EVALUATION OF CONSTRUCTION AND SHORT-TERM PERFORMANCE PROBLEMS FOR ASPHALT PAVEMENTS IN OREGON

by

James E. Wilson
Materials Engineer
Oregon Department of Transportation

and

R. G. Hicks
Associate Professor
Department of Civil Engineering
Oregon State University

July 1979

ABSTRACT

During the three-year period from 1974 to 1977, an increased occurrence of asphalt concrete pavement problems were noted throughout the United States during and after construction. In Oregon, construction and performance problems that were seldom experience prior to 1974 developed, and include:

(1) Incompactible mixes,
(2) Slow setting mixes,
(3) Flushing mixes,
(4) Low mix cohesion, and
(5) High incidence of "blue smoke" during mixing and laydown.

In an effort to determine the causes of these problems, questionnaires were sent to regional and field construction engineers in 1975 and 1976 to establish the type and extent of problems and to collect information for each job, such as construction procedures, material properties, and mix designs, which may be related to the observed problems. Based on these results, fourteen projects with and without problems were selected for additional study and evaluation. These evaluation included:

(1) Conducting performance surveys,
(2) Obtaining cores of good and bad sections,
(3) Performing test on the mixes, and
(4) Performing tests on the asphalt.

This report summarizes the results of the questionnaire, field survey and laboratory testing. Analysis of the results indicates:

(1) Many of the reported problems in Oregon were due to extreme variations in material properties, such as high fines, high asphalt content, and low asphalt viscosity.

(2) Variations in asphalt temperature susceptibility between grade and between suppliers, as well as use of drum dryer type paving plants and inconsistent addition of dust collector materials may also have contributed to the observed variations in material properties.

The study addresses a significant problem which has been observed throughout the United States. Hopefully, it will indicate to others that many factors can contribute to construction and performance problems and that all factors need to be carefully considered.

ACKNOWLEDGEMENTS

Much of the data collected as a part of this study was summarized by David Hilgendorf, Steven Seed and Laurie Broderick, students at Oregon State University. The data were provided by the Oregon Department of Transportation and the Federal Highway Administration, Region 10. Debra Whitcomb typed the manuscript.

DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those held by Oregon Department of Transportation or Oregon State University.

TABLE OF CONTENTS

INTRODUCTION

During the three-year period from 1974 to 1977, several problems were noted throughout the Pacific Northwest during and after construction of asphalt pavements. For example, in Oregon, paving construction and short-term performance problems that were seldom experienced prior to 1974 have developed, including:

(1) Incompactible Mixes. Mixes in which required density was difficult and sometimes impossible to obtain.

(2) Slow Setting Mixes. Mixes which are displaced or scuffed easily by traffic. Slow setting mixes are also referred to as "tender" mixes.

(3) Flushing Mixes. Mixes which exhibit flushing and instability in the wheel tracks shortly after construction.

(4) Low Mix Cohesion. This has resulted in either ravelling or early surface deterioration due to stripping, and has increased the need for antistripping agents.

(5) High Incidence of "Blue Smoke" during Mixing and Laying of Pavements. This has resulted in difficulties in satisfying air pollution requirements.

These same problems, as well as early thermal cracking, have been reported in 26 states throughout the United States according to a recent AASHTO survey (1).

Contractors and users have tended to blame the asphalt for many of these problems, paricularly since new sources have been brought on line over the past five years. However, other changes have also taken place during this same period, such as the increased use of dryer drum mixers, vibratory compactors development of efficient dust collection systems, mix storage silos, and lower quality aggregates, as well as efforts to product asphalt mixes using less energy (e.g. lower mix temperatures). All of these additional factors make it difficult to assess which factors most affect the observed construction and short-term performance problems.

This paper reports on attempts to determine those factors most affecting construction and short-term performance problems in Oregon.

QUESTIONNAIRE SURVEY

In an effort to resolve these problems, the Oregon State Highway Division developed a questionnaire, distributed in 1975 to Regional and Field Construction Engineers, to establish the extent and causes of pavement problems experienced in 1974. The type of information requested is presented in Table 1. A similar, but more comprehensive questionnaire (Table 2) was sent out in 1976 to document the problems of pavements constructed in 1975 and 1976.

The results of both questionnaires were summarized by the Oregon State Highway Division and are presented in Tables 3 through 5. All of the data pointed to the fact that problems such as shown in Table 3 were increasing, and something had to be done to remedy the situation. Table 4 indicates that projects constructed with asphalts of all types and from most suppliers were experiencing problems. Table 5 summarizes the effect of some construction practices on the occurrence of pavement problems. These data indicate that aggregate type, mix temperature, type of roller and type of plant may contribute to the surface flushing and tender mix problem. Table 6 summarizes all factors which could contribute to the problem experienced in Oregon. Wilson (2) originally indicated that the problems could

TABLE 1. Questionnaire for Construction and Maintenance Use of Paving Grade Asphalt Cements in 1974

Project ______________________________, Contract No. __________

Engineer ____________________, Paving Contractor ______________

Asphalt Cement Brand ______________ Grade ________, Tons Used ______

Type Bit Mixture (PMBB, AC-B,C,D.E) __________, Asph. Macadam ____________

Date - Beginning of Paving ______________, Finished Paving ____________

Type Aggregate (Quarry, Gravel, Nat. Sand) CA ________, FA ____________

Air Temperature During Paving - Average ____________, Range ____________

Plant Manufacturer ________________, Type (drum mix, conv.) ________

Model (Size Batch or Tons per Hour) ______________________________

Type Burner Fuel Used __________________, Grade ______________

Manufacturer and Model of Paving Machine ______________________________

Manufacturer and Model of Pick-up Machine ______________________________

Manufacturer, Type and Model of Rollers, Breakdown ______________________

Intermediate ______________________

Finish ______________________

Mix Temperature Behind Paver - Average ______________, Range ____________

Mix Moisture Content at Plant - Average ______________, Range ____________

Asphalt problems at plant or distributor (Poor coating, adhesion, etc.) ________

____

____

____

Problems at mix laydown or asphalt application (Tender rolling, slow set, etc.) ____

____

____

____

Describe observed differences between an AR grade asphalt and a prior used penetration grade ____

____

Additional comments: ____

____

TABLE 2. Asphalt Paving Questionnaire for 1975-76

Project____, Type Mix: PMBB, AC - B, C, E

Engineer________________________________, Cont. No._________, Prefix __________

Paving Contractor____________________, Paving Dates _________, Mix Tonage _______

Asphalt Cement: Brand and Grade____________________________, Tons Used ________

Aggregate: Type___Quarry, Gravel, Nat. Sand F.A.; Stockpile Des. Sizes __________

Plant: Manu. - Model _______________, Rated Cap._______, Type: Drum Mix, Conv.__

Type Burner Fuel Used________________, Grade __________, Gal./Ton______________

Paver - Manu., Model _______________________, Pick-up Mach.____________________

Rollers ___ Manu. Type (Vib., Pneu., Steel), Model Weight: Breakdown __________ __________, Finish ______________, If vibratory - ampl.______, freq. _________

Weather during paving ______________, Air Temp. - Ave.___________, Range _______

Mix Temperature: @ Plant_________ @ Laydown _________ Asphalt Temp.______________

Approx. Mix % Moisture @ Plant_____@ Laydown ________ @ Tons/Hour_______________

Rolling No. Passes: Breakdown___________Int. ___________Finish _______________ Approx. time from laydown to breakdown________ to finish________ to completion_____

% Compaction, Core Ave._______Range _____; Nuclear Ave._____Range______, % tests within 92%: Core_____No. Tests______; Nuclear______ No. Tests __________

Traffic: During Const. none, minor, moderate, heavy; Immed. after const. - none, minor, moderate, heavy; Hours after laydown for - construction________Public_________

Design "S" Value: Base - 1st _____2nd_______,Top -1st___ 2nd___, IRS: Base___Top_____

Design Grad.: P$1\frac{1}{2}$"___P$\frac{1}{4}$"___P#10___ #40 ___ P#200 ___% Asph.: Base___ Top ___

Ave. Prod. Grad.: P$1\frac{1}{2}$"___ P$\frac{1}{4}$" ___P#10 ___ P#40 ___ P#200 ___ % Asph.: Base___ Top___

Percent of Production within Grad. - A.C. design tolerances, Base_______Top_________

Tender pavement: % of total travel lanes - Base ___ Top ___; Condition ___ shoving, rutting, other _____; occurance ____During construction, after 1 week, other ________

Surface Flushing: None, slight, moderate, heavy; Type-slick, boil, other _______; % of total traffic lanes - Base _____Top ____; Location-wheel track, stop-hill area, other ________; Occurrance - During const., after 1 week, other _______________

Ave. Asphalt Ab. Viscosity/Pen.: Original _________, RTFC Res. ________________, Recovered ________________Date of Recovery ______________________

Comments regarding problems relative to construction, materials used, pavement._______

____

____

____

TABLE 3. Summary of 1975-76 Questionnaire - Percentage of Projects Experiencing Indicated Problem

YEAR	TENDER SLOW-SET	SURFACE FLUSHING	TENDER, WITH FLUSHING	LOW LEVEL OF COMPACTION*	PAVEMENT SURFACE EROSION	LOW ASPHALT-AGGREGATE COHESION**
Before 1974	No Problem	No Problem	No Problem	94.5	Minor	1
1974	40	9	3	92.6	Moderate	6
1975-1976	23	24	13	92.0	Considerable	15

* Average Percent Compaction

** Retained Strength Less Than 70%

TABLE 4. Summary of 1975-76 Questionnaire - Effect of Asphalt Type on Pavement Problems, Dense Pavements

(a) Percentage of Projects with Tender Mixes

ASPHALT TYPE	SUPPLIER			
	A	B	C	D
AR 2000 (3-6-6-4)*	0	67	33	0
AR 4000 (64-6-15-14)	55	17	20	0
AR 8000 (22-2-0-0)	23	0	-	-

(b) Percentage of Projects with Flushing Pavements

ASPHALT TYPE	SUPPLIER			
	A	B	C	D
AR 2000 (3-6-6-4)	0	100	17	75
AR 4000 (64-6-15-14)	23	67	13	25
AR 8000 (22-2-0-0)	9	50	-	-

* Numbers refer to the number of projects in the sample evaluated for each supplier.

TABLE 5. Summary of 1975-76 Questionnaire - Effect of Construction Practices on Percentage of Projects Exhibiting Problems, Dense Pavements

ITEM	VARIABLE	TENDER SLOW-SET	SURFACE FLUSHING
Aggregate	Gravel (101)*	36	29
	Quarry (79)	10	15
Type of Plant	Drum (62)	11	18
	Conventional (118)	31	25
Type of Roller	Vibratory (90)	29	29
	Steel (90)	15	17
Laydown Temperature	275°F- (60)	15	12
	275°F+ (72)	39	24
Level of Compaction	92%+ (84)	11	12
	92%- (96)	16	10
Mix Gradation Within Tolerance	80%+ (110)	21	21
	80%- (70)	26	17

* Number of Projects in Sample

TABLE 6. Factors Contributing to Oregon Pavement Problems as of 1976

PROBLEM TYPE	CONTRIBUTING FACTORS
Asphalt Related	Changes in Specifications Crude Supply Change Energy "Crunch"
Aggregate Related	Single Stockpile Air Pollution Limitations Reduced Aggregate Quality Elimination of Plant Screens
Equipment Related	Mixing and Laydown Temperatures Increased Mix Moisture High Mix Production Rate Reduced Mix Uniformity Vibratory Rollers

be attributed to the asphalt, the aggregate, or the equipment used.

The results of the questionnaires were evaluated by a committee from OSHD, which suggested that a modification of the AR grading asphalt specification should be considered (3). The committee compared the extent of nonconformance to asphalt specifications, including AASHTO M-226 AR Grading, 1973 Pacific Coast Uniform Penetration Grading (3), and AASHTO M-226 AC Grading (3). The study indicated good conformance to the AR Grading specifications and considerable nonconformance to both the penetration and AC Grading specifications. In the penetration grading, two suppliers of asphalt had low flash, low kinematic viscosity, high thin film oven loss, or low percent of original penetration. The AC Graded asphalt from the same two suppliers had low original penetration or high viscosity for the thin film oven residue.

Based on these findings, it was decided to modify the Oregon 1977 AR Specifications to require flash test by the Pensky-Martens method and include maximum limits for RTFC residue loss in weight. This, the committee felt, would result in asphalt similar to that supplied prior to 1974, when few problems had been experienced.

The proposed change in asphalt specifications created considerable discussion between the suppliers and the users, particularly since the cause of the problems could have been attributed to other factors, including aggregate and construction related factors (Table 6). Hence, a committee composed of representatives from suppliers, contractors, Oregon Department of Transportation and Oregon State University was formed to evaluate selected projects in detail to determine the cause of the problems experienced in the 1974-1976 period. Based on information from the 1975-1976 questionnaire, fourteen projects were selected for survey and sampling by the committee.

FIELD EVALUATION

Of the fourteen projects selected throughout Oregon for this part of the study, seven were identified as problem pavements, while seven were considered to be without problems. The basis for the selection was to include a wide range of asphalt grades, suppliers, contractors and construction practices in the projects to be evaluated. A summary of all variables considered in the selection is given in Table 7.

The locations of the fourteen projects evaluated are shown in Figure 1, which indicates that a regional factor was also included in the overall evaluation. Nine projects are located west of the Cascades, and five are located east of the Cascades. Typical pavement cross-sections for all projects are given in Figure 2. All mixes were to conform to one of the Oregon Specifications given in Table 8 (4).

CONSTRUCTION, MIX DESIGN AND INITIAL PERFORMANCE INFORMATION

Construction and mix design information for all fourteen projects was collected and summarized. This information was developed from the data obtained through the 1976 questionnaire, and is given in Tables A-1 through A-3 of Appendix A.

The information obtained from the questionnaire on initial performance is summarized in Table 9. As indicated, seven of the fourteen projects exhibited tenderness and/or flushing during or shortly after construction. Selected construction information is presented in Table 10. These data suggest no clear-cut trend that asphalt grade, aggregate type, plant type, type of roller, temperature, production rate, or percent water at laydown had any significant effect on the occurrence of the problem.

TABLE 7. Basis for Selection of Projects to be Evaluated

FACTOR	VARIABLE
Performance	Good Bad
Asphalt Grade and Supplier	AR-2000, AR-4000, AR-8000 Six Suppliers
Construction Practices	Drum Mixer Conventional Mixer
Location	West of Cascades East of Cascades

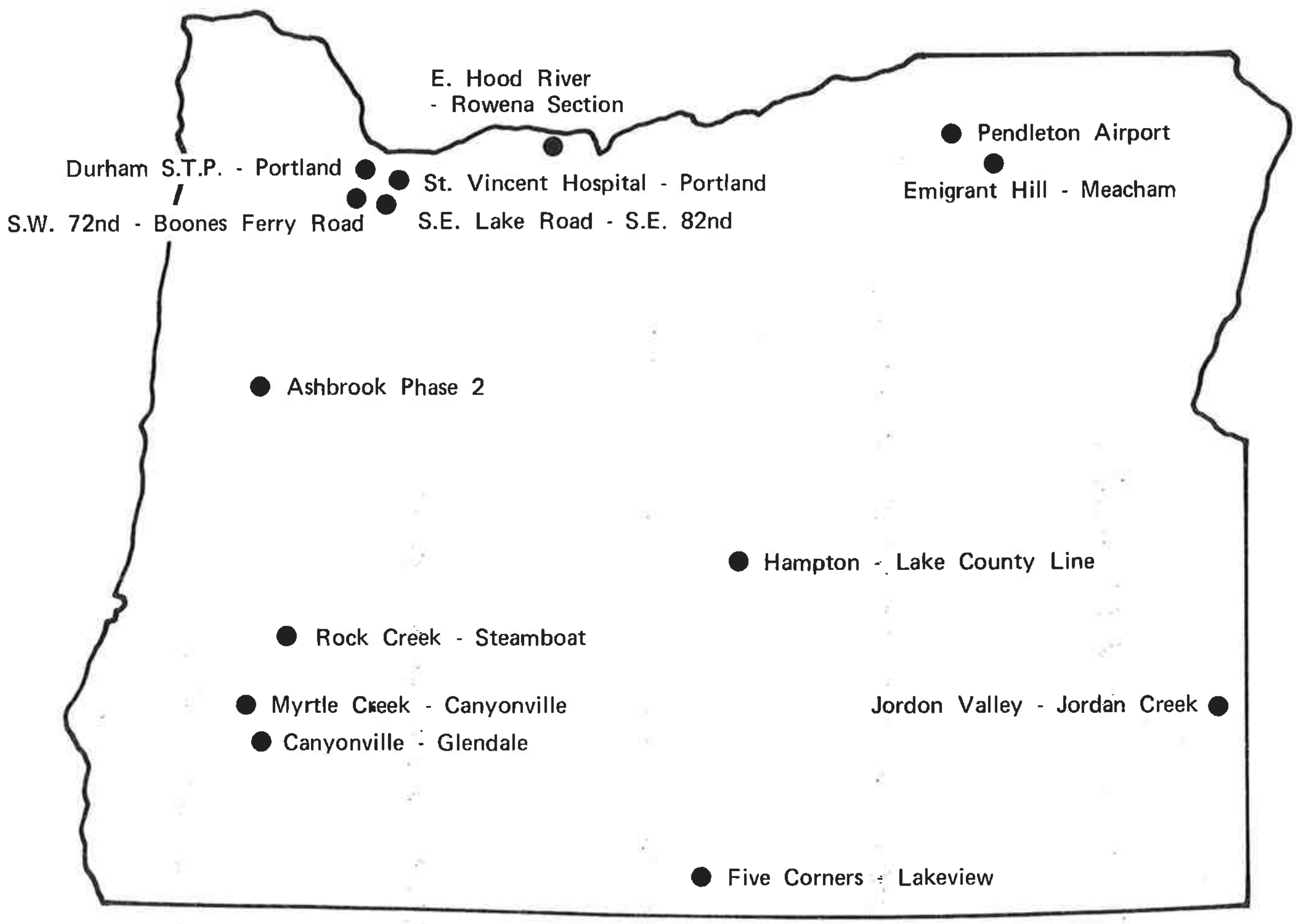


FIGURE 1. Location of Fourteen Projects Evaluated in Oregon for Slow-Set and Surface Flushing Problems.

