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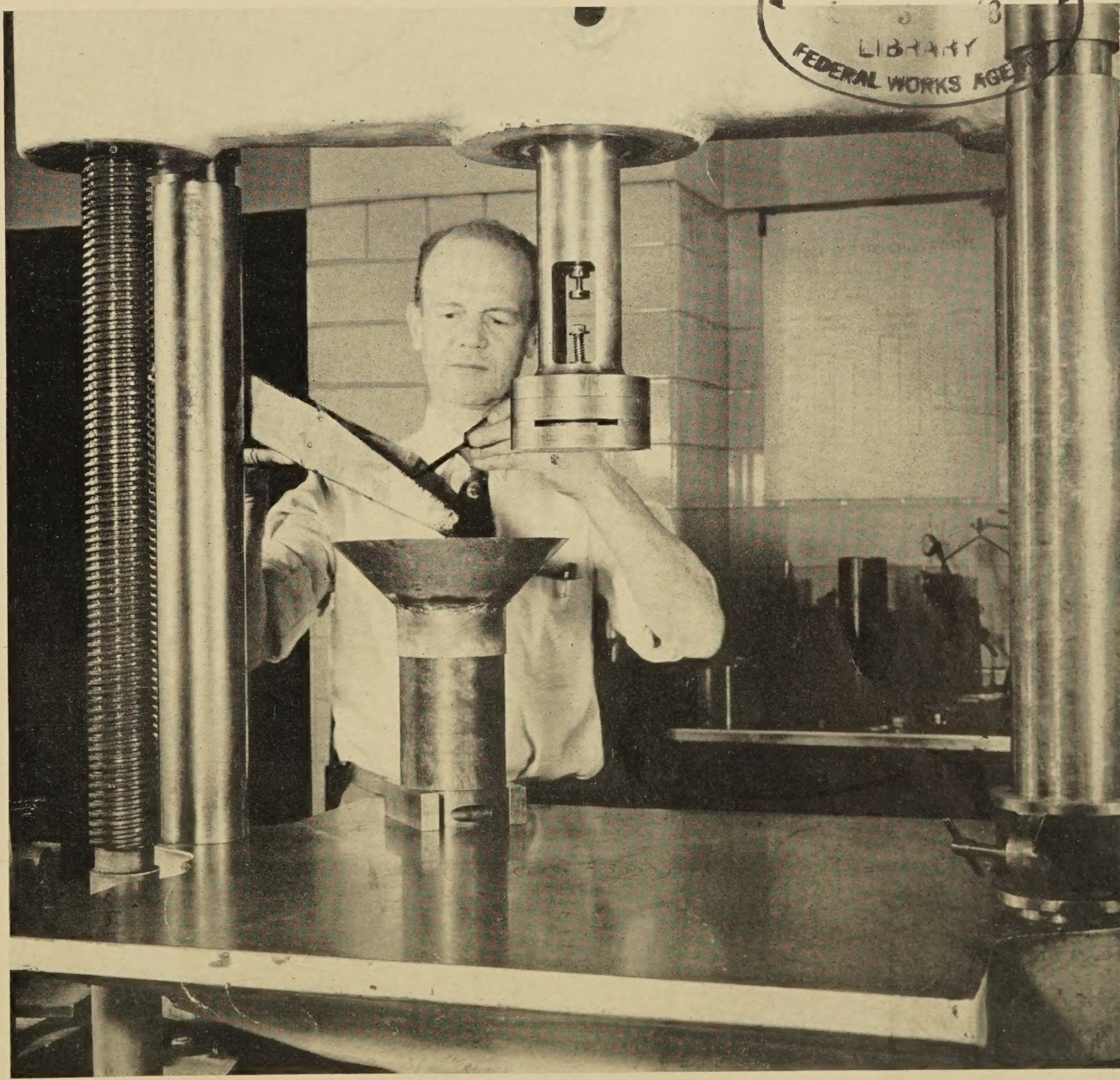

Preparing a bituminous mixture for a compression test

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E. A. STROMBERG, Editor

The Effect of Characteristics of Asphalts on Physical Properties of Bituminous Mixtures

BY THE DIVISION OF PHYSICAL RESEARCH
PUBLIC ROADS ADMINISTRATION

Laboratory tests on a particular bituminous mixture and a review of other investigations of the physical properties of bituminous mixtures indicate that these physical properties can be correlated, before and after accelerated or natural weathering, with the characteristics of the contained binder. Changes occurring in the binders of asphaltic mixtures that influence the durability of pavements under service conditions can be measured directly by tests on the bitumen recovered from the mixtures, or indirectly by the changes in the physical properties of the mixtures.

Reported by R. H. LEWIS, Senior Chemist, and J. Y. WELBORN, Materials Engineer

IN RECENT years many investigations have been made dealing with the durability of various types of pavements in which asphaltic materials have been used as binders. Two general methods of attack have been followed in these investigations:

1. Study of the physical properties of asphaltic mixtures and correlation of these properties with durability. Compressive strength, flexural strength, shear resistance, impact, Hubbard–Field stability, abrasion, and other tests have been used by various investigators as a means of studying the physical properties of mixtures. Some of the studies were made on representative samples taken from pavements, their physical properties determined by one or more of the above tests, and the results correlated with pavement condition. Other studies have been made on laboratory-prepared mixtures and their physical properties determined before and after subjecting to various accelerated weathering tests.

2. Study of the characteristics of asphaltic binders before and after exposure to laboratory oxidation tests or to actual service conditions and correlation of the test results with pavement durability. Some investigators have studied the durability problem by recovering the asphaltic binders from pavements and correlating the characteristics of the asphalt with service behavior. Other studies have been made by determining the effect of laboratory oxidation tests on the asphaltic material itself and comparing the characteristics of the residues with those of the original material.

A review of published literature on the study of the durability of asphaltic materials reveals that there has been little attempt to correlate the physical properties of bituminous mixtures with the characteristics of the bitumen contained therein. Vokac (*16*, *17*) [1] made a comprehensive study of the correlation of physical tests with service behavior and was able to evaluate pavement condition by certain characteristics of compressed specimens. He also found that characteristics of the asphalts recovered from the mixtures could be correlated with pavement condition. Hillman (*3*) has shown that the Hubbard–Field stability of sand-asphalt mixtures is dependent upon the consistency of the contained bitumen at the test temperature and that the relationship varies for different asphalts. His work was done only on unweathered mixtures. Raschig and Doyle (*11*) in studying the flexural strength of asphaltic pavements concluded that the penetration and ductility of the asphalt in the mixture had the greatest influence on the modulus of elasticity and modulus of rupture.

[1] Italic numbers in parentheses refer to the bibliography, p. 94.

Table 1.—*Results of extraction tests and analysis of bitumens recovered before and after exposure in weatherometer*

Mixture designation	Type of molded specimen	Time of exposure in weather-ometer	Bitumen extracted	Loss in weight		Tests on recovered bitumen										
				Mixture basis	Bitumen basis	Penetration, 100 gm., 5 sec.				Soften-ing point	Ductility, 5 cm. per min.				Organic insoluble in 86° B. naphtha	Ash by ignition
						at 41° F.	at 59° F.	at 77° F.	at 95° F.		at 41° F.	at 50° F.	at 60° F.	at 77° F.		
COMPOSITE MATERIAL																
		Hours	*Percent*	*Percent*	*Percent*					*°F.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Percent*	*Percent*
A	Hubbard-Field	None	6.6	------	------	18	51	156	----	104.9	84	250+	250+	----	24.14	0.43
A-1	do	100	6.4	0.18	2.7	12	34	94	----	117.0	11	50	120	----	24.30	.41
A-2	do	300	6.2	.29	4.3	----	22	59	148	125.9	5.5	14.5	42	----	27.17	.82
A-3	do	900	6.0	.42	6.3	----	12	29	74	141.8	----	----	8.5	69	30.27	.69
B	Compression	None	6.6	------	------	18	51	156	----	104.9	84	250+	250+	----	24.14	.43
B-1	do	100	6.4	.12	1.8	14	41	117	----	112.2	20	200	210	----	24.92	.90
B-2	do	300	6.3	.18	3.2	----	24	65	159	124.4	6.5	19	113	----	26.87	.61
B-3	do	900	5.9	.33	4.9	----	14	34	85	139.3	----	----	12.5	90	30.26	.44
MATERIAL PASSING No. 4 SIEVE																
C	Hubbard-Field	None	6.7	------	------	18	50	158	----	105.8	91	168	175	----	24.00	.29
C-1	do	100	6.1	.20	3.1	12	33	92	----	117.3	12	78	165	----	24.81	.66
C-2	do	300	6.1	.29	4.4	----	21	57	142	127.1	6	14.5	115	----	27.90	.57
C-3	do	900	5.9	.42	6.6	----	11	26	64	144.8	----	----	5.5	69	31.62	.79
D	Compression	None	6.7	------	------	18	50	158	----	105.8	91	168	175	----	24.00	.29
D-1	do	100	6.3	.13	2.4	15	42	117	----	113.3	27	230	250+	----	24.63	.54
D-2	do	300	6.1	.22	3.4	----	24	67	168	123.5	6.5	30	128	----	26.49	.65
D-3	do	900	6.0	.33	5.0	----	14	33	81	139.8	----	----	10.5	98	30.71	.63

Table 2.—*Results of stability and compressive load tests on composite mixture before and after weathering, and penetrations of the contained asphalts at test temperatures*

Weathering of specimens tested and test temperature	Hubbard–Field stability		Compressive load	
	Load [1]	Penetration of contained asphalt at test temperature	Load [1]	Penetration of contained asphalt at test temperature
Unweathered, tested at:	*Lbs.*		*Lbs.*	
−10° F	17, 400 (3)	0. 8	2, 275 (2)	0. 8
10° F	13, 150 (3)	2. 7	----------	----------
25° F	----------	----------	1, 255 (2)	6. 8
40° F	7, 540 (4)	16	700 (2)	16
50° F	----------	----------	480 (2)	30
77° F	2, 230 (4)	156	165 (2)	156
140° F	350 (4)	7, 000	26 (2)	7, 000
Weathered 100 hours, tested at:				
25° F	11, 800 (3)	4. 8	----------	----------
40° F	8, 400 (3)	11. 5	1, 040 (2)	13
77° F	2, 980 (3)	93	335 (2)	117
140° F	560 (3)	3, 300	42 (2)	4, 900
Weathered 300 hours, tested at:				
25° F	12, 800 (3)	3. 8	----------	----------
40° F	9, 930 (3)	7. 4	1, 425 (2)	9. 3
77° F	3, 820 (3)	59	485 (2)	65
140° F	715 (3)	1, 580	68 (2)	1, 630
Weathered 900 hours, tested at:				
−15° F	21, 650 (2)	. 4	----------	----------
20° F	14, 850 (2)	1. 7	2, 640 (1)	1. 9
50° F	9, 550 (3)	7. 6	1, 565 (2)	8. 7
77° F	5, 030 (3)	29	845 (2)	34
140° F	1, 155 (2)	680	125 (1)	840

[1] Figures in parentheses indicate the number of specimens for which average values are given.

These and other investigations indicate that there is some correlation between the physical properties of asphaltic mixtures and some of the characteristics of the contained binder. Therefore, this investigation was initiated to determine what correlation existed between the physical properties of bituminous mixtures and the characteristics of the binder before and after weathering, all testing being done under closely controlled laboratory conditions.

CONCLUSIONS DRAWN FROM STUDY

While this investigation is not conclusive, due to the lack of data on the more standard types of asphaltic mixtures, the following trends were observed and appear to be worthy of consideration for future study:

1. The physical properties of a given mixture are dependent upon the consistency of the contained asphalt at the test temperature.

2. The Hubbard–Field stability of a given mixture after weathering is the same as the stability of an unweathered mixture when the test is made at a temperature at which the contained asphalt has the same consistency.

3. Test data from other investigations indicate that there is some characteristic of asphalts which causes comparable mixtures prepared with different asphalts to vary in physical properties even when the contained asphalts are of the same consistency.

4. Since the data from several investigations show that the bitumens extracted from pavements of the type that tend to crack usually have low penetrations and ductilities at 77° F., it would seem logical to make physical tests on asphaltic mixtures at low temperatures in the range corresponding to these penetrations and ductilities and to correlate the results with the properties of the contained asphalts at these temperatures.

5. Since durability of the asphalt in bituminous mixtures is dependent upon the changes occurring in the asphalt during mixing and subsequent weathering, those asphalts that have the greatest resistance to change should be the most durable. This study indicates that changes in the asphalt contained in a mixture can be measured directly by tests on the recovered bitumen or indirectly by changes in the physical properties of the mixture.

6. The durability of asphaltic pavements, as influenced by the consistency of the asphalt, depends upon the climatic environment in which they are located. The critical penetration of the bitumen at which pavement cracking occurs is higher in cold climates than in warm climates.

7. Correlations of the changes occurring in the thin-film oven test with changes in the physical properties of asphaltic mixtures and in the characteristics of the contained bitumen might aid in the development of specification limits based on the thin-film oven test which would insure durable asphalts.

KENTUCKY ROCK ASPHALT IDEAL FOR LABORATORY INVESTIGATION

This investigation was of a preliminary nature and was of limited scope since the test data were obtained on one asphaltic mixture only. Kentucky rock asphalt was selected because of its uniformity, its compactibility at normal temperatures, and the reputed high quality of its contained asphalt. The high penetration of the asphaltic binder and the high percentage of voids in the compressed specimens made this material especially suitable for study under accelerated weathering conditions. The ready compactibility of the rock asphalt without heating provided for uniformity in the characteristics of the binder in the individual test specimens, and the changes incurred during weathering were not masked by changes resulting from the mixing and molding operations that often produce erratic results in weathering tests of hot bituminous mixtures.

