Progress Report on Changes in Asphaltic Concrete in Service

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This paper describes the experimental asphaltic concrete pavements constructed in Delaware to evaluate the changes in the asphalt and the properties of mixtures during construction and in service. Two experimental asphalts from specific sources, each laid over a rigid (old portland cement concrete) and a flexible (old surface treatment) base, were used.

The present report includes data from three series of samples, those taken during construction and those taken after one and two years of service. Comparison of results obtained by three different laboratories—Bureau of Public Roads, Asphalt Institute, and Delaware State Highway Department—also is provided.

At present no specific conclusions can be drawn but laboratory tests indicate that differences in behavior of the same asphalt at various locations in the road may be as great as or greater than differences in the asphalts from the two crude sources used in this study. Other than minor reflection cracking from the concrete base on the rigid sections, no deterioration in the pavements has been noted at any location.

• THE AD HOC Advisory Committee of the Highway Research Board, appointed to explore problems of mutual interest and concern to users and producers of asphaltic materials, has stressed investigations of (a) asphalt test characteristics and (b) the service behavior of asphalts from different sources. In June 1957, all State Highway Departments and the U.S. Bureau of Public Roads were asked to consider sponsoring research projects directed toward obtaining such data.

Accordingly, the Delaware State Highway Department undertook the research presented in this progress report. The report describes the project and shows the trends being developed. Inasmuch as the project will be continued, final conclusions are not yet possible.

LOCATION AND DESCRIPTION OF PROJECT

The experimental test section is located on FAS road 30 between Rising Sun and Woodside, Del. It was constructed as a part of a resurfacing project, the total length of which is 3.66 mi. The experimental test section is approximately 0.9 mi of this total.

This location was selected because of the uniqueness of the existing roadway to be resurfaced. The roadway consisted of a 9-ft lane of portland cement concrete 9 in. thick, adjacent to a 13-ft lane of bank-run sand-gravel base 6 in. thick.

The portland cement concrete had been covered the previous year (1957) with a single surface treatment of RC-3 cutback asphalt and aggregate. The sand-gravel base had been double surface-treated using MC-0 cutback asphalt for the prime application followed by two applications of RC-3 cutback asphalt and aggregate. The surface over the concrete pavement was in excellent condition with very little reflection cracking over the concrete joints; there was no evidence of bleeding and the condition of the surface was generally uniform throughout the length of the project.

The sand-gravel or flexible base portion was less uniform than the portland cement concrete side. There were a number of cracked areas resulting from base failures, and bleeding had occurred in the wheel tracks in some areas because of excess asphalt.

Figure 1. Finished roadway.

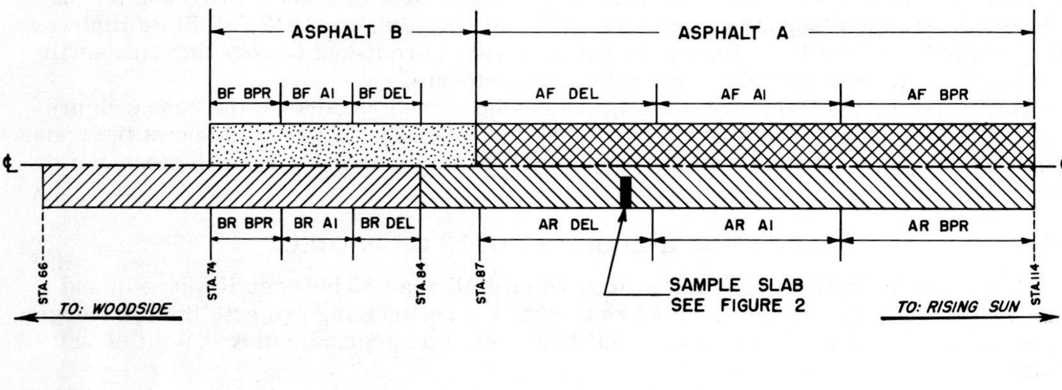

Figure 2. Delaware test road experimental road test section.

The entire length of original roadway was to be resurfaced with 3 in. of the State's standard hot-mix, hot-laid asphaltic concrete. The resurfacing consisted of $1\frac{3}{4}$ in. of binder course and $1\frac{1}{4}$ in. of wearing course. The finished roadway is shown in Figure 1.

The wearing course for the experimental portions of the project was constructed using two asphalts of the 60-70 grade from known crude sources and methods of manufacture.

The entire binder course and the wearing course outside the experimental areas were constructed using an asphalt of 70-85 penetration grade refined from a mixed crude.

Three laboratories are cooperating in making the tests—the Asphalt Institute, the Bureau of Public Roads, and the Delaware State Highway Department.

The plan and detailed location of the experimental sections are shown in

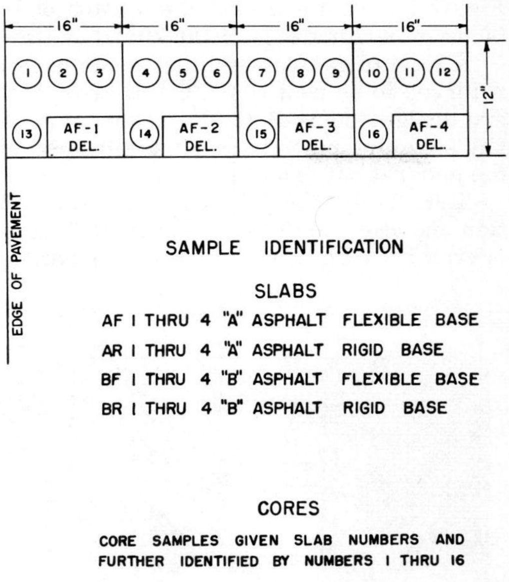

Figure 3. Pavement sampling pattern.

Figure 4. Cored sample from test section.

Figure 2. Test sections are located on both sides of the pavement to provide comparisons of performance of the surfaces over rigid and flexible bases.

A total of twelve sampling areas have been designated. The special asphalts are referred to as asphalts A and B, respectively. The rigid and flexible base portions are designated as R and **F**, respectively (slab samples such as BF-AI and BR-AI for any sampling period are always located directly opposite each other). Figure 3 shows the general pattern of sampling in each area.

The 12- by 16-in. blocks were sawed from the pavement immediately after construction and after one year of service; the blocks were then cored in each individual cooperator's laboratory. The cored samples obtained after two years of service were

Figure 5. Typical slab area after two years.

TABLE 1

Property	Asphalt A	Asphalt B
Penetration grade	60-70	60-70
Crude source	Venezuela (Lagunillas)	Middle East (Safaniya)
Type distillation	Vacuum or tube	Vacuum or tube
Date sampled (gal)	Sept. 15, 1958	Sept. 15, 1958
Sample quantity (gal)	10 (AI) 5 (DEL & BPR)	10 (AI) 5 (DEL & BPR)

TABLE 2

PROPERTIES OF ORIGINAL ASPHALTS

	Asphalt A			Asphalt B		
	Del.	BPR	AI	Del.	BPR	AI
Specific gravity, 77 F	1.023	1.023	1.024	1.030	1.030	1.030
Penetration, 100 g, 5 sec, 77 F	60	62	61	65	66	66
Softening point, R&B (°F)	118	123	125	118	124	124
Ductility, 5 cm/min, 77 F (cm)	100	250	150	100	250	150
Flash point (°F):						
C.O.C.	585	580	610	610	570	595
P.M.	-	505	-	-	-	-
Solubility in CCl_4 (%)	99.9	99.9	99.2	99.9	99.8	99.9
Inorganic matter insol (%)	-	0.10	0.03	-	0.22	0.02
Furol viscosity at 275 F (sec)	-	279	-	-	285	-
Oliensis spot test	Neg.	Neg.	-	Neg.	Neg.	-
Loss on heating at 325 F (%)	0.04	0.02	0.03	0.03	0.02	0.03
Pen residue, 100 g, 5 sec, 77 F (%)	56	55	55	60	59	60
Orig. pen (%)	93	89	90	92	89	91
Film oven test, ⅛-in. film, 5 hr, 325 F:						
Loss (%)	-	0.09	0.08	-	0.08	0.11
Pen residue, 100 g, 5 sec, 77 F (%)	-	40	40	-	42	41
Orig. pen (%)	-	65	66	-	64	62
Soft point of residue (°F)	-	133	132	-	135	134
Duct. res., 77 F, 5 cm/min (cm)	-	250	150	-	140	150

TABLE 3

AGGREGATE CHARACTERISTICS

Characteristic	BPR	AI	Del.
Los Angeles percent of wear	24.7[a]	21.6[a]	27.5[b]
Sodium sulfate soundness loss (%)	4.6	-	-
Specific gravity:			
Coarse aggregate:			
Apparent	-	2.823	-
Bulk	-	2.870	-
Absorption (%)	-	0.540	-
Fine aggregate:			
Apparent	-	2.808	-
Bulk	-	2.795	-
Absorption (%)	-	0.150	-
Combined:			
Apparent	2.81	2.814	2.79
Bulk	2.76	2.789	2.77
Absorption (%)	0.60	0.30	0.30
Sand equivalent	86	83	-

[a]Based on grading C, AASHO Method T96.
[b]Based on grading A, AASHO Method T96.

taken from the roadway before removal of the blocks (Figs. 4 and 5). Wearing course specimens were sawed from the binder course in the laboratory.

MATERIALS

Asphalts

The two special asphalts used in the study were sampled at the plant during the mixing operation. The samples were sealed in 1-gal containers and shipped to the individual cooperators for testing purposes. Pertinent information and sample identification are given in Table 1.

Test characteristics of each asphalt as determined by each cooperator are given in Table 2. It is apparent from this table that there is little difference in the usually-measured physical characteristics of the two asphalts. Both asphalts had about the same resistance to hardening in the thin-film test, although the BPR results did indicate some difference in the ductility of the thin-film residue. However, the significance of differences at such high values of ductility is not known.

Aggregate

The aggregate was crushed limestone and screenings from Downingtown, Penn. A 3,000-lb portion of the combined hot aggregate was obtained by dry mixing weighed components from each hot bin and dumping into a clean truck. The first batch was wasted to clean the pugmill. The second batch was dumped from the truck to a concrete platform and bagged by random sampling. Ten 100-lb bags of the aggregate were then prepared for each cooperator.

Aggregate characteristics are given in Table 3. Variations in percent of wear as indicated in the table may possibly be attributed to the different methods used by the cooperators. The Bureau of Public Roads value of 24.7 percent was based on grading C of AASHO Method T 96 and the 27.5 percent value determined by Delaware was based on grading A. Grading A requires a 1½-in. maximum size aggregate in contrast to a ⅜-in. maximum size aggregate of grading C. The low value of 21.6 percent wear was determined by the Asphalt Institute using grading C.

ASPHALT CONTENT BY DIFFERENT DESIGN METHODS

The actual grading of the aggregate and percentage of asphalt used in the asphaltic mix was established from similar mixes that, through years of service, have performed satisfactorily.

TABLE 4

DESIGN AND HOT BIN GRADATIONS

Gradation	Percent Passing Sieve							
	½-In.	⅜-In.	No. 4	No. 10	No. 20	No. 40	No. 80	No. 200
Hot bin[a]:								
Washed:								
BPR	100	90	64	42	30	13	8	6
AI	100	90	67	43	24	15	10	7
Dry (BPR)	100	90	65	42	22	14	8	6
Design mix[b] (dry):								
Del.	100	86	62	42	23	14	10	6
BPR	100	86	62	42	23	14	9	6
AI	100	86	62	42	23	15	10	7

[a]Performed in cooperator's laboratory.
[b]Average of 15 routine plant hot bin samples and 17 extractions.

