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

by

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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

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DISCLAIMER

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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.: P1½"___P¾"___P#10___ #40 ___ P#200 ___% Asph.: Base___ Top ___

Ave. Prod. Grad.: P1½"___ P¾" ___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

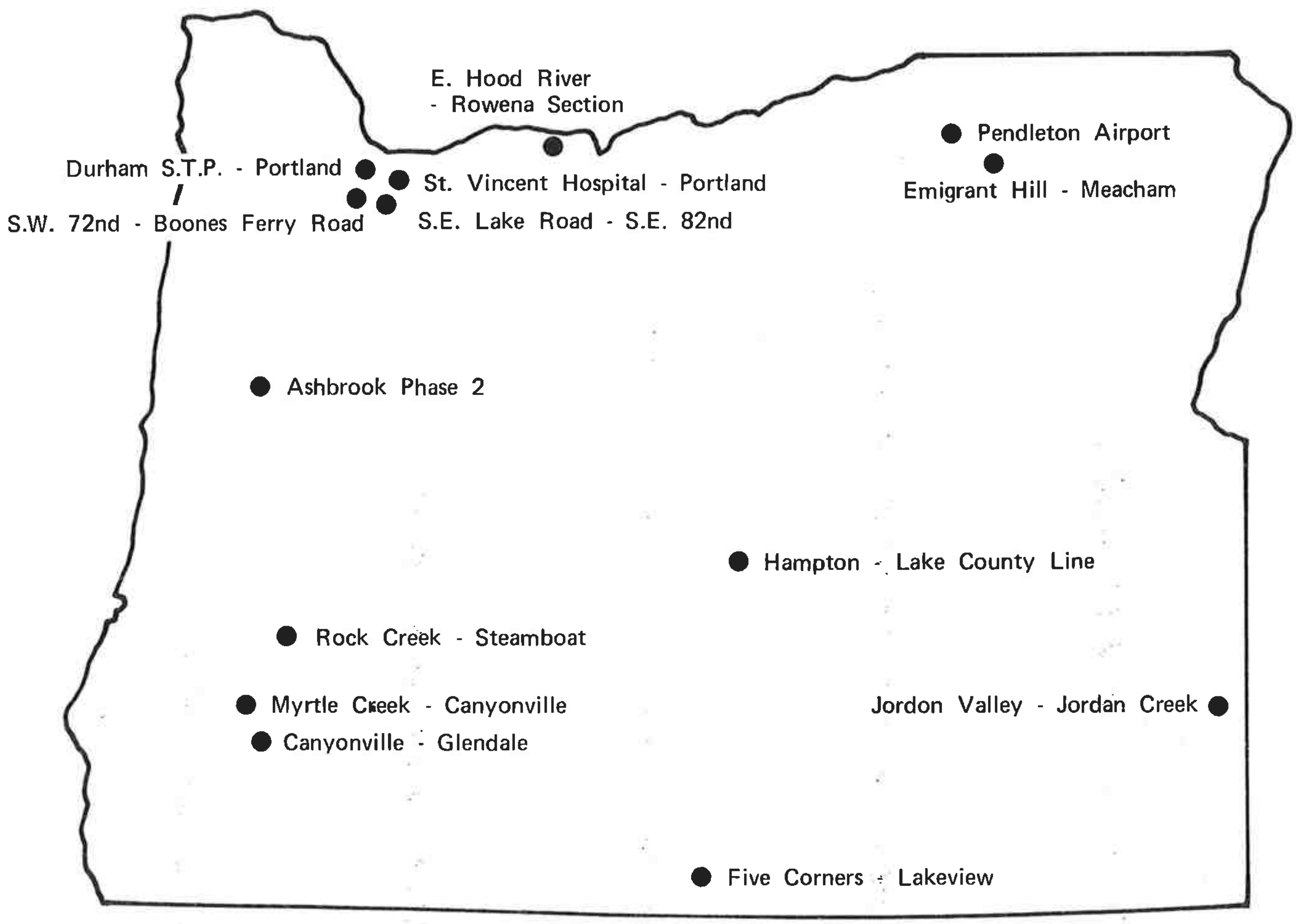

FIGURE 1. Location of Fourteen Projects Evaluated in Oregon for Slow-Set and Surface Flushing Problems.