Hubbard–Field stability and direct compression were selected as physical tests for this study. Compressed specimens were tested before and after weathering by exposure to ultraviolet light and heat under controlled conditions in a laboratory weatherometer. Two series of tests were made on the rock asphalt—one on the composite material as received, and the other on the portion of the mixture passing the No. 4 sieve. The gradation of the rock asphalt as received was as follows:

	Percent
Retained on ⅜-inch sieve	1. 4
Passing ⅜-inch sieve	98. 6
Passing No. 4 sieve	90. 8

All specimens were compressed at room temperature under a load of 3,000 pounds per square inch, the load being maintained for 2 minutes. Sufficient mixture was used to mold specimens 2 inches in diameter by 1 inch in height for the Hubbard–Field stability test, and 2 inches in diameter by 2 inches in height for the compression test. Volume and weight determinations were made for each compressed specimen and the density calculated as a check on the uniformity of compression. Four sets of stability and compression specimens were made for each of the two mixtures. One set was tested immediately and the other three were exposed to ultraviolet light and heat in a weatherometer. During weathering the temperature was maintained at 140° F. and the relative humidity at 40 to 50 percent. The exposure periods were 100, 300, and 900 hours. The specimens were weighed periodically and loss in weight calculated.

Hubbard–Field stability and compressive strength tests were made initially at 40° F., 77° F., and 140° F. on the unweathered mixtures. As the work progressed additional specimens were molded and tested at other temperatures. The specimens weathered for 100 and 300 hours were tested at 40° F., 77° F., and 140° F. and those weathered for 900 hours were tested at 50° F., 77° F., and 140° F. Tests of the weathered specimens were also made at lower temperatures to provide a more complete picture of the changes in strength that may occur under normal climatic conditions.

After testing for stability and compressive strength the bitumen was extracted with benzol and recovered by the Abson method. The stability and compression specimens were extracted and recovered separately for each mixture and exposure period. The recovered bitumens were tested for penetration and ductility at several temperatures, softening point, organic matter insoluble in 86° B naphtha, and ash by ignition. The results of the extraction tests, loss in weight during exposure, and tests on the bitumens recovered from the mixtures are given in table 1.

Table 2 gives the average results for Hubbard–Field stability and compressive load for the composite mixture. As seen in table 1 the test results on the material passing the No. 4 sieve were nearly the same as those of the composite material. The stability and compressive load values, which are not reported, were also similar. Therefore, in the

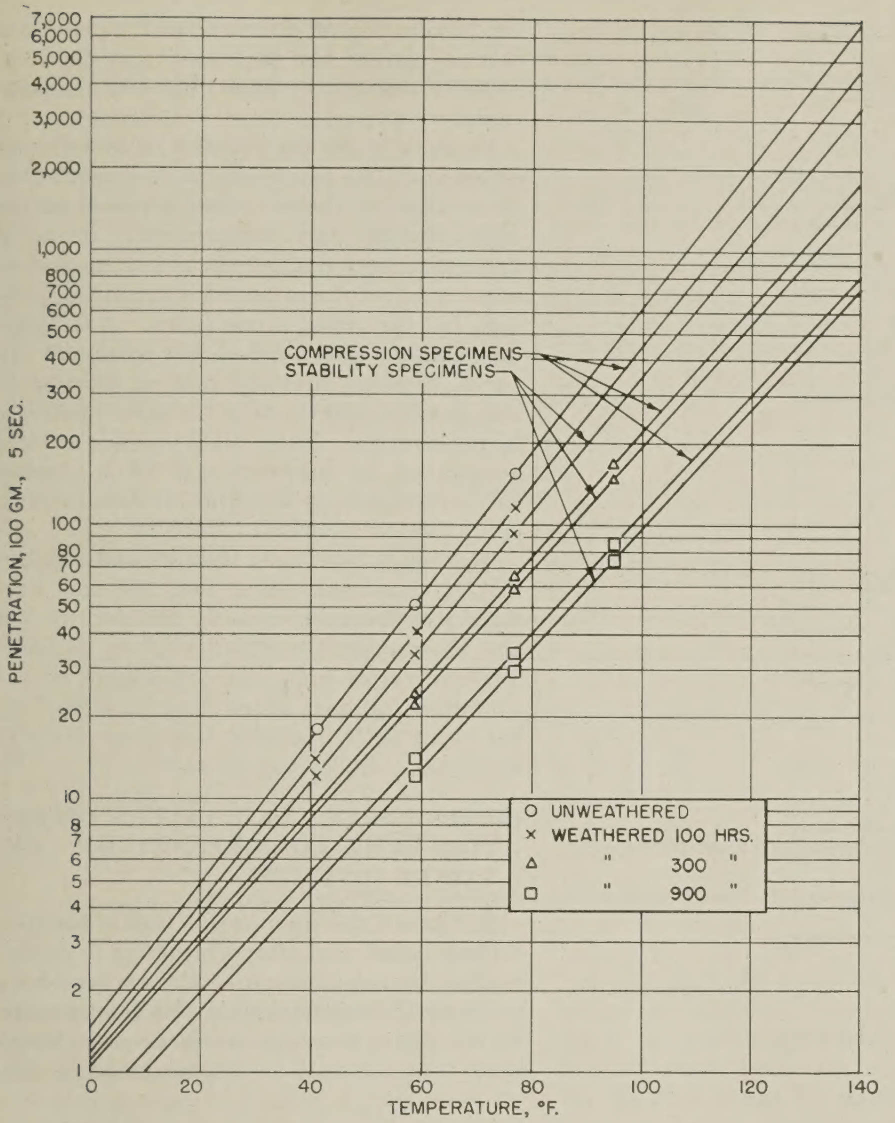

Figure 1.—Effect of test temperature on penetration of bitumens recovered from composite mixture before and after weathering.

HUBBARD-FIELD STABILITY VARIED WITH TEST TEMPERATURE

The effect of test temperature on Hubbard–Field stability before and after each period of weathering is shown in figure 2. When the log-stability was plotted against temperature a straight-line relation was found to exist for stability values below approximately 10,000 pounds. Further reductions in test temperature caused the stabilities to increase at a lower rate.

Figure 3 shows the effect of test temperature on compressive load, the data being plotted in the same manner as for the stability tests. These curves are straight lines for compressive load up to approximately 1,000 pounds where further reductions in test temperature give lower rates of increase. The test values for compressive load at 140° F. on the unweathered mixture do not fall on the straight-line portion of the curve, but this is probably due to the failure of the compression machine to record such low loads accurately.

The above data show the wide range in the strength of the bituminous mixture which results from changes in temperature and alterations due to exposure and weathering. Yet, pavements constructed of the same type of mixture are carrying extremely heavy traffic without showing displacement in summer or brittleness in winter.

The effect of temperature on the physical properties of a given bituminous mixture can be attributed entirely to the binder. As shown previously, the consistency of the asphalt contained in the stability and compression specimens was determined for each test temperature. To show the effect of the consistency of the binder on the physical properties of the unweathered and the weathered mixture, the following discussion only the test results for the composite material will be considered.

A previous study (*6*) has shown that a linear relationship exists when the log-penetration of an asphalt is plotted against the test temperature and that, by extending this line, it is possible to estimate the penetration of the asphalt at both higher and lower temperatures. In figure 1, the log-penetration–temperature relationships are shown for the bitumens recovered from the composite mixture before and after each period of weathering. From these curves it was possible to estimate the penetration of the bitumen contained in the stability and compression specimens at the temperature at which they were tested. These values also are given in table 2.

In studying the physical properties of bituminous mixtures there has always been the problem of selecting the most suitable temperature to use in making the tests. Endersby (*2*), in discussing the triaxial test, emphasized the need for selecting the most representative test temperature and suggested adjusting this temperature to the climate in which the mixture is used. In this study, temperatures for the stability and compressive load tests were selected so as to cover the temperature range to which the mixtures might be subjected under normal service conditions.

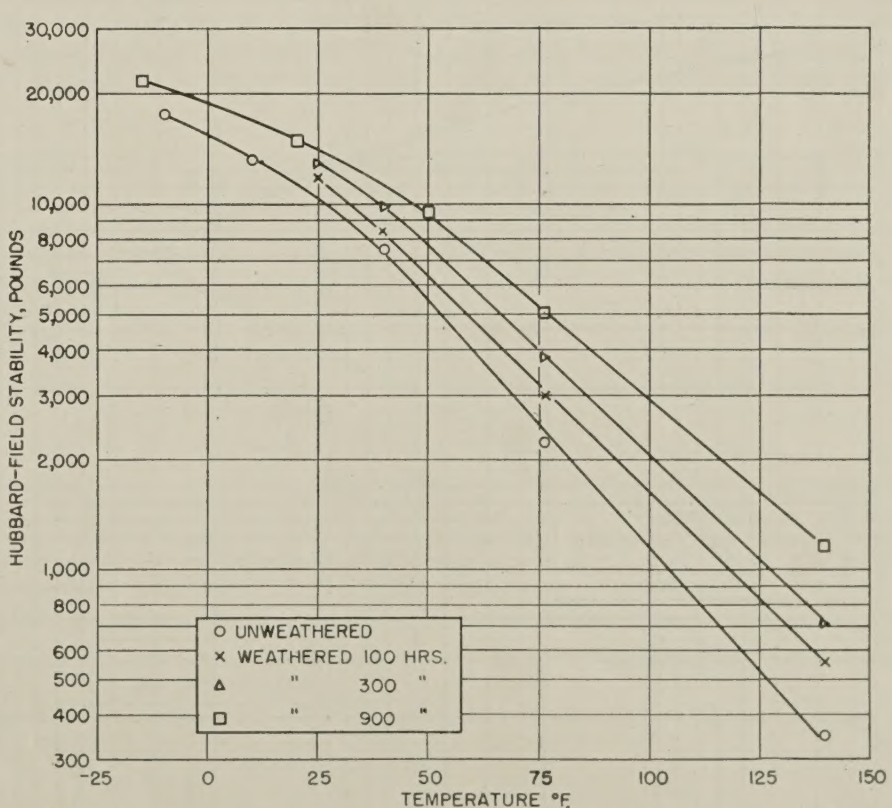

Figure 2.—Effect of test temperature on Hubbard–Field stability of mixture before and after weathering.

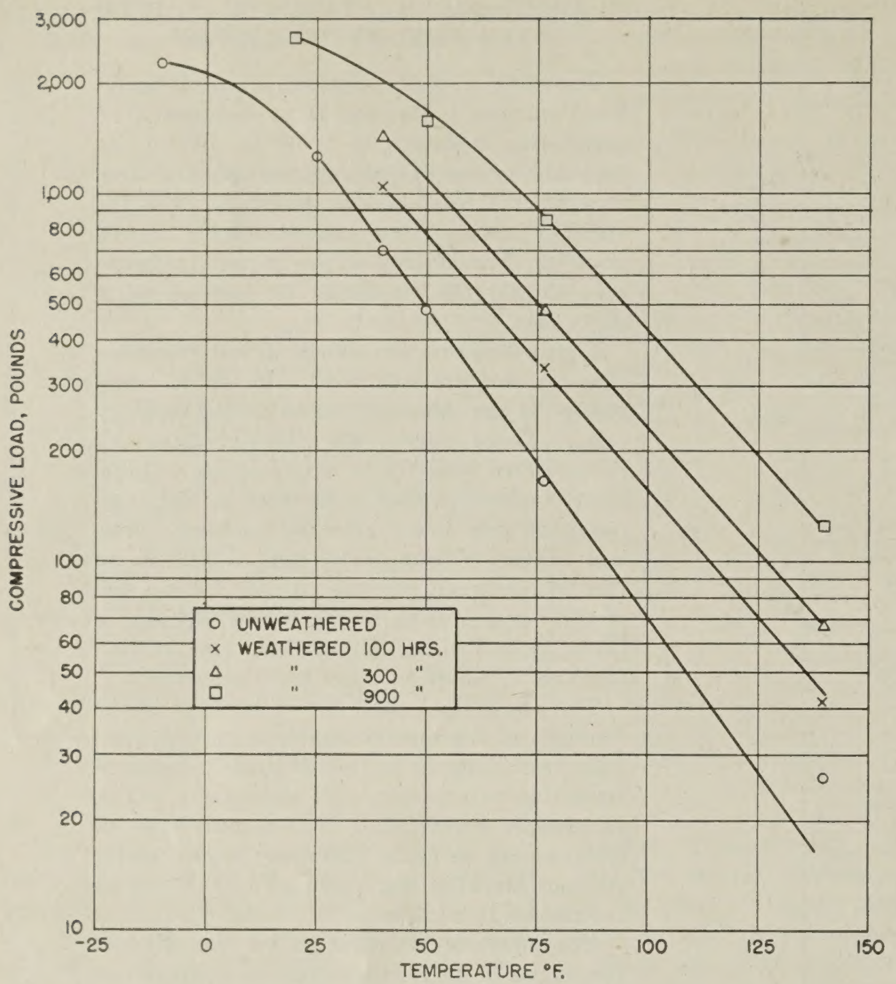

Figure 3.—Effect of test temperature on compressive load of mixture before and after weathering.

log-penetration of the contained asphalt was plotted against the log-stability or log-compressive load at corresponding test temperatures.

Figure 4 shows the stability of the mixture before and after weathering plotted against the penetration of the contained bitumen at the corresponding test temperature. It is of interest to note that all the points, regardless of the amount of weathering and test temperature, fall very close to one curve. A straight-line relation exists for the lower portion of this curve, showing that the rate of increase in stability is proportional to the rate of decrease in penetration. This relation holds until a penetration of approximately 10 is reached where further decrease in penetration causes a lower rate of increase in stability.

This relation between stability and penetration of the contained asphalt not only substantiates the work done by Hillman (*3*) but also shows that the stability of an asphaltic mixture varies with the consistency of the contained bitumen which may be altered by hardening or by reducing the temperature at which the stability test is made.