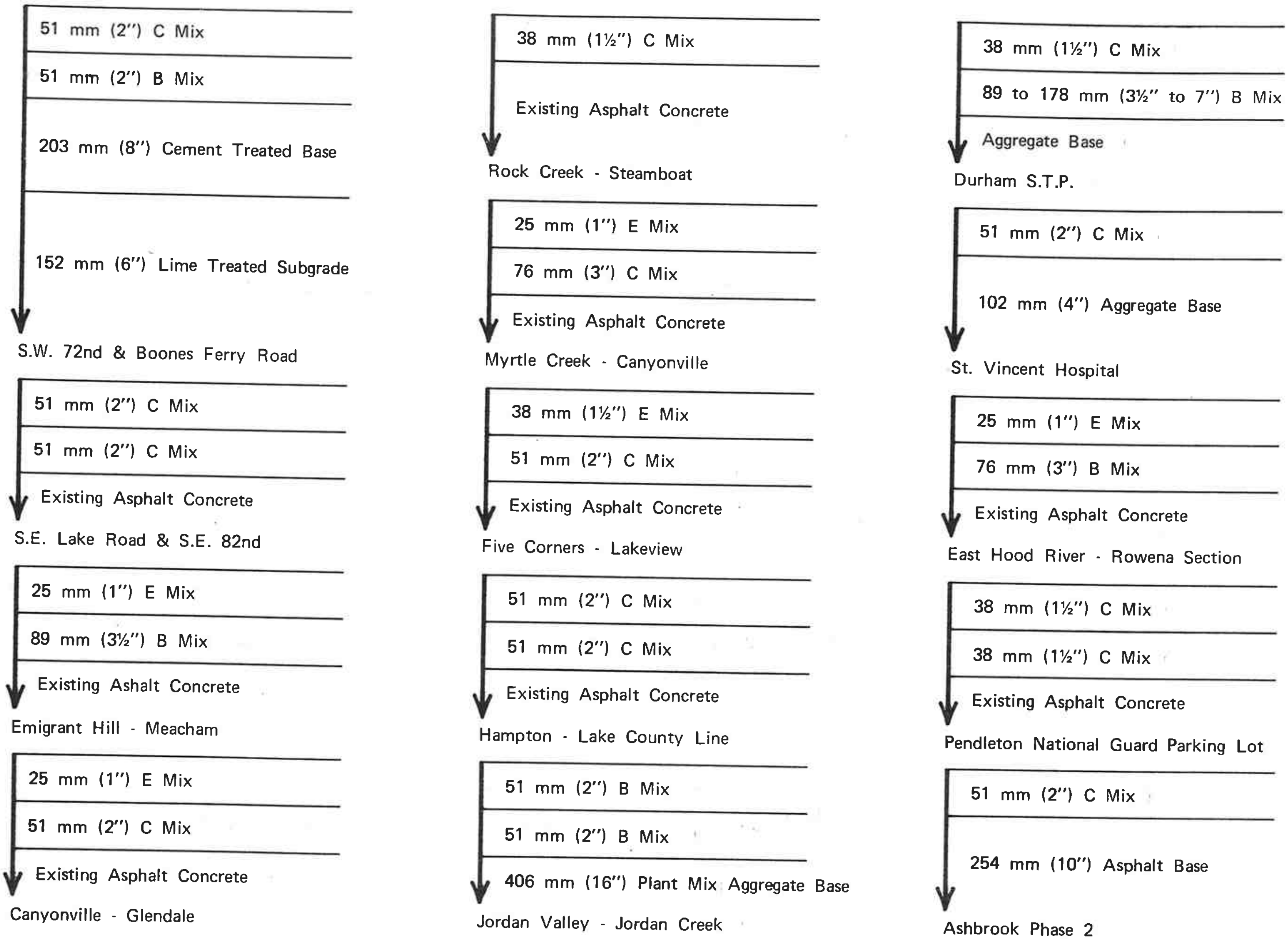


FIGURE 2. Typical Cross Sections for Pavement Sections Evaluated

TABLE 8. Oregon State Highway Division Asphalt Concrete Mix Specifications - Broad Band Gradation and Asphalt Content Limits

SIEVE SIZE	PERCENT PASSING		
	CLASS B	CLASS C	CLASS E
1"	100	-	-
3/4"	95 - 100	100	-
1/2"	-	95 - 100	100
3/8"	-	-	90 - 100
1/4"	52 - 72	65 - 85	51 - 71
No. 10	21 - 41	30 - 45	10 - 20
No. 40	8 - 24	8 - 26	-
No. 200	3 - 7	3 - 7	2 - 6
Asphalt Cement	4 - 8*	4 - 8*	4 - 9*

* Percent of total mix by weight

TABLE 9. Summary of Performance Information During Construction For Detailed Data, Refer to Table A-4 of Appendix A

NO PROBLEMS	TENDER	TENDER - FLUSHING
Canyonville - Glendale E mix	St. Vincent Hospital C mix	S.E. Lake & S.E. 82nd C mix
Durham Sewage Treatment Plant C and B mix	Pendleton National Guard Parking Lot C mix	Emigrant Hill - Meacham E and B mix
S.W. 72nd & Boones Ferry Road C mix	Ashbrook, Phase 2 C mix	Canyonville - Glendale C mix
E. Hood River - Rowena E mix	-	Five Corners - Lakeview C and E mix
Rock Creek - Steamboat C mix	-	-
Myrtle Creek - Canyonville E and C mix	-	-
Hampton - Lake Co. Line C mix	-	-
Jordan Valley - Jordan Creek B mix	-	-

TABLE 10. Summary of Selected Construction Information (From Tables A-1 and A-2)

ITEM	NON-PROBLEM PAVEMENTS*	PROBLEM PAVEMENTS*
Asphalt Grade	(2) AR-2000 (6) AR-4000 (2) AR-8000	(4) AR-2000 (6) AR-4000 (1) AR-8000
Aggregate Type	(7) gravel (5) quarry	(7) gravel (2) quarry
Type of Plant	(8) batch (2) drum	(6) batch (3) drum
Type of Finish Roller	(7) steel (3) vibratory	(6) steel (3) vibratory
Ambient Temperature	(2) >85°F (6) <85°F	(4) >85°F (3) <85°F
@ Plant Temperature	(1) >290°F (5) <290°F	(2) >290°F (6) <290°F
Production Rate	(4) >200 tons/hour (2) <200 tons/hour	(2) >200 tons/hour (3) <200 tons/hour
Percent Water at Laydown	(0) >1% (8) <1%	(2) >1% (4) <1%

* Numbers in parentheses refer to number of mix types investigated with this variable.

Selected information on the asphalt, obtained from cores cut during or shortly after construction is given in Table 11. Unfortunately, not all projects were sampled during or immediately after construction. Hence, only those projects with data are discussed in this section. For projects without problems (East Hood River - Rowena, Myrtle Creek - Canyonville), the asphalt viscosity and penetration from the cores were close to the RTFC values. For the problem pavements (Emigrant Hill - Meacham, Canyonville - Glendale, Five Corners - Lakeview), the recovered viscosity was less and the penetration was considerably greater than the RTFC values. This indicates that there was either insufficient hardening or some contamination of the asphalt, as all other construction factors appeared to have little influence. Although the data are skimpy, they do indicate that asphalt properties certainly could have contributed to some of the observed problems. However, there was no evidence to indicate what caused the softening of the asphalt.

FIELD SURVEY, SPRING 1977

Each of the fourteen projects was evaluated by a rating team for evidence of tenderness and flushing during the spring of 1977, as much as two years after construction.

For each project, a standard rating procedure was used. The project was first driven at the speed limit to obtain a measure of the overall condition and riding quality. Four to five sites were then selected for detailed examination to assess the condition in terms of ravelling, rutting, cracking, maintenance patching, surface condition, etc. To insure a uniform manner of collecting data, a standard survey form was used.

A summary of the field survey, showing average ratings of all projects is given in Table 12. In most cases, the amount of asphalt in the pavement ranged from average to slightly less than optimum for non-problem pavements and average

TABLE 11. Summary of Tests on Asphalt from Cores Taken Shortly After Construction

(a) Problem Pavements

PROJECT NAME	MIX TYPE	RTFC TESTS		TESTS ON RECOVERED ASPHALT	
		VISCOSITY poises @ 60°C	PENETRATION dmm @ 25°C	VISCOSITY poises @ 60°C	PENETRATION dmm @ 25°C
Emigrant Hill - Meacham	B	3704	60	2408	97
	E	6275	58	2660	88
Canyonville - Glendale	C	4100	33	997	161
Five Corners - Lakeview	C	2165	50	1098	68

(b) Non-Problem Pavements

PROJECT NAME	MIX TYPE	RTFC TESTS		TESTS ON RECOVERED ASPHALT	
		VISCOSITY poises @ 60°C	PENETRATION dmm @ 25°C	VISCOSITY poises @ 60°C	PENETRATION dmm @ 25°C
East Hood River - Rowena	E	4363	29	4110	24
Myrtle Creek - Canyonville	C	4100	33	4254	45

TABLE 12. Summary of Field Survey, Average Ratings of All Projects

(a) Roads Without Problems During Construction

PROJECT NAME	LOCATION NUMBER	OVERALL RATING	AMOUNT OF ASPHALT	SURFACE TEXTURE	RUTTING	RAVELLING
S.W. 72nd and Boones Ferry Road	A	Very Good	Average	Average to Slightly Open	Very Slight to None	Slight to None
	B	Very Good	Slightly Less than Optimum	Slightly Open	Very Slight to None	Slight to Moderate
Durham STP	A	Very Good	Average to Slight Excess	Average to Slightly Closed	None	None
East Hood River Rowena Section	A	Fairly Good	Average	Average	Slight	Slight
	B	Fairly Good	Less than Optimum	Very Open	Moderate	Slight to Moderate
Rock Creek Steamboat	A&B	Good	Average to Excess	Average to Closed	Moderate	None
Myrtle Creek Canyonville	A&B	Good	Average	Average	Slight	None
Hampton Lake County Line	A&B	Good	Average	Closed	Slight	None
Jordan Valley Jordan Creek	A&B	Good	Average	Average	Slight	Slight

(b) Roads With Problems During Construction

PROJECT NAME	LOCATION NUMBER	OVERALL RATING	AMOUNT OF ASPHALT	SURFACE TEXTURE	RUTTING	RAVELLING
St. Vincent Hospital	A	Average to Good	Average to Slight Excess	Closed	None	Slight to None
S.E. Lake Road 82nd Avenue	A	Good	Average to Slight Excess	Average to Slightly Closed	None	None
	B	Good	Average to Slight Excess	Average to Slightly Closed	Less than 3/8"	Slight to None
	C	Good	Average	Average to Slightly Closed	Very Slight	None
	D	Poor	Excess Flushing	Closed	None	None
	E	Poor	Excess Flushing	Closed	None	None
Pendleton National Guard Parking Lot	A	Fairly Good	Average	Somewhat Closed	None	Slight
Em igrant Hill Meacham	A	Good	Average	Open	Very Slight	None
	B,C,D	Good	Average	Open	None	None
Ashbrook Phase 2	A	Good	Average	Average to Slightly Open	Slight to None	Slight to None
Canyonville Glendale	A,B,C,D,E,F	Good	Average to Excess	Average to Closed	Slight	Slight

to excessive with flushing for problem pavements. Surface texture ranged from slightly open to closed for problem pavements and mainly closed to open for non-problem pavements. Both rutting and ravelling were reported to be slight to none and moderate to none for problem and non-problem pavements, respectively. None of the projects showed evidence of tenderness.

LABORATORY EVALUATION

Six cores were taken from each test site within a given project: three 10 cm (four-inch) diameter cores and three 15 cm (six-inch) cores. All 15 cm (six-inch) cores were broken down and refabricated according to ASTM D 1560 and D 1561 procedures (5). Bulk specific gravity, Hveem stability ("S"), and cohesion ("C") values and percent voids for the refabricated samples were obtained from the samples. Real specific gravity of the same samples were obtained by AASHTO T-209 procedure (6). The asphalt was then extracted for percent asphalt and tests on the asphalt and a sieve analysis on the recovered aggregate performed.

One 10 cm (four-inch) sample was tested according to ASTM D 1560 procedure to obtain in-place bulk specific gravity, Hveem "S" and "C" values, percent voids, and percent relative compaction. One 10 cm (four-inch) sample was sent to the Federal Highway Administration Laboratories in Vancouver, Washington, for determination of the resilient modulus, using the diametral procedure (7).

TEST RESULTS

Table 13 summarizes the average values for selected properties of the mix and of the asphalt itself. As can be seen, there is little difference in asphalt or mix properties between the problem and non-problem pavements. This is probably

TABLE 13. Selected Average Properties for Problem and Non-Problem Pavements

(a) Tests on Mix from Cores

PROPERTY	NON-PROBLEM		PROBLEM	
Class of Mix	"B" & "C"	"E"	"B" & "C"	"E"
Asphalt Content	7.0 (11)*	6.9 (8)	6.7 (21)	7.6 (7)
Percent Minus No. 200	6.0 (11)	5.1 (8)	6.1 (21)	5.0 (7)
Penetration, dmm	65.5 (11)	46.0 (8)	65.2 (17)**	42.0 (7)
Viscosity at 60°C, poises	2641 (11)	5227 (8)	3466 (18)**	5508 (7)
Viscosity at 135°C, cs	386 (11)	460 (8)	331 (18)**	449 (7)

(b) Tests on Cores

PROPERTY	NON-PROBLEM		PROBLEM	
Class of Mix	"B" & "C"	"E"	"B" & "C"	"E"
Air Voids	7.1 (11)	10.7 (8)	7.1 (20)	12.7 (6)
Stability	15.5 (6)	15.0 (1)	16.5 (8)	-
Modulus, psi	445,000 (11)	343,000 (6)	272,000 (16)	160,000 (7)

* Number in parenthesis is number of tests

** penetration and viscosity of asphalt recovered from Five Corners - Lakeview cores are not included in average for "B" and "C" mix.

due to the fact that the samples were taken as much as two years after the project was constructed.

This finding led the authors to look at variations from design values for projects experiencing flushing problems, tenderness problems, and no problems. The results of their analysis are summarized in Figures 3 through 8.*

Figure 3 summarizes for each project the variation of actual asphalt content and percent passing the No. 200 sieve from the mix design values. Note that for tender and/or flushing mixes, the variation from design asphalt content and percent passing the No. 200 sieve is generally greater than that of the non-problem pavements. Also for problem pavements, there is a greater incidence of excessive asphalt contents. Both observations definitely could be the principal factor contributing to the problems observed; however, some problem pavements exhibited low asphalt contents leading the authors to believe that asphalt content alone did not always relate to the occurrence of problems. Similar variations for the percent passing the No. 10 and 1/4-inch sieves show the same trend, as shown in Figure 4.

Figure 5 shows that the stability values of the recompacted mix are generally lower for flushing and tender pavements, as compared to non-problem pavements and are considerably lower than the design values. Stability tests were also performed on cores, although not to the same extent as on refabricated mix. Tests on cores show all stability values to be relatively low (15 to 17 average).

In-place air voids for the flushing and tender pavements were similar to those of non-problem pavements, as shown in Figure 6. Further, the average values are quite high (approximately 7% for the B and C mixes and 11% for the E mix). However, voids for the recompacted mixes were considerably lower for the problem pavements.