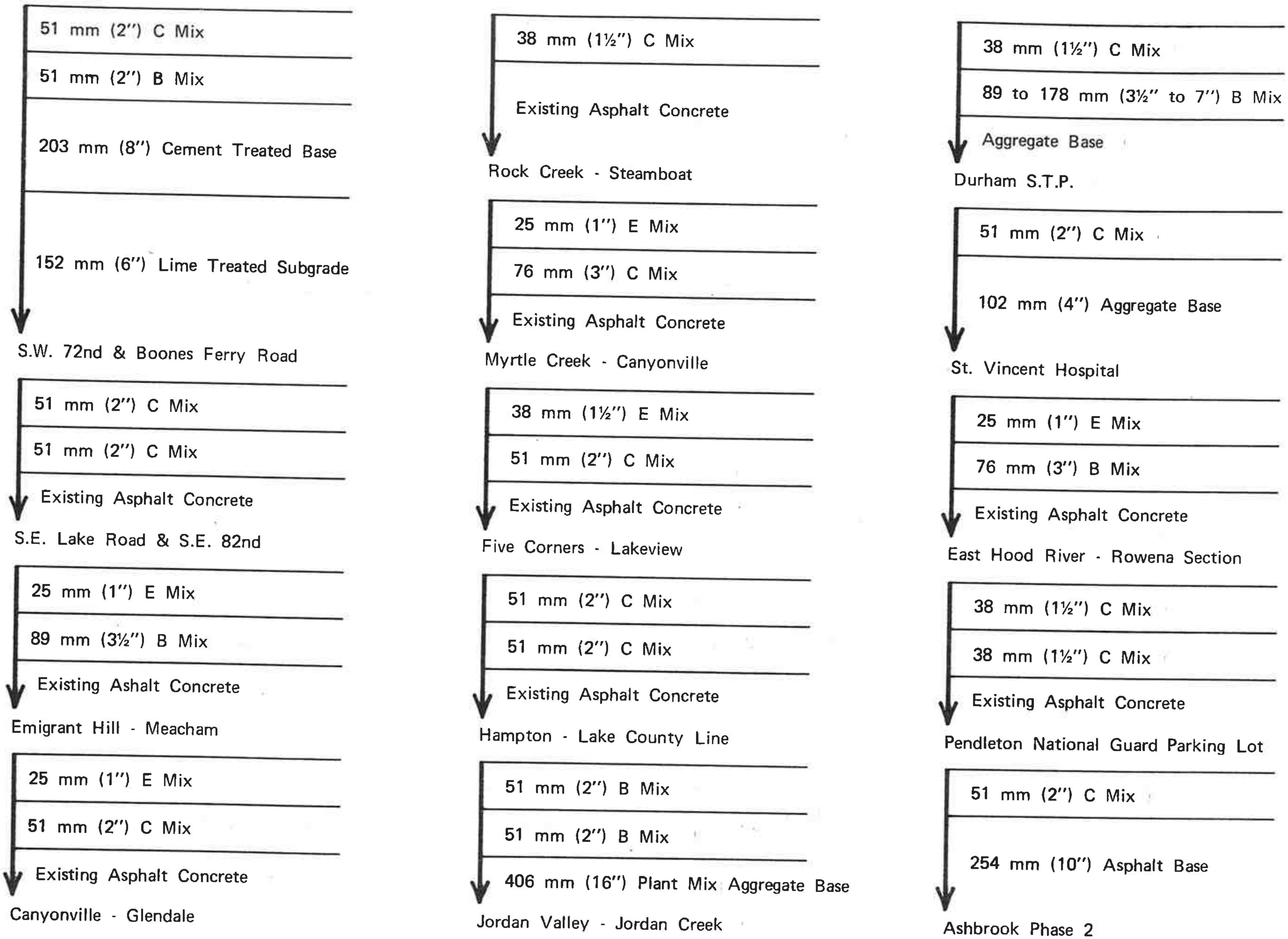

FIGURE 2. Typical Cross Sections for Pavement Sections Evaluated

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

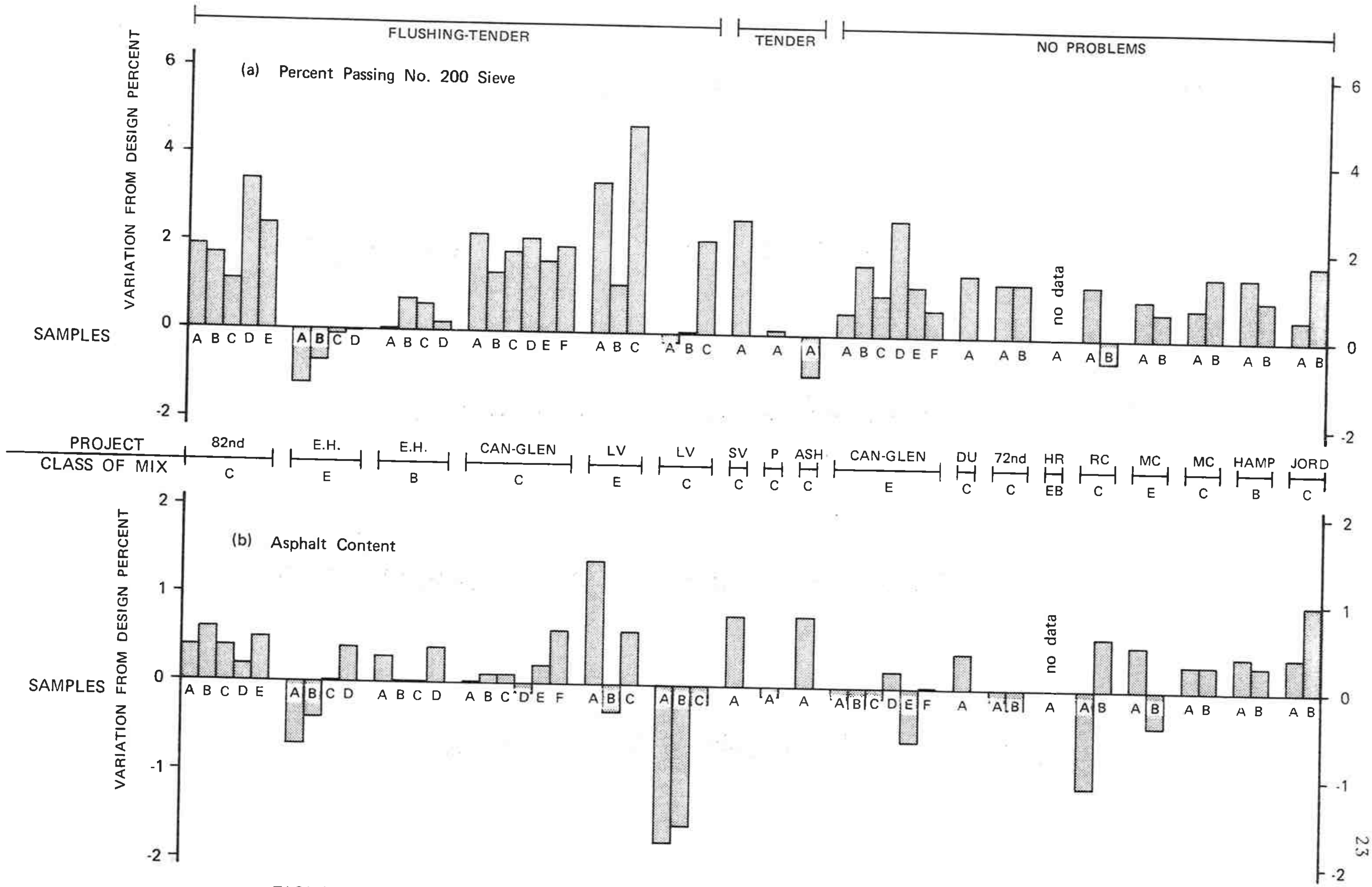

FIGURE 3 Variation from Mix Design of Percent Passing the No. 200 Sieve & Asphalt Content.