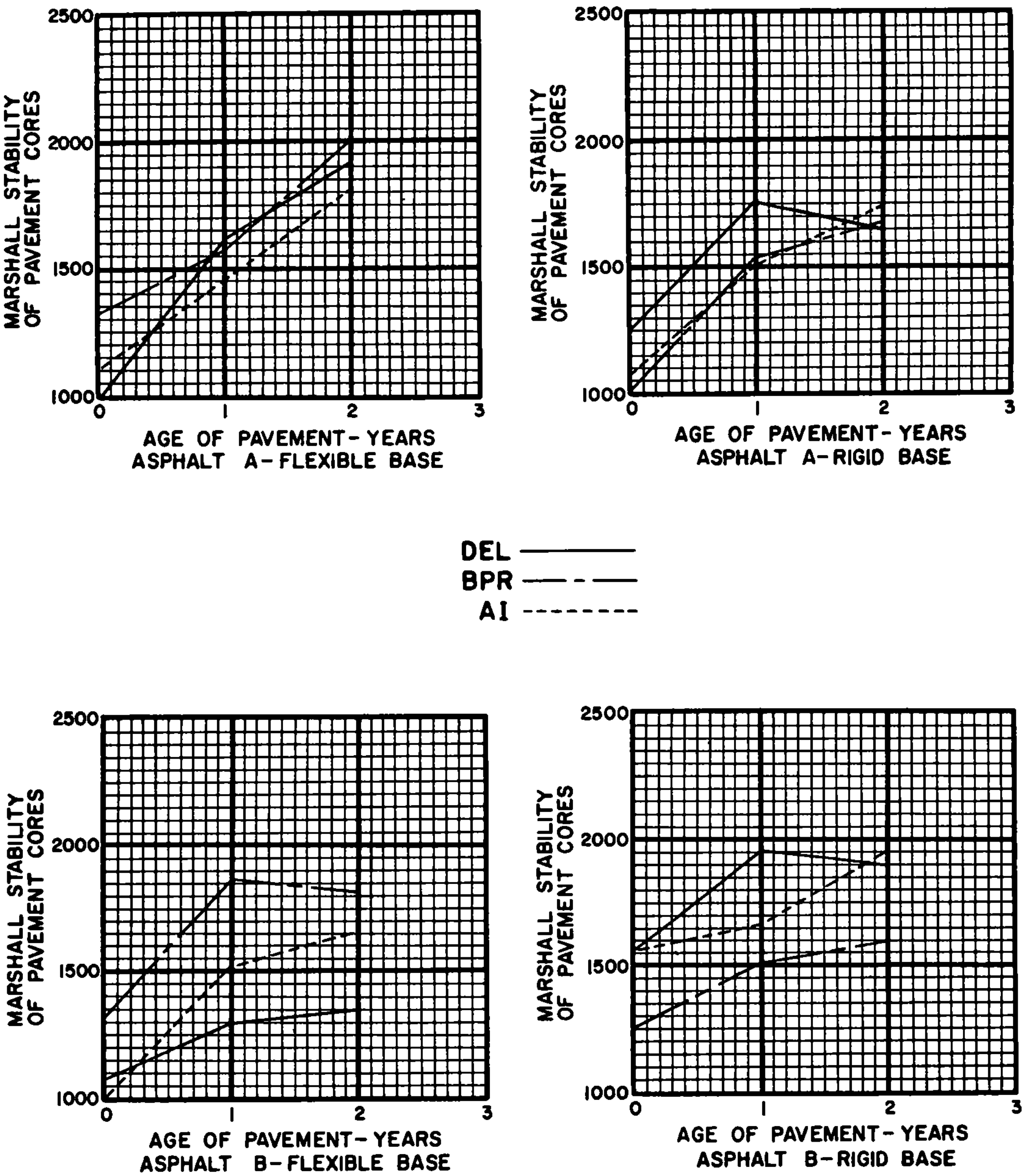

Figure 6. Marshall stability of pavement cores, with years of service.

TABLE 5

MARSHALL STABILITY TEST RESULTS OF LABORATORY PREPARED MIXTURES, ASPHALT A

Laboratory	Asphalt Content Mix Basis (%)	Specimens per Test	Specific Gravity		Mineral Voids Filled[a] (%)	Air Voids[a] (%)	Stability (lb)	Flow (1/100 in)
			Bulk	Theoretical[a]				
Del	4 5	4	2 438	2 59	65	5.9	1,410	16
	5 0	4	2 462	2 56	72	4.8	1,520	17
	5.5	4	2 438	2 55	75	4 4	1,390	20
	6 0	4	2 436	2.53	79	3.8	1,100	20
	6.5	4	2 473	2 51	91	1.5	1,270	17
BPR	4 31	4	2 420	2.612	58	7.4	1,610	10
	4 76	3	2 439	2 594	65	6 0	1,650	10
	5 21	4	2 464	2 575	74	4 3	1,730	12
	5.66	4	2 482	2 557	83	2 9	1,710	13
	6.10	6	2 489	2 539	88	2 0	1,640	16
	6 54	4	2 484	2 522	91	1 5	1,510	20
AI	4.0	3	2.459	2 630	60	6.5	1,952	10
	4 5	3	2 489	2 609	71	4.4	2,057	12
	5 0	3	2 513	2 588	81	2.9	2,132	13
	5.5	3	2.522	2.567	88	1.8	2,068	17
	6.0	3	2 520	2.547	93	1 1	1,977	23

[a]Based on apparent specific gravities given in Table 3.

TABLE 6

MARSHALL STABILITY TEST RESULTS OF LABORATORY PREPARED MIXTURES, ASPHALT B

Laboratory	Asphalt Content Mix Basis (%)	Specimens per Test	Specific Gravity		Mineral Voids Filled[a] (%)	Air Voids[a] (%)	Stability (lb)	Flow (1/100 in.)
			Bulk	Theoretical[a]				
Del.	4.5	4	2.431	2.59	63	6 2	1,280	15
	5 0	4	2 454	2 56	74	4 2	1,310	17
	5 5	4	2 450	2.55	77	3 9	1,400	17
	6 0	4	2.495	2 53	91	1 4	1,480	18
	6 5	4	2.484	2.51	94	1 1	1,480	21
BPR	4 31	3	2.439	2.615	60	6 7	1,820	8
	4 76	4	2.458	2 597	68	5 3	1,830	9
	5 21	3	2 479	2 571	77	3 8	1,870	10
	5 66	4	2 492	2.560	84	2 6	1,840	13
	6 10	4	2.494	2 542	89	1 9	1,690	17
	6 54	4	2 476	2.525	89	1 9	1,400	22
AI	4.0	3	2 632	2 632	60	6 5	2,005	11
	4.5	3	2 473	2 610	68	5 1	1,949	12
	5 0	3	2 501	2 590	78	3 4	1,952	13
	5 5	3	2 524	2 569	88	1 8	2,058	17
	6 0	3	2 517	2.549	92	1.3	1,981	21

[a]Based on apparent specific gravities given in Table 3.

TABLE 7

HVEEM STABILOMETER AND COHESIOMETER TEST RESULTS OF LABORATORY PREPARED MIXTURES, ASPHALT A

Cooperator	Asphalt Content Mix Basis (%)	Specimens per Test	Specific Gravity		Air Voids[a] (%)	Stabilometer Value	Cohesiometer Value (after Stabilometer Test)
			Bulk	Theoretical[a]			
BPR	4 31	3	2 480	2.607	4 9	53	459
	4 76	3	2 496	2.588	3 6	46	402
	5.21	3	2 516	2 569	2 1	34	339
	5 66	3	2.524	2.551	1 1	15	258
AI	3.0	3	2 437	2 674	8 9	54	234
	3 5	3	2 468	2 652	6 9	55	309
	4 0	3	2 491	2 630	5 1	53	335
	4.5	3	2 516	2 609	3 6	49	387
	5.0	3	2 525	2 588	2 4	34	332
	5.5	3	2.536	2 567	1 2	10	143

[a]Based on effective specific gravity of aggregate, 2.802, for BPR tests and apparent specific gravity, 2.814 , for AI tests.

However, it was of interest to compare the results of design studies, conducted by different laboratories using various methods. Three methods of design (Marshall, Hveem, and immersion-compression) were used. All laboratories made studies with the Marshall method; the Bureau of Public Roads and the Asphalt Institute conducted studies using the Hveem method, and the Bureau of Public Roads also conducted studies using the immersion-compression method.

Aggregates used in this study were proportioned to practically identical gradations by each cooperating laboratory. This was done by separating the aggregate into sieve-size fractions, down to the No. 20 sieve and recombining. The grading used in the design studies was determined from an average of 15 routine hot bin, dry gradations and 17 extracted aggregate dry gradations. It was agreed that the average of the 32 gradations would be used in the design studies to approximate as closely as possible field conditions.

Table 4 shows the design gradations used and the gradations of samples shipped to the individual cooperators. It indicates the normal variations to be expected in conducting aggregate gradation analysis, and also shows that for this aggregate there was little variation between washed and dry analysis.

To compute void contents of compacted bituminous mixtures by use of conventional formulas accurately, the specific gravity of the aggregate, which takes into account the absorption of asphalt, must be known. An aggregate effective specific gravity between the bulk and the apparent specific gravity would normally be the most accurate specific gravity for use in determining void values. The limestone aggregate used in this study has low water absorption characteristics approximately 0.5 percent; this indicates that void contents, obtained by using apparent and effective specific gravities, have negligible differences. The Public Roads data in Table 3 showed a difference between the apparent and bulk specific gravities of 0.05 and the Asphalt Institute and Delaware tests showed differences of 0.02. The latter is within the tolerance prescribed by the standard method for determination of specific gravity by AASHO test procedures.

Marshall Method

Marshall design methods were studied by all three cooperators. In Delaware and Public Roads design tests, the 50-blow mechanical compactor was used with the flat-type head. Hand-operated equipment was used by the Asphalt Institute. Void values obtained using the Marshall procedure are based on apparent specific gravities of the aggregate as determined by each individual cooperator.

Tables 5 and 6 show normally-expected trends for each cooperator. However, Asphalt Institute bulk specific gravity values are somewhat higher than bulk specific gravity values determined by the other two cooperators. The higher stability values determined by the Asphalt Institute are in agreement with their higher values of bulk

TABLE 8

HVEEM STABILOMETER AND COHESIOMETER TEST RESULTS OF LABORATORY PREPARED MIXTURES, ASPHALT B

Cooperator	Asphalt Content Mix Basis (%)	Specimens per Test	Specific Gravity Bulk	Specific Gravity Theoretical[a]	Air Voids[a] (%)	Stabilometer Value	Cohesiometer Value (after Stabilometer Test)
BPR	4 31	3	2.469	2 616	5 6	45	377
	4 76	3	2.480	2.597	4 5	43	272
	5.21	3	2.497	2.579	3 2	30	254
	5.66	3	2.504	2 560	2.2	14	232
AI	3.0	3	2 432	2 675	9 1	57	244
	3.5	3	2.476	2 653	6 7	57	278
	4 0	3	2 501	2 632	5.0	53	378
	4 5	3	2 512	2 610	3.8	47	391
	5 0	3	2 520	2.590	2.7	39	345
	5 5	3	2 539	2.569	1 2	10	151

[a]Based on effective specific gravity of aggregate, 2.811, for BPR tests and apparent specific gravity, 2.814, for AI tests.

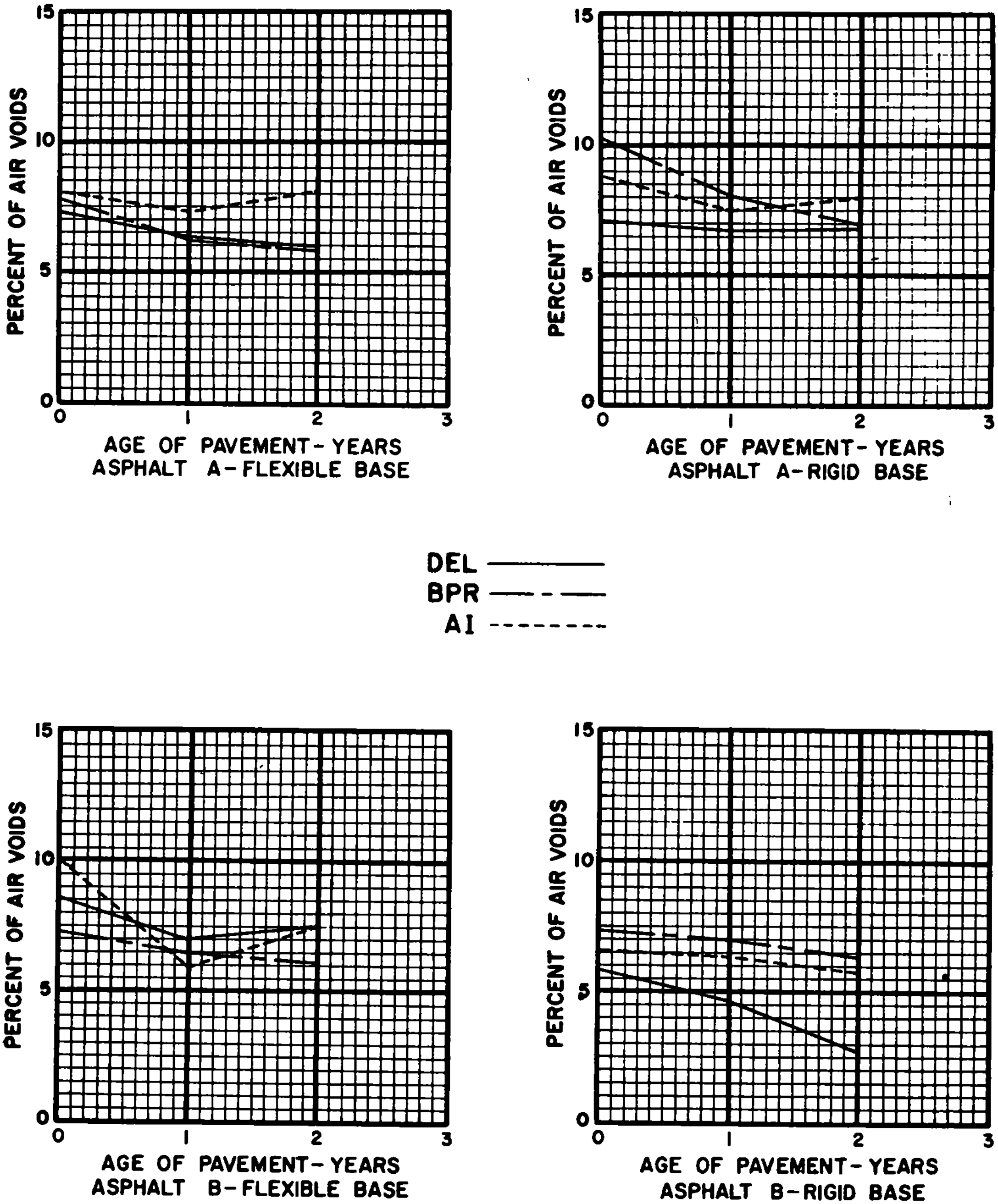

Figure 7. Percent of air voids, with years of service.

specific gravity. These higher bulk specific gravity and stability values could be attributed to the use of hand-operated equipment.