No clear trend is suggested in Figure 7 for percent compaction based on core density. However, the resilient modulus for the cores indicate that

*The key to these figures is given in Appendix B

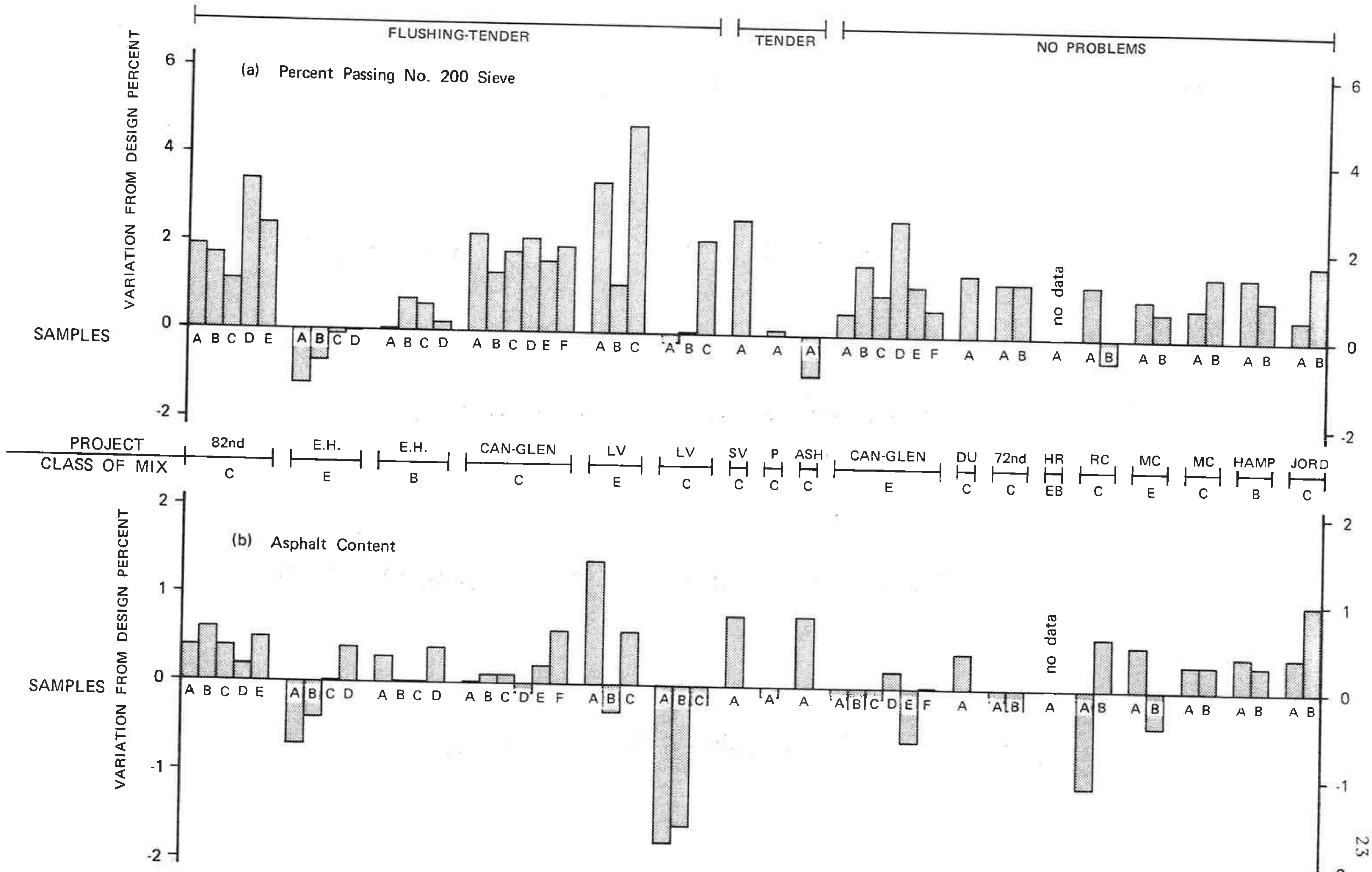


FIGURE 3 Variation from Mix Design of Percent Passing the No. 200 Sieve & Asphalt Content.

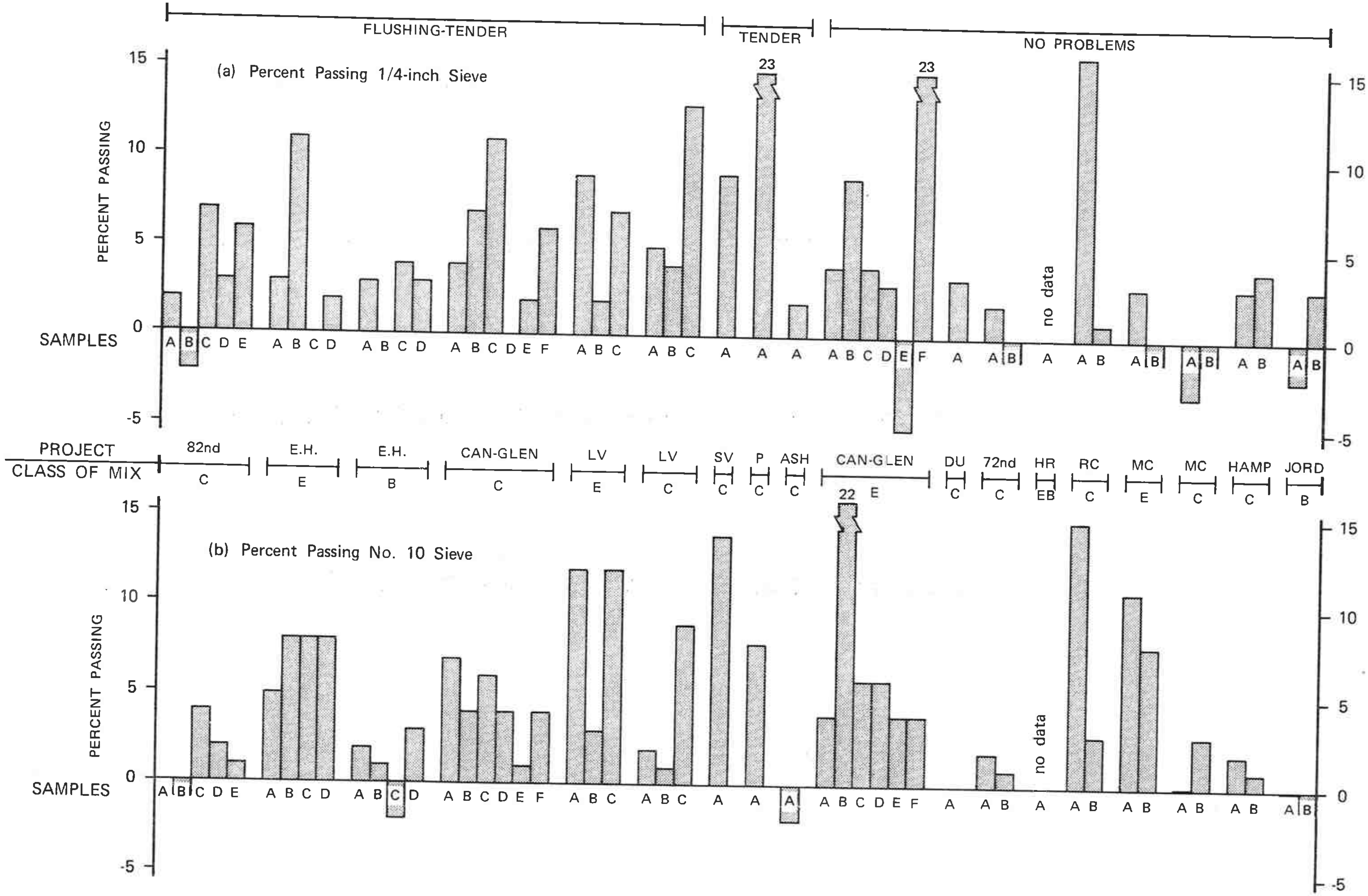


FIGURE 4 Variation from Mix Design of Percent Passing 1/4-inch Sieve & No. 10 Sieve.

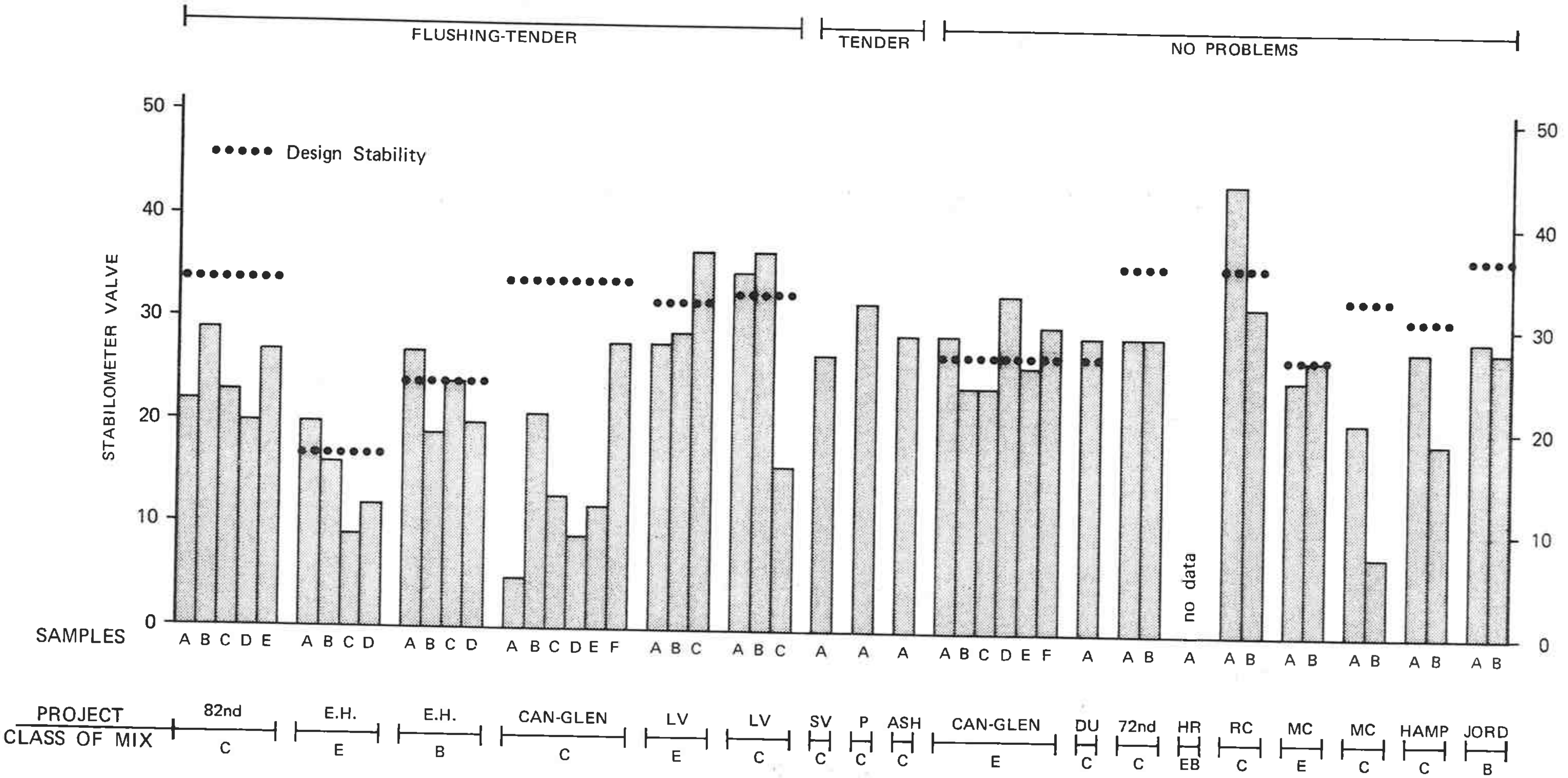


FIGURE 5 Compacted Mix Stability

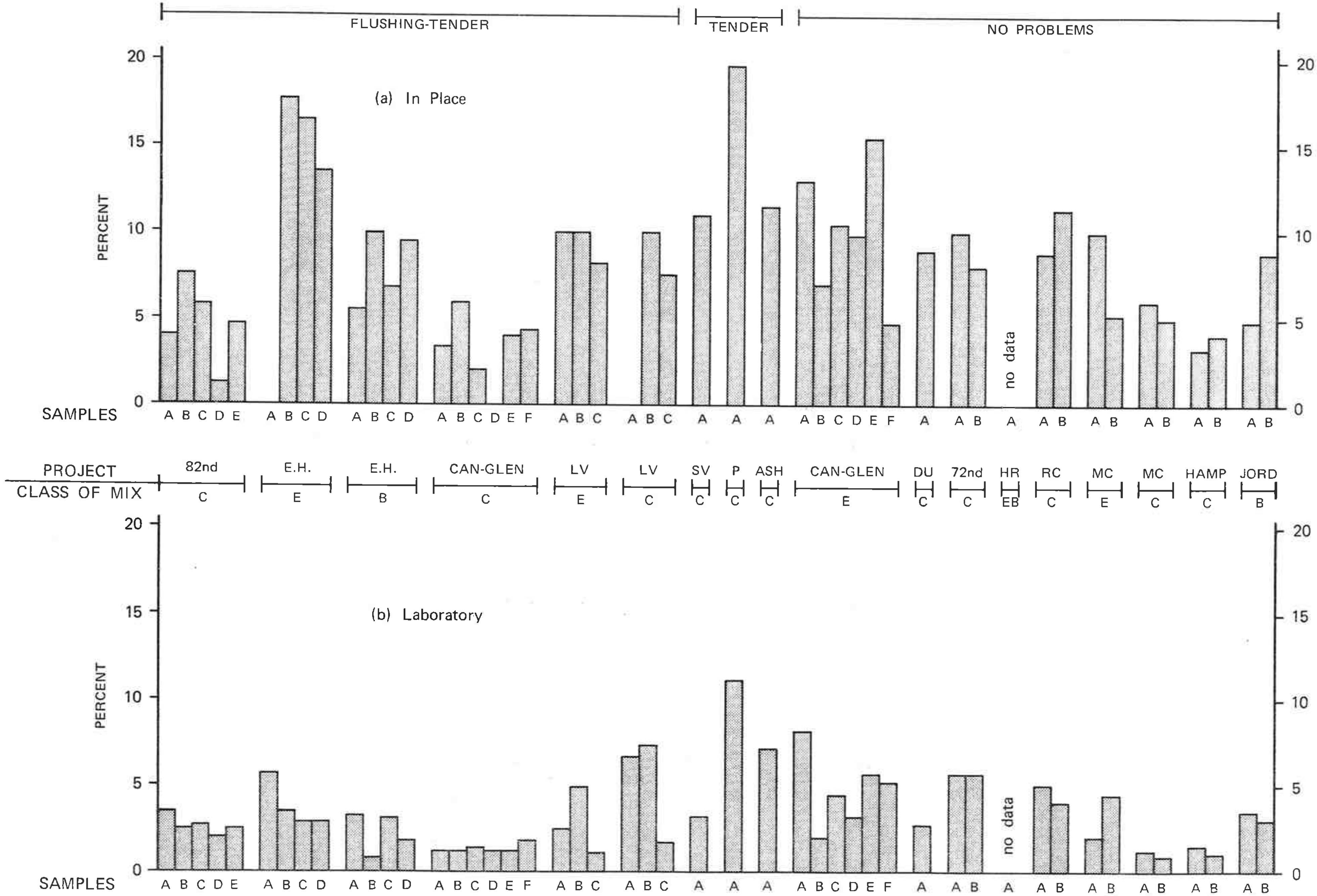


FIGURE 6 In Place and Laboratory Compacted Core Air Voids

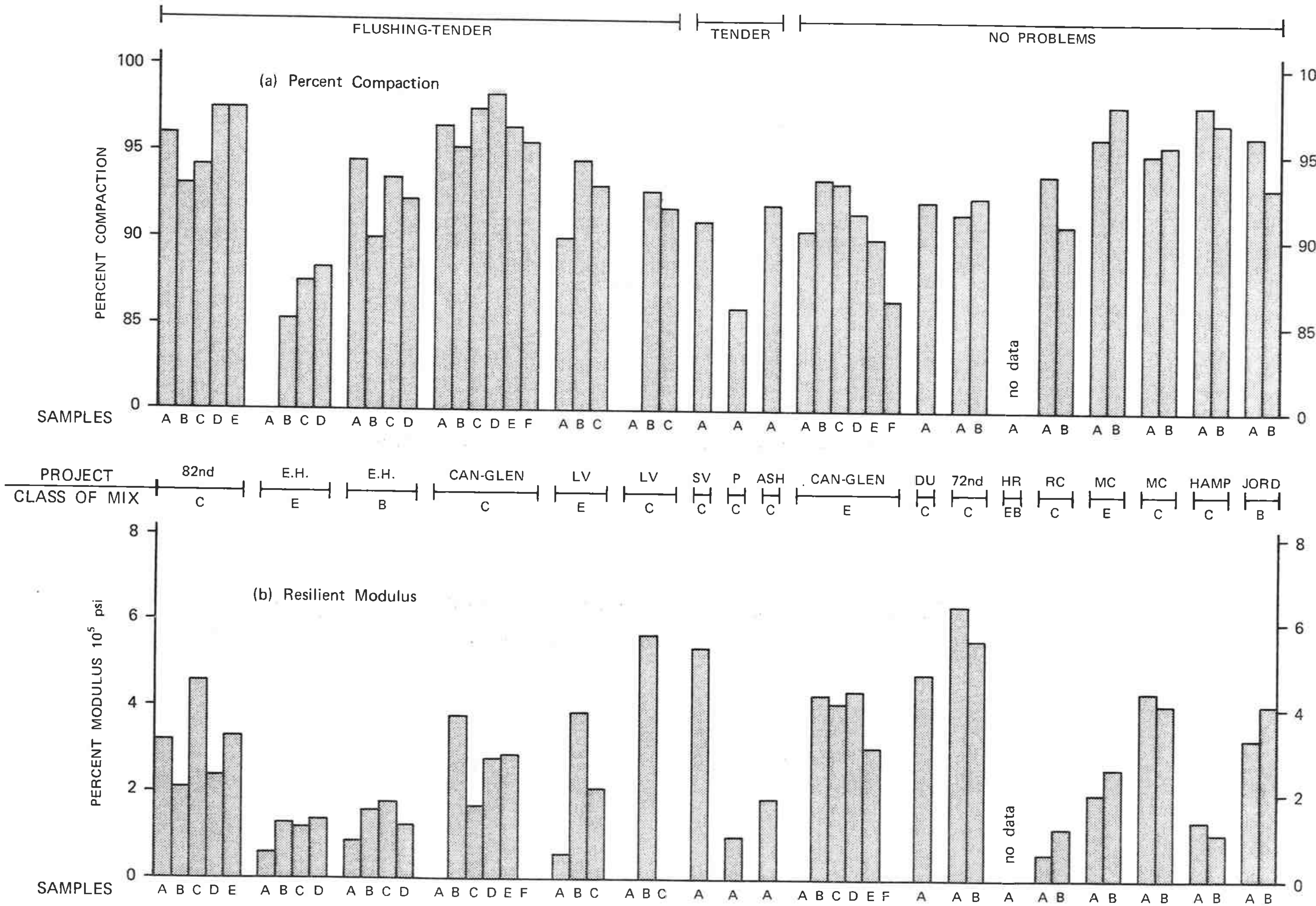


FIGURE 7 Level of Compaction and Resilient Modulus for Problem and Non-Problem Pavements.