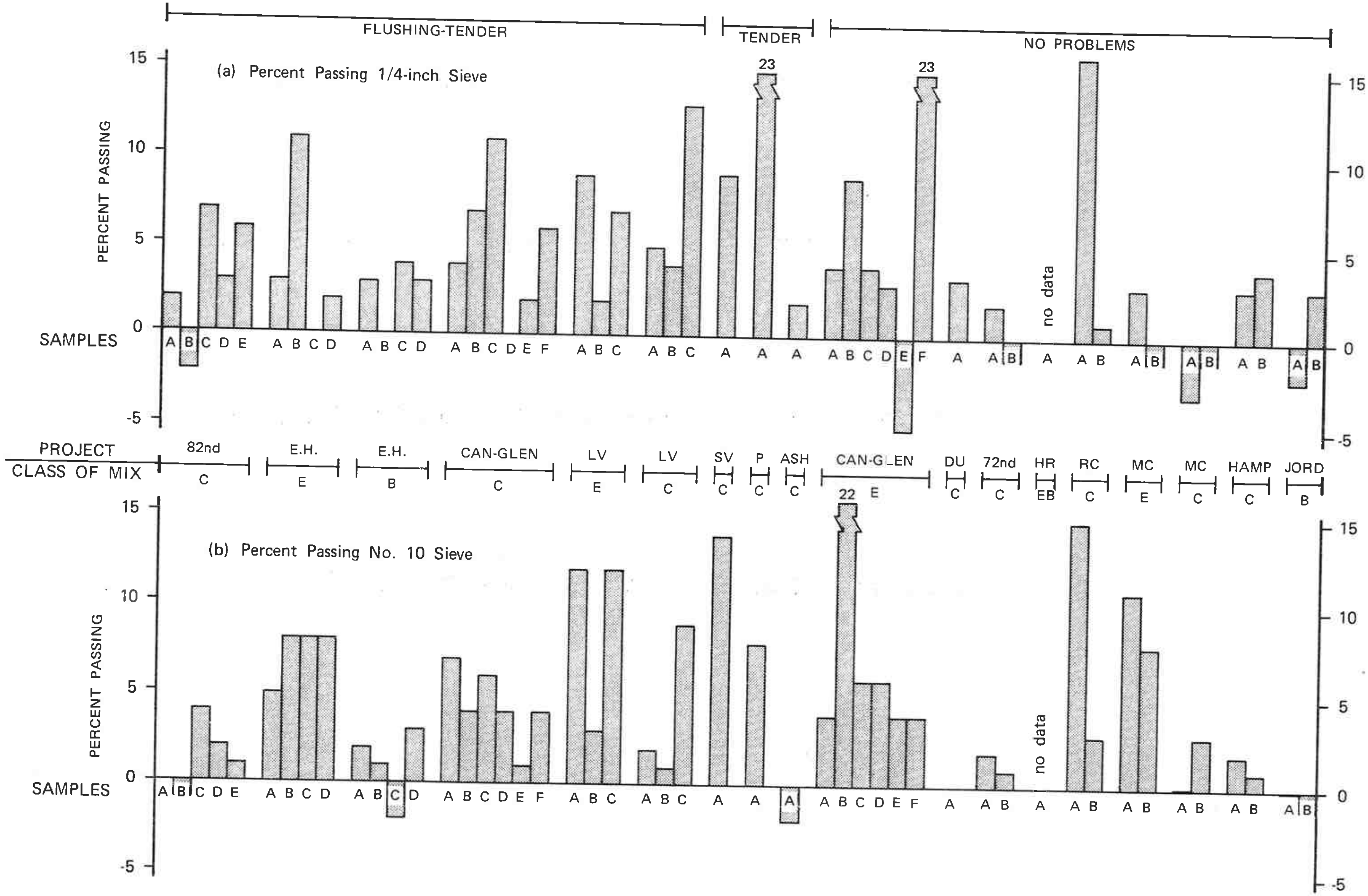

FIGURE 4 Variation from Mix Design of Percent Passing 1/4-inch Sieve & No. 10 Sieve.