Hveem Method

The Hveem Method of design was studied by the Bureau of Public Roads and the Asphalt Institute. Testing procedures used by each cooperator were essentially those of ASTM method D-1560.

Void percentages, however, were computed differently—Asphalt Institute void computations are based on the apparent specific gravity of the aggregate and Bureau of Public Roads void computations are based on the effective specific gravity of aggregate as determined by the Rice vacuum saturation procedure.

Table 7 and 8, Hveem stabilometer test results, show trends similar to the trends given in Tables 5 and 6. Hveem stabilometer and cohesiometer values are in accordance with the densities shown.

Immersion-Compression Method

The results of the immersion-compression design method, conducted by the Bureau

TABLE 9

SUMMARY DESIGN VALUES

	Asphalt A			Asphalt B		
	Del.	BPR	AI	Del.	BPR	AI
Marshall method:						
Design asphalt content mix basis (% by wt) for:						
Maximum density	6.0	6.0	5.7	6.0	6.0	5.7
Maximum stability	5.1	5.3	5.0	6.0	5.4	5.4
80 percent voids filled[a]	5.5	5.5	5.1	5.4	5.4	5.1
4 percent air voids[a]	5.4	5.3	4.6	5.2	5.2	4.6
Avg.	5.5	5.5	5.1	5.5	5.5	5.2
Bulk specific gravity at design asphalt content	2.474	2.475	2.515	2.481	2.487	2.510
Hveem method:						
Design asphalt content mix basis (% by wt) for stabilometer value of 35	-	5.2	5.0	-	5.1	5.1
Bulk specific gravity at design asphalt content	-	2.51	2.525	-	2.49	2.522
Air voids at design asphalt content (%)[b]	-	2.2	2.4	-	3.7	2.6
Immersion compression:						
Design asphalt content mix basis (% by wt) for percent voids[c]	-	4.6	-	-	4.6	-
Bulk specific gravity at design asphalt content	-	2.44	-	-	2.44	-
Compressive strength, dry (psi)	-	410	-	-	420	-
Retained strength (%)[d]	-	98	-	-	96	-

[a]Based on apparent specific gravities of aggregate as given in Table 3.
[b]Based of effective specific gravities as given in Table 7 or 8 for BPR and apparent specific gravity for AI.
[c]Based on effective specific gravity of 2.801 for asphalt A mixture and 2.803 for asphalt B mixture.
[d]Ratio of wet strength after 4 days immersion in water at 120 F compared to initial dry strength.

of Public Roads, are given in Table 9. .Void values were based on effective specific gravities of the aggregate as determined by the Rice vacuum saturation procedure.

Summary of Design Results

Table 9 summarizes the design values determined by each testing procedure. The table includes the individual asphalt contents determined for each of the four criteria used in setting the Marshall design value. The Marshall method design asphalt contents determined by Delaware, Bureau of Public Roads, and Asphalt Institute, were 5.5, 5.5, and 5.1 percent, respectively, for asphalt A, and 5.5, 5.5, and 5.2 percent for asphalt B. These asphalt contents are in accordance with the bulk specific gravities given.

The design asphalt contents determined by the Hveem Method by each laboratory are in closer agreement than the asphalt contents determined by the Marshall method. Design asphalt contents for both asphalts A and B range in value from 5.0 to 5.2 percent.

The immersion-compression design procedure was studied by the BPR only. The optimum asphalt content using this procedure was 4.6 percent for both asphalts, significantly lower than the optimum contents indicated by the other methods. There is no apparent explanation for this. All earlier work by the Bureau of Public Roads has indicated that the three methods should produce essentially the same design value.

PAVING MIXTURES

Samples of the mixtures were taken from the paver immediately before resurfacing. Results of gradation tests on the extracted aggregate are given in Table 10. The table indicates a maximum difference of two percentage points, between cooperators' results, in the amount of material passing the No. 200 mesh sieve. Also, Asphalt Institute and the Bureau of Public Roads percentages of material passing the No. 200 sieve are consistently higher than the percentages reported by Delaware. These slight differences could be due to the fact that Delaware's results are based on dry gradations in contrast to the wet gradations as used by the other two cooperators.

TABLE 10

AGGREGATE GRADATIONS AND BITUMEN CONTENTS OF LOOSE MIX SAMPLES FROM PAVER

Sample	Percent Passing Sieve								Percent Bitumen Mix Basis
	½-In.	⅜-In.	No. 4	No. 10	No. 20	No. 40	No. 80	No. 200	
Asphalt A:									
Flexible base[a]:									
Del.[b]	100	81.6	60.0	43.5	22.3	13.2	8.2	5.9	5.7
BPR[c]	100	84.6	60.1	42.9	22.0	13.7	8.9	6.8	5.6
AI[c]	100	81.1	58.6	41.5	22.4	14.3	9.6	7.4	5.6
Asphalt B:									
Rigid base[a]:									
Del.[b]	100	84.2	58.0	38.3	20.8	13.2	8.6	5.8	5.5
BPR[c]	100	89.4	63.5	41.0	22.2	14.6	9.8	7.4	5.6
AI[c]	100	86.9	62.8	39.7	21.7	14.5	10.2	7.8	5.6
Flexible base[d]:									
Del.[b]	100	85.6	63.6	42.1	21.8	13.4	8.3	5.1	5.7
BPR[c]	100	88.3	61.6	40.7	18.8	11.6	7.8	5.9	5.3
AI[c]	100	86.8	60.8	38.8	21.5	14.0	9.4	5.9	5.2

[a]Represents mixture used in pavement of BPR sampling area.
[b]Wet gradations.
[c]Dry gradations, AASHO Method T-30.
[d]Represents mixture used in pavement of Delaware Sampling area.

TABLE 11

AGGREGATE GRADATION AND BITUMEN CONTENTS OF WEARING COURSE IMMEDIATELY AFTER CONSTRUCTION (1958)

Sample	Delaware[a]								
	Percent Passing								Percent AC
	½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	
AF-1	100	86 5	58 1	40 4	21 8	14 1	9 3	6 8	5 42
AF-2	100	87 9	61 5	42 8	23 4	15 1	9 7	7 0	5 67
AF-3	100	81 2	55 1	37 0	21 2	13 8	9 5	6 9	5 30
AF-4	100	85 4	57 9	38 0	22 2	14 5	9 7	7 0	5 40
Avg	100	85 2	58 1	39 6	22 1	14 3	9 5	6 9	5 44
AR-1	100	86 7	60 6	38 1	21 0	12 9	8 4	6 1	5 56
AR-2	100	86 6	60 1	38 2	21 2	13 0	8 3	5 9	5 77
AR-3	100	87 1	61 6	41 3	21 9	13 5	8 5	6 1	5 80
AR-4	100	85 9	62 1	41 2	22 1	13 7	8 5	5 4	5 74
Avg	100	86 5	61 1	39 8	21 5	13 3	8 4	5 8	5 71
BF-1	100	87 0	64 1	44 2	23 8	15 3	9 8	6 9	5 74
BF-2	100	82 6	59 3	40 8	22 0	14 2	9 5	6 8	5 75
BF-3	100	86 4	62 5	41 9	22 8	14 5	9 2	6 5	5 75
BF-4	100	84 2	60 2	41 8	23 5	14 8	9 7	5 9	5 72
Avg	100	85 0	61 5	42 2	23 0	14 7	9 5	6 5	5 74
BR-1	100	87 0	61 5	40 8	22 4	14 7	9 9	7 2	5 79
BR-2	100	88 4	63 9	41 6	22 4	14 5	9 6	6 9	5 76
BR-3	100	84 9	61 8	40 1	21 6	14 0	9 3	6 8	5 79
BR-4	100	87 6	62 2	41 4	22 3	14 5	9 8	7 3	5 81
Avg	100	86 9	62 3	40 9	22 1	14 4	9 6	7 0	5 78
Avg (flex)	100	85 2	59 6	40 9	22 6	14 5	9 7	6 7	5 59
Avg (rigid)	100	86 8	61 7	40 3	23 1	13 9	9 0	6 5	5 75
Grand (avg)	100	86 0	60 8	40 6	22 2	14 2	9 3	6 6	5 67

Sample	Bureau of Public Roads[b]								
	Percent Passing								Percent AC
	½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	
AF-1	100 0	87 1	59 5	42 3	20 8	13 2	9 0	7 0	5 1
AF-2	99 7	86 4	63 9	45 9	22 9	14 8	9 9	7 5	5 9
AF-3	100 0	84 9	61 8	45 3	23 4	15 2	10 3	7 8	5 5
AF-4	100 0	85 0	59 9	43 2	22 7	14 9	10 0	7 8	5 7
Avg	99 9	85 8	61 3	44 2	22 4	14 5	9 8	7 5	5 6
AR-1	99 6	86 4	58 7	39 3	20 6	13 3	8 8	6 7	5 3
AR-2	100 0	86 8	60 4	39 7	21 3	13 4	8 7	6 5	5 2
AR-3	100 0	89 5	61 5	40 5	21 3	13 2	8 5	6 4	5 3
AR-4	99 9	88 5	59 8	39 7	20 8	13 4	9 0	6 9	5 3
Avg	99 9	87 8	60 1	39 8	21 0	13 3	8 8	6 6	5 3
BF-1	99 9	90 4	62 7	43 0	23 8	16 5	11 8	9 4	5 3
BF-2	100 0	86 5	61 5	43 4	25 3	18 3	14 4	12 2	5 8
BF-3	93 8	82 8	58 2	39 9	21 8	14 8	10 3	7 9	5 2
BF-4	100 0	88 6	61 2	42 0	23 5	16 2	11 6	9 2	5 6
Avg	98 4	88 5	61 8	42 8	24 2	17 0	12 6	9 7	5 6
BR-1	100 0	85 6	59 4	40 1	21 5	14 6	10 1	7 8	5 5
BR-2	100 0	87 6	60 7	40 6	21 6	14 8	10 4	8 2	5 2
BR-3	100 0	88 6	62 2	42 4	23 3	16 0	11 4	9 0	5 0
BR-4	100 0	87 3	60 8	41 0	22 1	15 1	10 6	8 3	5 2
Avg	100 0	87 9	61 3	41 9	23 2	16 1	11 6	8 3	5 4
Avg (flex)	99 2	86 5	61 2	43 1	23 0	15 5	10 9	8 6	5 5
Avg (rigid)	99 9	87 5	60 4	40 1	21 6	14 2	9 7	7 5	5 3
Grand (avg)	99 5	87 0	60 8	41 8	22 3	14 9	10 3	8 0	5 4