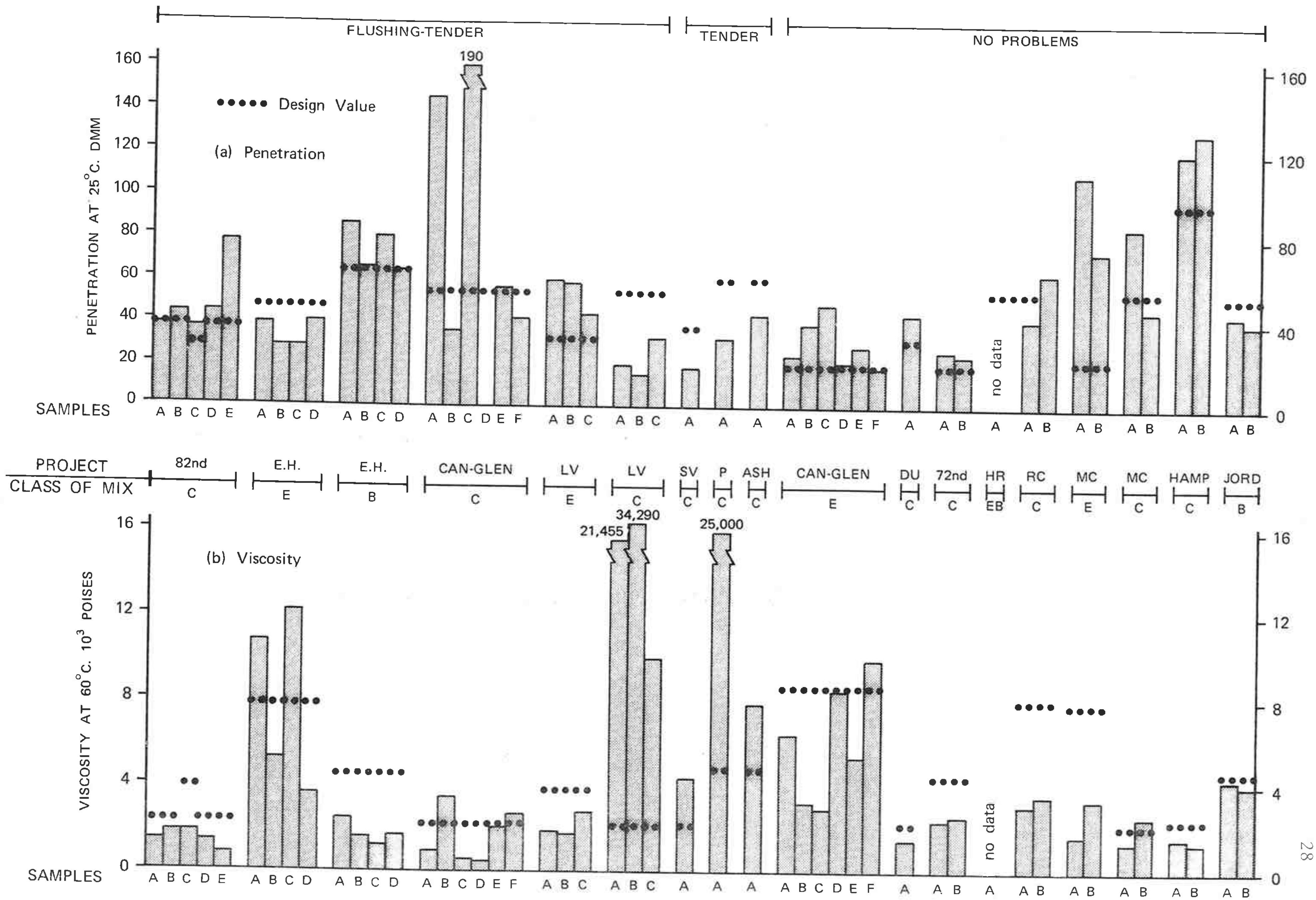


FIGURE 8 Variation in RTFC Residue Penetration and Viscosity for Problem and Non-Problem Pavements.

flushing and tender mixes generally have lower values.

As far as the effect of the asphalt on the problems, there is substantial variation in asphalt penetration and viscosity for both problem and non-problem pavements (Figure 8). The non-problem mixes tended to have lower viscosities at 60°C (140°F) and lower penetrations. This implies a steeper temperature-viscosity curve for the non-problem pavements.

Table 14 summarizes the most probable causes of the problems for the projects which were investigated. In most cases, the problems appear to be associated with variations in aggregate gradation, high asphalt contents or low asphalt viscosity during construction.

DISCUSSION

As mentioned previously, much of the blame for recent problems in asphalt pavements has been directed to the asphalt itself, particularly since new sources have been brought on line over the past five years. It is generally believed that many of the problems are due to wide differences in the:

(1) Asphalt temperature-viscosity curves from various suppliers,

(2) Penetration at 25°C (77°F) from the various suppliers, and

(3) Lack of uniformity in the final product during paving.

However, the results of this study indicate that the problems are the result of high asphalt content and fines. The causes of this could be associated not only with changes in asphalt, but also with other new developments which have taken place during this same period. This includes increased use of dryer drum mixers, mix storage silos, and lower quality aggregate, as well as increased efforts to produce asphalt mixes with less energy (lower mix temperatures) and less air pollution (greater fines in the mix). All of these additional factors make it difficult to properly evaluate the influence of the asphalt on the increase in construction and short-term performance problems because, once the asphalt is sampled and tested, it is subject to a variety of additional actions (mixing, storage,

TABLE 14. Probable Causes of Tenderness and/or Flushing During Construction for Problem Pavements

PROJECT	CAUSES OF PROBLEMS
S.E. Lake Road and 82nd Avenue C mix	(1) 0.5 to 3.0% excess passing the No. 200. (2) 0.2 to 0.6% excess asphalt. (3) Low viscosity asphalt.
Emigrant Hill - Meacham E mix	(1) 3 to 12% excess passing the 1/4-inch sieve. (2) 5 to 8% excess passing the No. 10 sieve. (3) Low viscosity asphalt. (4) High moisture content in mix.
Emigrant Hill - Meacham B mix	(1) Low viscosity asphalt. (2) High moisture content.
Canyonville - Glendale C mix	(1) Up to 2% excess passing the No. 200 sieve. (2) 3 to 12% excess passing the 1/4-inch sieve. (3) 2 to 7% excess passing the No. 10 sieve. (4) Low viscosity asphalt.
Five Corners - Lakeview E mix	(1) Up to 5% excess passing the No. 200 sieve. (2) 3 to 8% excess passing the 1/4-inch sieve. (3) Up to 13% excess passing the No. 10 sieve. (4) Up to 1½% excess asphalt.
Five Corners - Lakeview C mix	(1) Low viscosity asphalt during construction.
Saint Vincent Hospital C mix	(1) Up to 2% excess passing the No. 200 sieve. (2) Up to 17% excess passing the 1/4-inch sieve. (3) Up to 14% excess passing the No. 10 sieve. (4) No data on asphalt viscosity at time of construction.
Pendleton National Guard Parking Lot C mix	(1) Up to 23% excess passing the 1/4-inch sieve. (2) Up to 8% excess passing the No. 10 sieve. (3) No data on asphalt viscosity at time of construction.
Ashbrook, Phase 2 C mix	(1) Insufficient aggregate fracture of crushed gravel. (2) No data on asphalt viscosity at time of construction.

etc.) which can have a profound influence on the mix behavior during construction and shortly thereafter.

FACTORS CONTRIBUTING TO THE PROBLEM

Asphalt

In the Pacific Northwest in particular and the United States in general, the asphalt cements supplied can be very diverse. In Oregon, the ranges of properties for an AR-4000 are shown in Table 15. Though all of these materials meet the specifications (viscosity at $60^{o}C$ of 3000 to 5000 poises after aging), their initial properties, including temperature susceptibility, vary. For example, in 1976, the penetration of the original asphalt ranged from a low of 48 to a high of 134. The same could probably also be said for the AC graded asphalt cements; that is, they may initially have uniform properties, but after aging or mixing, their properties are diverse.

Figures 9 through 11 indicate how the temperature-viscosity relationship for asphalt supplied in Oregon has varied from 1973 to 1977 for AR-4000*. There is a slight change in the relationships between 1973 and 1975, with one of the suppliers (Supplier A) providing an asphalt with a very flat temperature-viscosity curve. In 1977, all temperature-viscosity curves were similar, indicating that Supplier A had changed its product to conform to the other products supplied.

If one examines the change in Supplier A's product from 1973 to 1977 (Figure 12), the asphalt supplied in 1973 and 1975 differs from that supplied in 1977. The 1973-75 product should be more susceptible to tenderness because of the lower viscosities at temperatures in the range of 25 to $60^{o}C$.

As indicated earlier, there were virtually no problems at all in 1973. Problems did occur in 1974-1976. This would tend to indicate other factors

* Using a modified version of Heukelom's nomograph (8).

TABLE 15. Summary of Average Properties Supplied in Oregon, AR-4000

(a) Supplier A

PROPERTY	1973	1974	1975	1976	1977
ORIGINAL					
Flash COC, °F	550	465	460	475	510
Penetration at 77°F	95	140	130	134	70
Viscosity at 140°F	1520	1125	1250	1244	1667
Viscosity at 275°F	325	340	350	366	262
AGED ASPHALT (AFTER RTFC)					
RTFO Loss, %	0.48	1.47	1.35	1.43	0.43
Viscosity at 140°F	4700	4250	4475	4762	3776
Viscosity at 275°F	550	635	625	654	404
Penetration of Residue, dmm	58	69	65	60	42

(b) Supplier B

PROPERTY	1973	1974	1975	1976	1977
ORIGINAL					
Flash COC, °F	490	510	450	515	510
Penetration at 77°F	89	66	55	56	56
Viscosity at 140°F	1425	1760	1900	1865	1878
Viscosity at 275°F	305	250	245	268	268
AGED ASPHALT (AFTER RTFC)					
RTFO Loss, %	0.65	0.64	0.55	0.55	0.40
Viscosity at 140°F	4375	4075	4100	4380	4097
Viscosity at 275°F	470	384	330	457	381
Penetration of Residue, dmm	52	40	33	32	32

(c) Supplier C

PROPERTY	1973	1974	1975	1976	1977
ORIGINAL					
Flash COC, °F	525	520	460	495	510
Penetration at 77°F	75	69	60	44	70
Viscosity at 140°F	1350	1340	1500	1575	1667
Viscosity at 275°F	250	260	260	298	262
AGED ASPHALT (AFTER RTFC)					
RTFO Loss, %	0.90	0.52	0.34	0.60	0.43
Viscosity at 140°F	4220	3810	4100	4363	3776
Viscosity at 275°F	400	410	400	439	404
Penetration of Residue, dmm	40	38	33	29	42

(d) Supplier D

PROPERTY	1973	1974	1975	1976	1977
ORIGINAL					
Flash COC, °F	535	560	450	560	555
Penetration at 77°F	51	44	48	48	53
Viscosity at 140°F	2450	2750	2400	2212	2083
Viscosity at 275°F	260	285	264	291	252
AGED ASPHALT (AFTER RTFC)					
RTFO Loss, %	0.25	0.13	0.22	0.06	0.37
Viscosity at 140°F	4620	4640	4600	3880	4227
Viscosity at 275°F	350	365	360	350	353
Penetration of Residue, dmm	35	33	31	33	32

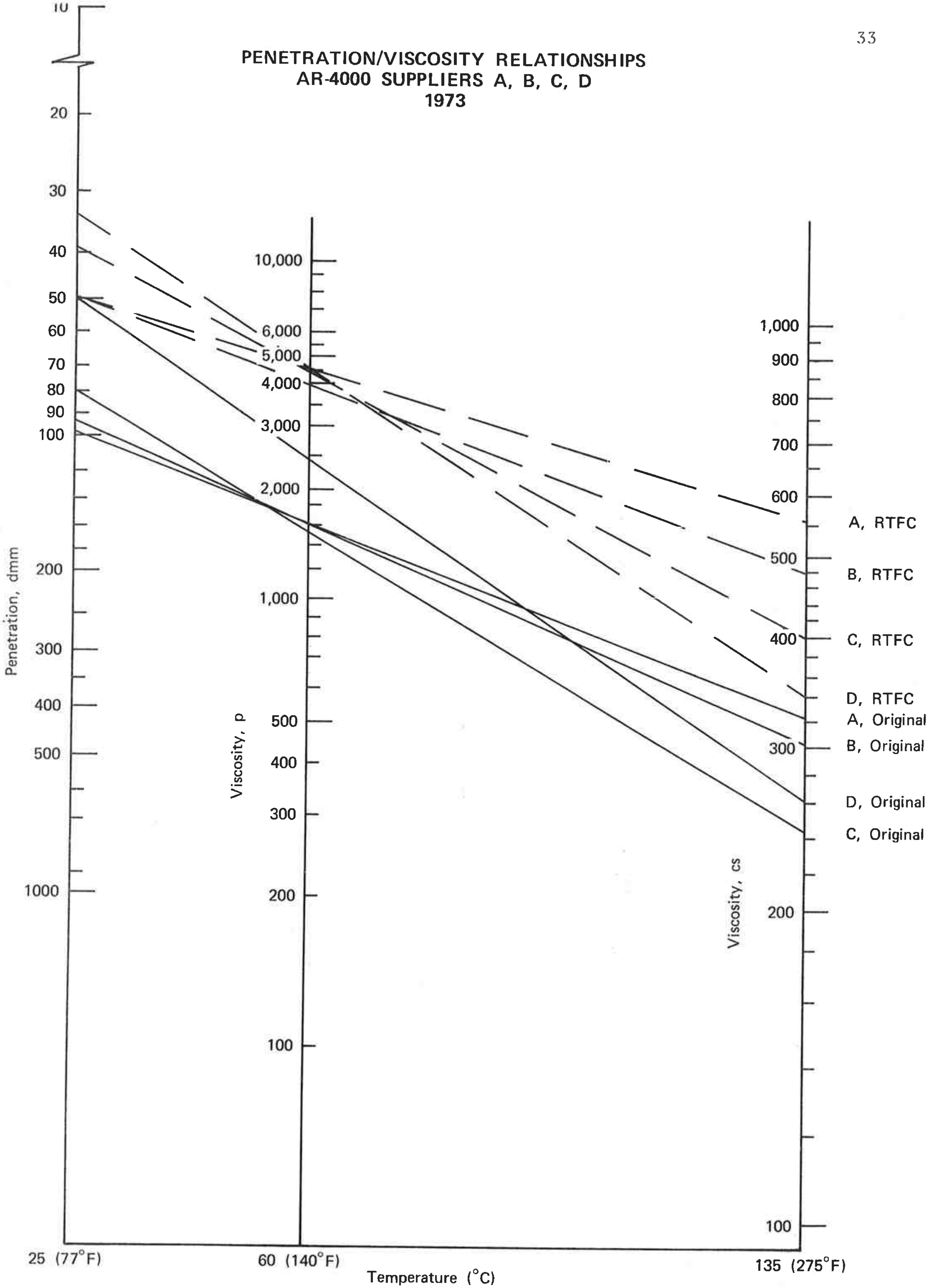
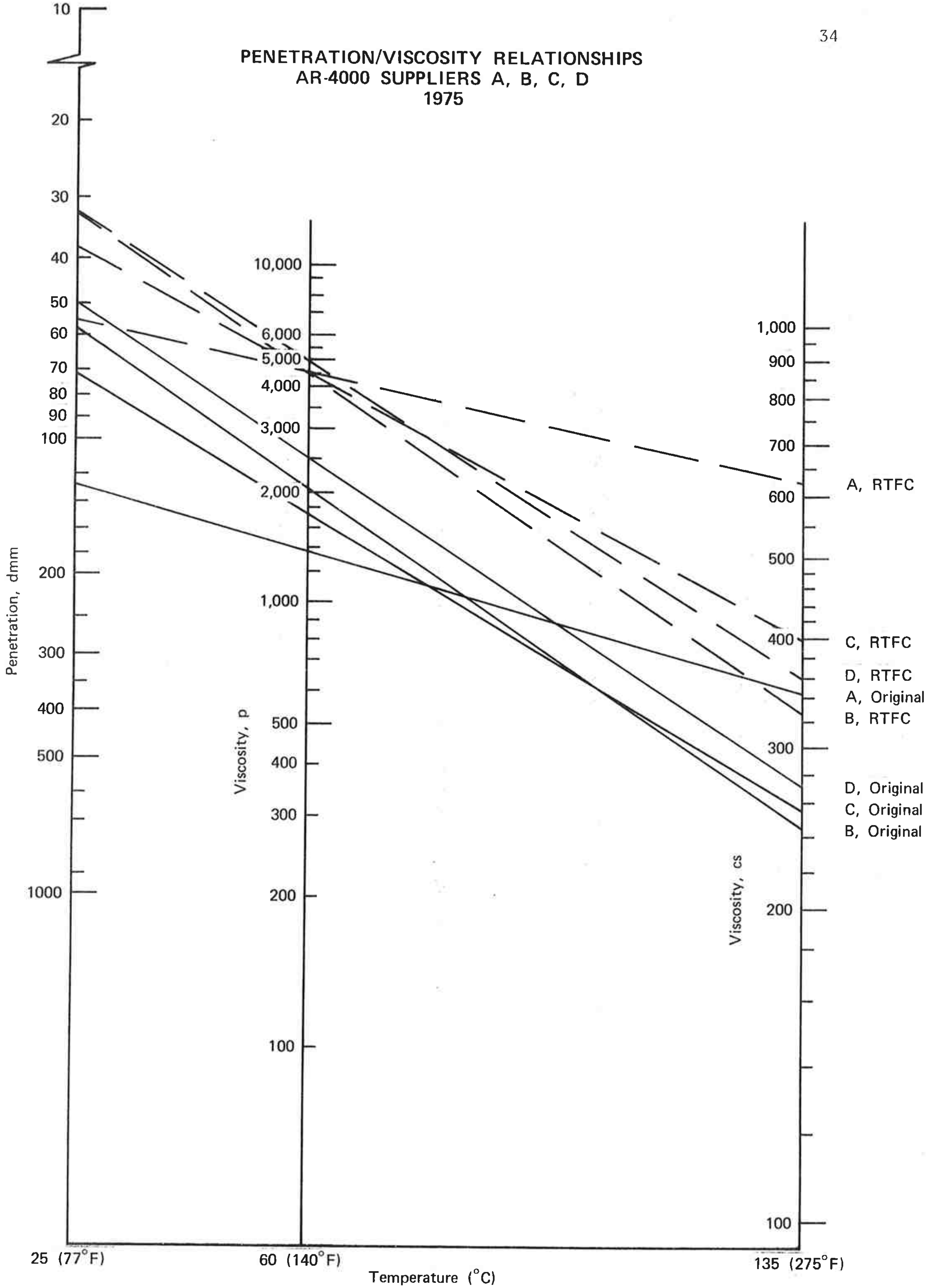