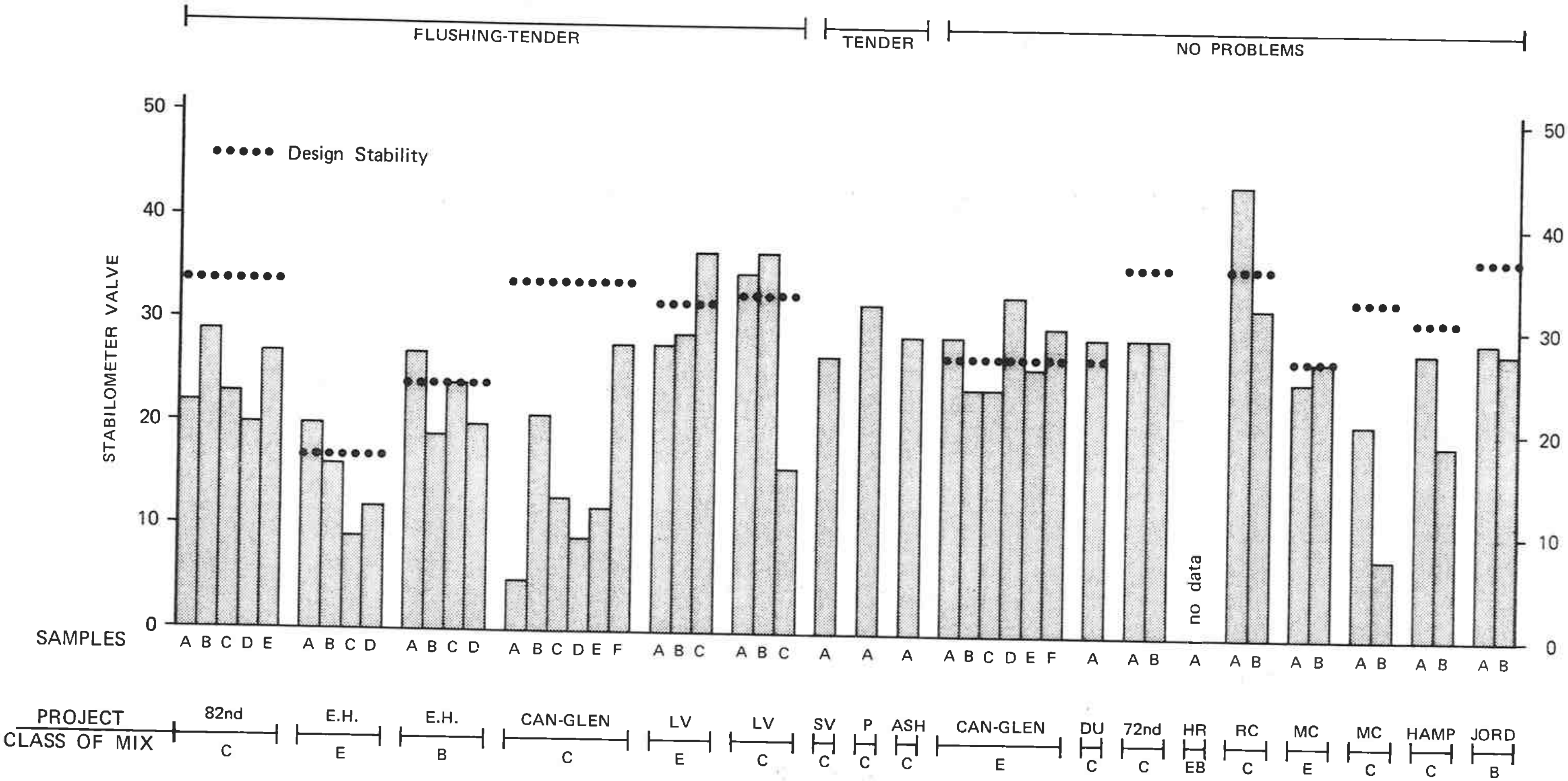

FIGURE 5 Compacted Mix Stability

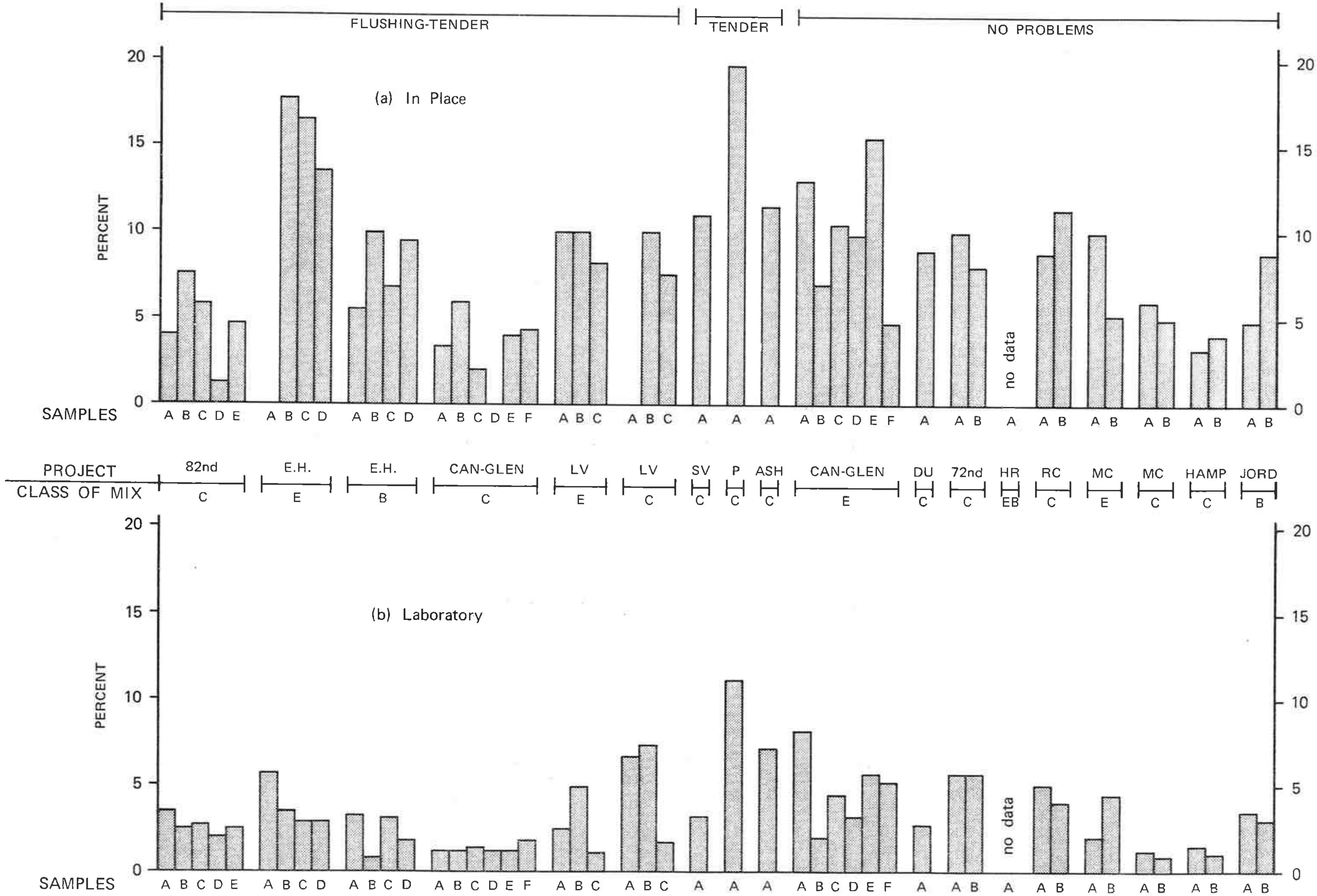

FIGURE 6 In Place and Laboratory Compacted Core Air Voids

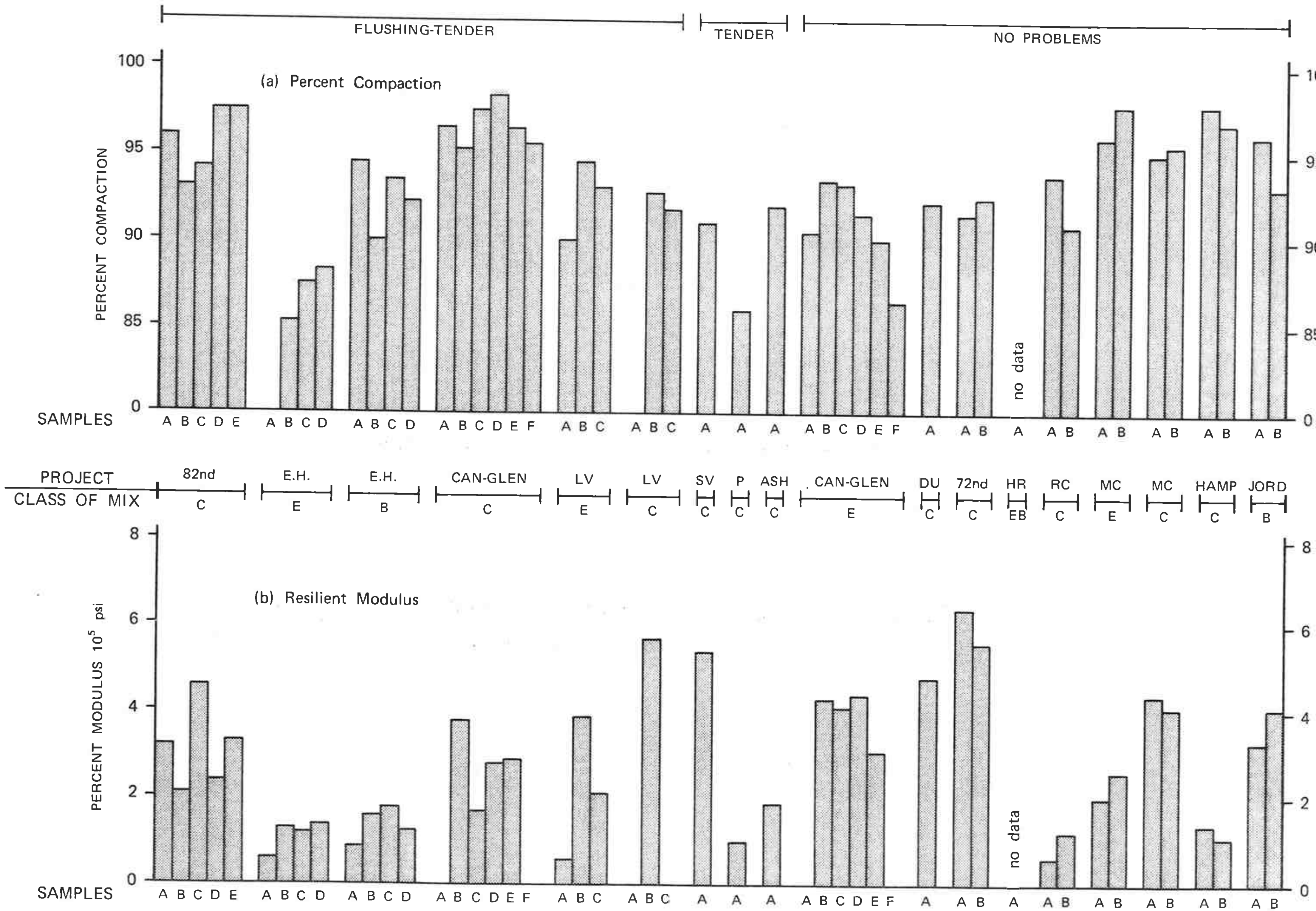

FIGURE 7 Level of Compaction and Resilient Modulus for Problem and Non-Problem Pavements.