COMPRESSIVE LOAD VALUES DIFFER FOR SAME CONSISTENCY OF CONTAINED BITUMEN

In figure 5 the compressive load of the rock asphalt before and after weathering is plotted against the penetration of the contained asphalt at the corresponding test temperature. In this figure two separate curves were developed—one for tests on the unweathered mix-

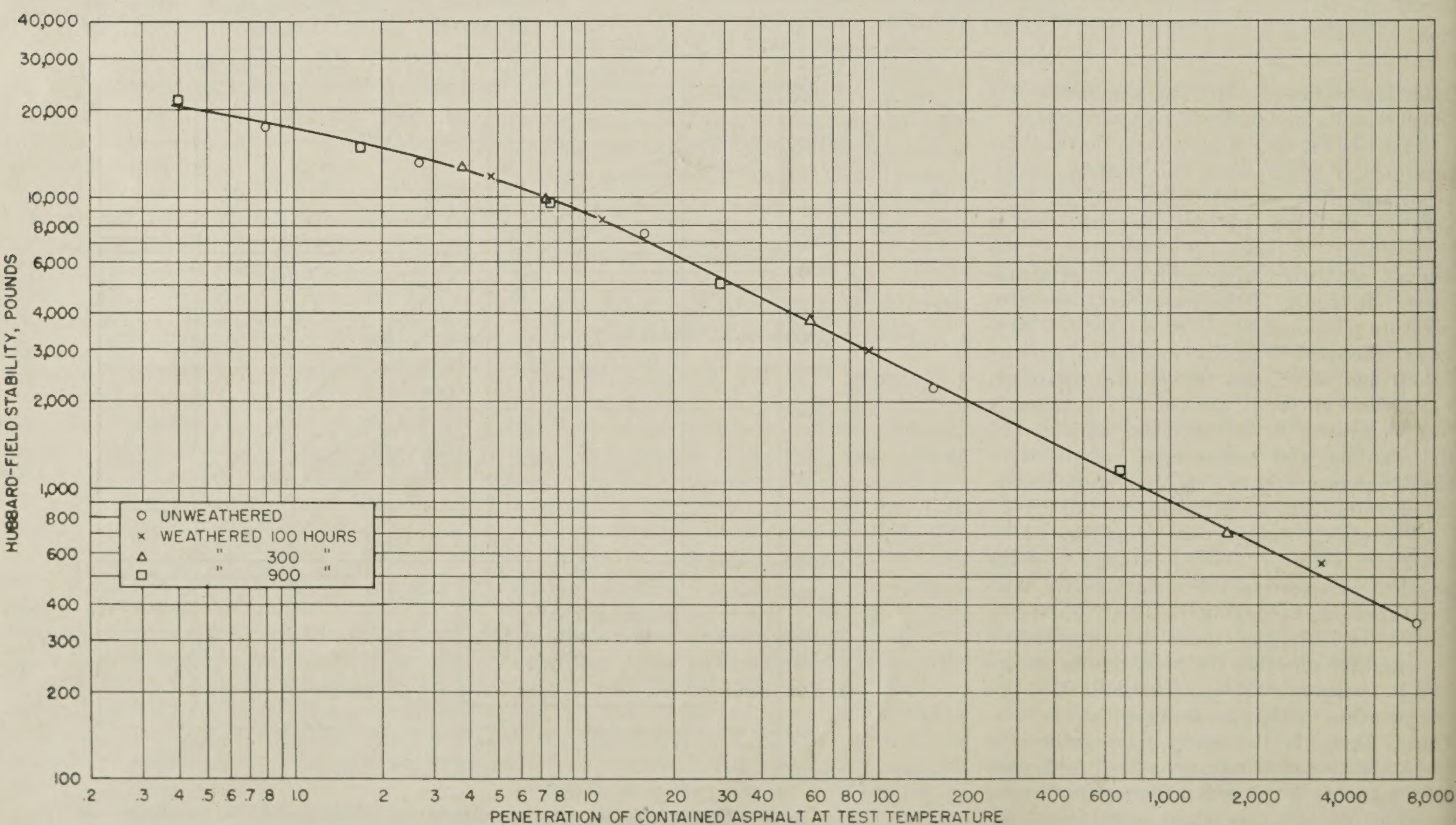

Figure 4.—Relation between Hubbard–Field stability and penetration of contained asphalt at test temperature.

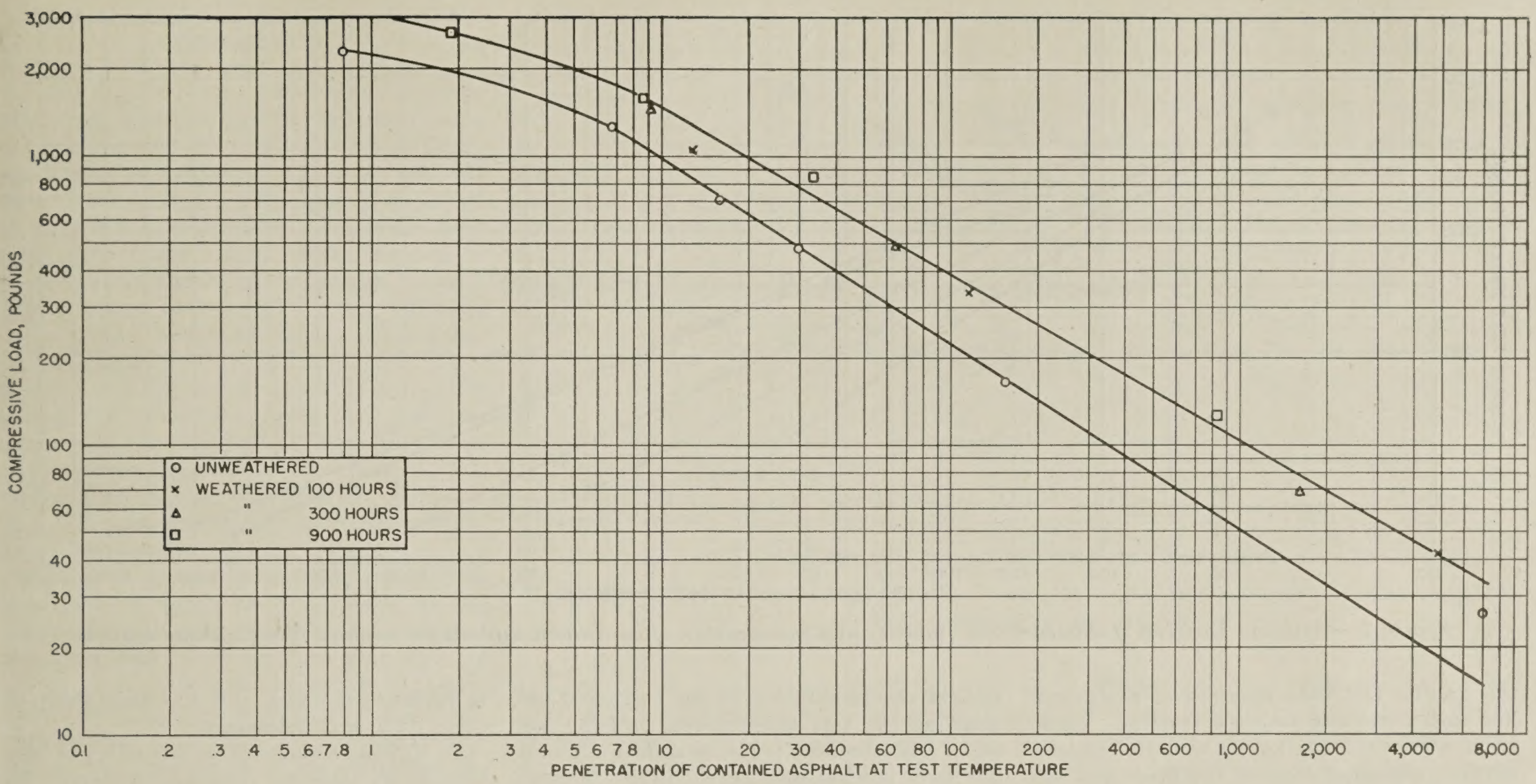

Figure 5.—Relation between compressive load and penetration of contained asphalt at test temperature.

ture tested at different temperatures, and the other for tests on all the weathered specimens tested after the three exposure periods at the different temperatures. The shape of these curves is similar to that in figure 4 for the stability specimens. The lower parts of the curves are straight lines, showing a uniform rate of change in compressive load with change in penetration. Below approximately 10 penetration the rate of increase in compressive load decreases.

The cause of the formation of two separate curves for the compression data while only one was formed for the stability data is not apparent at the present time. It is possible that during accelerated weathering of the molded specimens an outer crust was formed, and when tested in compression the circumferential hardening gave additional support. Due to the manner in which the stability specimens are tested, this outer crusting probably would not affect the values to any extent. The relatively high loss of volatile material from the asphalt in the rock asphalt would accelerate the outer hardening. Similar work on mixtures prepared with standard asphalt cements may aid in showing the cause for the formation of separate curves for the unweathered and weathered mixture when tested in compression.

Vokac (*15, 16*) has shown that in the compression testing of bituminous mixtures the fundamental characteristics of modulus of elasticity and elastic limit may be readily obtained and applied to the study of mixtures under service conditions. In making the compression tests on the rock-asphalt mixtures used in this investigation, load-deformation curves were obtained on the compression specimens before and after weathering for 900 hours, and the modulus of elasticity calculated for each condition. The modulus of elasticity is the unit stress divided by the unit strain within the elastic limit or over that portion of the stress-strain curve that is a straight line. The curves formed for the rock-asphalt specimens had some curvature at the beginning of

Table 3.—*Modulus of elasticity of compression specimens before and after weathering.*

Weathering of specimens tested and test temperature	Modulus of elasticity	Penetration of contained asphalt
	Lbs per sq. in.	
Unweathered, tested at:		
−10° F.	49,250	0.8
20° F.	14,850	5.0
50° F.	5,500	30
77° F.	2,200	156
Weathered 900 hours, tested at:		
20° F.	46,350	1.9
50° F.	19,650	8.7
77° F.	10,200	34

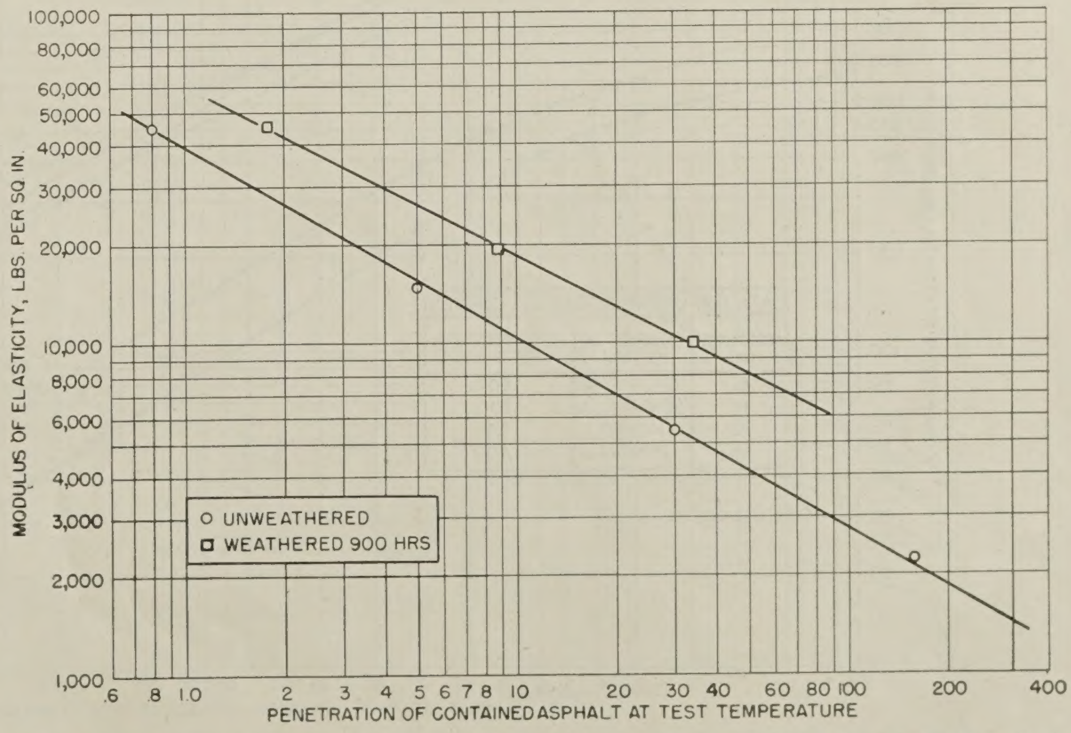

Figure 6.—Relation between modulus of elasticity and penetration of contained asphalt at test temperature.