Sample	Asphalt Institute[b, c]								
	Percent Passing								Percent AC
	½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	
AF-1	-	-	-	-	-	-	-	-	-
AF-2	-	-	-	-	-	-	-	-	-
AF-3	-	-	-	-	-	-	-	-	-
AF-4	-	-	-	-	-	-	-	-	-
Avg	100	82 3	54 2	37 5	21 9	14 8	10 4	8 1	5 1
AR-1	-	-	-	-	-	-	-	-	-
AR-2	-	-	-	-	-	-	-	-	-
AR-3	-	-	-	-	-	-	-	-	-
AR-4	-	-	-	-	-	-	-	-	-
Avg	100	86 8	62 1	40 4	22 4	14 5	9 7	7 5	5 5
BF-1	-	-	-	-	-	-	-	-	-
BF-2	-	-	-	-	-	-	-	-	-
BF-3	-	-	-	-	-	-	-	-	-
BF-4	-	-	-	-	-	-	-	-	-
Avg	100	87 5	61 8	40 4	22 3	14 8	10 2	7 8	5 6
BR-1	-	-	-	-	-	-	-	-	-
BR-2	-	-	-	-	-	-	-	-	-
BR-3	-	-	-	-	-	-	-	-	-
BR-4	-	-	-	-	-	-	-	-	-
Avg	100	84 1	57 0	38 7	21 9	14 7	10 5	8 3	5 6
Avg (flex)	100	84 9	58 0	39 0	22 1	14 8	10 3	8 0	5 4
Avg (rigid)	100	85 5	59 6	39 6	22 2	14 6	10 1	7 9	5 6
Grand (avg)	100	85 1	58 7	39 3	22 1	14 7	10 2	7 9	5 5

[a] Dry gradation
[b] Wet gradation, AASHO Method T-30
[c] Gradations made on composite samples

TABLE 12

AGGREGATE GRADATION AND BITUMEN CONTENTS OF WEARING COURSE AFTER ONE YEAR (1959)

Delaware[a]

Sample	Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	100	88 0	59 5	40 2	21 6	14 0	9 7	7 4	5 4
AF-2	100	84 1	58.0	39 7	21 9	14 4	9 9	7 5	5 2
AF-3	100	83 9	54 6	38 4	21 6	14 2	9 6	7 3	5 1
AF-4	99 9	85 3	56 1	39 0	21 7	14 0	9 3	6 3	5 2
Avg	100	85 3	57 1	39 3	21 7	14 2	9 6	7 1	5 2
AR-1	100	87 9	62 3	42 3	22 9	14 5	9 0	6 5	5 6
AR-2	100	92 4	67 1	44 3	23 6	14 8	9 3	6 6	5 8
AR-3	100	91 1	65 5	43 3	23 1	14 3	8 9	6 5	5 7
AR-4	100	89 0	62 1	41 8	22 6	14 2	9 0	6 7	5 6
Avg	100	90 1	64 3	42 9	23 1	14 5	9 1	6 6	5 7
BF-1	100	88 5	62 9	42 8	23 6	15 5	10 3	7 6	5 4
BF-2	100	89 8	62 7	42 3	23 2	15 1	10 0	7 3	5 5
BF-3	100	89 6	63 9	43 0	23 3	15 1	9 9	7 2	5 7
BF-4	100	89 6	63 8	42 9	23 1	15 0	9 8	7 1	5 6
Avg	100	89 4	63 3	42 8	23 3	15 2	10 0	7 3	5 6
BR-1	100	87 3	58 4	40 5	22 4	14 6	9 9	7 4	5 6
BR-2	100	86 8	59 1	41 0	21 7	13 1	7 9	5 5	5 7
BR-3	100	84 4	59 0	41 5	22 8	14 7	10 0	7 3	5 7
BR-4	100	86 1	59 2	41 3	22 5	14 6	9 8	7 3	6 0
Avg	100	86 2	58 9	41 1	22 4	14 3	9 4	6 9	5 8
Avg (flex.)	100	87 4	60 8	41 1	22 5	14 7	9 8	7 2	5 4
Avg (rigid)	100	81 1	61 6	42 0	22 7	14 4	9 2	6 7	5 7
Grand avg	100	87 7	60 9	41 5	22 6	14 5	9 5	7 0	5 6

Bureau of Public Roads[b]

Sample	Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	99 8	85 6	60 9	46 0	23 7	15 2	9 8	7 7	5 7
AF-2	100 0	84 3	62 7	45 6	23 5	15 3	10 1	8 0	5 7
AF-3	100 0	83 5	59 6	43 0	22 7	15 0	9 9	7 7	5 5
AF-4	100 0	84 7	60 5	43 6	22 9	14 6	10 5	8 1	5 8
Avg	99 9	84 5	60 9	44 3	23 2	15 0	10 1	7 9	5 7
AR-1	99 3	89 5	61 6	41 1	22 5	14 9	9 7	7 7	5 1
AR-2	100 0	90 3	62 2	41 2	21 5	14 0	9 3	7 3	5 6
AR-3	100 0	87 3	59 2	39 1	19 8	13 0	8 7	6 9	5 6
AR-4	96 2	84 5	58 3	38 8	20 3	13 2	9 2	7 0	5 3
Avg	98 9	87 9	60 3	40 1	21 0	13 8	9 2	7 2	5 4
BF-1	98 5	87 0	59 9	41 5	24 4	17 4	12 9	10 8	5 5
BF-2	99 8	89 2	62 7	42 7	24 2	17 1	12 4	10 2	5 6
BF-3	99 3	88 3	60 7	40 5	22 0	15 1	10 6	8 4	5 4
BF-4	100 0	88 3	61 1	42 3	24 3	16 3	11 9	9 4	5 3
Avg	99 4	88 2	61 1	41 8	23 7	16 5	12 0	9 7	5 5
BR-1	100 0	88 4	59 3	39 9	21 9	15 0	10 3	8 1	5 4
BR-2	99 5	87 5	60 4	40 0	21 3	14 7	10 3	8 2	5 5
BR-3	100 0	88 8	61 6	40 7	22 4	15 2	10 5	8 2	5 7
BR-4	99 6	86 2	59 4	39 7	21 1	14 4	10 0	8 0	5 2
Avg	99 8	87 7	60 2	40 1	21 7	14 8	10 3	8 1	5 5
Avg (flex.)	99 7	86 4	61 0	43 0	23 5	15 8	11 0	8 8	5 6
Avg (rigid)	99 3	87 8	60 3	40 1	21 4	14 3	9 8	7 7	5 4
Grand avg	99 5	87 1	60 6	41 5	22 4	15 0	10 4	8 2	5 5

Asphalt Institute[b, c]

Sample	Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	-	-	-	-	-	-	-	-	-
AF-2	-	-	-	-	-	-	-	-	-
AF-3	-	-	-	-	-	-	-	-	-
AF-4	-	-	-	-	-	-	-	-	-
Avg	100	85 4	59 3	41 2	22 6	15 4	10 9	8 5	5 3
AR-1	-	-	-	-	-	-	-	-	-
AR-2	-	-	-	-	-	-	-	-	-
AR-3	-	-	-	-	-	-	-	-	-
AR-4	-	-	-	-	-	-	-	-	-
Avg	100	88 8	60 4	40 7	21 5	13 7	9 1	6 9	5 6
BF-1	-	-	-	-	-	-	-	-	-
BF-2	-	-	-	-	-	-	-	-	-
BF-3	-	-	-	-	-	-	-	-	-
BF-4	-	-	-	-	-	-	-	-	-
Avg	100	88 0	61 2	42 4	23 8	16 2	11 4	8 8	5 6
BR-1	-	-	-	-	-	-	-	-	-
BR-2	-	-	-	-	-	-	-	-	-
BR-3	-	-	-	-	-	-	-	-	-
BR-4	-	-	-	-	-	-	-	-	-
Avg	100	88 1	59 4	40 0	21 9	14 7	10 4	8 1	5 4
Avg (flex.)	100	86 7	60 3	41 8	23 2	15 8	11 2	8 7	5 5
Avg (rigid)	100	88 4	59 9	40 4	21 7	14 2	9 8	7 5	5 5
Grand avg	100	87 9	60 2	41 1	22 5	15 0	10 5	8 1	5 5

[a]Dry gradation
[b]Wet gradation, AASHO Method T-30
[c]Gradations made on composite samples

TABLE 13

AGGREGATE GRADATION AND BITUMEN CONTENTS OF WEARING COURSE AFTER TWO YEARS (1960)

Sample	Delaware[a] Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	100	84 6	56 3	38 2	20 7	13 7	9 3	7 0	4 9
AF-2	100	84 8	57 1	40 2	22 1	14 7	10 0	7 5	5 3
AF-3	100	84 0	55 3	39 2	22 1	14 8	10 2	7 7	5 0
AF-4	100	85 1	56 8	39 6	22 3	15 0	10 3	7 7	5 2
Avg	100	84 6	56 4	39 3	21 8	14 6	10 0	7 5	5 1
AR-1	100	90 1	63 6	42 1	22 1	13 7	8 5	6 1	5 3
AR-2	100	88 6	64 8	43 2	23 0	14 5	9 2	6 7	5 3
AR-3	100	88 4	65 0	43 0	22 4	14 1	9 1	6 7	5 6
AR-4	100	89 0	64 2	42 5	22 5	14 3	9 3	6 9	5 5
Avg	100	89 2	64 4	42 7	22 5	14 2	9 0	6 6	5 4
BF-1	100	88 0	60 8	40 8	22 1	14 2	9 3	6 7	5 1
BF-2	100	86 7	62 2	41 8	22 3	14 4	9 4	6 7	5 4
BF-3	100	88 8	62 9	42 4	22 3	14 5	9 5	6 8	5 5
BF-4	100	89 0	64 3	43 6	22 8	14 7	9 6	6 8	5 5
Avg	100	88 1	62 3	42 3	22 4	14 5	9 5	6 8	5 4
BR-1	100	85 1	57 5	39 4	21 5	14 1	9 7	7 4	5 4
BR-2	100	83 9	56 3	39 2	21 3	13 9	9 5	7 1	5 5
BR-3	100	86 4	59 7	40 0	21 4	13 9	9 6	7 3	5 5
BR-4	100	88 7	60 6	41 2	22 1	14 4	9 9	7 5	5 5
Avg	100	86 0	58 2	39 9	21 6	14 1	9 7	7 3	5 5
Avg (flex)	100	86 4	59 5	40 7	22 1	14 5	9 7	7 1	5 3
Avg (rigid)	100	87 5	61 5	41 3	22 0	14 1	9 4	7 0	5 5
Grand avg	100	86 9	60 5	41 0	22 1	14 3	9 6	7 0	5 4

Sample	Bureau of Public Roads[b] Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	100 0	87 8	61 8	43 9	23 6	15 4	10 1	7 8	5 5
AF-2	99 5	86 4	60 5	43 4	22 9	15 2	10 1	7 9	5 6
AF-3	100 0	87 2	60 8	43 5	22 4	14 8	10 0	7 9	5 7
AF-4	100 0	86 5	60 9	43 5	22 4	14 8	10 0	8 0	5 7
Avg	99 9	87 0	61 0	43 6	22 8	25 1	10 1	7 9	5 6
AR-1	100 0	89 7	59 7	39 1	20 4	13 4	8 9	7 0	5 2
AR-2	100 0	90 7	62 1	40 7	21 3	13 9	9 3	7 3	5 5
AR-3	100 0	89 8	61 2	40 5	20 7	13 5	9 1	7 3	5 6
AR-4	100 0	89 0	60 7	39 6	20 8	13 5	8 8	6 9	5 4
Avg	100 0	89 8	60 9	40 0	20 8	13 6	9 0	7 1	5 4
BF-1	100 0	88 3	61 3	42 5	24 0	17 3	13 3	11 4	5 5
BF-2	100 0	88 4	61 2	41 9	23 6	16 6	12 0	9 8	5 6
BF-3	100 0	89 0	61 1	41 2	21 8	14 8	9 9	7 5	5 6
BF-4	100 0	89 3	61 9	41 1	22 7	15 6	10 8	8 3	5 6
Avg	100 0	88 8	61 4	41 7	23 0	16 1	11 5	9 2	5 6
BR-1	100 0	88 4	60 3	40 4	22 4	15 2	10 4	8 2	5 4
BR-2	100 0	88 8	59 9	39 7	22 0	15 0	10 2	7 9	5 4
BR-3	100 0	87 9	60 6	39 7	21 7	14 8	10 2	7 9	5 4
BR-4	100 0	88 6	60 9	40 8	21 9	15 0	10 5	8 3	5 4
Avg	100 0	88 6	60 9	40 9	22 5	15 5	10 9	8 7	5 5
Avg (flex)	99 9	87 9	61 2	42 6	22 9	15 6	10 8	8 6	5 6
Avg (rigid)	100 0	89 1	60 7	40 1	21 4	14 3	9 7	7 6	5 4
Grand avg	99 9	88 5	60 9	41 3	22 2	14 9	10 2	8 1	5 5