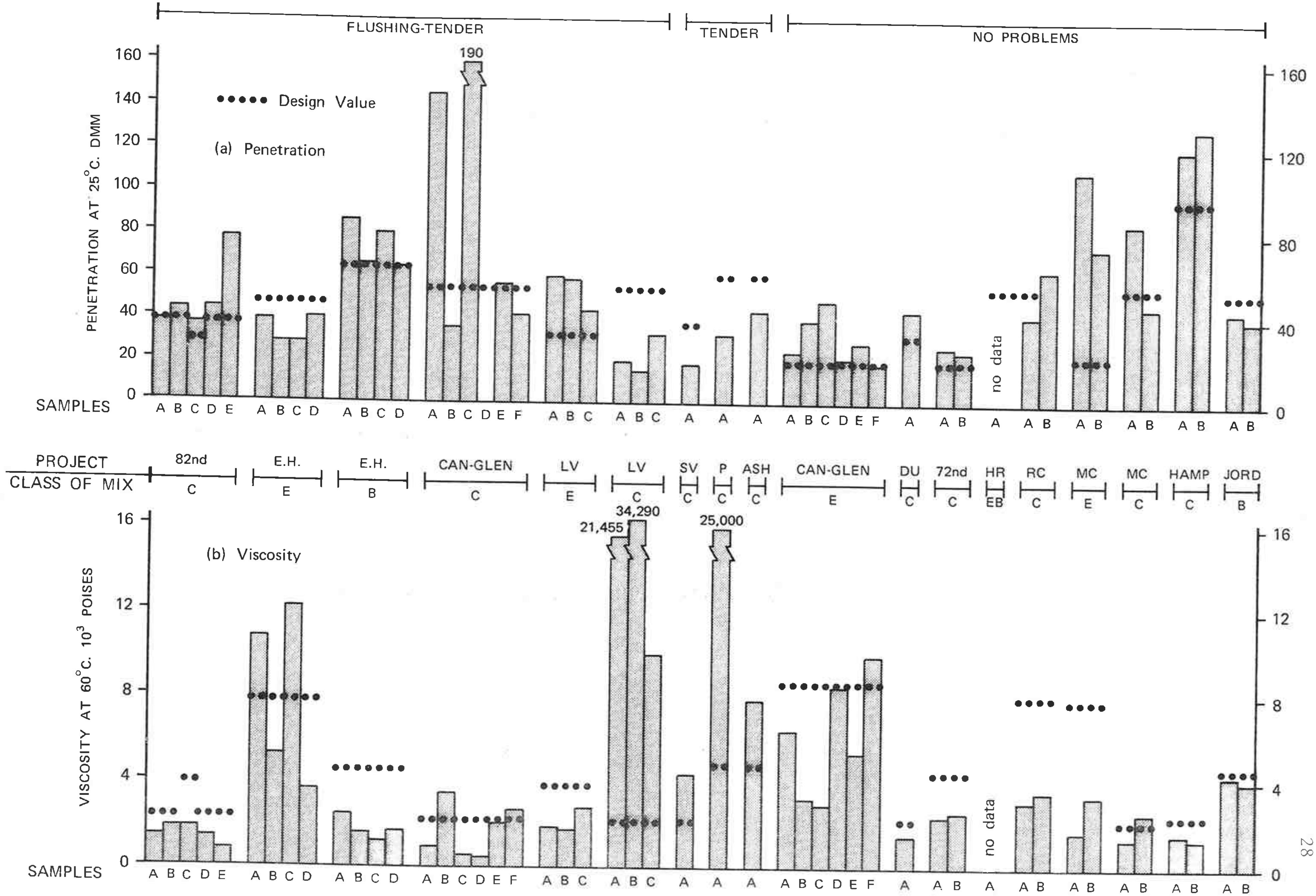

FIGURE 8 Variation in RTFC Residue Penetration and Viscosity for Problem and Non-Problem Pavements.

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°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°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

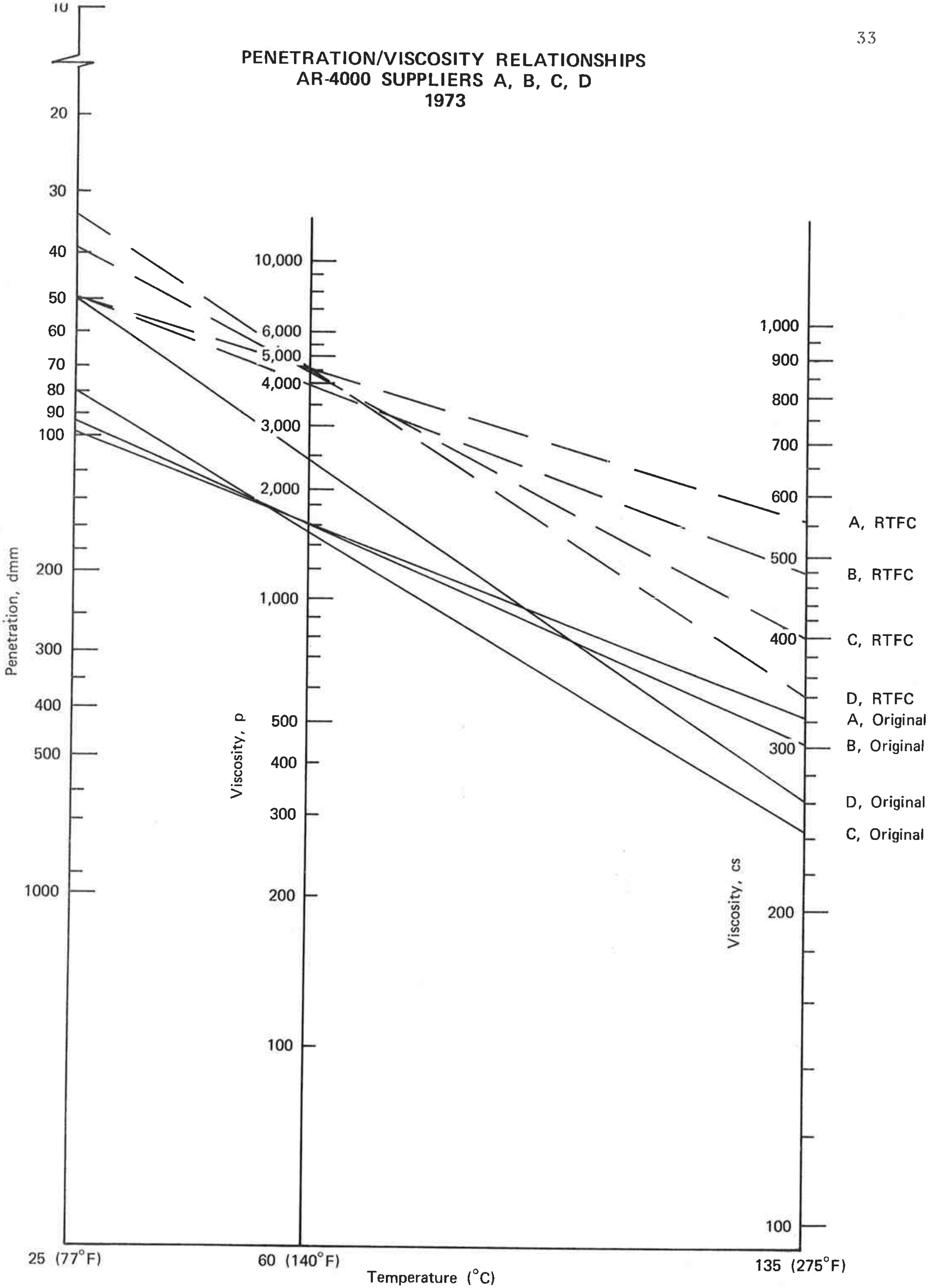
PENETRATION/VISCOSITY RELATIONSHIPS
AR-4000 SUPPLIERS A, B, C, D
1973
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
A, RTFC
B, RTFC
C, RTFC
D, RTFC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