PENETRATION/VISCOSITY RELATIONSHIPS
AR-4000 SUPPLIERS A, B, C, D
1973
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
A, RTFC
B, RTFC
C, RTFC
D, RTFC
A, Original
B, Original
D, Original
C, Original
25 (77°F)
60 (140°F)
135 (275°F)
Temperature (°C)

FIGURE 9



10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Penetration, dmm
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, p
1,000
900
800
700
600
500
400
300
200
100
Viscosity, cs
A, RTFC
C, RTFC
D, RTFC
A, Original
B, RTFC
D, Original
C, Original
B, Original
25 (77°F)
60 (140°F)
135 (275°F)
Temperature (°C)

FIGURE 10

PENETRATION/VISCOSITY RELATIONSHIPS
AR-4000, SUPPLIERS A, B, C, D
1977

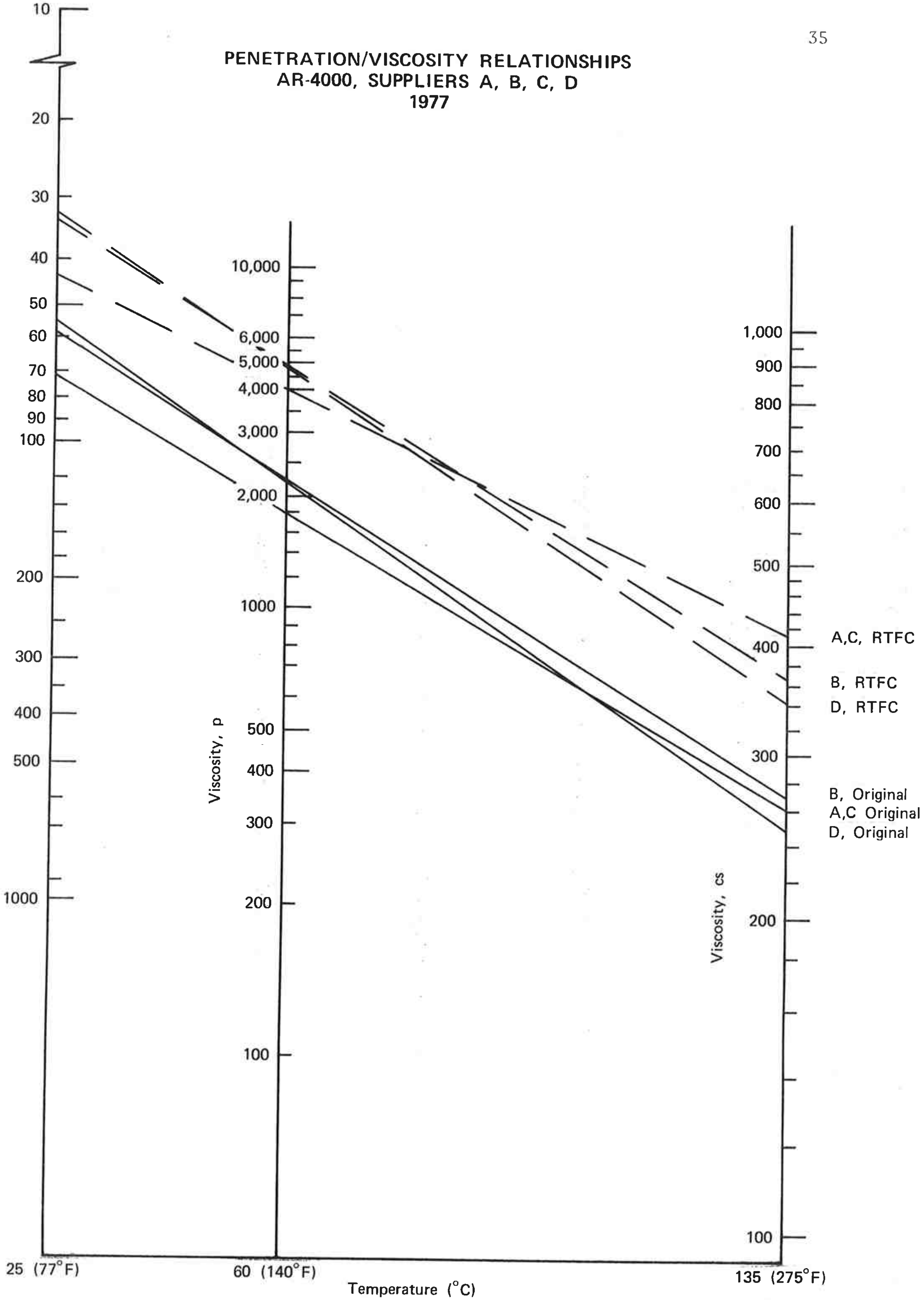


FIGURE 11

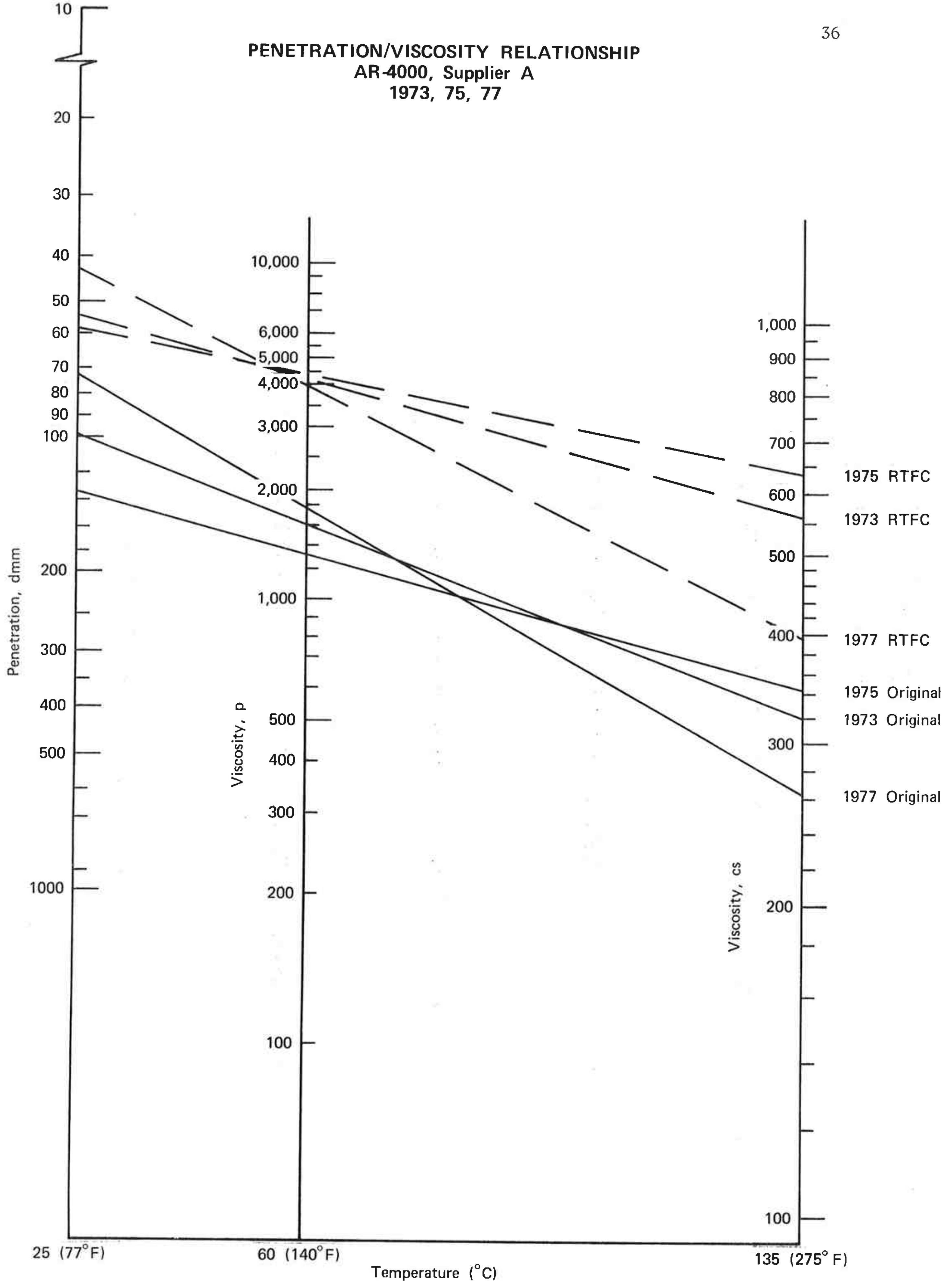

PENETRATION/VISCOSITY RELATIONSHIP
AR-4000, Supplier A
1973, 75, 77
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
1975 RTFC
1973 RTFC
1977 RTFC
1975 Original
1973 Original
1977 Original
25 (77°F)
60 (140°F)
135 (275° F)
Temperature (°C)

FIGURE 12

might have contributed to the problems, as there appears to be no great differences in the 1973-1976 asphalts. No problems were reported in 1977. This seems reasonable, as the asphalts supplied in 1977 were more consistent and all exhibited a relatively steep temperature-viscosity curve.

Table 4, presented earlier, indicated the percentage of projects by asphalt suppliers exhibiting problems. As shown, all asphalts supplied in 1974-1976 exhibited tenderness or flushing problems. A higher percentage of Supplier A asphalts exhibited tenderness problems, as might be expected from their flat temperature-viscosity curves. However, since the asphalt they supplied in 1974-76 was not significantly different than that supplied in 1973, the asphalt alone could not be the major factor contributing to the reported problems. All asphalts contributed to flushing problems, leading one to believe that all mixes may have been over asphalted.

In addition, the asphalts supplied do not behave uniformly when the storage and mix temperatures or the time of mixing is varied. This effect is illustrated in Figure 13 for California asphalts, showing the change in viscosity at 140^{o}F with time of exposure in the Rolling Thin Film Oven (RTFC) Test and with temperature. Note the differences in performance. The "Valley" asphalts stay within the AR-4000 range when mix temperature is varied, but "Coastal" types do not. In fact, the "Coastal" asphalt mixes drop one full grade, to AR-2000 and remain softer longer than mixes made from "Valley" asphalt (9). This factor appears to have contributed to the problems noted at Emigrant Hill - Meacham, Canyonville - Glendale and Five Corners - Lakeview.

It should be noted that changes in asphalt viscosity with mix temperature have also been observed in the field (9). Figure 14 shows this effect. Mixes made below 300^{o}F are softer than those made above 300^{o}F (9). This trend, however, was not observed in the fourteen projects evaluated, probably because of the small data base.

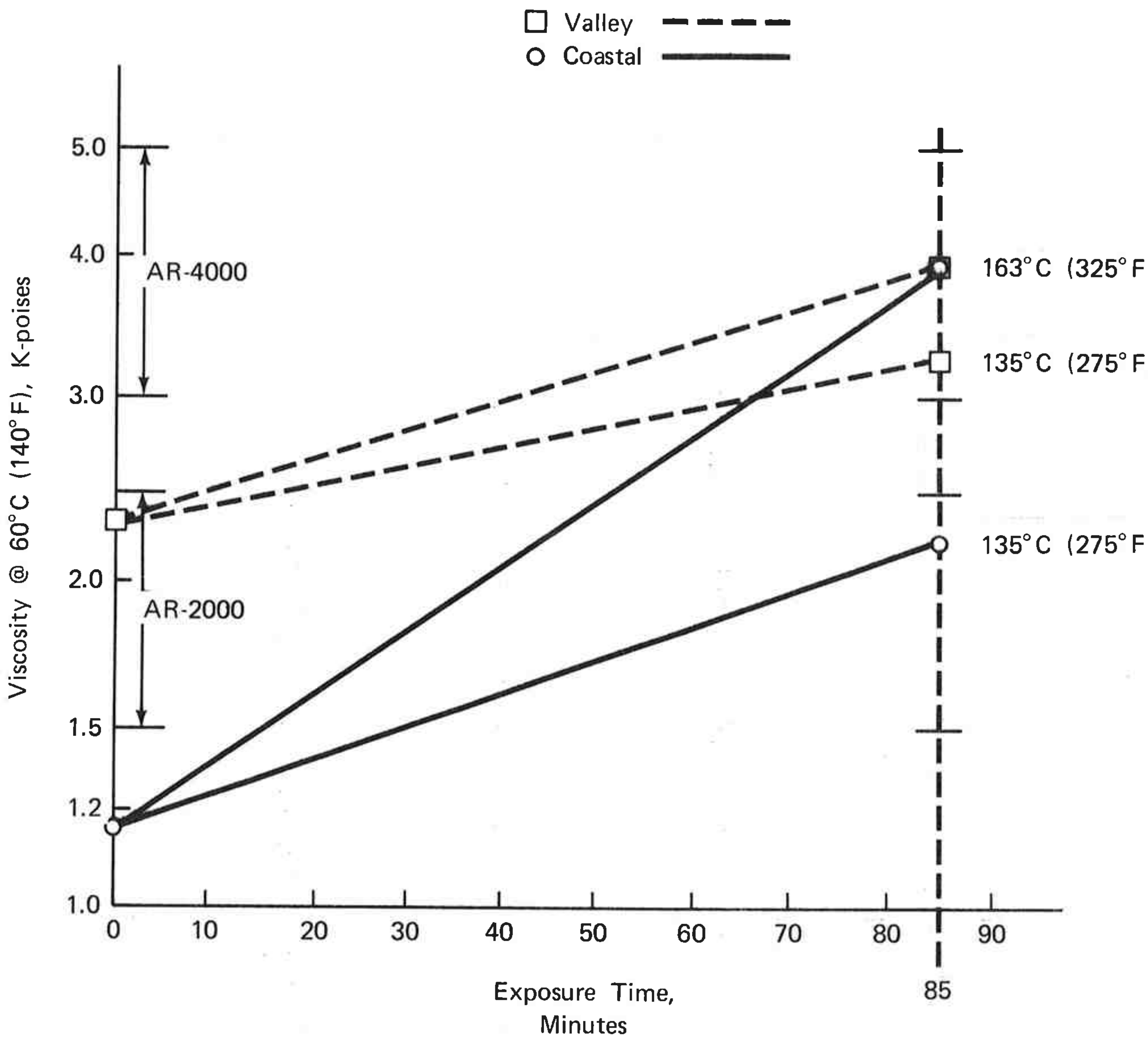


FIGURE 13 Effect of Mixing Time and Temperature on Asphalt Viscosity at 60°C (140°F) (9)