Sample	Asphalt Institute[b, c] Percent Passing ½-In	⅜-In	No 4	No 10	No 20	No 40	No 80	No 200	Percent AC
AF-1	-	-	-	-	-	-	-	-	-
AF-2	-	-	-	-	-	-	-	-	-
AF-3	-	-	-	-	-	-	-	-	-
AF-4	-	-	-	-	-	-	-	-	-
Avg	100	85 7	58 4	40 6	22 4	15 0	10 8	8 5	5 3
AR-1	-	-	-	-	-	-	-	-	-
AR-2	-	-	-	-	-	-	-	-	-
AR-3	-	-	-	-	-	-	-	-	-
AR-4	-	-	-	-	-	-	-	-	-
Avg	100	89 7	61 7	41 5	21 9	13 9	9 4	7 4	5 6
BF-1	-	-	-	-	-	-	-	-	-
BF-2	-	-	-	-	-	-	-	-	-
BF-3	-	-	-	-	-	-	-	-	-
BF-4	-	-	-	-	-	-	-	-	-
Avg	100	89 5	62 2	43 0	23 8	15 7	11 0	8 5	5 6
BR-1	-	-	-	-	-	-	-	-	-
BR-2	-	-	-	-	-	-	-	-	-
BR-3	-	-	-	-	-	-	-	-	-
BR-4	-	-	-	-	-	-	-	-	-
Avg	100	88 8	60 9	41 2	22 8	15 3	11 0	8 7	5 5
Avg (flex)	100	87 6	60 3	41 8	23 1	15 4	10 9	8 5	5 5
Avg (rigid)	100	89 3	61 3	41 4	22 4	14 6	10 2	8 1	5 6
Grand avg	100	88 4	60 8	41 8	22 7	15 0	10 5	8 3	5 5

[a] Dry gradation
[b] Wet gradation, AASHO Method T-30
[c] Gradations determined on individual blocks and averaged

TABLE 14

MARSHALL TEST PROPERTIES OF PAVEMENT CORE SAMPLES IMMEDIATELY AFTER CONSTRUCTION (1958)

Sample	Delaware					Bureau of Public Roads					Asphalt Institute				
	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)
AF-1	1,041	17 3	2 34	96 6	7 9	1,220	14	2 348	94	8 2	1,069	18	2 362	93 7	8 0
AF-2	-	-	-	-	-	1,270	15	2 343	94	8 4	913	18	2 354	93 3	8 3
AF-3	820	14 0	2 36	97 0	7 1	1,400	13	2 389	96	6 4	1,137	16	2 353	93 3	8 4
AF-4	860	16 5	2 36	96 6	7 1	1,330	13	2 372	95	7 3	1,293	17	2 384	94 6	7 1
Avg	910	15 9	2 35	96 7	7 4	1,330	14	2 363	95	7 6	1,100	17	2 363	93 7	8 0
AR-1	1,290	15 4	2 37	96 6	6 7	1,040	15	2 328	93	9 0	1,113	18	2 343	92 9	8 7
AR-2	1,340	15 0	2 22	95 8	8 3	890	15	2 267	91	11 4	963	17	2 323	92 1	9 5
AR-3	1,140	17 0	2 35	96 2	7 5	1,080	16	2 282	92	10 8	968	16	2 336	92 7	9 0
AR-4	1,230	19 5	2 39	95 0	5 9	1,060	13	2 307	93	9 8	1,224	17	2 356	93 4	8 2
Avg	1,250	16 7	2 36	95 8	7 1	1,020	15	2 296	92	10 3	1,070	17	2 340	92 8	8 9
BF-1	1,010	19 8	2 31	93 5	9 4	-	-	2 373	95	7 4	837	20	2 315	91 7	9 9
BF-2	1,900	15 5	2 30	96 3	9 8	-	-	2 358	95	8 0	834	17	2 308	91 5	10 1
BF-3	-	-	-	95 5	-	1,230	12	2 382	96	7 0	754	18	2 307	91 4	10 2
BF-4	1,340	15 0	2 38	95 5	6 7	1,450	13	2 382	96	7 0	865	17	2 320	91 9	9 7
Avg	1,080	16 8	2 33	95 1	8 6	1,340	12	2 374	96	7 3	820	18	2 313	91 6	10 0
BR-1	-	-	2 35	97 9	7 8	1,400	15	2 363	95	7 8	1,376	19	2 394	94 9	6 8
BR-2	1,600	19 0	2 38	98 7	6 7	1,110	16	2 325	94	9 3	1,390	17	2 349	93 0	8 6
BR-3	1,560	17 4	2 43	99 9	4 7	1,150	11	2 351	95	8 2	1,662	20	2 431	96 3	5 4
BR-4	1,590	18 0	2 44	99 2	4 3	1,330	15	2 447	98	4 5	1,757	17	2 441	96 7	5 0
Avg	1,550	18 0	2 40	99 2	5 9	1,250	14	2 372	95	7 4	1,550	18	2 404	95 2	6 5
Avg (flex.)	1,000	16 4	2 34	95 9	8 0	1,320	13	2 368	95	7 5	960	18	2 338	92 7	9 0
Avg (rigid)	1,380	17 0	2 38	97 5	6 5	1,130	14	2 334	94	8 8	1,310	18	2 372	94 0	7 7
Grand (avg)	1,200	16 9	2 36	96 7	7 1	1,220	14	2 351	95	8 2	1,140	18	2 355	93 3	8 3

[a]Based on laboratory bulk specific gravities given in Table 19
[b]Based on values of MTD given in Table 19

TABLE 15

MARSHALL TEST PROPERTIES OF PAVEMENT CORE SAMPLES AFTER ONE YEAR (1959)

Sample	Delaware					Bureau of Public Roads					Asphalt Institute				
	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)
AF-1	1,320	18	2 38	96 2	6 3	1,232	15	2 338	94	8 6	1,197	17	2 347	93 1	8 5
AF-2	1,340	17	2 37	95 8	6 9	1,309	15	2 372	95	7 3	1,561	14	2 395	95 0	6 7
AF-3	1,630	15	2 38	96 2	6 3	1,788	11	2 434	98	4 9	1,554	14	2 398	95 1	6 6
AF-4	2,160	17	2 40	97 0	5 6	1,965	14	2 446	98	4 4	1,496	15	2 368	93 9	7 8
Avg	1,610	17	2 38	96 2	6 3	1,574	14	2 397	96	6 3	1,450	15	2 377	94 3	7 4
AR-1	1,420	18	2 35	95 0	7 6	1,735	12	2 350	94	8 2	1,085	18	2 354	93 3	8 3
AR-2	1,630	18	2 37	95 8	6 7	1,456	11	2 359	95	7 8	1,674	15	2 370	94 0	7 7
AR-3	1,980	16	2 36	95 4	7 2	1,447	9	2 343	94	8 4	1,540	14	2 379	94 3	7 4
AR-4	1,980	16	2 41	97 4	5 1	1,397	14	2 345	94	8 4	1,710	14	2 394	94 9	6 8
Avg	1,750	17	2 37	95 8	6 7	1,509	12	2 349	94	8 2	1,500	15	2 374	94 1	7 6
BF-1	1,180	15	2 35	94 7	8 0	1,738	11	2 371	95	7 5	1,314	16	2 380	94 3	7 4
BF-2	1,090	17	2 38	95 9	6 6	2 038	13	2 425	98	5 4	1,582	14	2 430	96 3	5 4
BF-3	1,440	17	2 38	95 9	6 6	1,811	13	2 389	96	6 8	1,527	13	2 437	96 6	5 1
BF-4	1,460	16	2 37	95 5	6 8	1,852	11	2 401	97	6 3	1,668	15	2 414	95 7	6 0
Avg	1,290	16	2 37	95 5	7 0	1,860	12	2 396	96	6 5	1,520	15	2 415	95 7	6 0
BR-1	1,550	19	2 43	97 9	4 8	1,265	15	2 314	93	9 7	1,471	17	2 389	94 7	7 0
BR-2	1,840	18	2 46	99 2	5 8	1,336	10	2 312	93	9 8	1,484	15	2 378	94 3	7 4
BR-3	2,070	19	2 43	97 9	4 6	1,490	11	2 434	98	5 0	1,722	17	2 404	95 3	6 5
BR-4	2,300	20	2 40	96 7	3 4	1,928	11	2 468	99	3 7	1,969	15	2 452	97 1	4 6
Avg	1,940	19	2 43	97 9	4 7	1,505	12	2 382	96	7 0	1,651	16	2 406	95 4	6 4
Avg (flex.)	1,450	17	2 38	95 6	6 6	1,717	13	2 397	96	6 4	1,490	15	2 396	95 4	6 7
Avg (rigid)	1,850	18	2 40	96 9	5 7	1,507	12	2 366	95	7 6	1,630	16	2 390	94 7	7 0
Grand avg	1,650	17	2 39	96 3	6 1	1,612	12	2 381	96	7 0	1,540	15	2 393	94 9	6 9

[a]Based on laboratory bulk specific gravities given in Table 19.
[b]Based on values of MTD given in Table 19

TABLE 16

MARSHALL TEST PROPERTIES OF PAVEMENT CORE SAMPLES AFTER TWO YEARS (1960)

Sample	Delaware					Bureau of Public Roads					Asphalt Institute				
	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)	Stability (lb)	Flow (1/100 in)	Bulk Specific Gravity	Percent of Laboratory Density[a]	Air Voids[b] (%)
AF-1	1,590	21	2 39	94 6	6 2	1,779	12	2 357	95	7 9	1,585	17	2 351	93 2	8 4
AF-2	1,730	17	2 37	-	6 0	1,800	13	2 390	96	6 6	1,896	17	2 387	94 6	7 0
AF-3	1,760	19	2 40	95 4	6 8	2,374	11	2 451	98	4 2	1,927	17	2 367	93 9	7 8
AF-4	2,170	17	2 39	95 4	5 3	2,065	11	2 410	97	5 8	1,834	17	2 356	93 4	8 2
Avg	1,810	19	2 39	95 0	6 1	2,004	12	2 402	96	6 1	1,810	17	2 365	93 8	7 9
AR-1	1,770	18	2 39	95 8	6 5	1,729	11	2 394	96	6 4	1,581	19	2 361	93 6	8 0
AR-2	1,560	16	2 37	89 7	7 6	1,543	14	2 381	96	7 0	1,629	17	2 360	93 6	8 1
AR-3	1,470	18	2 38	95 0	7 0	1,729	10	2 376	95	7 2	1,756	16	2 384	94 5	7 1
AR-4	1,760	18	2 35	96 6	5 9	1,665	10	2 372	95	7 3	1,923	14	2 393	94 9	6 8
Avg	1,640	17	2 37	95 4	6 8	1,666	11	2 381	96	7 0	1,725	17	2 375	94 2	7 5
BF-1	1,250	16	2 32	93 1	9 4	1,852	14	2 413	97	5 8	1,634	17	2 337	92 6	9 0
BF-2	1,440	16	2 39	92 7	6 8	1,850	14	2 433	98	5 0	1,853	16	2 354	93 3	8 4
BF-3	1,280	16	2 37	-	6 4	1,779	12	2 388	96	6 8	1,313	12	2 428	96 2	5 5
BF-4	1,390	17	2 37	95 9	7 4	2,002	11	2 395	96	6 5	1,804	16	2 371	93 9	7 7
Avg	1,340	16	2 36	93 9	7 5	1,871	13	2 407	97	6 1	1,650	15	2 373	94 0	7 7
BR-1	1,800	20	2 43	94 7	4 9	1,321	13	2 341	94	8 6	1,756	17	2 402	95 2	6 5
BR-2	1,870	18	2 45	95 9	4 0	1,357	14	2 354	95	8 1	1,865	17	2 401	95 1	6 5
BR-3	1,840	18	2 48	97 9	3 4	1,694	11	2 428	98	5 2	2,050	16	2 433	96 4	5 3
BR-4	2,020	17	2 46	98 3	2 8	2,002	13	2 472	99	3 5	2,146	16	2,455	97 3	4 4
Avg	1,880	18	2 46	96 7	3 8	1,594	13	2 398	97	6 4	1,954	17	2 417	96 0	5 7
Avg (flex)	1,576	17	2 40	94 5	6 8	1,938	12	2 405	97	6 1	1,730	16	2 369	93 9	7 8
Avg (rigid)	1,760	18	2 41	96 1	5 3	1,630	12	2 390	96	6 7	1,860	17	2 399	95 1	6 6
Grand avg	1,670	18	2 39	95 3	6 0	1,784	12	2 397	96	6 4	1,785	16	2 384	94 5	7 2

[a]Based on laboratory bulk specific gravities given in Table 19
[b]Based on values of MTD given in Table 19