FIGURE 9

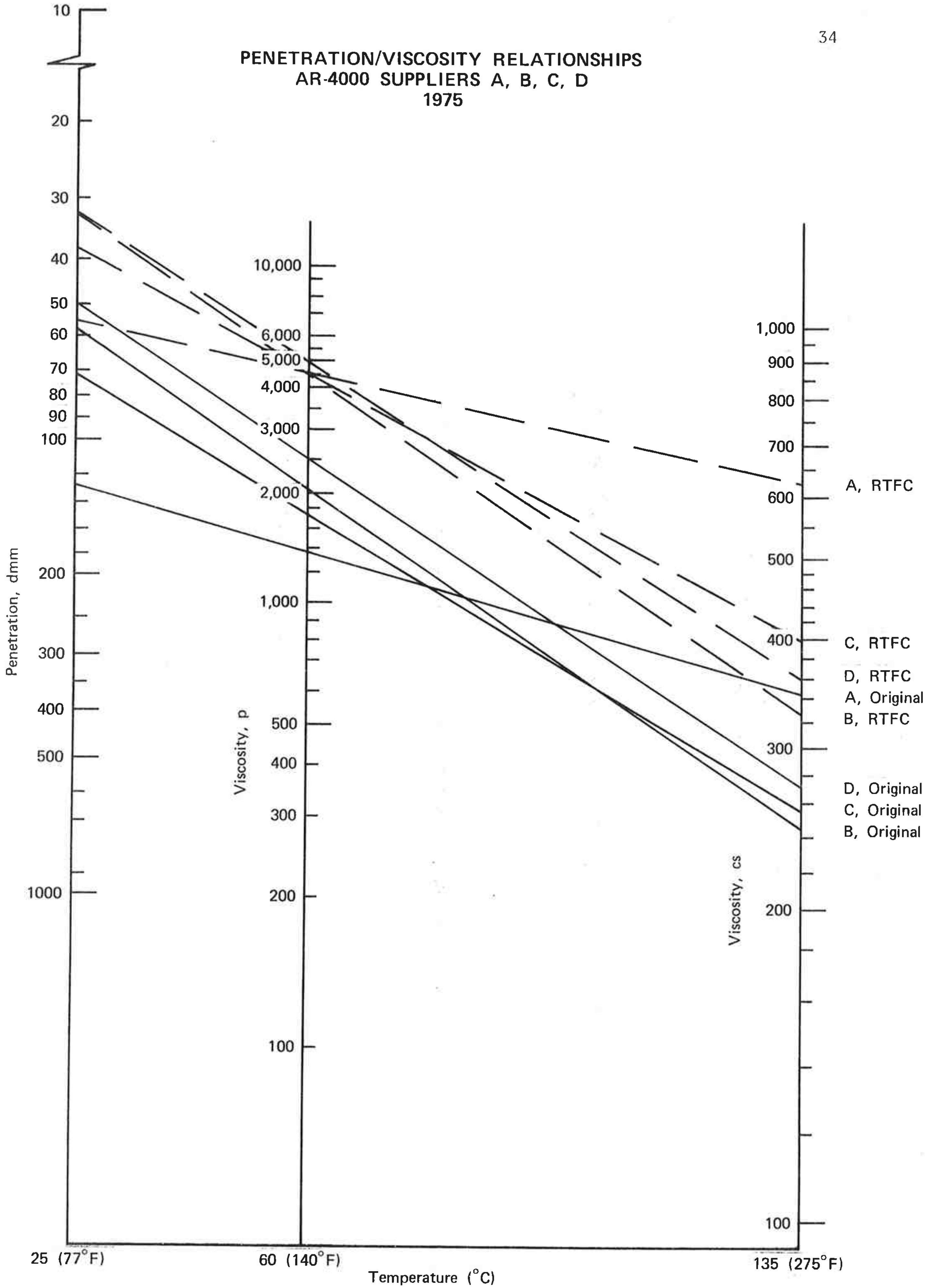
PENETRATION/VISCOSITY RELATIONSHIPS
AR-4000 SUPPLIERS A, B, C, D
1975
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
A, RTFC
C, RTFC
D, RTFC
A, Original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

FIGURE 10

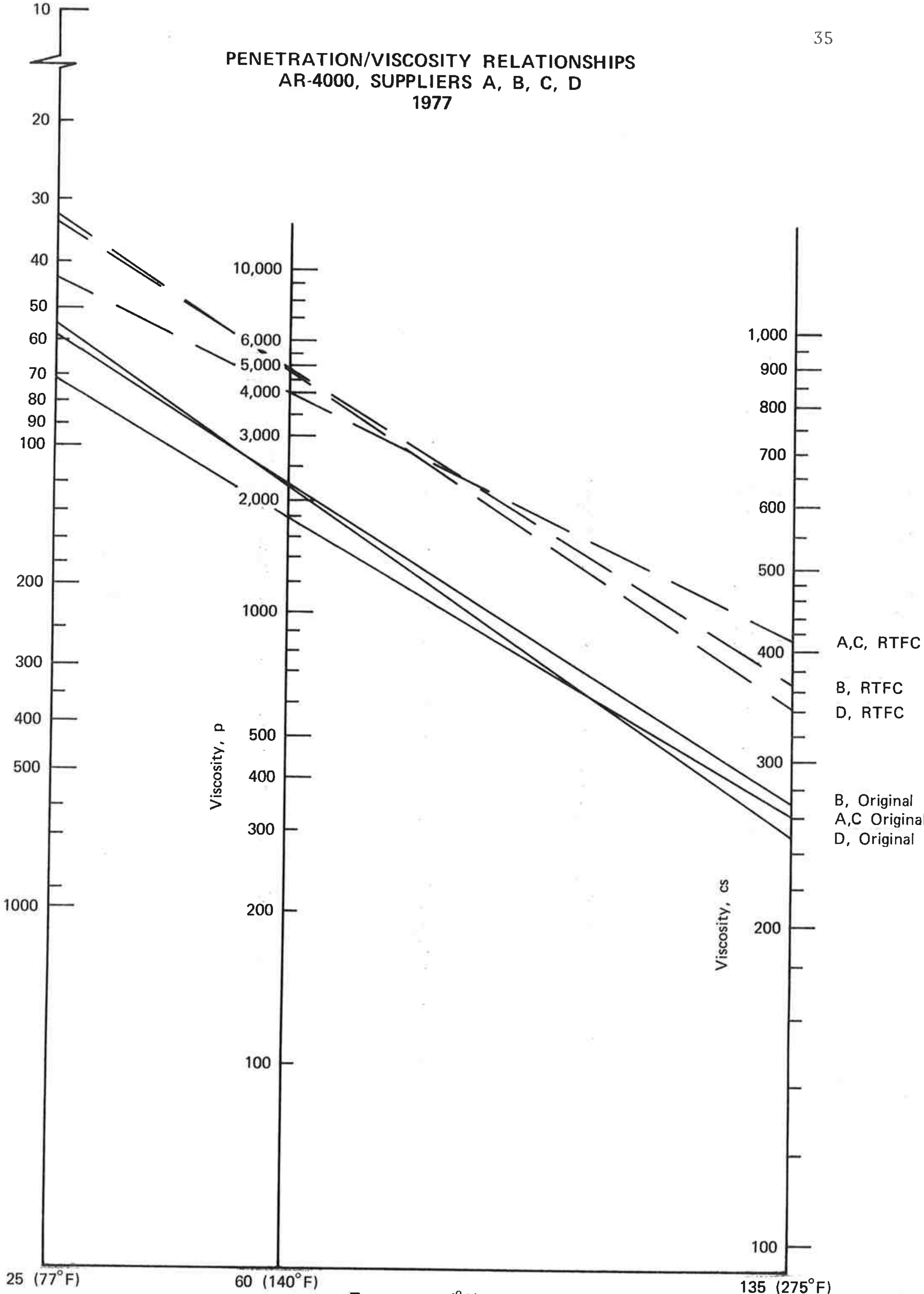
PENETRATION/VISCOSITY RELATIONSHIPS
AR-4000, SUPPLIERS A, B, C, D
1977
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
A,C, RTFC
B, RTFC
D, RTFC
B, Original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