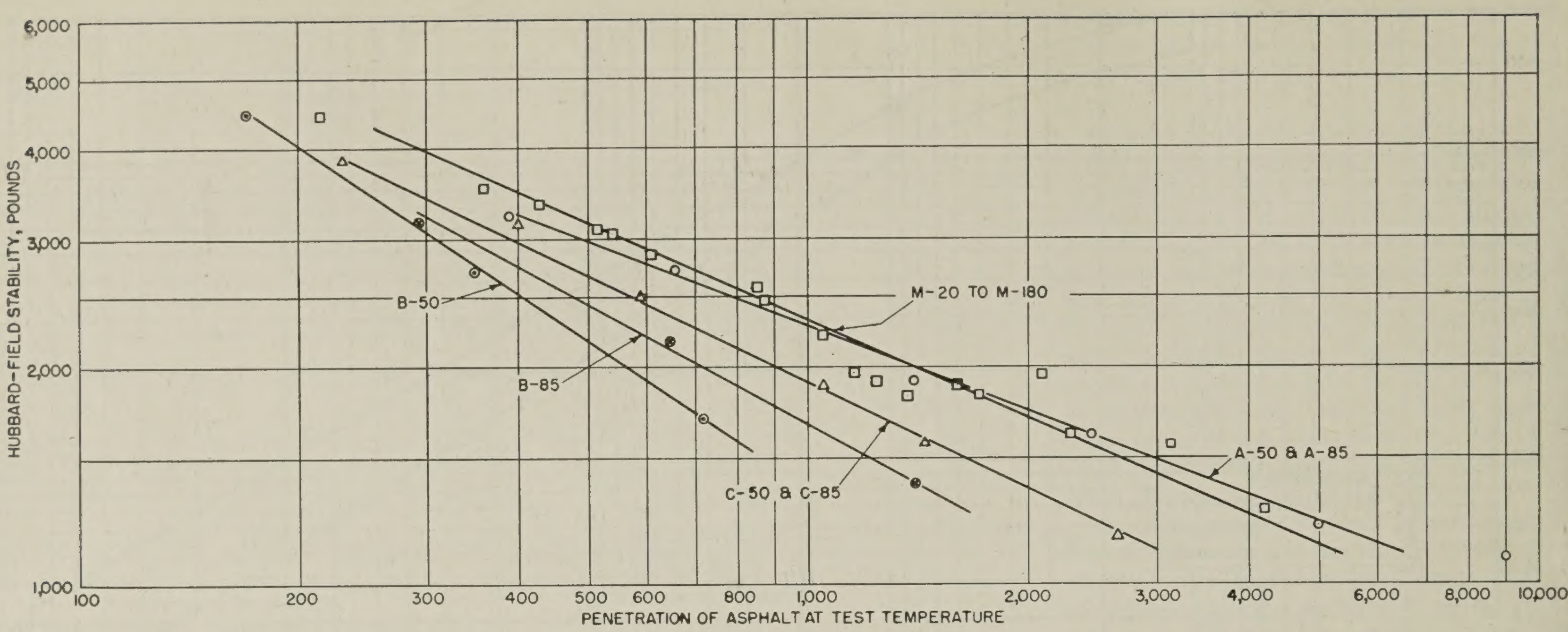

Figure 7.—Relation between Hubbard-Field stability and penetration of contained asphalt for asphalt from various sources.

the loading and then approached a straight line until the elastic limit was reached. Since these curves did not have a definite straight portion, and since some of the loads and deformations were of low magnitude, the moduli were calculated by taking the middle 75 percent of the total compression load and the corresponding deformation from the curves.

The modulus of elasticity values at the various test temperatures for the unweathered mixture and the mixture weathered for 900 hours are given in table 3, together with the penetration of the contained asphalt at the test temperature.

By plotting the modulus of elasticity against the penetration of the contained asphalt at the test temperature, both on log scale, relations were found as shown in figure 6. Two straight-line curves were formed, one for the unweathered mixture and the other for specimens weathered for 900 hours. This relation is similar to that for the penetration-compressive load curves shown in figure 5, except that the straight lines do not break when the penetration of the contained asphalt is reduced to approximately 10.

The effect of consistency of the binder on the physical properties of mixtures has been included in test data from other investigations, although in some cases no attempt was made to correlate the two, and a further study of these data is of interest.

In Hillman's study (*3*) of the effect of consistency on stability, data were presented for stabilities and penetrations of the contained bitumen at temperatures of 104° F., 122° F., and 140° F. for asphalts from several sources. The relations between stability and penetration of the contained bitumen at the test temperature for some of these asphalts are shown in figure 7. Although the tests were made only at the high temperatures and cover a relatively narrow range, there was considerable difference between the stability-penetration relationships for the various asphalts.

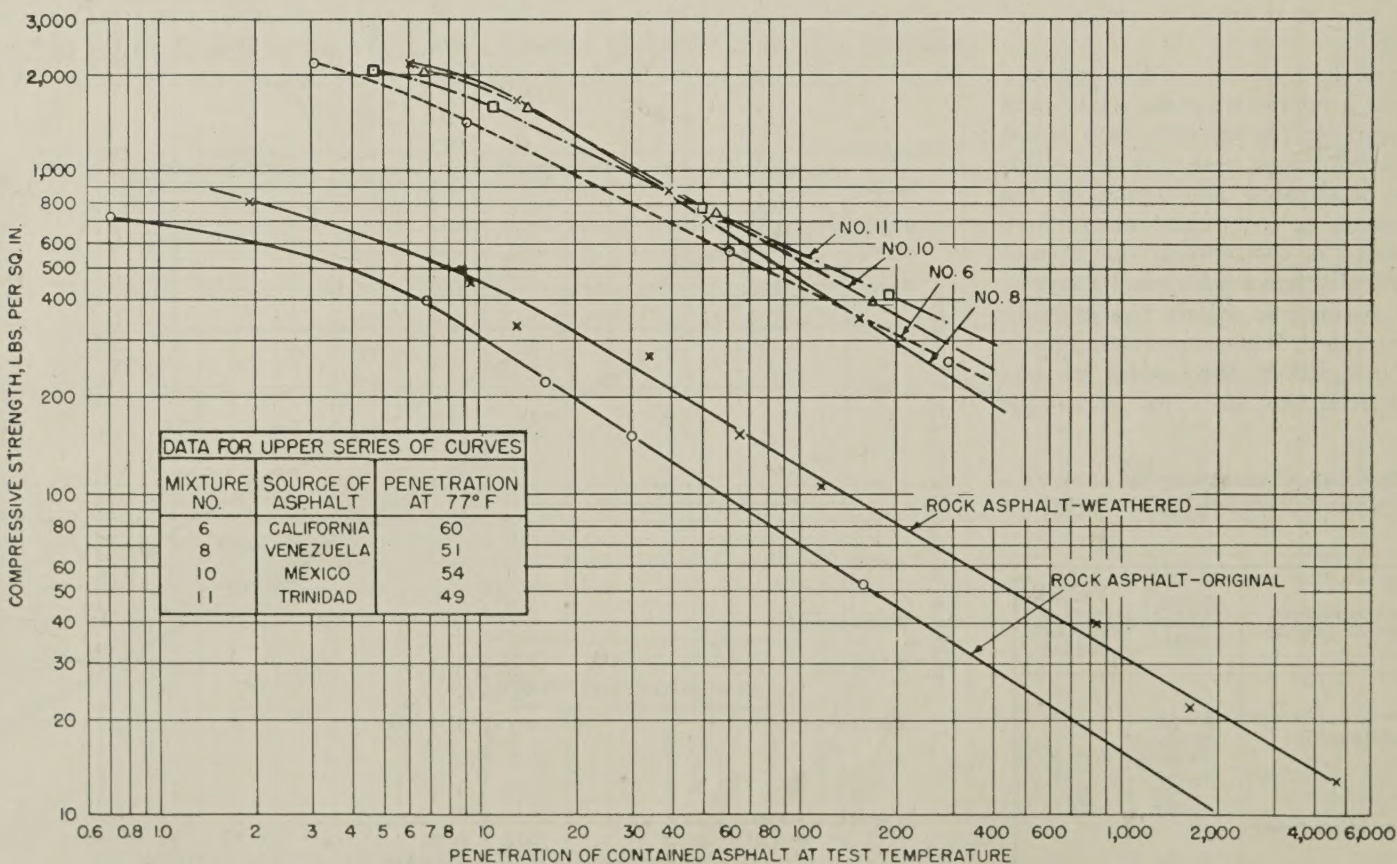

Figure 8.—Relation between compressive strength and penetration of contained asphalt at test temperature for asphalts from various sources.

DATA OF OTHER INVESTIGATIONS CONSIDERED

Vokac (*17*), in studying the thermal susceptibility of asphaltic paving mixtures, made compressive strength tests at 34° F., 77° F., and 140° F. on mixtures containing asphalts from several sources. Although only the effect of temperature on compressive strength was given, penetration data were taken from another investigation (*6*) for similar asphalts and correlated with the compressive strength values at the three temperatures. The penetration-compressive strength relations for some of these asphalts are shown in figure 8. Although the compression tests were made on mixtures of the sheet-asphalt type, the shape of the curves is similar to those for the rock asphalt used in this investigation. Asphalts from different sources showed somewhat different relationships.

Figure 9 shows some penetration-compression data taken from a report by the Barber Asphalt Corporation (*1*). Here compressive strength tests were made on a sheet-asphalt mixture at three temperatures, using asphalt cements from several sources. Penetrations were reported at three temperatures so that the consistency of the contained asphalt at the temperatures of the compression test could be determined. As in figure 8, the straight-line portion of the curves for the various asphalts shows some spread.

The data illustrated in figures 7, 8, and 9 show that there is some characteristic of an asphalt other than consistency that causes mixtures made with different asphalts to vary in stability and compressive strength.

In studying the effect of temperature on shear characteristics of bituminous paving compositions Skidmore (*13*) noted that as the test temperature was reduced, the rate of increase in shear strength decreased and for some asphalts the shear strength decreased rather than increased. Some of Skidmore's data are plotted in figure 10 to show the effect of temperature on the shear strength. From this study Skidmore concluded that:

> "1. The inherent characteristics and quantity of the bitumen in the mixture are much more important at low temperatures than at normal and higher temperatures in the pavement.
>
> "2. There is an optimum proportioning of the several ingredients of the paving mixture that will insure the best performance over the entire range of temperatures.
>
> "3. In regions where low temperatures obtain, the adoption of considerable softer bitumens than have been used commonly, will constitute one of the most important advances in the direction of better pavements."

Oliensis (*8*), in discussing mechanical tests on mixtures, pointed out that due to the difference in susceptibility of asphalts either relatively good or relatively poor test results can be obtained for mixtures with any given asphalt, provided the particular temperature selected for the designated mechanical test has a favorable or unfavorable influence on the strength of the mixture because of the consistency of the binder at the test temperature. He also noted that all laboratory tests proposed thus far for determining the quality and durability of mixtures or the contained asphalt are in essence tests of consistency or tests in which consistency plays a predominant role.

He further stated:

> "* * * Hence, if reliable durability tests are to be developed in the laboratory on the finished mixture, our research engineers must bend their efforts to devising other tests, in which either the varying consistency of the incorporated asphalt plays no role whatever, or in which the role it does play is frankly recognized and allowed for by having both the compaction and testing processes conducted at such temperatures (perhaps different ones for mixtures containing different asphalts) as will insure equal compaction, and equal consistency of the bituminous binders at the moment when the mixtures are being tested."

Vokac(*16*, *17*), in analyzing the data from the study of the correlation of physical tests on asphalt mixtures with service behavior, showed that, in general, those mixtures with the highest compressive strengths, Hubbard–Field stabilities, and moduli of elasticity were usually from pavements of the type that tend to crack. The asphalt extracted from these pavements, in general, had the lowest penetration and ductilities and the highest softening points. The mixtures representing the sound pavements had lower compressive strengths, stabilities, and moduli of elasticity with corresponding higher penetrations and ductili-

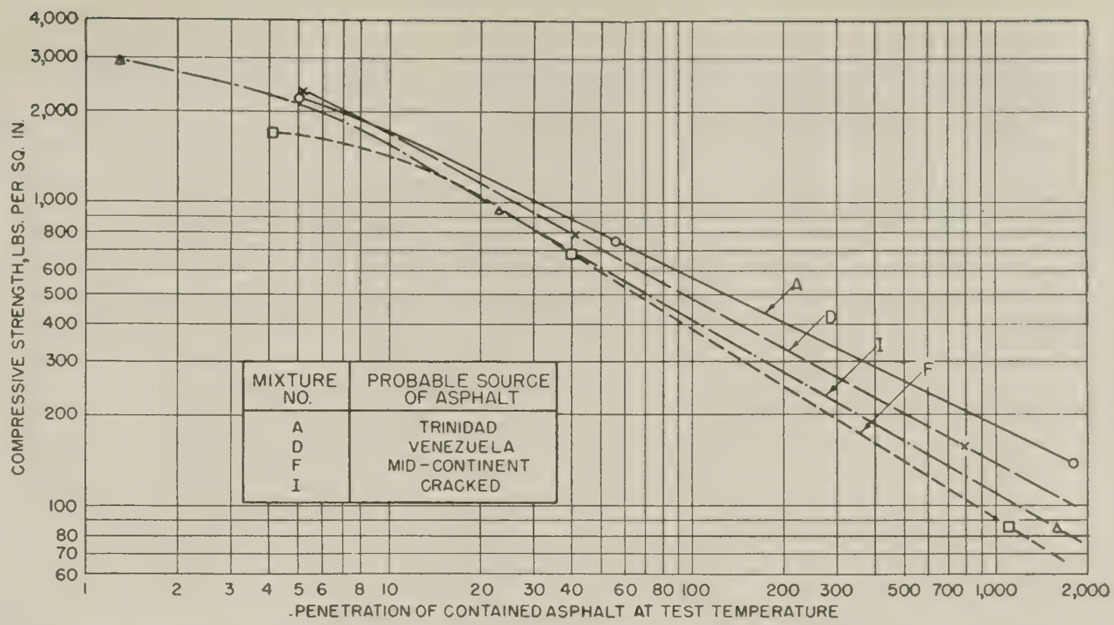

Figure 9.—Relation between compressive strength and penetration of contained asphalt for asphalts from various sources.

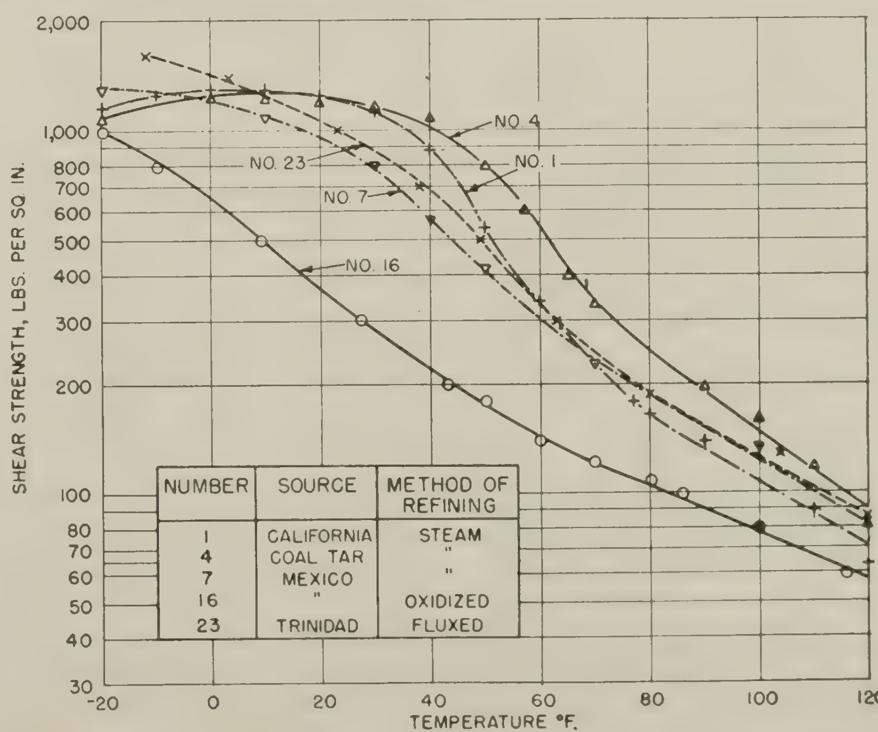

Figure 10.—Effect of test temperature on shear strength of mixtures containing various bituminous materials.