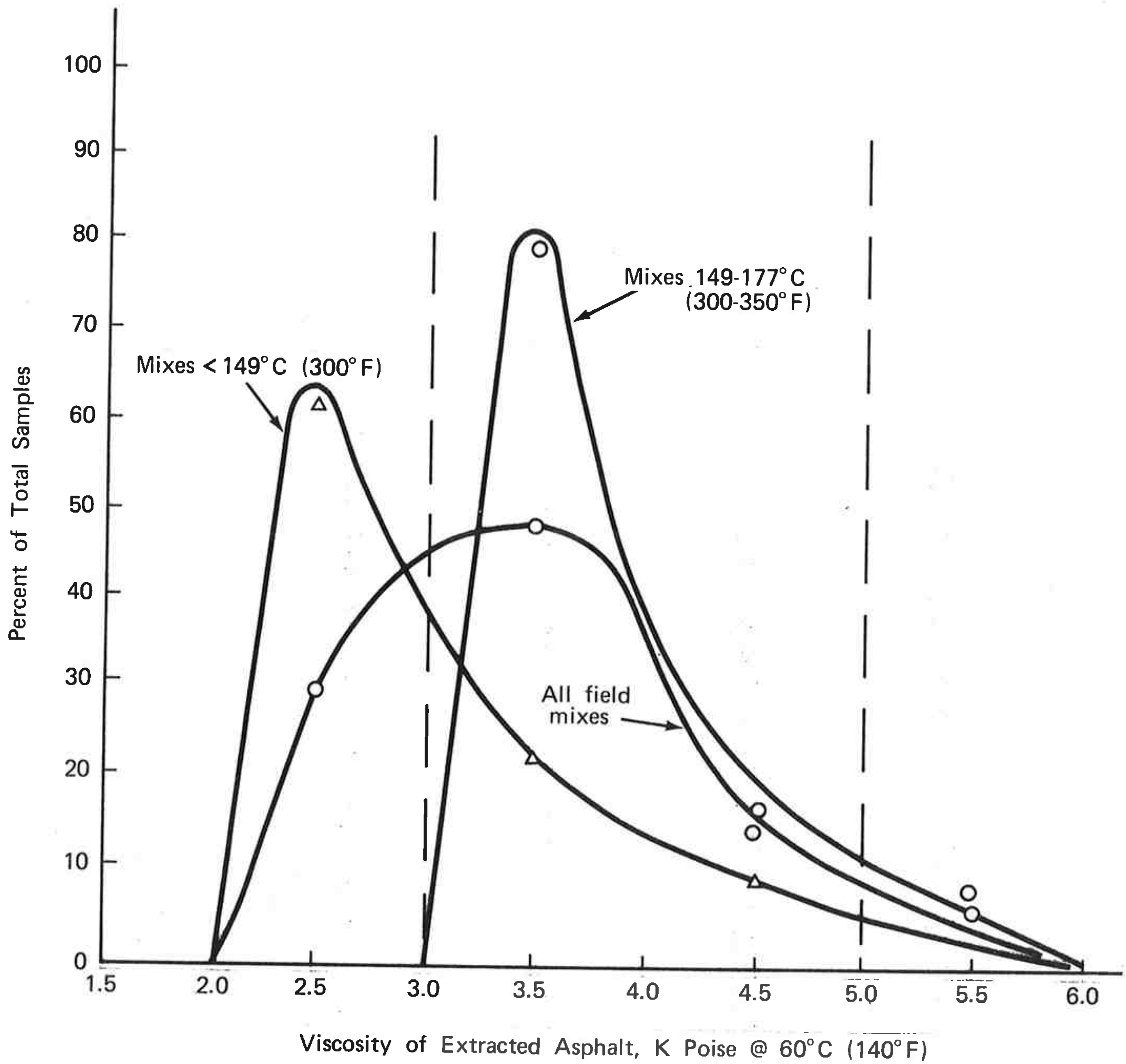


FIGURE 14 Effect of Mix Temperature on Asphalt Viscosity
(Extraction of Field Cores)

Asphalt Plants

The advent of dryer drum mixers has generally brought:

(1) Lower mixing temperatures

(2) Steam associated with utilization of wet aggregates,

(3) Less control of the final aggregate gradation, due to stockpiling techniques, and

(4) Higher production rates, sometimes resulting in less uniform products.

The first, and perhaps the second, factor affect the final properties of the asphalt. The last two factors, however, should not greatly affect asphalt properties, but could greatly affect the mix properties and associated variations. The variations noted as a part of this study tend to indicate that tighter controls are necessary.

Mix Storage

Storage temperature and duration have been reported to contribute to slow setting behavior of mixes in Oregon. One contractor had difficulties holding an AR-4000 asphalt mix in heated silos, as the asphalt hardened excessively. This required the use of a softer grade AR-2000. If this mix were not held in storage for a certain period of time, it could result in slow set problems.

Laydown Equipment

As greater production rates have developed, speeds of laydown equipment have also increased. This may result in less compaction behind the screed. For example, in Oregon, the relative density behind the screed has dropped about five percentage points during the period from 1972 to 1977. Whether this has any effect on producing incompactible mixes is not yet known, but should be looked into in future studies.

Vibratory Compactors

The use of vibratory rollers has proven extremely effective in cutting compaction costs; however, excessive use of vibration without some type of finish rolling (using a steel wheel or pneumatic) could lead to flushing and slow set problems. Increased flushing was reported in a California study of vibratory compactors (10), while possible slow set problems were identified in an Oregon State University study for the U.S. Forest Service (11). In this latter study, emulsion asphalt mixes were prepared to the same density and with the same mix proportions, using both a Marshall hammer and a vibratory hammer. Repeated load triaxial tests were performed on these mixes at various stages after compaction to obtain the resilient modulus (Figure 15). Note that mixes prepared with the Marshall hammer set much more quickly than those prepared with the vibratory hammer, even though the final stiffness values were essentially the same. This would indicate that a careful look needs to be taken to establish the influence of this factor on construction and short-term performance problems.

Dust Collection Systems

With the increased need for efficient dust collection, many mixes are experiencing high and non-uniform percent passing the No. 200 sieve. The non-uniformity appears to be associated with the manner that the dust is introduced into the mix. These factors, together with the utilization of lower mixing temperatures (resulting in softer asphalts) and higher asphalt contents to coat the aggregate have resulted in mixes with lower stabilities and lower voids. These mixes have contributed to flushing and instability problems, which are many times attributed to the asphalt alone.

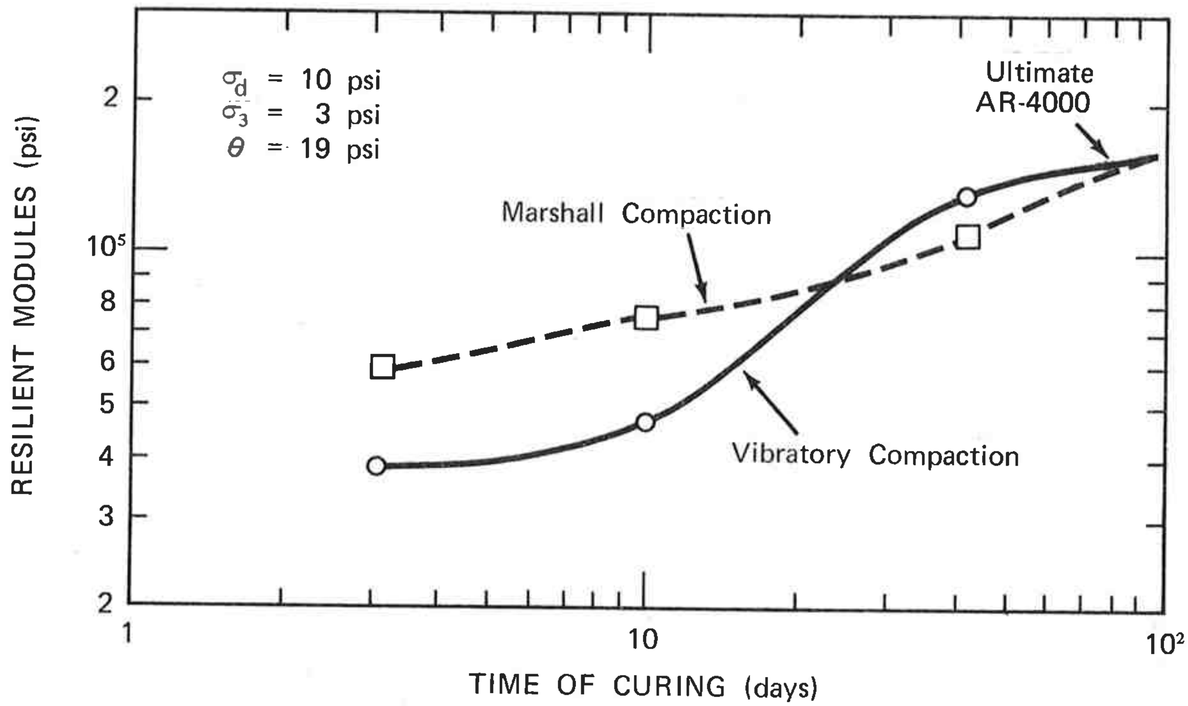


FIGURE 15 Variation in Resilient Modulus with Time of Curing for Specimens Prepared Using Marshal and Vibratory Compaction Procedures (11)

Aggregate Related Factors

Aggregate gradation, quality, uniformity and moisture content may also affect the construction operations or short-term performance of asphalt mixes. As contractors moved to the use of single stockpiles, or the elimination of plant screens, the uniformity of the final product varied, resulting in situations where there were areas of "too much" or "too little" asphalt in the mix. Further, as the quality of the aggregate decreased, more asphalt was required to ensure a high index of retained strength value. This tended to result in over asphalting and in problems such as instability and bleeding. Further, with dryer drum mixers, the contained moisture requirements in the mix have generally been waived. Though studies have shown that this water may not be detrimental to long-term performance, it may have contributed to construction and short-term problems, and hence must be carefully considered.

CONCLUSIONS AND RECOMMENDATIONS

Many factors contribute to construction and short-term performance problems. The asphalt cement is but one factor which needs to be carefully considered. In particular, one needs to evaluate how asphalt properties change over a full range of construction and service temperatures to identify their contribution to the indicated problems. However, one should not limit the investigation to the asphalt itself. Other developments may also contribute to construction and short-term performance problems and these need to be carefully considered.

CONCLUSIONS

The results of this study, although not completely conclusive, indicated that:

(1) The tender and flushing problems observed in Oregon were generally associated with high asphalt contents and/or fines, or low asphalt viscosities during construction.

(2) There is no clear evidence to indicate that changes in asphalt from 1973 to 1977 have contributed to the problems.

(3) Variations from mix design gradations and asphalt contents tended to be greater in problem pavements than in non-problem pavements.

RECOMMENDATIONS

The results of this study have led to the following recommendations, many of which have been adopted or are being considered by the Oregon Department of Transportation.

(1) Aggregates of High Quality, Produced in Separate Stockpiled Sizes of Uniform Properties. Two stockpiles for all plants and scalping or washing of gravel or primary crushed aggregates is now required. Production of at least three separate stockpiled size fractions for drum mix type plants has been recommended to improve control of gradation.

(2) Asphalt Cement of Proper Grade and of Uniform Physical and Chemical Properties. Control of asphalt cement physical properties has been approved by the May 1, 1977 specification modification by insuring a more uniform product. Restrictions to eliminate contamination of the asphalt from silicones and petroleum product release agents is now required. Restriction of plant burner fuel used and adequate curing

of tack and prime coat has been recommended to prevent the asphalt properties from being modified.

(3) Mixture of Optimum Design Produced Within Specification Tolerance Limit For Gradation, Asphalt Content, Temperature and Moisture Content. Enforcement of all mix production tolerance limits is necessary to minimize construction and short-term performance problems. Requirements such as a one-percent moisture content limit for mix at laydown is now specified and the use of silo "gob" hoppers, and minimizing holding of mix to laydown have been recommended.

(4) Equipment Operated in an Effective Manner to Provide Adequate and Uniform Mixing, Laydown and Compaction of the Pavement. It is necessary to require the use of paving plant aggregate proportioning capability. This includes plant screening of dried aggregates from coarse aggregate and fine aggregate stockpiles and combining three separated sizes by weight within the plant for conventional plants. Proportioning from at least three stockpiled sizes of aggregate by belt scale weight has been recommended for plants without screens. Further, it has been recommended to restrict paving plant production rates to that specified by the manufacturer, designate limits for laydown machine operating speed and require prequalification of rollers.

(5) Temperatures Specified to Provide Optimum Mixing, Laydown and Compaction of Pavements. Limitations on paving laydown temperatures for Class "B" and "C" mixes to a surface temperature of at least 5°C (40°F) and an air temperature of 5°C (40°F) and rising, or 10°C (50°F) and falling is now required. New specifications for Class "E" mix now require the surface temperature of pavements on which it is to be placed to be at least 15°C (60°F) and the air temperature to be 10°C (50°F)

and rising or 15°C (60°F) and above. Curing of Class "E" pavements is essential to develop surface toughness. The use of proper uniform mixing and compaction temperatures based on asphalt viscosity and lift thickness is essential for all pavements.

(6) Policy on a Statewide Basis to Provide a Positive Basis for Acceptance and Rejection of Materials and Enforcement of Specifications. An assured active policy for enforcement of specifications to provide a firm basis for acceptance or rejection of material is required. A concentrated effort towards adequate testing frequency, thorough training of inspectors and testing personnel, adequate testing equipment and complete field test laboratory facilities is necessary.

REFERENCES

(1) AASHTO Committee on Materials, Survey of Recent Asphalt Paving Problems, 1978.

(2) Wilson, J.E., "Summary of Oregon's Recent Paving Problems," Presented at the 14th Pacific Coast Conference on Asphalt Specifications, May 1977.

(3) Wilson, J.E., "Summary of Oregon's 1977 Modification of the AR Grading Specifications," Presented at the 14th Pacific Coast Conference on Asphalt Specifications, May 1977.

(4) Standard Specifications for Highway Construction, Oregon State Highway Division, 1974.

(5) 1978 Annual Book of ASTM Standards, Part 15, Road Paving, Bituminous Materials, Skid Resistance, ASTM 1978.

(6) AASTHO. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, Part II, July 1978. Association of State Highway and Transportation Officials.

(7) Schmidt, J.R., "A Practical Method for Measuring the Resilient Modulus of Asphalt Treated Mixes," Highway Research Board Record 404, Highway Research Board, 1972, pp. 22-32.

(8) Heukelom, W., "An Improved Method of Characterizing Asphaltic Bitumens with the Aid of their Mechanical Properties," Proceedings, Association of Asphalt Paving Technologists, Volume 42, 1973. pp. 67-94.

(9) Kari, W.J., "Paving Asphalt Quality in the Pacific Northwest," Chevron USA Memorandum, San Francisco, CA, October 1976.

(10) Cechetini, James A. and George B. Sherman, "Vibratory Compaction of Asphalt Concrete Pavements," Proceedings, Association of Asphalt Paving Technologists, Volume 43, 1974. pp. 384-408.

(11) Hicks, R.G., et al., "Evaluation of Open Graded Emulsion Mixes as Road Surfaces," Final Summary Report to U.S. Forest Service, Region 6, Portland, Oregon, June 1978. 44 pp.