FIGURE 11

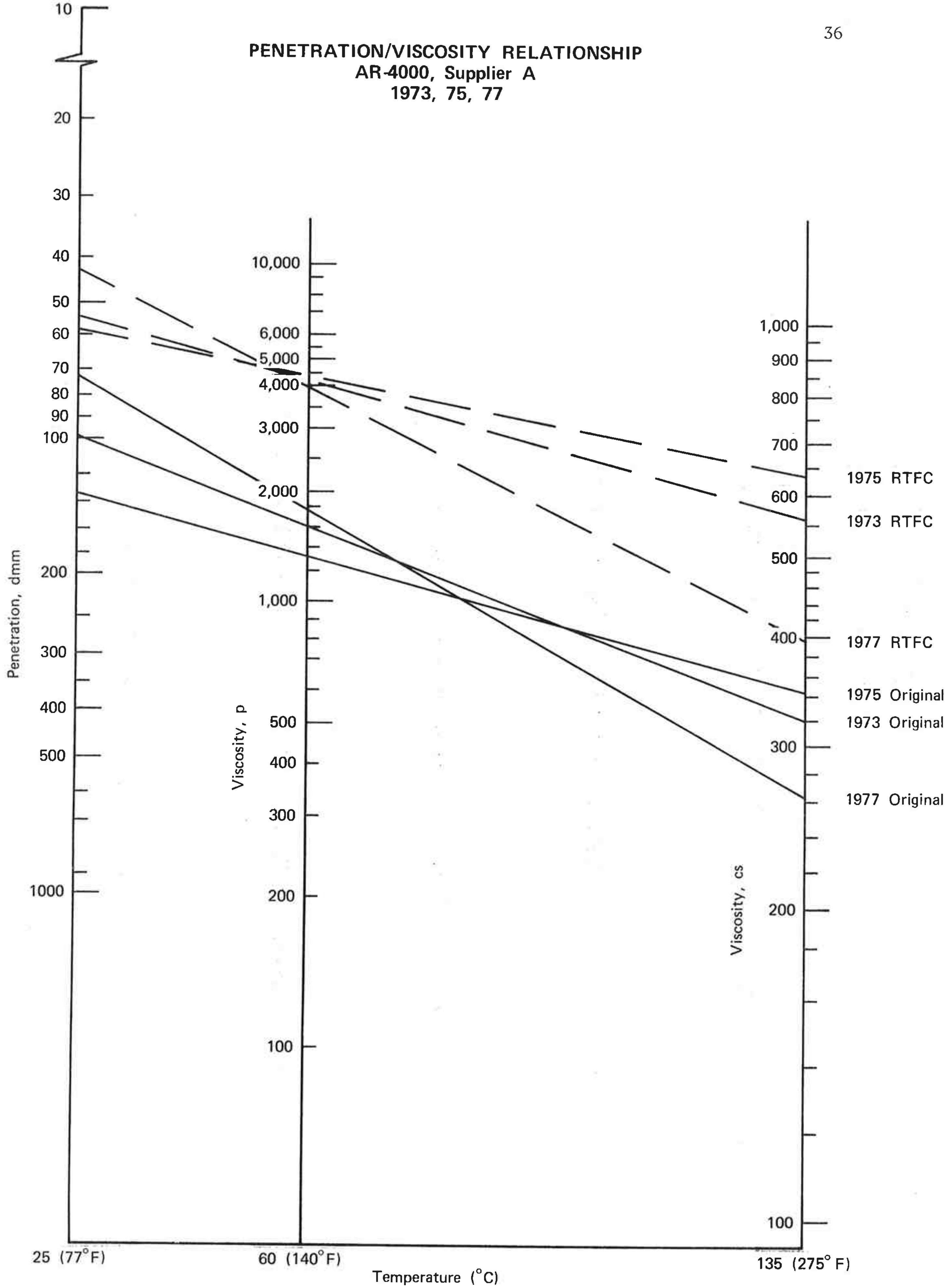
PENETRATION/VISCOSITY RELATIONSHIP
AR-4000, Supplier A
1973, 75, 77
Penetration, dmm
10
20
30
40
50
60
70
80
90
100
200
300
400
500
1000
Viscosity, p
10,000
6,000
5,000
4,000
3,000
2,000
1,000
500
400
300
200
100
Viscosity, cs
1,000
900
800
700
600
500
400
300
200
100
1975 RTFC
1973 RTFC
1977 RTFC
1975 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°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°F are softer than those made above 300°F (9). This trend, however, was not observed in the fourteen projects evaluated, probably because of the small data base.

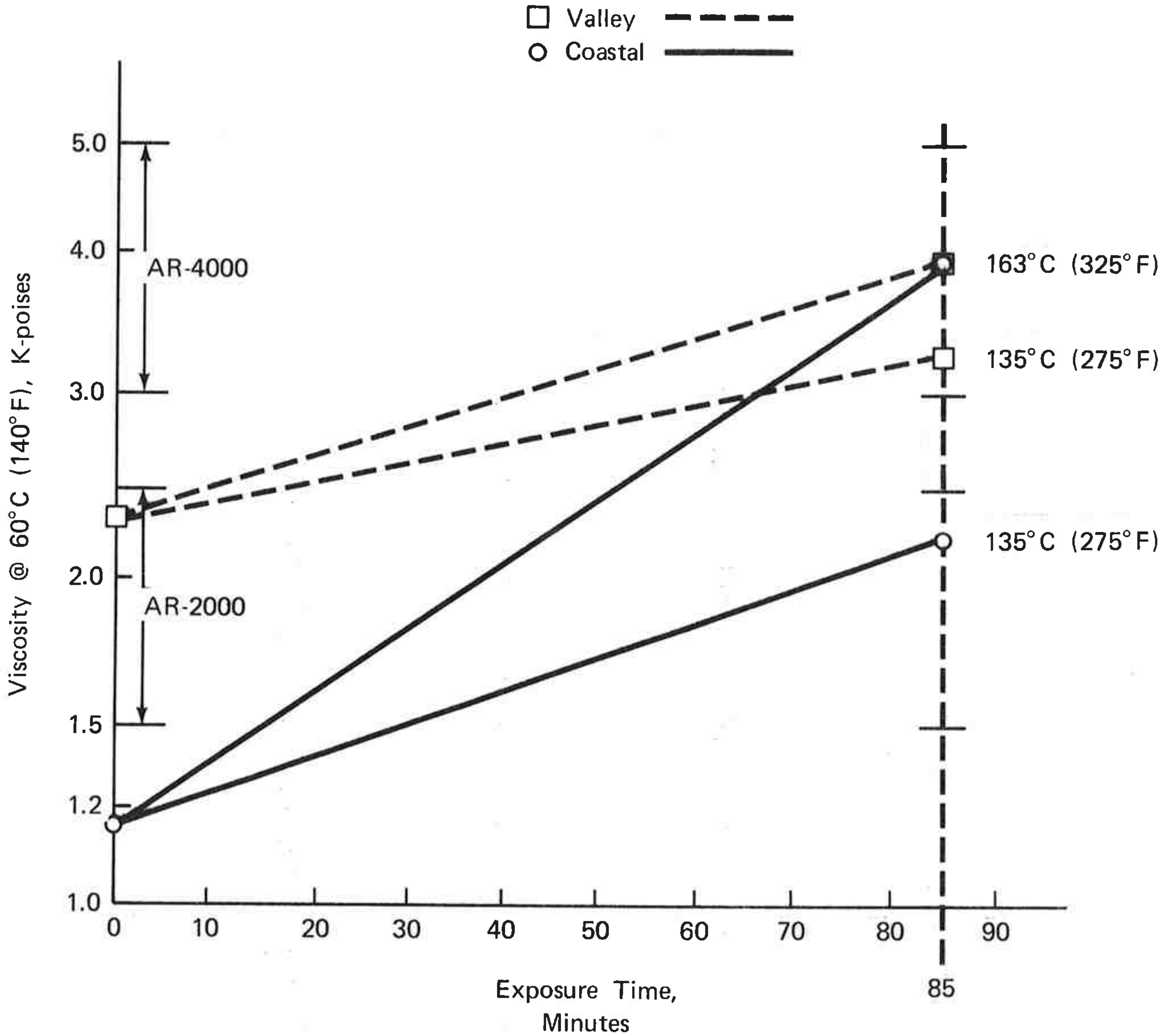

FIGURE 13 Effect of Mixing Time and Temperature on Asphalt Viscosity at 60°C (140°F) (9)