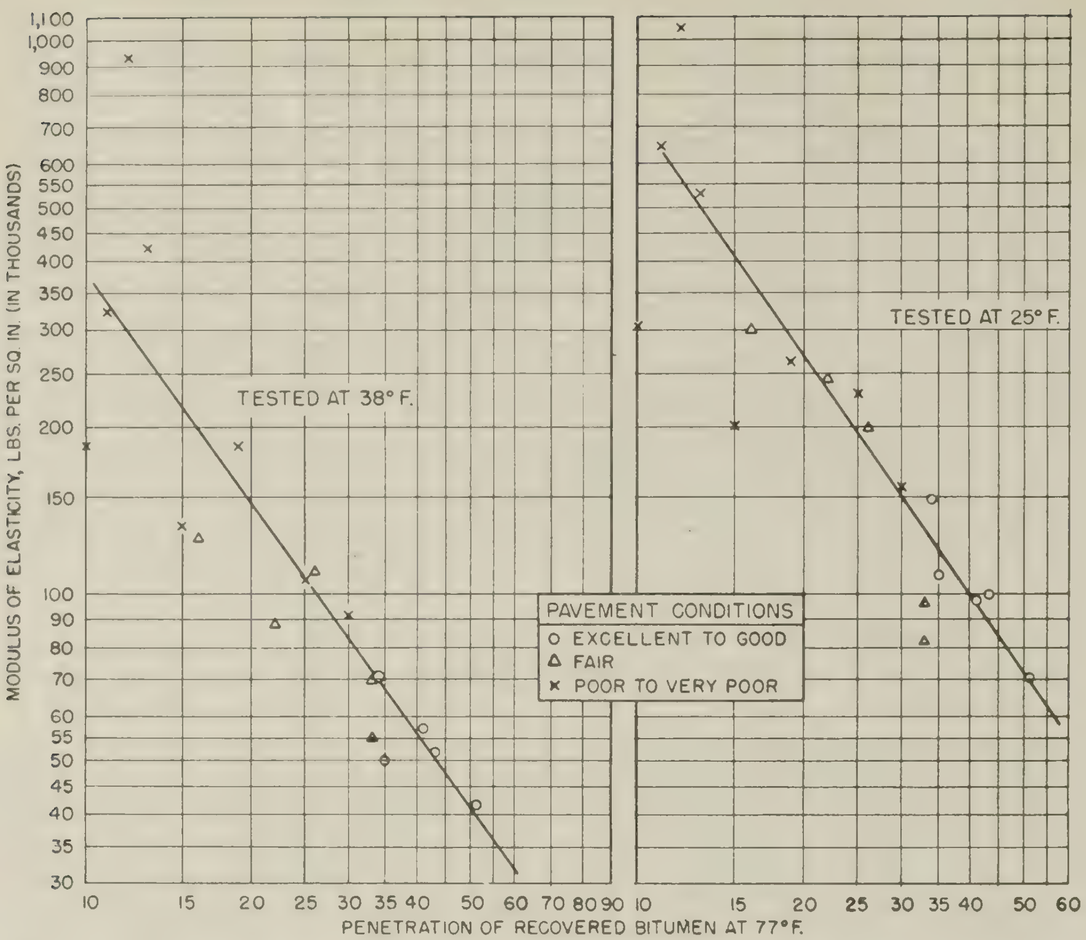

Figure 11.—Relation between modulus of elasticity and penetration of contained asphalt for pavement samples.

ties and lower softening points of the contained asphalt.

In an investigation of the behavior of asphalts in paving mixtures, Raschig and Doyle (*11*) concluded that the penetration and ductility of the asphalt in the mixture had the greatest influence on the modulus of elasticity and modulus of rupture and, in general, the condition of the pavement was poorest where the penetration and ductility were lowest. The physical properties of the mixtures were determined by flexural tests on beams cut from pavement samples. Although the tests on the beams were made at 25° F. and 38° F. and the penetration of the recovered asphalt was made at 77° F., a good correlation of these properties was obtained. Figure 11 shows the relation between the moduli of elasticity at 25° F. and 38° F. and the penetration of the contained asphalt at 77° F.

CONSISTENCY VARIES WITH CLIMATIC CONDITIONS

Shattuck (*12*), Hubbard and Gollomb (*4*), Powers (*9*), Thomas (*14*), and others also have shown that pavement conditions can be correlated with penetration of the contained asphalt, and some of these investigators have shown the correlation of ductility and softening point of the asphalt with durability. A summary of the data presented by these investigations is given in table 4.

It is apparent from these investigations that the characteristics of the asphalt contained in the mixture are of fundamental importance in studying the durability of asphaltic pavements. Since durability is dependent upon the ultimate hardness of the contained asphalt, usually measured at 77° F., the range in temperatures to which pavements are subjected also should be considered.

The pavement samples analyzed by Shattuck, Thomas, Hubbard, and Vokac were taken from the northeastern and north-central part of the United States where severe cracking of the pavements occurred when the asphalt had hardened to a penetration of 20. However, Powers noted, in Arizona, that where the penetration of the contained asphalt was above 10 the pavements subjected to Arizona climate were free from cracking. The analysis of asphaltic concrete mixtures from Cuba by the Public Roads Administration (*10*) showed that the average penetration of asphalts from pavements in good condition was 9 and for cracked pavements the average penetration was 5.

The minimum ductility and maximum softening point of the recovered asphalts, as related to the cracking of pavements, also appear to be dependent upon the climatic temperatures to which pavements are subjected. Although ductility and softening point are inherent characteristics of an asphalt, asphalts from various sources have widely different penetration-ductility and penetration-softening point relationships.

In the studies cited above, the characteristics of the recovered asphalts were those at the time of pavement rating. Very few data are available that give the inherent characteristics of the original asphalts and particularly the changes in the asphalts due to plant mixing and laying. Because the characteristics of the asphalts contained in the mixture at the beginning of the pavement life are not known, changes in the inherent characteristics due to the age of pavement cannot be ascertained. Consequently, the relative resistance of the various asphalt cements cannot be evaluated.

For the natural rock-asphalt mixture studied in this investigation, the correlation of the physical properties of the mixture with the penetration of the contained asphalt shows that for a given mixture the physical properties are dependent on the consistency of the asphaltic binder at the test temperature. This finding is substantiated by similar correlations of the data from other investigations. However, it is well known that when different asphalts are exposed to the high temperatures encountered in plant mixing, weathering un-

Table 4.—*Correlation of pavement condition with physical properties of recovered bitumen*

Source of data	Location of pavements	Condition of pavement	Tests on recovered bitumen		
			Penetration 77° F.	Ductility 77° F.	Softening point
				Cm.	*° F.*
Shattuck (*12*)[1]	Detroit, Mich.	Very good	20+	50+	
		Good	20+	25+	
		Badly cracked	20−	25−	
Thomas (*14*)	Minnesota	Good [2]	41		
		Fair [2]	26		
		Poor [2]	20		
Hubbard and Gollomb (*4*).	Ohio, Mich., N. Y., Ind., D. C.	Sound	30+		
		Prone to crack	30−		
		Cracking type	20−		
Vokac (*16, 17*)	Ohio, Pa., Md., Va., Mo., Ill., Ind., Mich., N. Y., N. J., D. C.	Sound	25+	24+	
		Prone to crack	18–25	4–24	160−
		Cracking type	18−	4−	160+
Powers (*9*)	Arizona	Good	10+	10+	160−
		Cracked	10−	10−	160+
Public Roads Administration (*10*)	Cuba	Good [2]	9	1.5	199
		Cracked [2]	5	0.5	217

[1] Italic numbers in parentheses refer to the bibliography, p. 94.
[2] Average values.

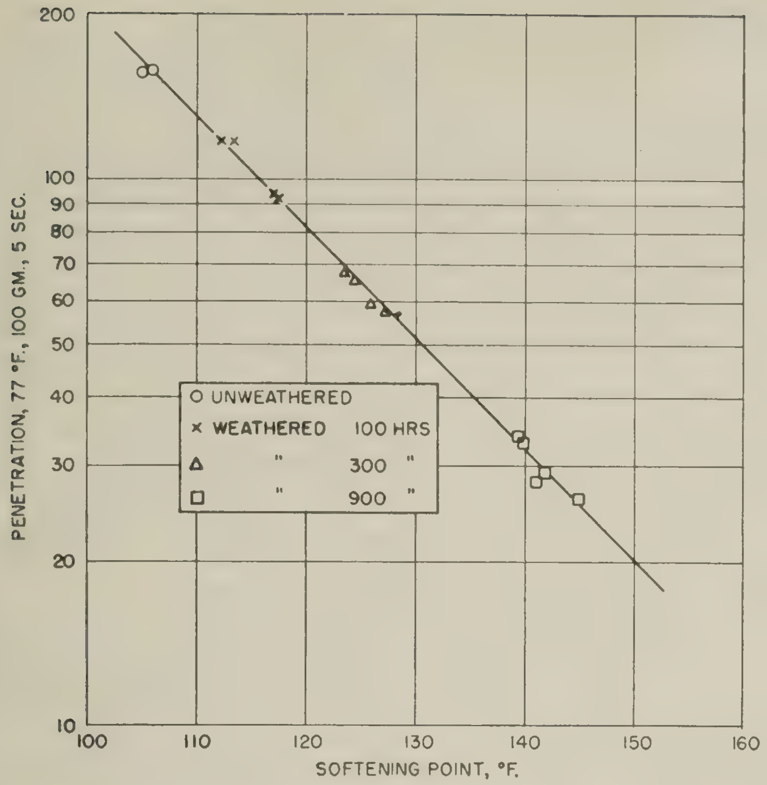

Figure 12.—Relation between softening point and penetration of bitumen recovered from mixtures before and after weathering.

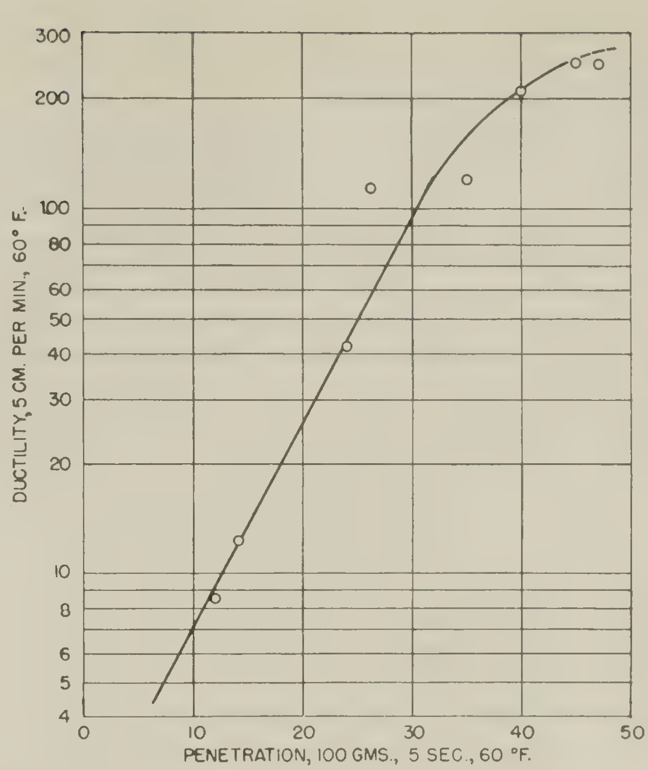

Figure 13.—Relation between penetration and ductility of bitumen recovered from mixtures before and after weathering.

der service conditions, or exposure to any of the various laboratory oxidation tests, the rate of change in their characteristics is a variable. Therefore, it is to be expected that the relation between the physical properties of asphaltic mixtures and the properties of the asphaltic binder will vary with different asphalts and that it will also be affected by the type and grading of the aggregate, the degree of heat used in mixing, degradation of the aggregate during consolidation, and the degree of consolidation. It seems probable that in some of the studies that have been made of the durability of bituminous mixtures, variables such as these may have masked the changes that have occurred in the asphalt binder.

RETENTION OF ORIGINAL CHARACTERISTICS A MEASURE OF DURABILITY

Previous investigations (*5*, *7*) have shown that certain correlations between penetration, ductility, and softening point are useful in studying changes induced in asphalts by weathering under actual service conditions or by oxidation tests in the laboratory. When an asphalt is subjected to oxidation the decrease in penetration is accompanied by an increase in softening point and usually by a decrease in ductility. After various periods of weathering or oxidation it has been shown that when the softening points of the various residues are plotted against the corresponding log-penetrations smooth curves are formed which, for many asphalts, are straight lines. If the penetrations are plotted against the log-ductility of the various residues smooth curves can be drawn through the points. For each asphalt these relations exist either for residues obtained from laboratory oxidation tests or bitumens recovered from mixtures after exposure to heat or actual service conditions.