TABLE 17

HVEEM TEST PROPERTIES OF PAVEMENT CORE SAMPLES BY ASPHALT INSTITUTE

Sample	Immediately After Construction				After One Year				After Two Years			
	Bulk Specific Gravity	Stability Value	Percent of Laboratory Density[a]	Air Voids[b] (%)	Bulk Specific Gravity	Stability Value	Percent of Laboratory Density[a]	Air Voids[b] (%)	Bulk Specific Gravity	Stability Value	Percent of Laboratory Density[a]	Air Voids[b] (%)
AF-1	2 372	17	94.1	7 6	2 371	25	94 0	8.3	2 368	22	93 9	7 8
AF-2	2 353	14	93 3	8 3	2 406	26	95 4	6 3	2 399	21	95 1	6 5
AF-3	2 360	18	93 6	8 1	2 393	23	94 9	6 7	2.376	20	94 2	7 4
AF-4	2 383	25	94.5	7 2	2 378	24	94 3	7 4	2 356	21	93 4	8 2
Avg	2 367	19	93.9	7 8	2 387	25	94 7	7 2	2.375	21	94 2	7.5
AR-1	2 340	22	92 8	8.8	2 370	28	94 0	7 7	2.403	30	95.3	6.4
AR-2	2 321	18	92 0	9 6	2 370	28	94 0	7 7	2 367	27	93 9	7.8
AR-3	2.330	22	92 4	9 2	2 373	27	94 1	7 6	2.400	24	95.2	6 5
AR-4	2 358	23	93 5	8 1	2 388	30	94 7	7 0	2 379	28	94 3	7.3
Avg	2.337	21	92 7	8.9	2.375	28	94 2	7 5	2 387	27	94 7	7 0
BF-1	2.314	22	91 7	9 9	2.407	25	95 4	6 3	2 348	20	93 0	8 6
BF-2	2.317	16	91 8	9 8	2.407	24	97 9	3 9	2 343	20	92 8	8 8
BF-3	2.300	15	91 1	10 5	2 439	23	96.6	5.1	2 391	27	94 7	6.9
BF-4	2 330	21	92.3	9 3	2.423	21	96 0	5 7	2 344	22	92 9	8.8
Avg	2 315	19	91 7	9 9	2 435	23	96 5	5.3	2 357	22	93 4	8 3
BR-1	2 398	24	95.0	6 7	2 405	30	95 3	6 4	2.415	28	95.7	6 0
BR-2	3 343	20	92 8	8 8	2 385	26	94 5	7 2	2.389	22	94.7	7 0
BR-3	2.452	30	97 1	4 6	2.399	26	95 0	6 6	2 426	27	96.1	5.6
BR-4	2.437	30	96 6	5.1	2 455	34	97 3	4.4	2 455	27	97.3	4.4
Avg	2 383	26	95 4	6.3	2 411	29	95 5	6 2	2 421	26	96 0	5 8
Avg (flex.)	2 341	19	92 8	8 8	2 411	24	95 6	6.2	2 366	22	93.8	7 9
Avg (rigid)	2.372	24	94 0	7.6	2 393	29	94 9	6.8	2 404	27	95.8	6 4
Grand avg	2.357	21	93.4	8.2	2.402	26	95 2	6 5	2 385	24	94 5	7.1

[a]Based on laboratory bulk specific gravities given in Table 19.
[b]Based on values of MTD given in Table 19.

TABLE 18

COMPRESSIVE STRENGTH TESTS OF CORES FROM ASPHALTIC PAVEMENT BY PUBLIC ROADS

Identification	Immediately After Bulk Specific Gravity	Construction Compressive Strength (psi)	After One Year		After Two Years	
			Bulk Specific Gravity	Compressive Strength (psi)	Bulk Specific Gravity	Compressive Strength (psi)
AF-1	2.348	312	2 338	448	2.357	382
AF-2	2.343	360	2.372	527	2.390	489
AF-3	2.389	382	2 434	571	2.451	497
AF-4	2.372	369	2.446	525	2.410	426
Avg.	2.363	356	2.397	518	2.402	448
AR-1	2.328	350	2.350	470	2.394	450
AR-2	2.267	292	2 359	525	2.381	438
AR-3	2.282	286	2.343	456	2.376	356
AR-4	2.307	308	2.345	446	2.372	414
Avg.	2.296	412	2 349	474	2.381	414
BF-1	2.373	308	2.371	533	2.413	470
BF-2	2.358	321	2.425	561	2.433	481
BF-3	2.382	319	2 389	553	2.388	394
BF-4	2.382	329	2.401	501	2.395	450
Avg.	2.374	319	2.396	537	2.407	449
BR-1	2.363	308	2.314	334	2.341	314
BR-2	2.325	294	2.312	378	2.354	358
BR-3	2 351	302	2.434	446	2.428	406
BR-4	2.447	356	2.468	473	2.472	392
Avg.	2.334	315	2.382	408	2.398	391
Avg. (flex.)	2.368	338	2.397	527	2.405	449
Avg. (rigid)	2.334	312	2 366	441	2.390	391
Grand avg.	2.351	325	2.381	484	2.397	420

TABLE 19

SPECIFIC GRAVITIES USED BY COOPERATORS

Item	Specific Gravity					
	Marshall			Hveem		Immersion Compression
	Del.	BPR	AI	BPR	AI	BPR
Aggregate:						
A mixes	2.79	2.81	2.814	2.802[a]	2.814	2.801[a]
B mixes	2.79	2.81	2.814	2.811[a]	2.814	2.803[a]
Asphalt:						
A mixes	1.023	1.023	1.024	1.023	1.024	1.023
B mixes	1.030	1.030	1.030	1.030	1.030	1.030
Laboratory bulk specific gravity[b]:						
A mixes	2.474	2.475	2.522[c]	2.521	2.522	2.492
B mixes	2.481	2.487	2.524[c]	2.501	2.524	2.486
Maximum theoretical density[c]:						
A mixes	2.540	2.559	2.567	2.559[a]	2.567	2.559[a]
B mixes	2.550	2.562	2.569	2.562[a]	2.569	2.562[a]

[a]Based on Rice saturation vacuum precedure.
[b]Based on mixture containing 5.5 percent asphalt; used in computing percentage of laboratory density for pavement samples.
[c]AI used Marshall bulk specific gravities to compute percent compaction.
[d]Del. and AI values based on 5.5 percent asphalt in mixture and apparent specific gravity of aggregate.

TABLE 20

PROPERTIES OF ASPHALTS RECOVERED FROM WEARING COURSE

Sample	Immediately After Construction									After One Year (1959)									After Two Years (1960)								
	Pen 100 g, 5 sec, 77 F			Softening Point (°F)			Ductility 77 F, 5 cm/min			Pen 100 g, 5 sec, 77 F			Softening Point (°F)			Ductility 77 F, 5 cm/min			Pen. 100 g 5 sec, 77 F			Softening Point (°F)			Ductility 77 F, 5 cm/min		
	Del.	AI	BPR	Del.	AI	BPR	Del	AI	BPR	Del	AI	BPR	Del.	AI	BPR	Del	AI	BPR	Del	AI	BPR	Del	AI	BPR	Del.	AI	BPR
AF-1	34	-	34	133	-	137	17	-	250+	19	-	27	153	-	142	10	-	79	22	24	24	-	145	146	-	42	78
AF-2	38	-	32	138	-	139	26	-	226	25	-	24	-	-	145	-	-	85	23	22	21	-	146	146	-	38	71
AF-3	36	-	33	140	-	137	31	-	250+	25	-	22	145	-	142	19	-	129	21	22	22	-	145	147	-	42	55
AF-4	30	-	34	142	-	137	19	-	160	19	-	26	147	-	140	22	-	152	21	22	23	-	145	144	-	45	88
Avg.	35	33	33	138	136	137	23	150+	208+	22	30	25	148	138	142	17	150+	111	22	23	22	-	145	146	-	42	73
AR-1	30	-	33	136	-	137	78	-	242	-	-	24	-	-	142	-	-	93	21	21	22	144	146	145	23	50	69
AR-2	40	-	31	133	-	140	68	-	250+	22	-	25	145	-	136	15	-	96	21	23	17	136	148	147	20	27	28
AR-3	46	-	30	131	-	140	91	-	180	20	-	24	153	-	142	10	-	62	22	22	19	143	146	145	20	38	55
AR-4	42	-	32	133	-	138	82	-	250+	24	-	27	149	-	140	20	-	149	22	24	18	140	146	147	26	55	58
Avg.	40	32	32	133	136	139	80	150+	220+	22	31	25	149	138	140	15	150+	100	22	23	19	141	146	146	22	43	52
BF-1	38	-	36	135	-	136	91	-	143	22	-	25	145	-	146	20	-	41	26	27	27	152	146	144	39	45	62
BF-2	34	-	38	135	-	136	85	-	250+	27	-	29	144	-	141	22	-	65	24	25	28	154	148	142	27	26	79
BF-3	42	-	39	131	-	134	100	-	214	27	-	28	147	-	144	15	-	97	25	-	24	153	-	147	23	-	33
BF-4	31	-	38	135	-	135	42	-	150	25	-	30	141	-	141	40	-	95	26	31	25	144	142	145	35	85	36
Avg	36	40	38	134	132	135	80	150+	188+	25	39	28	145	136	143	24	150+	75	25	28	26	151	145	145	31	52	52
BR-1	34	-	-	135	-	-	51	-	-	25	-	30	149	-	143	21	-	76	23	27	26	148	145	146	22	43	44
BR-2	30	-	36	140	-	138	23	-	173	23	-	28	149	-	144	11	-	46	26	25	23	144	147	146	23	28	45
BR-3	29	-	38	145	-	136	14	-	191	24	-	33	144	-	140	32	-	72	28	28	25	140	145	146	44	39	34
BR-4	32	-	41	136	-	135	34	-	250+	27	-	36	142	-	137	33	-	181	30	29	33	132	145	139	39	41	131
Avg.	31	36	38	139	135	136	31	150+	205+	25	37	32	146	134	141	24	150+	94	27	27	27	141	145	144	32	38	63

PAVEMENT SAMPLES

As previously indicated, the primary objectives of the research are to measure the changes occurring in characteristics of the pavement and asphaltic binder during service and to establish specific relationships between the various characteristics.

To accomplish this, pavement samples were taken immediately after construction, and after one and two years of service. Further periodic tests will be made until the conclusion of the study.

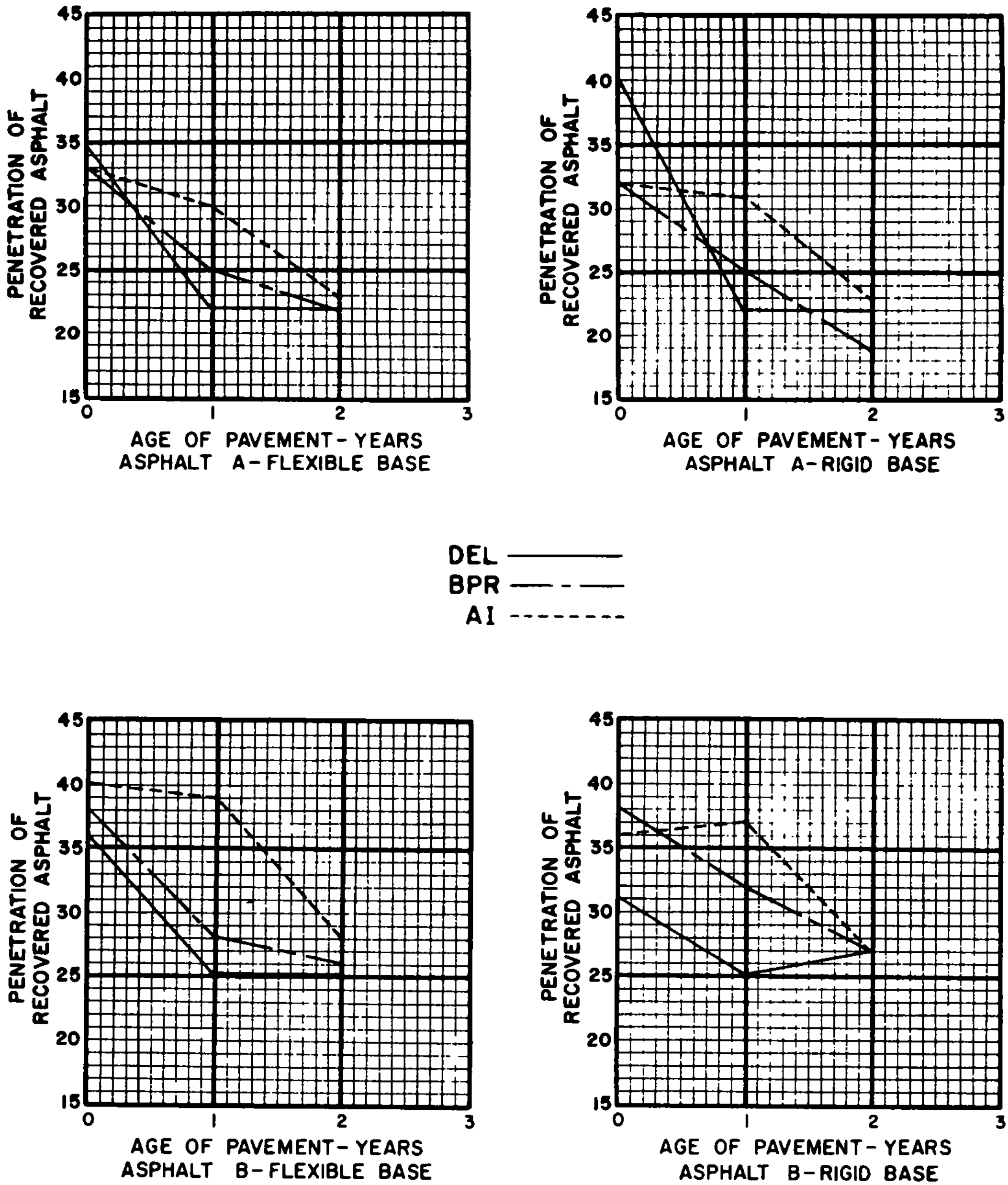

Figure 8. Penetration of recovered asphalt, with years of service.