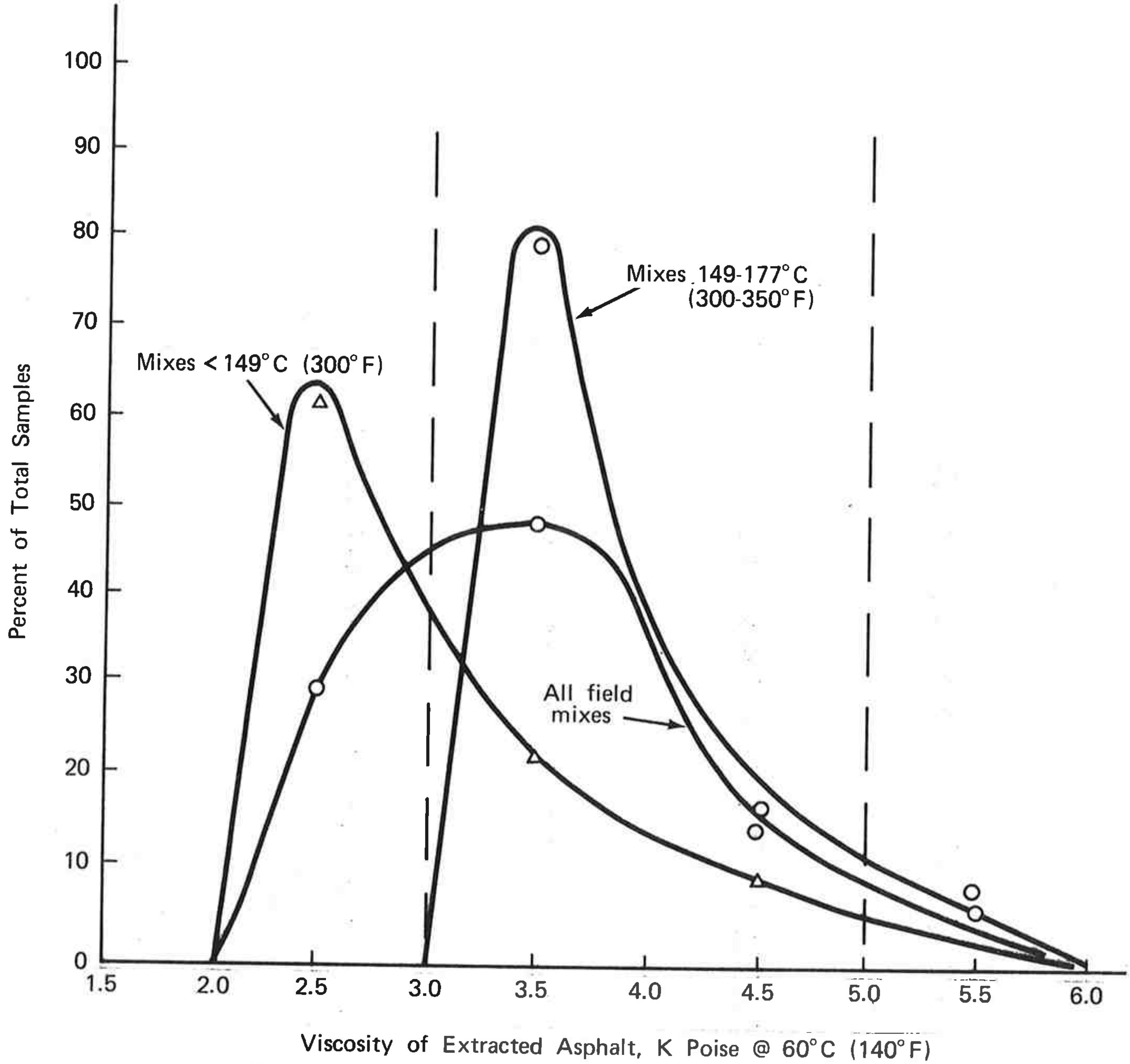

FIGURE 14 Effect of Mix Temperature on Asphalt Viscosity (Extraction of Field Cores)

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.

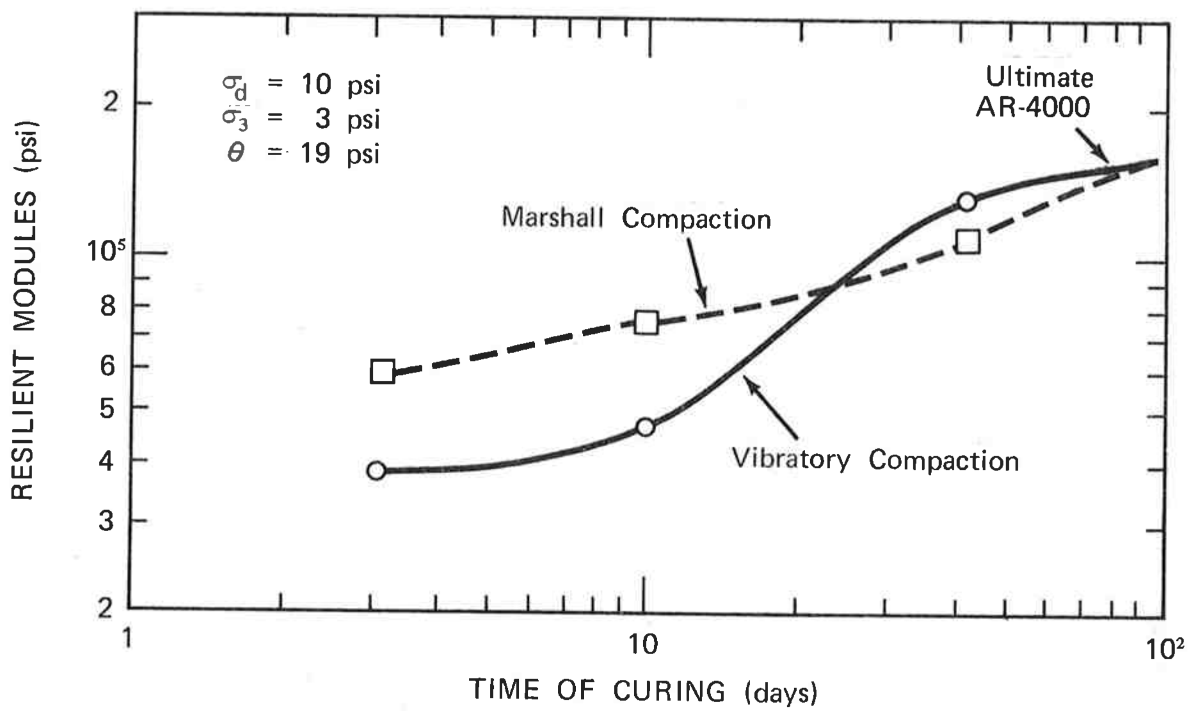

FIGURE 15 Variation in Resilient Modulus with Time of Curing for Specimens Prepared Using Marshal and Vibratory Compaction Procedures (11)

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