APPENDICES

Appendix A

TABLE A-1. Summary of Construction Information

PROJECT NAME	PAVING DATES	MIX TYPE	TOTAL TONS	ASPHALT SUPPLIER	GRADE	AGGR. TYPE	ASPHALT PLANT	RATED CAPACITY	BURNER FUEL	TYPE OF PAVER	PICK UP MACHINE	BREAKDOWN ROLLER	INTERMEDIATE ROLLER	FINISH ROLLER
S.W. 72nd and Boones Ferry	9/76	C	18,000	Union	AR 4000	Gravel	Batch	Twin 15,000	Natural Gas	Blaw Knox	-	Steel	-	11T Steel
Durham STP Portland	1975-1976	C,B	9,700	Union	AR 4000	Gravel	Batch	Twin 15,000	Natural Gas	Barber Greene	-	10 T Steel	10 T Steel	10 T Steel
St. Vincent Hospital*	1976	C	2,600	Union	AR 2000	Gravel	Batch	Twin 15,000	Natural Gas	Barber Greene	-	10 T Steel	10 T Steel	10 T Steel
East Hood River Rowena Section	7/76	B E	133,454 32,313	Union Union	AR 2000 AR 4000	Quarry	Batch	5,000	Diesel #2	Barber Greene	Kokal	Vibratory	-	Steel
Pendleton National Guard Parking Lot*	6/76	C		Douglas	AR 4000	Gravel	Batch	3,000	Propane	Blaw Knox	-	10-12 T Vibratory	-	3-5 T Steel
Emmigrant Hill Meacham*	6-8/76	B	141,737	Douglas Shell	AR 4000 AR 2000	Quarry	Drum	-	-	Blaw Knox	Kokal	Vibratory	Pneumatic	Steel
Emmigrant Hill Meacham*	9-10/76	E	27,684	Douglas Shell	AR 8000 AR 4000	Quarry	Drum	-	-	Blaw Knox	Kokal	Vibratory	Pneumatic	Steel
Ashbrook Phase 2*	1976	C	-	Chevron	AR 4000	Gravel	Batch	4,000	Natural Gas	Barber Greene	-	Steel	-	Steel
Canyonville-Glendale*	7-10/75	C	75,000	Shell	AR 4000	Gravel	Batch	16,000	Diesel #2	Blaw Knox	Clarco	Vibratory	-	Vibratory
Canyonville-Glendale	8-10/75	E	42,768	Shell Chevron	AR 8000 AR 8000	Gravel	Batch	16,000	Diesel #2	Blaw Knox	Clarco	Vibratory	-	Vibratory
Rock Creek Steamboat	10/75	C	47,300	Chevron	AR 4000 AR 8000	Quarry	Drum	16,000	Diesel #2	Blaw Knox	-	-	-	10 T Steel
S.E. Lake Road and S.E. 82nd*	5-8/76	C	19,648	Union	AR 2000	Gravel	Batch	Twin 15,000	Natural Gas	Blaw Knox	-	Vibratory	-	Steel
Myrtle Creek Canyonville	8-10/75	E E	129,000 26,400	Shell Chevron	AR 4000 AR 8000	Gravel	Batch	16,000	Diesel #2	Blaw Knox	Clarco	Vibratory	-	Vibratory
5 Corners-Lakeview*	10/75 6/76	C	13,000	Witco	AR 2000	Quarry	Batch	4,000	Diesel	Blaw Knox	-	10 T Vibratory	10 T Vibratory	10 T Vibratory
5 Corners-Lakeview*	1976	E	12,271	Witco	AR 4000	Quarry	Batch	4,000	Diesel	Blaw Knox	-	10 T Vibratory	10 T Vibratory	10 T Vibratory
Hampton Lake County Line	5-6/75	C	30,058	Chevron	AR 2000	Gravel	Batch	6,000	-	Cedar Rapids	Kokal	Vibratory	Vibratory	Vibratory
Jordan Valley Jordan Creek	8-9/76	B	21,230	Husky	AR 4000	Gravel	Drum	200	Diesel	Blaw Knox	Kokal	Vibratory	Vibratory	10 T Steel

* Denotes problem pavements

TABLE A-2. Summary of Construction Information

PROJECT NAME	TRAFFIC CONDITION		WEATHER	AMBIENT TEMPERATURE	MIX TEMPERATURE		WATER AT LAYDOWN, %	NUMBER OF ROLLER PASSES			TOTAL ROLLING TIME, HR	% COMPACTION		PRODUCTION RATE, TONS/HOUR
	DURING	IMMED. AFTER			PLANT	LAYDOWN		BREAK-DOWN	INTER-MEDIATE	FINISH		AVE	RANGE	
S.W. 72nd and Boones Ferry Road	None	None	Fair	65°F	295-300	280-285	0.4-0.5	4	0	2	1	93.4	92.1-94.7	235
Durham STP	Mod.	Mod.	Fair	-	-	-	0.3-0.4	-	-	-	-	97.0	-	<100
St. Vincent Hospital*	Mod.	Mod.	Fair	-	-	-	0.3-0.4	-	-	-	-	90.0	-	<80
S.E. Lake Road S.E. 82nd*	Heavy	Heavy	Fair	-	-	-	-	-	-	-	-	93.0	92.6-93.4	-
E. Hood River - Rowena Section (E mix)	Mod.	Mod.	Sunny	40-95	240	225	0.5	3	2	3	1/2-1	92.1	87.5-95.1	240
E. Hood River - Rowena Section (B mix)	Mod.	Mod.	Sunny	40-95	275	250	0.2	3	2	3	1/2-1	92.1	87.5-95.1	350
Pendleton National Guard Parking Lot*	None	-	Sunny	-	280	270	-	-	-	-	-	-	-	-
Emigrant Hill - Meacham* (B mix)	Mod.	Mod.	Cool-Mod.	35-80	250	215	1+	3-5	3-5	3	1	-	-	300-400
Emigrant Hill - Meacham* (E mix)	Mod.	Mod.	Cool-Mod.	35-80	250	215	1+	3-5	3-5	3	1	-	-	300-400
Ashbrook Phase 2*	None	None	Cool	60	300	275	0.005	-	-	-	-	-	90.0-92.0	80-100
Canyonville - Glendale* (C mix)	Heavy	Heavy	Warm	65-100	279	261	0.1	3	0	3	2	92.9	92.5-100	-
Canyonville - Glendale* (E mix)	Heavy	Heavy	Warm	50-90	260	233	0.2	2	0	2	1	-	-	-
Rock Creek - Steamboat	Mod.	Mod.	Fair	38-70	250-275	240-260	0.3	-	-	-	-	-	-	500
Myrtle Creek Canyonville (C mix)	Heavy	Heavy	Warm	43-88	279	261	0.2	3	0	3	2	92.4	89.0-96.0	-
Myrtle Creek Canyonville (E mix)	Heavy	Heavy	Warm	48-80	250	236	0.4	2	0	2	1	92.4	89.0-96.0	-
5 Corners - Lakeview (C mix)	Mod.	Mod.	Fair	61-92	300	295	-	2	0	2	1	-	-	125
5 Corners - Lakeview (E mix)	Mod.	Mod.	Fair	61-92	237	224	-	2	0	2	1	-	-	136
Hampton - Lake County Line	-	-	Fair	70-80	-	-	-	3	3	varied	2	92.6	89.5-94.9	-
Jordan Valley - Jordan Creek	Mod.	Mod.	Fair	40-85	280	250	0.8	2	1	1	2	91.8	87.8-94.6	185

* Denotes problem pavements

TABLE A-3. Summary of Original Mix Design Information

PROJECT NAME	COURSE	PERCENT PASSING								PERCENT ASPHALT	STABILITY		INDEX OF RETAINED STRENGTH	MIX TYPE
		3/4	1/2	3/8	1/4	#4	#10	#40	#200		1st COMPACTION	2nd COMPACTION		
S.W. 72nd and Boones Ferry Road	Base	100	95	78	60	47	25	12	5.0	6.4	35	43	78	C
	Wearing	100	95	78	60	47	25	12	5.0	6.0	35	43	78	C
Durham S.T.P.	Base	100	97	85	70	59	34	13	5.0	6.6	34	41	100	B
	Wearing	100	97	85	70	59	34	13	5.0	6.3	34	43	100	C
St. Vincent Hospital*	Wearing	100	97	88	78	63	38	18	5.0	5.5	43	53	96	C
S.E. Lake Rd. S.E. 82nd*	Base	100	97	85	70	59	34	13	5.0	6.6	34	40	100	C
	Wearing	100	97	85	70	59	34	13	5.0	6.3	34	43	100	C
E. Hood River Rowena Section	Base	100	90	77	60	50	30	14	5.0	5.5	38	35	97	B
	Wearing	100	100	92	58	40	15	9	4.0+	6.7	23	37	90	E
Pendleton National Guard Parking Lot*	Wearing	100	99	85	70	59	34	13	5.0	5.5	-	-	-	C
Emigrant Hill - Meacham*	Base	97	87	76	62	56	31	12	4.0	6.8	33	34	96	B
	Wearing	100	100	94	65	47	14	4	4.0+	7.0	17	27	100	E
Ashbrook Phase 2*	Wearing	100	99	86	70	58	34	14	5.0	5.9	35	45	75	C
Canyonville - Glendale*	Base	100	98	89	71	59	38	13	5.0	6.5	33	50	78	C
	Wearing	100	100	92	58	42	14	5	4.0+	7.0	27	44	47	E
Rock Creek Steamboat	Base	100	96	79	60	48	26	12	5.0	7.9	37	41	95	C
	Wearing	100	96	79	68	48	26	12	5.0	7.1	36	48	58	C
Myrtle Creek Canyonville	Base	100	98	89	71	59	38	13	5.0	6.5	33	50	78	C
	Wearing	100	100	92	58	42	14	5	4.0+	7.0	27	44	47	E
5 Corners Lakeview*	Base	100	98	87	70	57	34	11	5.0	8.0	33	26	77	C
	Wearing	100	96	81	58	43	16	5	4.0+	8.0	32	44	83	E
Hampton Lake County Line	Base	100	98	86	70	60	35	16	5.0	8.5	20	8	73	C
	Wearing	100	98	86	70	60	35	16	5.0	8.0	31	18	67	C
Jordan Valley Jordan Creek	Base	100	86	72	60	51	32	15	5.0	6.8	32	32	77	B
	Wearing	100	86	72	60	51	32	15	5.0	6.3	37	44	68	B

* Denotes Problem Pavements
\+ Includes 1% Portland Cement

TABLE A-4. Performance Information - During Construction

PROJECT NAME	MIX TYPE	TENDER MIX		SLOW SETTING MIX		RUTTING		FLUSHING		COMMENTS
		%	WHEN	%	WHEN	%	WHEN	%	WHEN	
S.W. 72nd and Boones Ferry Road	C	None	-	None	-	None	-	None	-	Roller had to keep close to paver
Durham STP	C	None	-	None	-	None	-	None	-	-
St. Vincent Hospital*	C	Yes	During Construction	Yes	During Construction	-	-	-	-	Tender at outset, but has stabilized
S.E. Lake Road S.E. 82nd*	C	2	During Construction	-	-	-	-	2	-	-
East Hood River Rowena Section	E	None	-	None	-	None	-	None	-	-
Pendleton National Guard Parking Lot*	C	Yes	During Construction	Yes	During Construction	None	-	None	-	-
Emigrant Hill - Meacham*	E B	- 100	- Dur. Constr.	- -	- -	Slight 100	- 1-6 months	Slight 5	- -	Mix ruts in warm weather
Ashbrook Phase 2*	C	Yes	During Construction	Yes	During Construction	None	-	None	-	-
Canyonville-Glendale*	C E	Yes None	- -	- None	- -	Slight None	- -	Slight None	- -	-
Rock Creek, Steamboat	C	None	-	None	-	None	-	None	-	-
Myrtle Creek Canyonville	E,C	None	-	None	-	None	-	None	-	-
5 Corners - Lakeview*	E,C	-	-	-	-	-	-	8	Dur. Constr.	No problems on C mix
Hampton - Lake Co.	C	None	-	None	-	None	-	None	-	-
Jordan Valley Jordan Creek	B	None	-	None	-	None	-	None	-	No Tenderness

TABLE A-5. Summary of Tests on Asphalt Obtained from Cores Shortly After Construction

PROJECT NAME	DATE OF CONSTRUCTION	ASPHALT VISCOSITY		ASPHALT PENETRATION		RECOVERED VISCOSITY	RECOVERED PENETRATION	DATE OF RECOVERY
		ORIGINAL	RTFO	ORIGINAL	RTFO			
S.W. 72nd and Boones Ferry Road	9/76	1575	4363	46	29	-	-	NA**
Durham STP	75-76	-	-	-	-	-	-	NA
St. Vincent Hospital*	76	-	-	-	-	-	-	NA
S.E. Lake Road and S.E. 82nd*	5-8/76	746	2251	80	38	-	-	NA
East Hood River Rowena Section - B mix	7/76	746	2251	80	38	4110	24	11/15/76
East Hood River Rowena Section - E mix	7/76	1575	4363	46	29	4110	24	11/15/76
Pendleton National Guard Parking Lot*	-	-	-	-	-	-	-	NA
Emigrant Hill - Meacham - B mix*	6-8/76	1148	3704	114	55	2408	97	8/26/76
Emigrant Hill - Meacham - E mix*	9-10/76	2315	6275	66	38	2660	88	8/26/76
Ashbrook Phase 2*	76	-	-	-	-	-	-	NA
Canyonville - Glendale - C mix*	7-10/75	1900	4100	55	33	997	161	NA
Canyonville - Glendale - E mix	8-10/75	3437	7773	36	22	-	-	NA
Rock Creek Steamboat	10/75	-	-	-	-	-	-	NA
Myrtle Creek Canyonville	8-10/75	1900	4100	55	33	4254	45	9/22/75
Five Corners - Lakeview - C mix*	10/75, 6/76	1144	2165	76	50	1098	68	8/23/76
Five Corners - Lakeview - Mod. E mix	76	2400	4600	48	31	-	-	8/23/76
Hampton - Lake County Line	5-6/75	-	-	-	-	-	-	NA
Jordan Valley - Jordan Creek	8-9/76	1969	4565	75	45	-	-	NA

* Denotes Problem Pavements

** NA - Not Available

TABLE A-6 . Summary of Test on Laboratory Compacted Mix From Cores - No Problems

PROJECT NAME	LOCATION	MIX TYPE	GRADATION, % PASSING BY WEIGHT 3/4	1/2	1/4	#10	#40	#200	% ASPHALT CONTENT	BULK SPECIFIC GRAVITY	RICE GRAVITY	% AIR* VOIDS	"S" VALUE	ASPHALT PROPERTIES PENETRATION @ 77°F	VISCOSITY @ 275°F	VISCOSITY @ 140°F
S.W. 72nd and Boones Ferry Road	A	C	100	97	62	27	13	6.2	5.9	2.35	2.49	5.6	29	27	317	2434
	B	C	100	98	59	26	13	6.2	5.8	2.34	2.48	5.6	29	25	303	2648
	AVE		100	97	61	26	13	6.2	5.9	2.34	2.49	5.6	29	26	310	2541
Durham STP	A	C	100	100	73	34	15	6.4	6.7	2.40	2.47	2.8	29	44	262	1509
East Hood River Rowena Section	NO DATA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rock Creek Steamboat	A	C	100	100	76	41	19	6.2	6.1	2.33	2.46	5.3	44	42	387	3119
	B	C	100	96	61	29	11	4.5	7.8	2.22	2.31	3.9	32	63	694	3626
	AVE		100	98	68	35	15	5.4	7.0	2.27	2.38	4.6	38	53	541	3373
Myrtle Creek Canyonville	A	E	100	99	61	25	12	4.9	7.5	2.41	2.46	2.0	25	110	416	1690
	B	E	100	99	57	22	11	4.6	6.6	2.36	2.47	4.4	27	75	533	3201
	AVE		100	99	59	23	11	4.7	7.0	2.38	2.47	3.2	26	93	475	2446
Myrtle Creek Canyonville	A	C	100	98	68	38	16	5.7	6.8	2.43	2.46	1.2	21	86	242	1414
	B	C	100	97	70	41	19	6.4	6.8	2.44	2.46	0.8	8	46	314	1609
	AVE		100	97	69	40	17	6.0	6.8	2.43	2.46	1.2	14	66	278	1990
Hampton Lake County Line	A	C	100	98	73	38	18	6.4	8.4	2.18	2.21	1.4	28	121	425	1609
	B	C	100	99	74	39	18	5.9	8.3	2.18	2.20	0.9	19	130	413	1484
	AVE		100	98	73	38	18	6.1	8.3	2.18	2.20	1.2	24	126	419	1547
Jordan Valley Jordan Creek	A	B	95	79	58	39	17	5.5	6.7	2.21	2.29	3.5	29	44	439	4389
	B	B	99	88	63	37	18	6.7	7.3	2.20	2.27	3.1	28	41	449	4141
	AVE		97	84	60	38	17	6.1	7.0	2.20	2.28	3.3	29	43	444	4265
Canyonville Glendale	A	E	100	100	62	18	8	4.5	6.9	2.31	2.52	8.3	29	25	475	6493
	B	E	100	98	67	36	14	5.6	6.8	2.43	2.48	2.0	25	39	350	3339
	C	E	100	100	62	20	9	4.9	6.9	2.37	2.48	4.4	25	49	384	3076
	D	E	100	97	61	20	11	6.6	7.2	2.42	2.50	3.2	33	22	508	8536
	E	E	100	99	53	18	9	5.1	6.4	2.35	2.49	5.6	27	29	475	5444
	F	E	100	100	81	18	8	4.6	7.0	2.37	2.50	5.2	30	19	535	10,044
	AVE		100	99	64	21	10	5.2	6.9	2.38	2.49	5.2	28	30	454	6154

* Air Voids (%) = $\frac{\text{Rice Gravity} - \text{Bulk Specific Gravity}}{\text{Rice Gravity}} \times 100$