The penetration, softening point, and ductility results for the bitumens recovered from the unweathered and the various weathered rock-asphalt specimens of this investigation are shown plotted in the above manner in figures 12 and 13. In figure 12, all the points formed by plotting softening point against the log-penetration fall very close to a straight line. Because of the softness and the high ductility of the recovered bitumens, it was necessary to determine ductilities at temperatures lower than 77° F. to show changes in the asphalt induced by weathering.

Figure 13 shows penetration plotted against log-ductility, both at 60° F., for the bitumens recovered from the mixture before and after weathering. As compared to many asphalt cements the ductility of the asphalt recovered from the rock-asphalt mixture is high for a given penetration both before and after weathering.

Previous studies (*5*, *7*) have shown that changes occurring in asphalt cements during mixing and after exposure of the mixture under service conditions can be predicted by heating the asphalt in a ⅛-inch film at 325° F. for variable periods of time. The bitumen recovered from the unweathered rock-asphalt mixture used in this study was subjected to the thin-film oven test for 5 hours and the residue tested for penetration, softening point, and ductility. The characteristics of the residue were very similar to those of the bitumen recovered from the stability specimens exposed for 900 hours in the weatherometer, as may be seen in table 5.

Table 5.—*Comparison of tests on asphalts subjected to thin-film oven test and weatherometer exposure*

Material tested	Penetration 77° F.	Softening point	Ductility 77° F.
		°F.	*Cm.*
Thin-film oven test, 5 hours	28	141	81
Weatherometer exposure, 900 hours	29	142	69

The increase in organic matter insoluble in 86° B. naphtha can also be used to determine changes in asphalts caused by exposure to accelerated laboratory oxidation tests or to weathering under service conditions. In studying the effect of the thin-film oven test on 85–100 penetration asphalts (*7*) from nearly all sources, it was found that the naphtha-insoluble matter in the residues ranged from 107 to 139 percent of the insoluble matter in the original materials. Table 1 of this report shows the naphtha-insoluble matter in the bitumens recovered from the rock-asphalt mixtures before and after weathering. The unweathered asphalt from the composite mixture contained 24.14 percent insoluble matter. After weathering for 900 hours this had increased to 30.27 percent for the asphalt in the stability specimens and 30.26 percent for the asphalt in the compression specimens. These increases expressed in terms of the weight of original material were 117 percent for the bitumen recovered from the stability specimens and 119 percent for the compression specimens.

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The Analysis of Motor-Vehicle Registration Records

BY THE DIVISION OF FINANCIAL AND ADMINISTRATIVE RESEARCH PUBLIC ROADS ADMINISTRATION

Reported by G. P. ST. CLAIR, Chief of Division and SIDNEY B. CLARK, Statistician

This study of the District of Columbia motor-vehicle registration and title records was made primarily for the purpose of developing sampling techniques that would be applicable in all States. The results indicate that the use of standard sampling procedures, adapted specifically to the registration system in the individual State, will produce accurate data regarding the numbers of motor vehicles in existence or in use at a given time and their distribution by year model, weight, body type, and other characteristics. Analysis of certificate-of-title records provides useful information regarding the motor-vehicle market, including the volume and fluctuation of new- and used-car sales, the interstate migration of motor vehicles, and dealers' inventories of used cars.

INFORMATION regarding the motor vehicle, its life, and its habits is of the utmost importance in highway research. It is of great value also to motor-vehicle manufacturers, suppliers, and users and to those who are interested in observing economic trends. A virtual gold mine of such information is found in the records of the State motor-vehicle departments. Unfortunately, this treasure is of the type for which we must dig if we are to find pay dirt. The motor-vehicle departments maintain and use these records primarily for purposes of administration and law enforcement. Motor-vehicle administrators are becoming increasingly aware of the value of the statistics at their command; and a number have installed the most modern methods of record-keeping. They have also been very cooperative in making their files available for study. The fact remains, however, that the adaptation of motor-vehicle records and statistics to the uses of highway research and planning is the responsibility of the agencies engaged in this work. All that can be asked of the motor-vehicle departments is a willingness to cooperate in the endeavor, within the limits of their statutory powers and duties.

Although published registration statistics are valuable if interpreted properly, they fail to give answers to some of the most important questions regarding the motor vehicle. They do not tell us how many vehicles are in existence at a given time, although they are often improperly used for that purpose. They do not tell us how many have been scrapped during a year or the number which have been moved from one State to another. Nor do they give us accurate information from which the age-distribution and service-life characteristics of motor vehicles can be determined. All of this information, however, is contained in the registration and title records, or can be derived, at least approximately, from an analysis thereof. Because of the very large number of motor vehicles, particularly passenger cars, registered in most States, there is an opportunity for the use of sampling methods to obtain at reasonable expense accurate estimates of the items of information most desired.

In order to develop techniques for such a sampling procedure, arrangements were made with the District of Columbia Department of Vehicles and Traffic for the conduct of a pilot study of its registration and title records. This study was in three parts: First, a sample study of private passenger-car registrations in the registration year 1943; second, a sample study of all motor-vehicle registrations in the registration year 1944; and third, a sample study of certificates of titles issued during the calendar year 1941. In the District of Columbia the annual registration period begins on March 1, although registrations for the new year are accepted prior to that date. The plates of the previous year are valid through the month of March.

THE REGISTRATION STUDIES

The registration records of the District of Columbia consist principally of three files: An alphabetical or name file; a serial or plate-number file; and a motor-number file. The alphabetical and serial files are maintained on an annual basis. The motor-number file is not chronological in any sense. The cards are filed by engine number and upon them is recorded the ownership history of every vehicle titled in the District of Columbia since the inception of the file.

In the District of Columbia, as in about 20 of the States, the procedure on transfer of ownership of a vehicle is for the original owner to retain the number plates and attach them to his new vehicle, if he acquires one. The result is that the District of Columbia registration record is a record of ownerships,

GLOSSARY

Original registration: The first registration of a vehicle in a given year.

Subsequent registration: Any registration of a vehicle, other than the original registration, during a given year.

Renewal: The registration, in a given year, of a vehicle which was in registration status at the close of the previous year.

- *Regular renewal:* A renewal made by the same owner.
- *Cross-over renewal:* A renewal made by a different owner from the one who registered the vehicle in the previous year.

Withdrawal: A vehicle withheld from registration but which in some subsequent year will be returned to the registration lists.

Return: The registration of a former withdrawal, i. e., that of a vehicle which had not been registered in the next previous year but had been registered in a year prior to that, and had not lost title status in the State.

Immigration: A vehicle moved in from another State and not registered in the new State of residence prior to the year under study.

- *Duplicating immigration:* A migrant vehicle registered in both the State of origin and the State of destination in the same year.
- *Cross-over immigration:* A migrant vehicle registered in the State of origin in one year and in the State of destination in the next year.

Transfer: A transaction by which a number plate is changed from one vehicle to another.

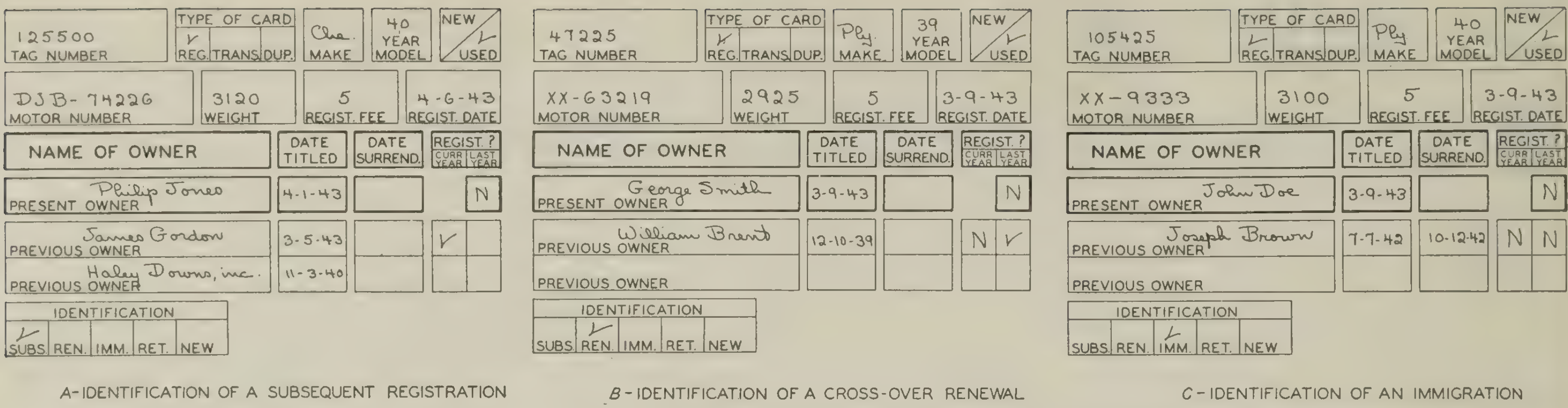

Figure 1.—Enumeration card used in study, illustrating identification of a subsequent registration, a cross-over renewal, and an immigration.

rather than of vehicles; for the same number plate may represent two or more vehicles registered by the same owner in a single year. The transaction represented by the change of a number plate from one vehicle to another is called a transfer. The serial file, therefore, contains one or more cards for each number plate issued. The first of these cards represents the first registration of a vehicle by the given owner. In addition there may be one or more transfers, and there may also be so-called duplicate cards, which represent minor transactions of little consequence.

Since the objective of the study was to obtain information regarding vehicles rather than about their owners, it was necessary to find a means of drawing a representative sample of vehicles from a file of ownerships. To resolve this difficulty, the concept of originals and subsequents was developed. An *original* was defined as the first registration of a vehicle in the given year. A *subsequent* was defined as any registration of a vehicle other than the first. For example if, on March 1, an owner renews the registration of the vehicle he registered in the previous year, that is considered an original registration. If, on July 1, he records the trade-in of the old car for a brand new one, that also is an original registration, although it will appear in the records as a transfer. On the other hand, if he trades in for a used car which had been registered in the same year by the previous owner, that transaction is considered a subsequent registration, although it too would appear on the records as a transfer. If a person not previously owning a car buys and registers a used car which had already been registered by the previous owner within the year, that is considered a subsequent, although it appears in the records as a registration. Thus an original or a subsequent may appear at any point in the sequence of registration and transfer cards under a given serial number.

It may be noted, parenthetically, that, in a State where the plates go with the car on transfer of ownership, the serial or plate-number file may be sampled directly, without recourse to the concept of originals and subsequents. This procedure is, however, an essential step in the case of a State where the plates are retained by the registrant.

Once this concept had been introduced, it became apparent that if a representative sample of all cards in the serial file were drawn, and each card (other than duplicates) was identified as either an original or a subsequent, the cards representing originals would constitute a representative sample of the number of vehicles registered during the year. This identification could not be made on the cards as they were drawn from the serial file. It was necessary to make a search in the motor-number file, the alphabetical file of the previous year, and other available files and records in order to make the complete identification desired.

It was first decided to draw every *n*th card in the serial file, but it soon developed that the job would be much easier if all the cards under every *n*th serial number were drawn. This procedure involved a species of cluster sampling, since a given serial number might contain from 0 to 4 or more cards. The absence of a card under a given serial number meant that no registration was issued under that number during the year. There was a relatively large number of such cases in the years 1943 and 1944, because the District of Columbia was still using 1942 number plates with annual tabs to indicate registration in the given year. Thus, if a vehicle was registered under a given serial number in 1942 and then, because of being scrapped or moved out of the District was not registered in 1943 or 1944, no card would be found under that serial number in the registration file for the later year.

It was of interest, for the sake of economy, to select as small a sample as would give the desired accuracy, which was conceived in terms of a relative error of no more than 2 percent (at the 95 percent level of significance) for the estimates of total vehicles registered. In the 1943 study a 4-percent sample (every 25th serial number) of private passenger-car registrations was drawn, producing a total of 6,144 individuals. In the 1944 study a 5 percent sample, consisting of 8,324 individuals, was taken. For the other vehicle types the relative size of sample varied from 30 percent, or 6,167 individuals, in the case of trucks, to 100 percent in the case of busses and other types of which the total was small.

In addition to the segregation of originals from subsequents, it was desired to obtain certain descriptive information about the vehicles registered during the year; and for this reason the process of identification included the determination of whether each original was a renewal, a return, a new car, or an immigration. A *renewal* is defined as the registration, in a given year, of a vehicle which was in registration status at the close of the previous year. Renewals may be further subdivided into *regular renewals*, i. e., those made by the same owner, and *cross-over renewals*, defined as renewals made by a different owner from the one who registered the vehicle in the previous year. Ordinarily, such transactions occur during the overlapping registration period

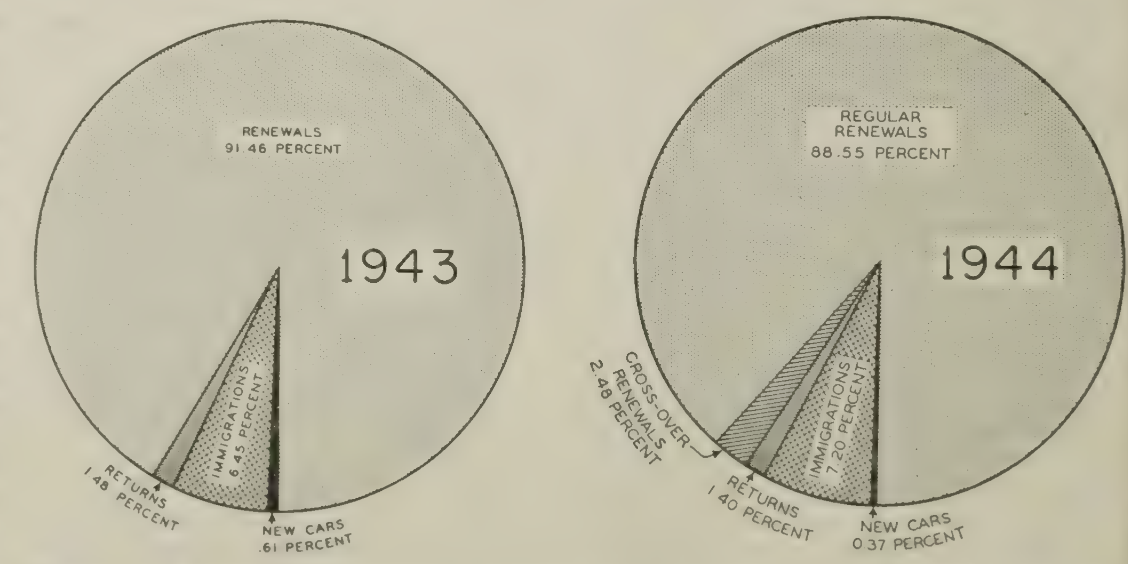

Figure 2.—Relative distributions of private passenger cars registered in 1943 and in 1944.

when new registrations are being issued while plates for the expiring year are still valid.