The block samples shown in Figure 3, were used for extraction tests and tests on recovered asphalt.

Gradations

Gradations were made on the aggregate from each individual block sample by Delaware and the Bureau of Public Roads. The test values reported by the Asphalt Institute are results of composite block samples for sampling periods 1 and 2. Third sampling

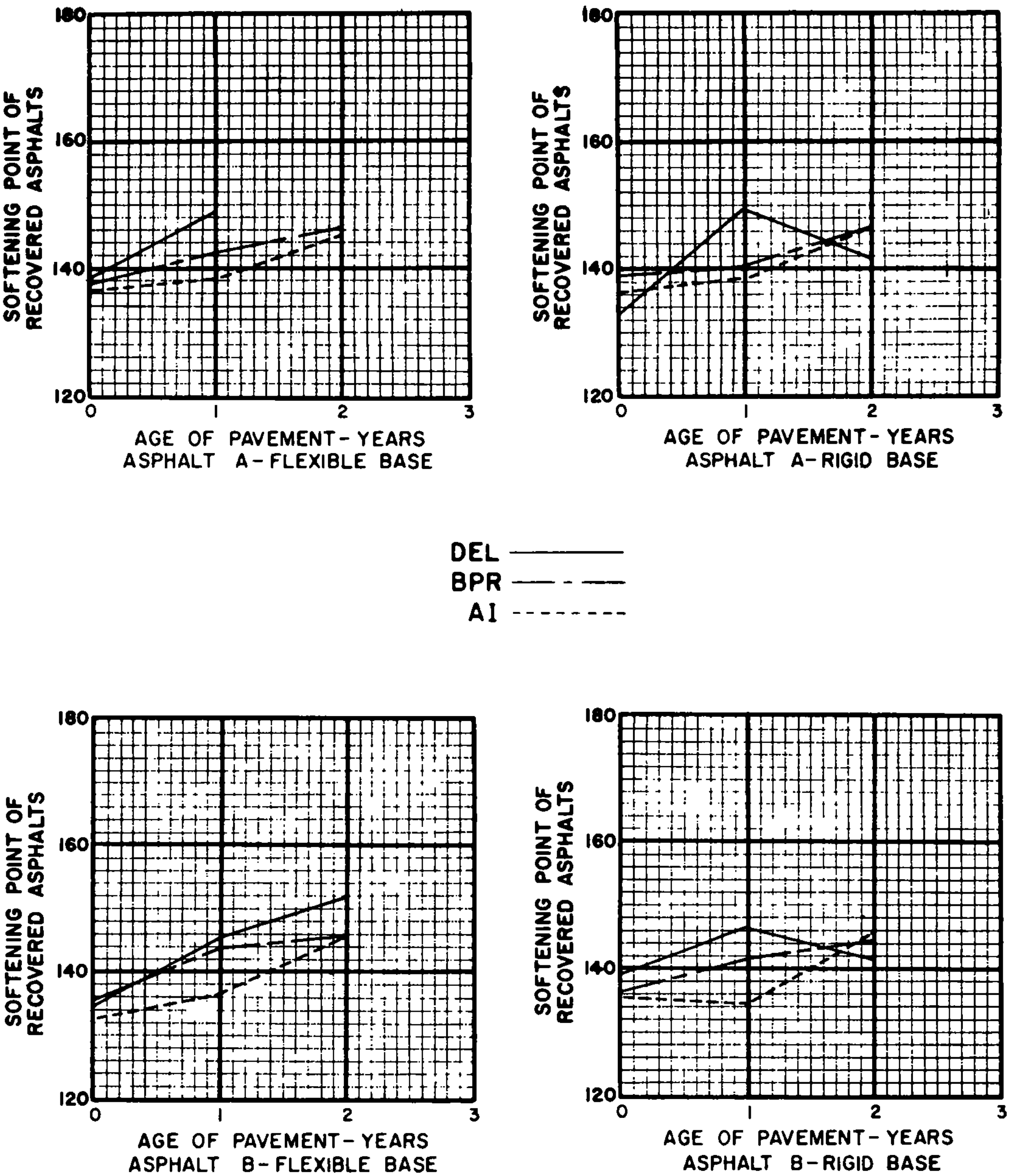

Figure 9. Softening point of recovered asphalts, with years of service.

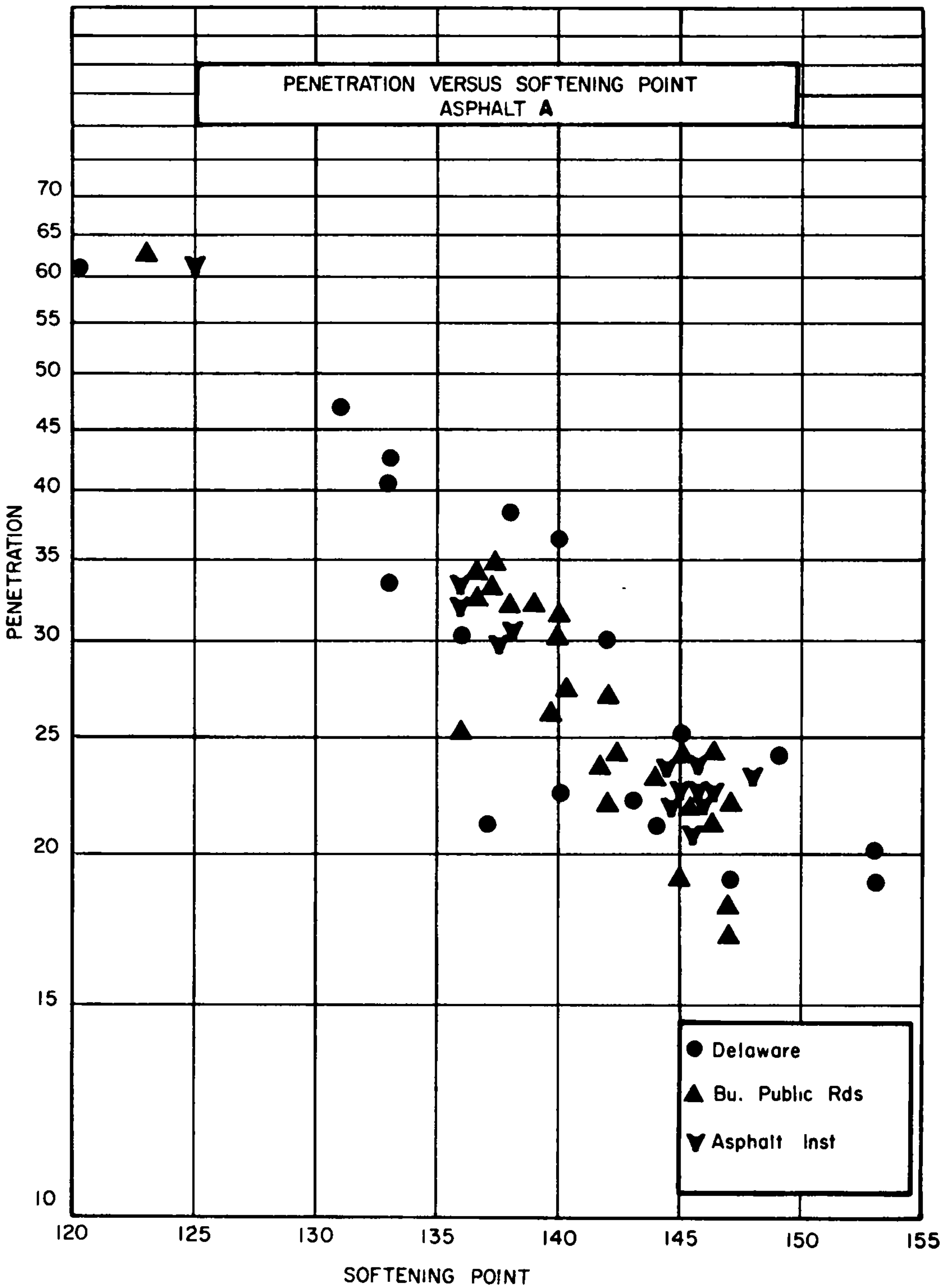

Figure 10. Penetration vs softening point, asphalt A.

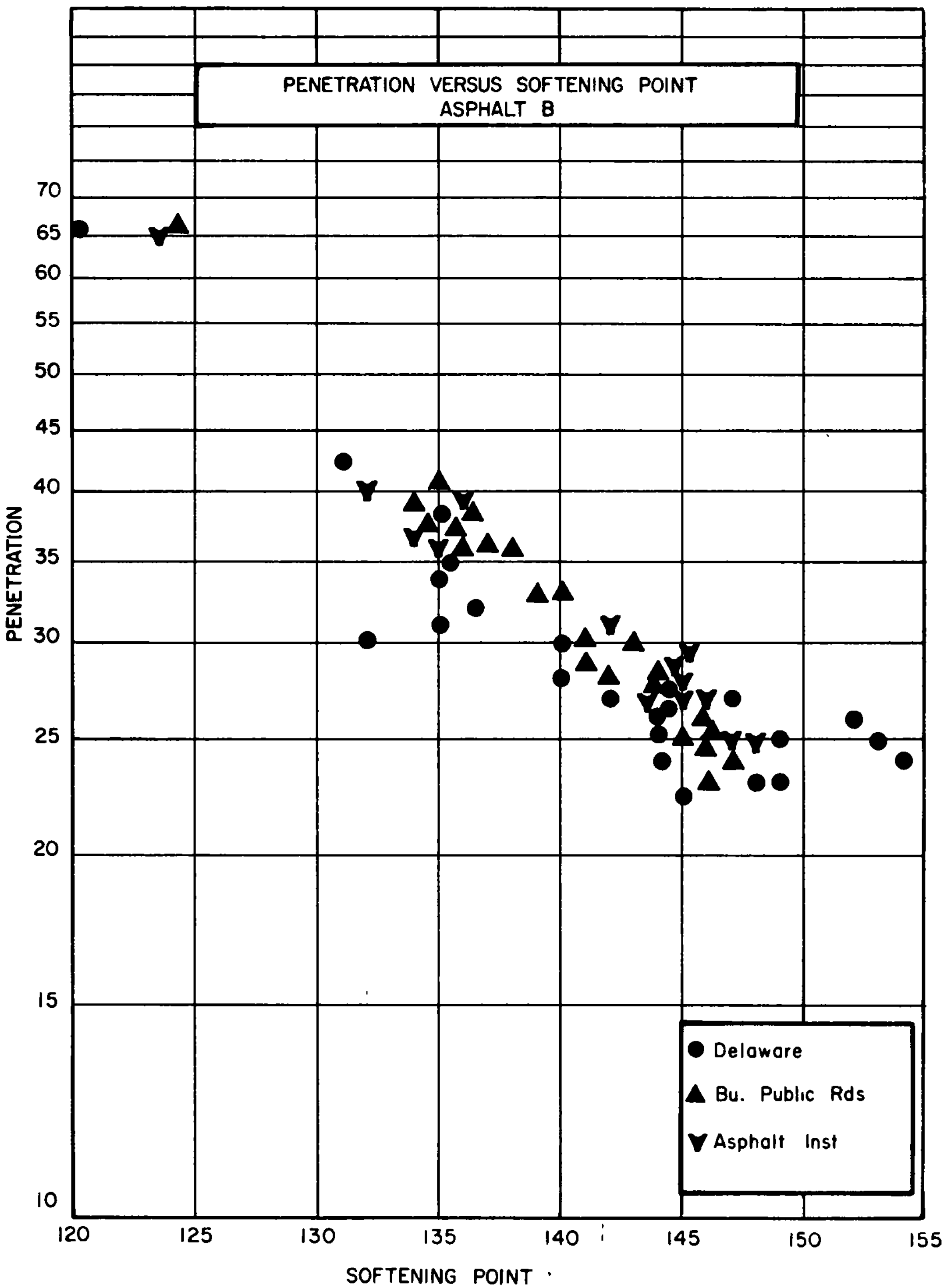

Figure 11. Penetration vs softening point, asphalt B.

