Demonstration Project No. 39,
FHWA-DP-39-29, August 1980

7. National Seminar on Asphalt Pavement, Recycling, Dallas-Ft. Worth, Texas, Transportation Research Board, National Research Council,
October 14-16, 1980

8. Evaluation of Recycled Asphalt Concrete Pavements, Kossuth County, Iowa, by Richard P. Henely,
SN-1179(6), 1980

9. Recycling Materials for Highways,
National Cooperative Highway Research Program
Synthesis of Highway Practice #54, 1978

10. Recycling Asphalt Pavements: Ellensburg, Washington,
by R.V. LeClerc, R.L. Schermerhorn, and J.P. Walter,
FHWA Demonstration Project No. 39
FHWA-DP-39-3, August 1978

11. Washington State Department of Transportation's Second Asphalt Concrete Recycling Report - Yakima River to West Ellensburg Interchange,
by J.P. Walter,
DOT-FH-11-8007, March 1981

12. Recycling Asphalt Pavements, Interim Report on Hot Recycling, by U.S. Department of Transportation Demonstration Project No. 39, FHWA-DP-39-15, April 1979

13. Development and Implementation of Washington State's Pavement Management System by Thomas L. Nelson and R.V. LeClerc, WA-RD 50.1, February 1983.