Each year there is a small number of vehicles that are withheld from registration by their owners, later to be returned to the registration lists: these are called *withdrawals.* A *return* represents the registration of a former withdrawal, i. e., that of a vehicle which was not registered in the next previous year, but which had been registered in a year prior to that, and had not lost title status in the District of Columbia during the interval between registrations. In this study the assumption was made that the returns of one year equal the withdrawals of the preceding year.

An *immigration* is defined as a vehicle moved in from another State and not registered in the District of Columbia prior to the year under study. Immigrations are of two kinds: *duplicating immigrations,* defined as migrant vehicles which were registered in both State of origin and State of destination in the year under study; and *cross-over immigrations,* consisting of migrant vehicles registered in the State of origin in one year and in the State of destination in the next year. If all States made studies of this sort it would be possible, by the exchange of information, to distinguish accurately between duplicating and cross-over immigrations. In the District of Columbia study, cross-over immigrations were taken as equalling all immigrations for which titles were issued prior to March 31, plus one-half of those titled in April. This assumption was influenced by the known registration practices of the adjacent States of Maryland and Virginia.

The identification process is illustrated in figure 1, which shows the type of enumeration card used in the study. Figure 1*A* illustrates the identification of a subsequent. Philip Jones titled the car on April 1, 1943, and registered it on April 6. The symbol N in the box headed "Registered last year?" indicates that he did not register this car in 1942. The next previous owner, James Gordon, titled the car on March 5, 1943, and registered it in the current year, 1943. Since this car was previously registered in the current year by James Gordon, the sample card represents a subsequent registration.

Figure 1*B* illustrates the identification of a cross-over renewal. The present owner did not register the car in 1942, but the next previous owner did. The transfer of title occurred during the cross-over period, in the month of March.

Figure 1*C* illustrates the identification of a cross-over immigration. That it was an immigration is proved by the fact that it was first titled in the District of Columbia as a used car. Because it was first registered in the District in 1943, it is by definition a 1943 immigration. It was, however, first titled by Joseph Brown on July 7, 1942. Therefore, since it was in the District of Columbia at the opening of the 1943 registration year, it qualifies as a cross-over immigration.

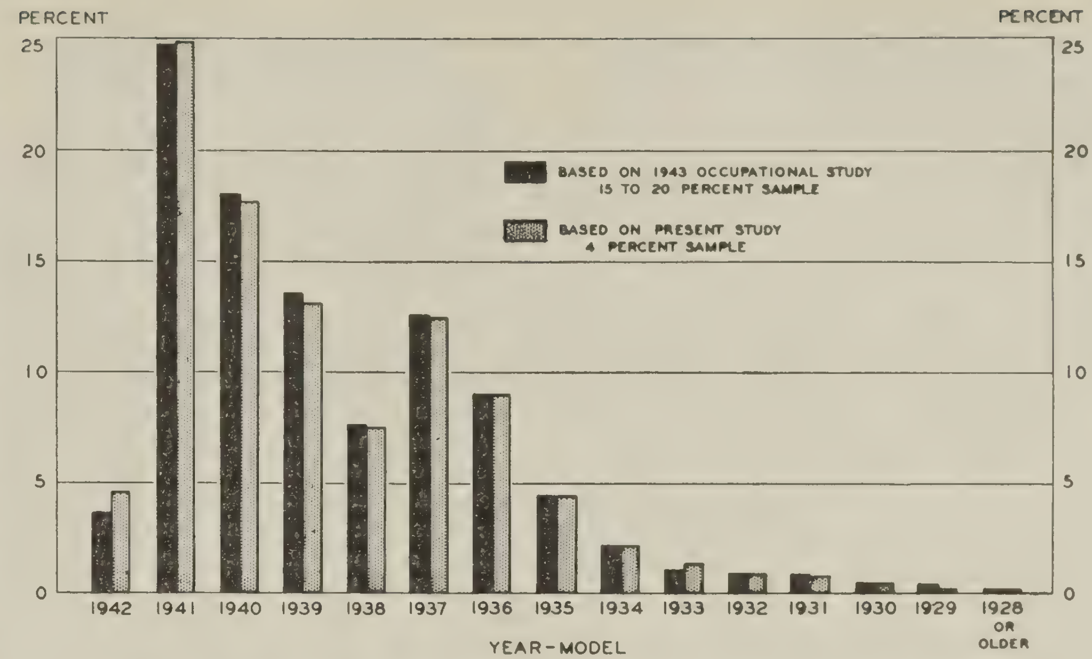

Figure 3.—Year-model distributions of private passenger cars registered in 1943.

A brief summary of the results of the registration studies is given in figures 2–4. The left-hand chart in figure 2 gives the percentage distribution of private passenger cars registered in 1943 with respect to renewals, returns, new cars, and immigrations. More than 91 percent of the passenger cars registered were renewals. This is a much higher percentage than would be encountered in a normal year, because new car production had been suspended and the used-car market was also relatively inactive under war conditions. The number of new cars registered was naturally very small. Immigrations, on the other hand, constituted about 6½ percent of the vehicles registered. The number of returns, although relatively small, was much greater than the number of new cars. It seems probable that the number of returns, which are indicative of vehicles kept in storage throughout the registration year 1942, would have been greater in a war year than in a normal year.

The right-hand chart in figure 2 shows the same distribution for the passenger car sample drawn in 1944. In the 1944 study, cross-over renewals were identified separately from regular renewals. Of the vehicles registered, 88½ percent were regular renewals and 2½ percent were cross-overs. The number of new cars was much less than in 1943, because the rationed supply of 1942 models was running out. Returns were somewhat less; and it may be said that this result was unexpected, since it was thought that 1944 would show a considerable return of cars from wartime storage. The percentage of immigrations was somewhat greater, accounting for 7 percent of the vehicles registered.

Figure 3 shows the year-model distribution of private passenger cars registered in 1943. The dark bars represent a year-model distribution obtained in an earlier study of the occupations of passenger-car owners, in which a sample of between 15 and 20 percent of the registrations was taken. The light bars represent the results given by the 4-percent sample taken in this study. It will be observed that the only difference of more than negligi-

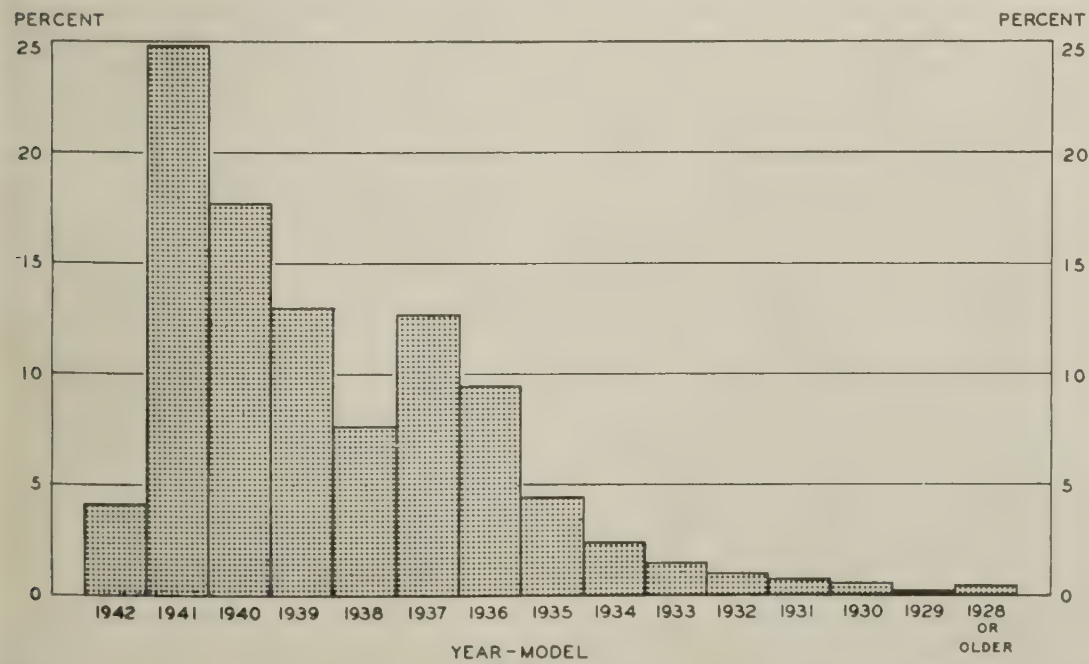

Figure 4.—Year-model distribution of private passenger cars in existence on March 1, 1943, which were subsequently registered for 1943.

ble size is found in the 1942 models. This disparity is accounted for by the fact that the occupational study was conducted with a cut-off date of June 30, 1943, while in the present study registrations of the entire year were sampled, so that all of the 1942 models were accounted for. This external check indicates that the sample size chosen was sufficient for an accurate representation of the year-model distribution.

Figure 4 shows the year-model distribution of private passenger cars in existence in the District of Columbia on March 1, 1943, which were subsequently registered for 1943. This figure serves to introduce the question of the determination of the number of vehicles in existence at the beginning or end of a given registration year. The drawing and identification of the sample served only to provide an estimate of the total number of vehicles that were registered in the year 1943. Since a certain number would be scrapped and others would be moved out of the District by their owners, the total number of vehicles registered would by no means represent the number existing at the end of the year.

An accurate estimate of the number of vehicles existing can be obtained from the registrations of a given year only by a throw-back to the beginning of the year. The process, as applied to the year 1943, is as follows: From the total number of vehicles registered in the year 1943 deduct the number of new vehicles registered and the number of duplicating immigrations; then add the returns of the year 1944, as representing 1943 withdrawals. The result is an estimate of the number of vehicles in existence in the District of Columbia at the beginning of the registration year 1943. Cross-over immigrations are not deducted, for these vehicles are either known or assumed to have been in the District at the beginning of the year.

The process described above is illustrated for private passenger cars in 1943, as follows:

Total number registered in 1943		114, 700
Less: New cars registered	700	
Duplicating immigrations	4, 400	
		−5, 100
Plus 1944 returns (representing 1943 withdrawals)		+1, 380
Total = Estimate of number of cars in existence at beginning of 1943		110, 980

In preparing the estimate of cars existing at the beginning of 1944, it was necessary to make an assumption regarding 1944 withdrawals, since no data on 1945 returns had been collected. A value equal to 1¼ times that of 1944 returns was selected, on the ground that there would be a somewhat greater accumulation of cars withheld from registration during 1944 than during 1943. The calculation for private passenger cars in 1944 is as follows:

Total number registered in 1944		98, 300
Less: New cars registered	360	
Duplicating immigrations	4, 630	
		−4, 990
Plus estimated 1944 withdrawals		+1, 725
Total = Estimate of number of cars in existence at beginning of 1944		95, 035

An important part of the study was the determination of the error involved in using the registration totals of a given year to represent the number of vehicles existing at the end of the year. Obviously, the sample estimate of cars existing at the beginning of 1943 should be compared with official total registrations for 1942; and similarly, cars existing at the beginning of 1944 should be compared with the official registrations for 1943. This comparison is given for passenger cars in figure 5. It will be observed that in both cases the official registration total was considerably in excess of the estimated number of cars existing. The divergence in 1942 was 22 percent and in 1943, 17 percent. Since registrations in the District of Columbia were declining rather rapidly during the war period, there is a likelihood that this discrepancy is greater than that which would be observed in a normal year. However, the sale of new cars induces scrappage, and in a year when such scrappage is of large magnitude, the discrepancy between registrations and cars existing might be rather high. In any event, the result of this sample study should serve as a warning of the danger of using registration totals as indicative of the number of vehicles existing at the end of the year.

The severity of the discrepancy indicated in figure 5 is mitigated somewhat if a distinction is made between cars existing at the end of the expiring registration year and cars existing at the beginning of the new year. Every year there will be a number of cars that are not scrapped until the owner is confronted with the necessity of buying new plates for an unserviceable vehicle. Such cars may actually be driven on the last day of the expiring year. Statistically, there seems to be no advantage in making a distinction between the end of the old year and the beginning of the new; and it is customary to consider a vehicle that is scrapped without being registered for the new year as belonging to scrappage of the expiring year. On the other hand, since the magnitude of year-end scrappage is probably greater than proportional to total scrappage during a year, consideration of these vehicles as existing at the end of the old year would reduce the discrepancy indicated in figure 5, perhaps by an appreciable percentage. The registration figures, however, do not afford a means of estimating the number of vehicles involved.