TABLE A-7. Summary of Tests on Laboratory Compacted Mix From Cores - Problems

PROJECT NAME	LOCATION	MIX TYPE	GRADATION, % PASSING BY WEIGHT						% ASPHALT CONTENT	BULK SPECIFIC GRAVITY	RICE GRAVITY	* % AIR VOIDS	"S" VALUE	ASPHALT PROPERTIES		
			3/4	1/2	1/4	#10	#40	#200						PENETRATION @ 77°F	VISCOSITY @ 275°F	VISCOSITY @ 140°F
St. Vincent Hospital	A	C	100	100	87	48	20	7.6	6.3	2.39	2.47	3.2	27	23	429	4433
S.E. Lake Road 82nd Avenue	A	C	100	99	72	35	16	6.9	6.7	2.38	2.47	3.6	22	39	257	1630
	B	C	100	100	68	33	15	6.7	6.9	2.43	2.49	2.4	29	43	373	1796
	C	C	100	99	77	38	16	6.1	6.7	2.41	2.48	2.8	23	37	261	1751
	D	C	100	98	73	36	16	8.4	6.5	2.44	2.49	2.0	20	45	239	1405
	E	C	100	99	76	35	17	7.4	6.8	2.44	2.50	1.6	27	78	210	768
	AVE		100	99	73	35	16	7.1	6.7	2.42	2.48	2.4	24	48	268	1470
Pendleton National Guard Parking Lot	A		100	100	93	42	14	5.1	5.4	2.28	2.57	11.3	32	33	1387	25,255
Emigrant Hill Meacham	A	E	100	100	68	19	6	2.8	6.3	2.47	2.62	5.7	20	38	855	10,760
	B	E	100	100	76	22	7	3.3	6.6	2.50	2.62	3.6	16	29	418	5328
	C	E	100	97	65	22	8	3.9	7.0	2.56	2.62	2.3	9	28	732	12,222
	D	E	100	100	67	22	8	4.0	7.4	2.56	2.62	2.3	12	40	371	3684
	AVE		100	99	69	21	7	3.5	6.8	2.52	2.62	3.5	14	34	594	7999
Emigrant Hill Meacham	A	B	100	86	65	33	13	4.0	7.1	2.49	2.56	2.7	27	86	515	2461
	B	B	97	86	62	32	14	4.7	6.8	2.47	2.49	0.8	19	66	248	1572
	C	B	98	81	58	29	13	4.6	6.8	2.47	2.54	3.1	24	80	216	1230
	D	B	93	82	65	34	13	4.2	7.2	2.52	2.57	1.9	20	64	258	1724
	AVE		98	84	62	32	13	4.4	7.0	2.49	2.54	2.0	23	74	309	1747
Canyonville Glendale	A	C	100	98	75	45	21	7.2	6.5	2.51	2.54	1.2	5	145	324	1014
	B	C	100	98	78	42	18	6.4	6.6	2.43	2.46	1.2	21	36	338	3525
	C	C	100	99	82	44	20	6.8	6.6	2.48	2.52	1.6	13	190	268	563
	D	C	100	99	71	42	21	7.1	6.3	2.50	2.53	1.2	9	--	244	497
	E	C	100	98	74	39	17	6.6	6.7	2.43	2.46	1.2	12	57	278	2130
	F	C	100	99	77	42	19	6.9	7.1	2.42	2.47	2.0	28	42	310	2683
	AVE		100	98	76	42	19	6.8	6.6	2.46	2.50		15	94	277	1735
Five Corners Lakeview	A	E	100	98	67	28	13	7.4	9.4	2.34	2.40	2.5	28	60	233	1888
	B	E	100	95	60	19	10	5.1	7.7	2.30	2.42	5.0	29	58	251	1830
	C	E	100	99	65	28	14	8.7	8.6	2.37	2.41	1.3	37	44	283	2847
	AVE		100	97	64	25	12	7.1	8.6	2.34	2.41	2.9	31	54	256	2188
Five Corners Lakeview	A	C	100	98	75	36	15	4.8	6.2	2.24	2.40	6.7	35	20	1370	21,455
	B	C	100	98	74	35	16	5.0	6.4	2.18	2.36	7.6	37	15	1225	34,290
	C	C	100	99	83	43	20	7.1	7.8	2.32	2.34	1.7	16	33	648	9792
	AVE		100	98	77	38	17	5.6	6.8	2.25	2.37	5.3	29	23	1081	21,846
Ashbrook Phase 2	A	C	100	99	72	32	13	4.1	6.7	2.22	2.39	7.1	29	44	804	7946

* Air Voids (%) = $\frac{\text{Rice Gravity - Bulk Specific Gravity}}{\text{Rice Gravity}} \times 100$

TABLE A-8. Summary of Tests on Field Cores - Non Problem Pavements

PROJECT NAME	LOCATION	IN-PLACE SPECIFIC GRAVITY	RECOMPACTED SPECIFIC GRAVITY	% COM-PACTION**	RICE GRAVITY	AIR VOIDS %*	"S" VALUE	"C"	RESILIENT MODULUS psi	SUPPLIER	GRADE
S.W. 72nd and Boones Ferry Road	A	2.22	2.43	91.4	2.47	10.1	13	195	635,000	Union	AR 4000
	B	2.26	2.44	92.6	2.45	7.8	15	199	561,000	Union	AR 4000
	AVE	2.24	2.43	92.0	2.46	8.9	14	197	598,000		
Durham STP	A	2.24	2.43	92.2	2.46	8.9	18	299	476,000	Union	AR 4000
East Hood River Rowena Section	NO DATA										
Rock Creek Steamboat	A	2.11	2.25	93.8	2.31	8.7	21	103	58,000	Chevron	AR 4000
	B	2.04	2.25	90.7	2.30	11.3	--	---	118,000	Chevron	AR 4000
	AVE	2.08	2.25	92.4	2.30	9.6	21	103	88,000		
Myrtle Creek Canyonville - E mix	A	2.32	2.42	95.9	2.45	5.3	--	---	201,000	Shell	AR 8000
	B	2.23	2.28	97.8	2.48	10.1	--	---	260,000	Shell	AR 8000
	AVE	2.28	2.35	97.0	2.47	7.7	--	---	231,000		
Myrtle Creek Canyonville - C mix	A	2.34	2.46	95.1	2.49	5.0	--	---	413,000	Shell	AR 2000
	B	2.35	2.45	95.5	2.47	4.9	--	---	439,000	Shell	AR 2000
	AVE	2.34	2.45	95.3	2.48	5.6	--	---	426,000		
Hampton Lake County Line	A	2.15	2.20	97.7	2.22	3.2	--	---	144,000	Chevron	AR 2000
	B	2.13	2.20	96.8	2.21	3.6	--	---	111,000	Chevron	AR 2000
	AVE	2.14	2.20	97.3	2.21	3.2	--	---	128,000		
Jordan Valley Jordan Creek	A	2.17	2.26	96.0	2.28	4.8	15	394	334,000	Husky	AR 4000
	B	2.09	2.25	92.9	2.29	8.7	11	301	408,000	Husky	AR 4000
	AVE	2.13	2.25	94.7	2.28	6.6	13	348	371,000		
Canyonville Glendale - E mix	A	2.16	2.39	90.4	2.48	12.9	--	---	-	Shell	AR 8000
	B	2.29	2.45	93.5	2.46	6.9	--	---	429,000	Shell	AR 8000
	C	2.22	2.38	93.3	2.48	10.5	--	---	408,000	Shell	AR 8000
	D	2.22	2.43	91.4	2.46	9.8	15	527	447,000	Shell	AR 8000
	E	2.13	2.37	89.9	2.52	15.5	--	---	314,000	Shell	AR 8000
	F	2.12	2.45	86.5	2.49	14.9	--	---	-	Shell	AR 8000
	AVE	2.19	2.41	90.9	2.48	11.7	15	527	400,000		

* Air Voids = $\frac{\text{Rice Gravity - In-place Gravity}}{\text{Rice Gravity}} \times 100$

** % Compaction = $\frac{\text{Bulk Gravity}}{\text{Recompacted Gravity}} \times 100$

TABLE A-9 . Summary of Tests on Field Cores - Problem Pavements

PROJECT NAME	LOCATION	BULK SPECIFIC GRAVITY	SPECIFIC GRAVITY	COMPACTION	RICE GRAVITY	AIR VOIDS %*	"S" VALUE	"C"	MODULUS OF RESILIENCE	BRAND	GRADE
St. Vincent Hospital	A	2.20	2.42	90.9	2.47	10.9			542,000	Union	AR 2000
S.E. Lake Road 82nd Avenue	A	2.38	2.48	96.0	2.48	4.0	22	175	324,000	Union	AR 2000
	B	2.29	2.46	93.1	2.48	7.7	12	211	211,000	Union	AR 2000
	C	2.32	2.46	94.3	2.46	5.7	15	239	464,000	Union	AR 4000
	D	2.42	2.48	97.6	2.45	1.2	10	403	246,000	Union	AR 2000
	E	2.41	2.47	97.6	2.49	4.8	24	436	327,000	Union	AR 2000
	AVE	2.36	2.46	95.9	2.47	4.4	17	293	314,000		
Pendleton National Guard Parking Lot	A	2.05	2.38	86.1	2.55	19.6	--	---	-	Douglas	AR 4000
Emigrant Hill E mix	A	--	--	--	--	--	--	---	64,000	Douglas	AR 8000
	B	2.15	2.52	85.3	2.62	17.9	--	---	132,000	Douglas	AR 8000
	C	2.21	2.53	87.4	2.64	16.3	--	---	124,000	Douglas	AR 8000
	D	2.22	2.52	88.1	2.57	13.6	--	---	144,000	Douglas	AR 8000
	AVE	2.19	2.52	86.9	2.61	16.1	--	---	116,000		
Emigrant Hill B Mix	A	2.42	2.56	94.5	2.56	5.5	--	---	88,000	Douglas	AR 4000
	B	2.25	2.50	90.0	2.50	10.0	--	---	161,000	Douglas	AR 4000
	C	2.35	2.51	93.6	2.52	6.7	--	---	178,000	Douglas	AR 4000
	D	2.34	2.54	92.1	2.59	9.6	--	---	113,000	Douglas	AR 4000
	AVE	2.34	2.53	92.6	2.54	7.9	--	---	135,000		
Canyonville	A	2.43	2.52	96.4	2.52	3.6	10	491	-	Shell	AR 4000
	B	2.32	2.44	95.1	2.47	5.7	--	---	384,000	Shell	AR 4000
	C	2.47	2.52	97.6	2.52	2.0	24	208	167,000	Shell	AR 4000
	D	2.49	2.54	98.0	2.54	2.0	--	---	281,000	Shell	AR 4000
	E	2.36	2.45	96.3	2.46	4.1	--	---	290,000	Shell	AR 4000
	F	2.34	2.45	95.5	2.45	4.5	--	---	-	Shell	AR 4000
	AVE	2.40	2.48	96.8	2.49					Shell	AR 4000
Five Corners Lakeview - E mix	A	--	--	--	--	--	--	---	-	Witco	AR 4000
	B	2.05	2.21	92.8	2.37	13.5	--	---	566,000	Witco	AR 4000
	C	2.13	2.32	91.8	2.35	9.4	--	---	-	Witco	AR 4000
	AVE	2.09	2.26	92.5	2.36	11.4	--	---	566,000		
Five Corners Lakeview - C mix	A	2.16	2.40	90.0	2.40	10.0	--	---	57,000	Witco	AR 4000
	B	2.18	2.31	94.4	2.42	9.9	--	---	387,000	Witco	AR 4000
	C	2.22	2.39	92.9	2.42	8.3	--	---	213,000	Witco	AR 4000
	AVE	2.19	2.37	92.4	2.41	9.1	--	---	219,000		
Ashbrook Phase 2	A	2.09	2.27	92.1	2.36	11.4	15	149	185,000	Chevron	AR 4000

* Air Voids (%) = $\frac{\text{Rice Gravity - Bulk Specific Gravity}}{\text{Rice Gravity}}$

Appendix B

KEY TO FIGURES 3 THROUGH 8

82nd / C	- S.E. Lake Road and S.E. 82nd, C mix
E.H. / E	- Emigrant Hill - Meacham, E mix
E.H. / B	- Emigrant Hill - Meacham, B mix
CAN-GLEN / C	- Canyonville - Glendale, C mix
LV / C	- Five Corners - Lakeview, C mix
LV / E	- Five Corners - Lakeview, E mix
SV / C	- St. Vincent Hospital, C mix
P / C	- Pendleton National Guard Parking Lot, C mix
ASH / C	- Ashbrook, Phase 2, C mix
CAN-GLEN / E	- Canyonville - Glendale, E mix
DU / C	- Durham Sewage Treatment Plant, C mix
72nd / C	- S.W. 72nd and Boones Ferry Road, C mix
HR / EB	- East Hood River - Rowena Section, E and B mixes
RC / C	- Rock Creek - Steamboat, C mix
MC / E	- Myrtle Creek - Canyonville, E mix
MC / C	- Myrtle Creek - Canyonville C mix
HAMP / C	- Hampton - Lake County Line, C mix
JORD / C	- Jordan Valley - Jordan Creek, C mix

Appendix C

CHANGES IN SPECIFICATIONS FOR ASPHALT CONCRETE PAVEMENT (SECTION 403): 1972 - 1978

YEAR	MATERIAL	CONSTRUCTION PROCESS	EQUIPMENT	CHANGE
1972				None recorded.
1973	X			Changed contained moisture of aggregate after drying to ≤ 1.0% from ≤ 0.5%, then later in year removed this requirement for drying aggregate and wrote present specification.
			X	Contract 7866 - Awarded in March. Woodburn Interchange to Hayesville Interchange. Probably the first project where a drum dryer was permitted for use. Had been used on Eagle Creek - Estacada in 1972, but not as part of specifications.
1974	X			Changed asphalt cement designations from 40-50, 60-70, 85-100 and 120-150 to AR-2000, AR-4000 and AR-8000 (Asphalt industry changed from penetration grade asphalt to viscosity graded asphalt.)
	X			Permitted aggregates to be produced and stockpiled in one size.
1975	X			Added Class "C" Modified Asphalt Concrete (open graded, 1/2" maximum size.)
		X	X	Deleted compaction density requirements for Class "E" mix and instead specified the size of roller and number of passes.
		X		On overlay projects less than 2 inches in thickness, deleted compaction requirements of 403.44 and substituted "at least three coverages of a 10-ton roller with additional rolling as necessary to attain thorough compaction.
1976	X			Combined Class "C" modified and Class "E" into one specification called Class "E" specification, which was about the same as the previous Class "C" Modified, except retained 3/8" maximum size aggregate. Added 1%± portland cement or hydrated lime to mix to help prevent separation of asphalt from mix.
	X			Deleted, then added back, a provision requiring 70% retained strength.
	X			Changed broad-band specification (403.11) to permit same grading requirements for fine aggregate in both "B" and "C" mixes.
	X			Deleted single stockpile of aggregates - required separate pile for both coarse and fine aggregates and permitted both coarse and fine aggregates to be in two piles.
	X			Added aggregate quality tests: Degradation and Abrasion to both coarse and fine aggregates, plasticity as per 703.07(d) to material passing 1/4-inch sieve, Soundness test to source and crushed aggregates, and deleterious substances (clay lumps and friable particles - AASHTO T112, lightweight pieces - AASHTO T113, wood particles-OSHD, reasonably free from all others).
	X			Included gradation tables for various size aggregates, both coarse and fine.

CHANGES IN SPECIFICATION FOR ASPHALT CONCRETE PAVEMENT (SECTION 403): Continued

YEAR	MATERIAL	CONSTRUCTION PROCESS	EQUIPMENT	CHANGE
1976	X			Later in year deleted specific requirements for clay lumps and friable particles (see above) and included them with the reasonably free list.
1977	X			Changed payment for anti-stripping additives from extra work basis to contractor's documented costs. However, State would only pay if mixture did not have at least 70% retained strength and aggregate and asphalt (contractor supplied) were acceptable. Contractor had to supply samples of asphalt cement from two different producer's sources (January 1977).
				April 1977. Started listing the specific gravity that quantities were based on. Required samples of asphalt cement contractor proposed to use. (Not applicable to quality of mixture.
	X			June 1977 - Deleted specific reference to asphalt cement above. Payment made for all anti-stripping additives used at documented cost.
	X			June 1977 - Increased tolerance for 1/4" and larger aggregate from 4% to 6%.
	X			October 1977 - Revised gradation for Class "E" mix so that coarse aggregate is the same for both "C" and "E", 1/2" maximum size.
	X			October 1977 - Deleted Class "D" from 403.11
1978	X			February 1978 - Revised scalping specification to require scalping on 1/2" or bigger screen when scalping is specified.
		X		April 1978 - Readded stockpiling requirements (no layer greater than 4 feet thick, removal in layers limited to ly feet in height). Specification had been inadvertantly omitted from earlier revisions.
	X			Silicones not allowed as asphalt concrete additives. May 1978.
			X	May 1978 - require mechanical sampling device on mixing plants without screens.
	X			May 1978 - added a "general scalping specification" specifying that scalping may be required if determined by an engineer.
		X		May 1978 - revised specification on weather limitations re placing of asphalt concrete (surface and air temperature of at least 40°F.
	X	X		May 1978 - Moisture content of mixture at time it is spread into final position shall not exceed one percent.
	X			July 1978 - Under 403.16, deleted phrase "wheel will produce the specified end results" and substituted "as specified herein"?