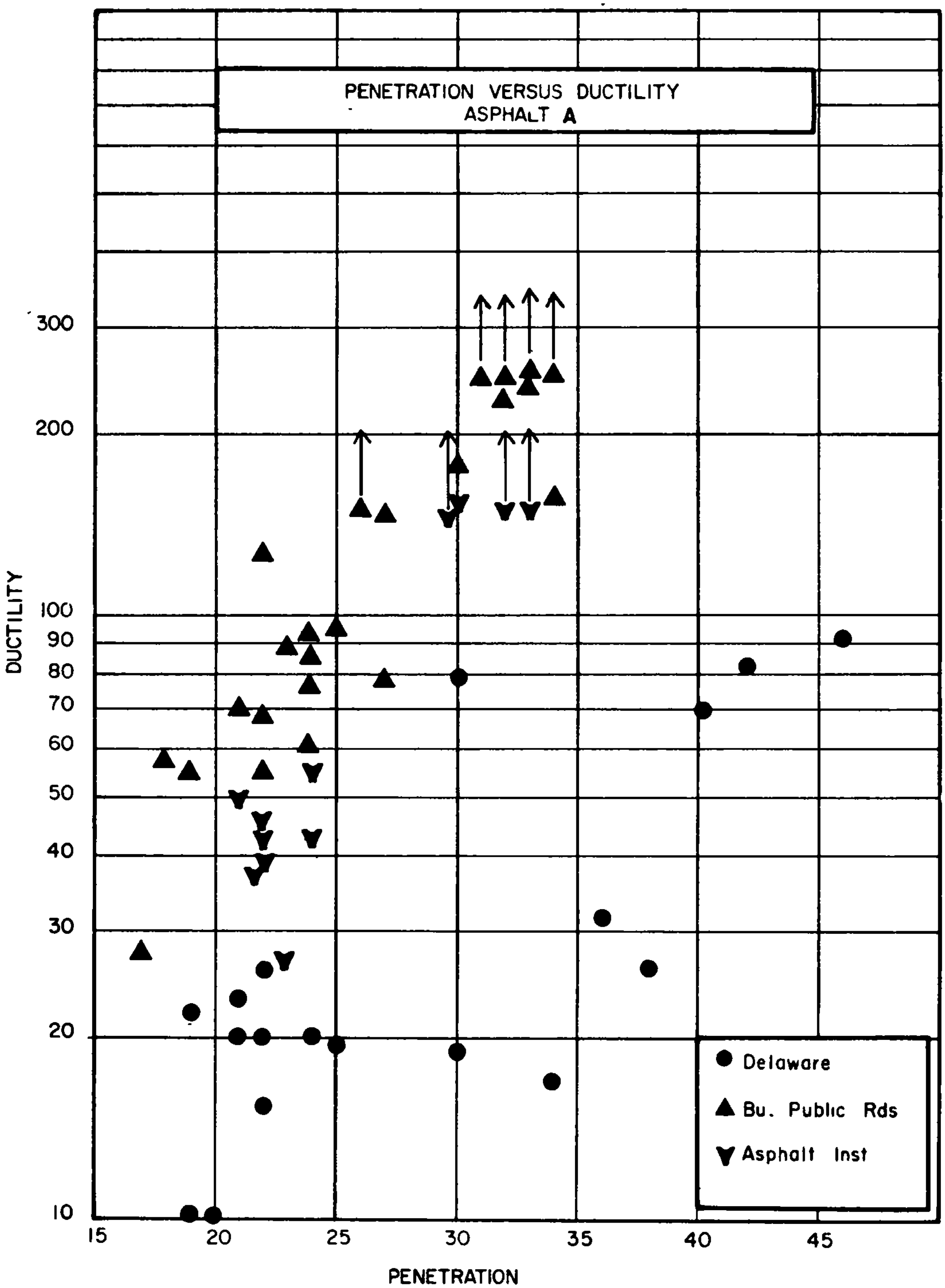

Figure 12. Penetration vs ductility, asphalt A.

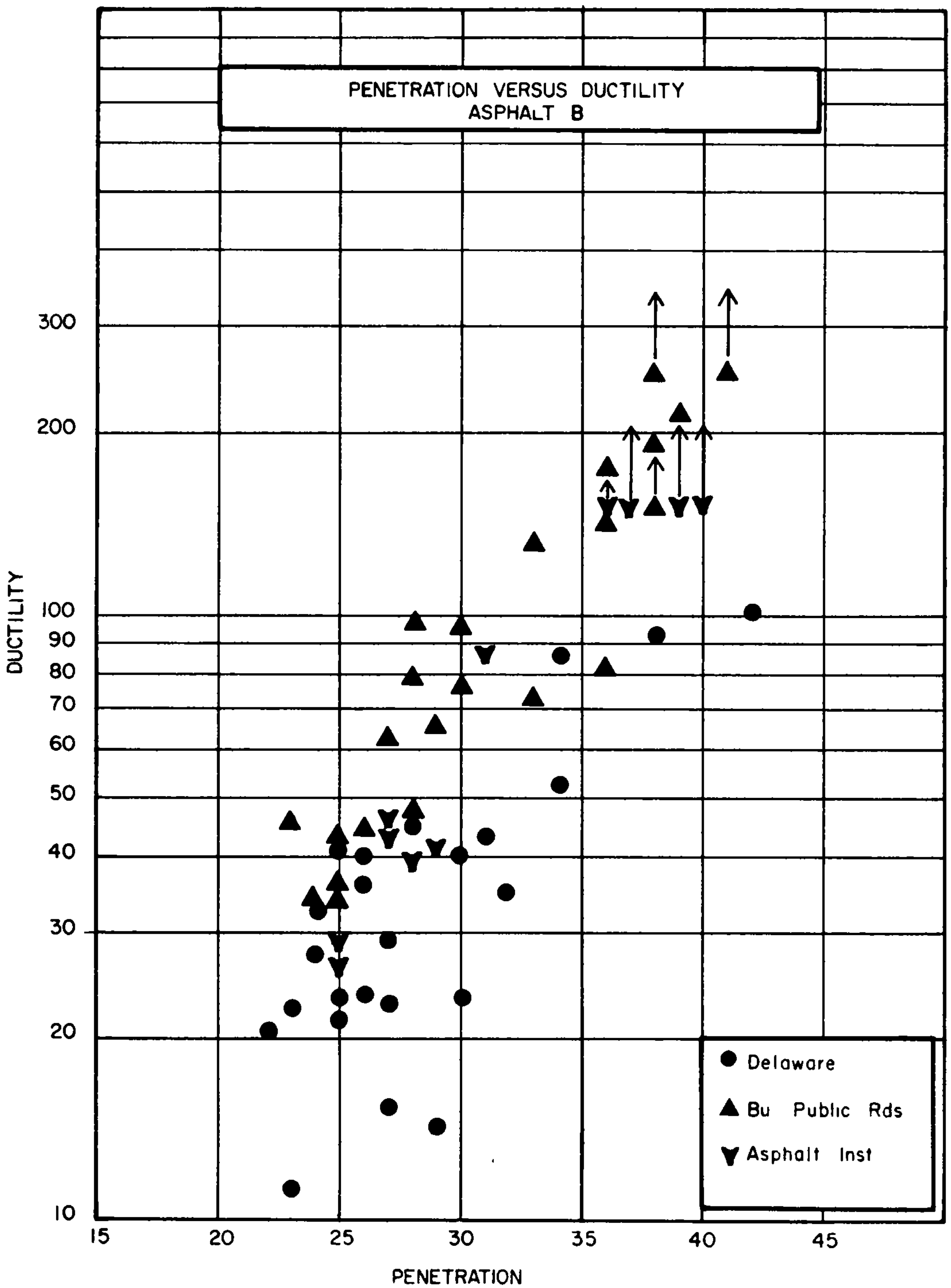

Figure 13. Penetration vs ductility, asphalt B.

period test values reported by the Asphalt Institute are averages of four block samples. All Delaware aggregate gradations were unwashed, whereas washed gradations were used by the Bureau of Public Roads and the Asphalt Institute.

Tables 11, 12, and 13 give the gradations and asphalt contents of the pavement samples. Analysis of these indicate that section AR is low in percentage of aggregate passing the No. 200 mesh sieve as compared with the other three sections.

Stability

The cored specimens were used for various stability tests. Delaware performed only Marshall tests. Bureau of Public Roads performed Marshall and unconfined compression tests, and the Asphalt Institute performed Marshall and Hveem tests. The Delaware and Asphalt Institute Marshall values are averages of four tests. Both unconfined compression and Hveem test specimens were made from stacked cores.

The results of Marshall tests are given in Tables 14, 15, and 16. Figure 6, which shows the relation of stability and age for each experimental section, indicates increases in stability over the two-year period in all sections. On the other hand, tests in the Hveem apparatus (Table 17) and compressive strength values (Table 18) show higher stabilities after the first year but decreasing stability after the second year. Figure 7 shows a definite reduction in air voids over the first year period, which is in line with the increase in stability, but average values for the two-year samples are erratic. The general trend is for a leveling off, but in some cases the two-year averages were slightly higher than the one-year values.

Table 19 gives the several specific gravities used by the three cooperators in computing voids and percent of laboratory density for the preceeding tables. The differences in test results between the cooperators are partially due to the use of different specific gravities. However, the primary reason for differences is probably due to experimental error or to actual differences in the pavement sampling areas. In the future it is planned to interchange samples to establish the effect of differences in sampling areas.

Changes in Asphalt Characteristics

Table 20 gives the normal changes evident from year to year. Even though there are some inconsistencies (ductility test results), there seems to be substantially good agreement among laboratories.

Figure 8 shows the relation of the penetrations of recovered asphalts from pavement samples with years of service. Four plates are shown, each representing an experimental condition; that is, asphalt A over a flexible or rigid base, and asphalt B for the same condition. The data plotted in the graphs are the average results obtained by each cooperator for each condition. Although there are some differences in the pattern obtained by the different laboratories, the data obtained after two years indicate good agreement between cooperators' results. This may be attributed to better standardization of the test methods used by each cooperator or it may indicate that early differences in different sections of the pavement tend to disappear with time. Asphalt Institute results for zero and one year are values for composite block samples (that is, a sample consisting of AF-1, 2, 3, and 4), whereas Delaware and Bureau of Public Roads results are averages of separate determinations for each block. Two-year samples were tested by the Asphalt Institute in the same manner as the other cooperating laboratories. The method of extraction was changed by Delaware for the two-year samples. Previously, extractions were performed by centrifuging (AASHO Method T164). Two-year samples were tested by the reflux method (Faulwetter extractor), in accordance with AASHO method T184. This was an attempt to limit the amount of dust being introduced into the extracted asphalt to a minimum. The asphalt solution from Method T164 and T184 was not supercentrifuged.

Figure 9 shows in general the normal increases expected except for the unusually high results obtained by Delaware for the one-year samples. This may be experimental error resulting from high dust content in the recovered sample.

Figures 10 and 11 show the relation of penetrations to softening points of recovered asphalts for both asphalt A and B respectively. Comparison of the slopes of the two plots shows that asphalt A has a slightly greater negative slope.

Figures 12 and 13 are plots of ductility vs penetration. There is considerable scatter in the data points but a close look at these plots indicates that the data for each laboratory tends to establish a particular curve. The curves established by each cooperator are approximately parallel.

Traffic

The effect of traffic on the experimental section has not shown any definite trends; however, certain individual samples indicate greater densities and stabilities for blocks 3 and 4. This may be due to traffic hugging or even crossing the centerline. The annual average 24-hr traffic including all vehicles during 1960 was approximately 1,050.

CONCLUSIONS

At present no specific conclusions can be drawn, but the laboratory tests indicate that variances in behavior of the same asphalt at different locations in the road may be as great as or greater than variances in the asphalts from the different crude sources used in this study. Other than minor reflection cracking from the concrete base on the rigid sections, no deterioration in the pavements has been noted at any locations.