It was also possible in this study to analyze the transition from the number of passenger cars existing at the beginning of the registration year 1943 to the number existing at the beginning of the registration year 1944. This transition, shown in the form of an accounting statement, is as follows:

Cars existing, March 1, 1943		110, 980
Changes during 1943 registration year:		
New cars registered	700	
Duplicating immigrations, 1943	4, 400	
Cross-over immigrations, 1943–44	2, 450	
Total vehicles added	7, 550	
Less scrappage and emigrations	−23, 495	
Net change in number of cars		−15, 945
Cars existing, March 1, 1944		95, 035

The process of accounting is evident: To the number of vehicles existing at the beginning

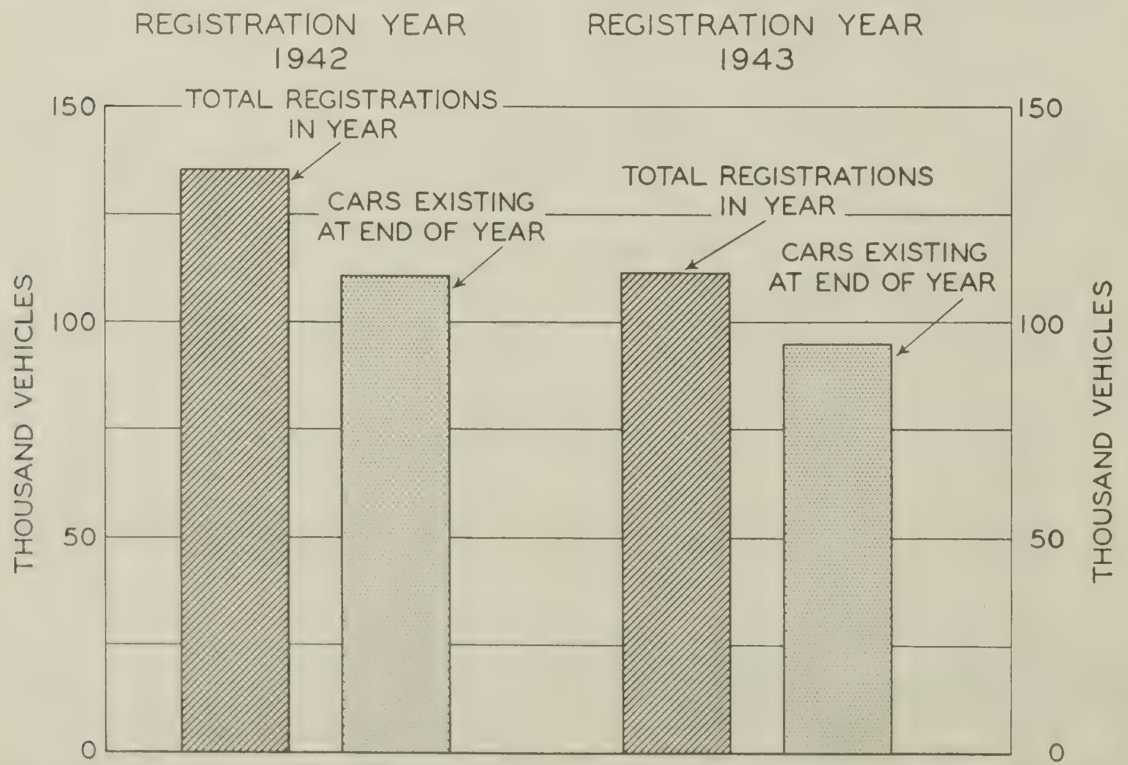

Figure 5.—Comparisons of official registrations of private passenger cars with estimated numbers of cars existing at the ends of corresponding years.

of 1943, add new cars registered in 1943, duplicating immigrations of 1943, and crossover immigrations of the 1943–44 transition period; and deduct the number of vehicles which were scrapped or moved out of the State during the year. Actually, the latter is the residual figure, since its value can only be derived from the estimated cars existing at the beginnings of the two years, and the new cars and immigrations of the period between them. If the system of analysis herein described were adopted by all or a large number of States, the exchange of information among them would make possible an estimate of emigrations; and the number of vehicles scrapped would be derived as the residual figure.

The indicated volume of scrappage and emigrations, 23,495, seems rather high, particularly in view of the fact that scrappage is generally considered to have been at a minimum during the war. It must be remembered, however, that the population of the District of Columbia was rather fluid during the war years. In addition to military men and others moving out of the area, there was a steady drift of District of Columbia residents into new residential developments of the surburban sections of Maryland and Virginia.

In the 1944 study, other items of information were collected and analyzed, including the occupations of passenger-car owners, the geographical distribution of passenger cars registered, the weight distribution of all vehicle types, registration fees and personal property taxes paid, and the body-type distribution of trucks and tractor trucks. Space does not permit discussion of these parts of the analysis. In general, it was concluded that studies of this character could be made annually in all States at not too great expense, and that the information gained would be of substantial value to highway research and to the motor-vehicle industry.

THE TITLE STUDY

In the District of Columbia, certificates of title are numbered serially as issued, and the completed application forms are placed in a serial file, together with any documents auxiliary to the transaction. Such documents include (1) titles held by the next previous owner and surrendered by the new owner upon application for the new title, and (2) titles issued by other States and surrendered upon application for a title in the District of Columbia. The first group bear dated assignments of title, two in case of a consumer-to-dealer-to-consumer transaction and one in the case of a consumer-to-consumer sale. The second group bear similar assignments if the immigration involved a sale transaction. This method of filing results in a fully chronological file, any segment of which can be analyzed or sampled at any time. Those titles issued during the calendar year 1941 were selected for this study.

All vehicle types and classes filed separately in the title records were subjected to study; but the greatest attention was concentrated on passenger cars, which accounted for nearly 81,000 of the 88,600 titles issued in 1941.

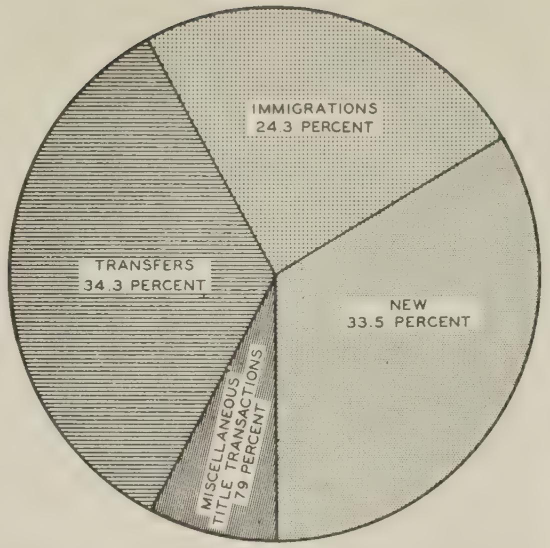

Figure 6.—Percentage distribution of private passenger-car title transactions in 1941.

Because of wide variation in the numbers of vehicles in the several classes to be sampled, the rate of periodic sampling varied from 1 in 50 for passenger cars to 1 in 3 for sightseeing vehicles.

The enumeration schedule was arranged so as to record the month of title issuance, year model of the vehicle, and the several kinds of titles, including new originals (issued for new vehicles), used originals (indicating an immigration), used transfers (issued upon transfer of ownership from one District of Columbia consumer-owner to another), and certain miscellaneous transactions, such as motor-number changes and titles issued to manufacturers and dealers, which were of little or no consequence in the study. A record was made also of the type of transaction, whether a dealer sale to consumer, a consumer-to-consumer sale, or an immigration not involving a sale transaction. Dates of title assignments were also taken off for those titles resulting from sales by District of Columbia dealers.

Figure 6 gives a summary of the results of the sampling of passenger-car titles. The miscellaneous transactions, in which there was no interest for this study, accounted for 7.9 percent of the total. Transfers of ownership accounted for the largest segment, 34.3 percent. The number of new cars titled was nearly as great, and immigrations accounted for 24.3 percent of the titles issued. The number of new car titles was 17.6 percent of total passenger-car registrations in 1941, immigrations were 12.8 percent, and transfers of ownership 18.1 percent. These figures illustrate the fact that a very large percentage of the cars registered in a normal year are involved in transactions of this sort.

Of the total passenger-car immigrations in 1941, estimated at 19,700, 57 percent were moved into the District of Columbia by the owners and 43 percent were brought in as a result of sale transactions. In 1941 many people were moving into the District because of National defense activities. In a normal year, or in an ordinary State, it is probable that sale transactions would account for a larger percentage of the immigrations.

A record was also made of the States from which the migrating vehicles came. Thirty-six States, including all of the 9 census regions, were represented in the sample total of 393 individuals. There is little doubt that, if the sample size had been sufficient, all of the 48 States would have been found present. However, the two neighboring States of Maryland and Virginia accounted for 68 percent of the total passenger-car immigrations to the District of Columbia in 1941.

Another interesting comparison is that between dealers' sales of used cars to consumers and consumer-to-consumer sales. Of the 724 sample individuals representing used-car sales, 23 percent were consumer-to-consumer sales, and 77 percent were dealer-to-consumer sales. It is probable that the percentage of consumer-to-consumer sales increased during the war years and is still high, because of the stringencies of the new-car market.

Although the 2-percent sample of 1941 passenger-car titles was inadequate to give a distribution of transactions by month of issue with a satisfactory degree of accuracy, the data were so analyzed; and the results displayed sufficient consistency and regularity of seasonal variation to justify their use in demonstrating the resources of the title file.

Figure 7 gives some of the results of this monthly analysis. Plotted values represent numbers of sample individuals. Maximum sales of new cars occurred in May, which was also the peak month for the Nation as a whole in 1941. The data are plotted by date of title assignment from dealer to purchaser, rather than by date of issue of the new title, thereby giving a more accurate representation of the time of sale. The tendency of used-car sales to follow the trend of new-car sales is plainly evident, although the peak in the month of May is decidedly less sharp.

The evidence of this figure seems to belie the often-quoted statement that two used cars must be sold for every new car. The data shown, however, do not include used-car sales by District of Columbia dealers to dealers and consumers in the suburban and rural areas surrounding the District. Furthermore, consumer-to-consumer sales and sales by dealers in other States (mainly Maryland and Virginia) are also omitted. If the Maryland and Virginia titles were analyzed for a common period with those of the District of Columbia, the characteristics of the used-car market in the District could be pretty well determined.

Figure 7 also portrays an estimate, in terms of sample individuals, of dealers' inventories of used cars at the end of each month, a quantity which it is necessary to have if it is desired to convert from cars existing to cars in use at any time. The following example will illustrate the method of arriving at these figures. If the dates of title assignments show that a car was sold to a dealer prior to December 31, 1940 and was sold by the dealer after that date, the car was obviously a part of dealers' inventories on that date. The used-car sales of each month (as given by date of title assignment from dealer to

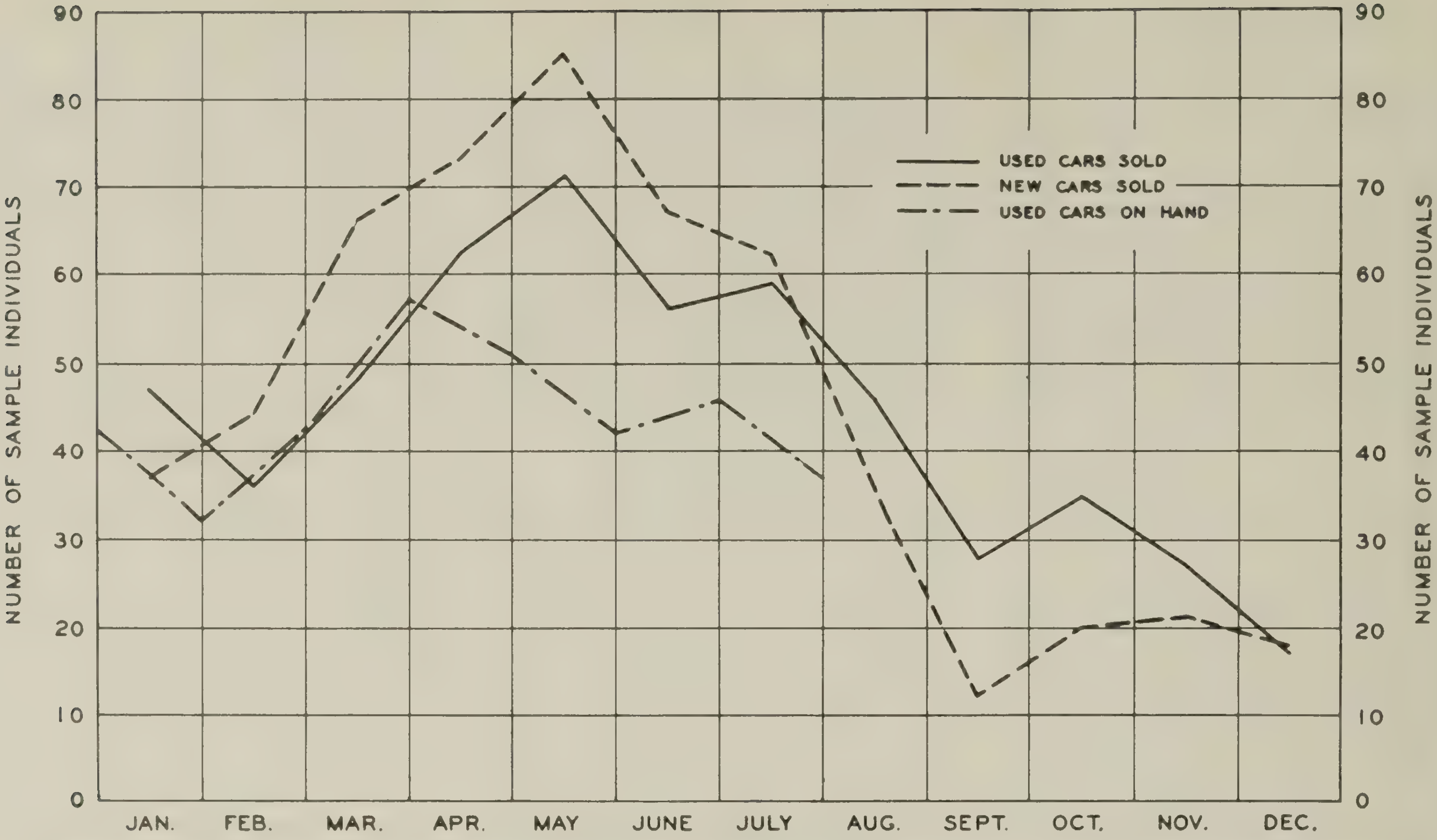

Figure 7.—Monthly distribution of dealers' sales of new and used cars, and used cars on hand at end of month, in 1941.

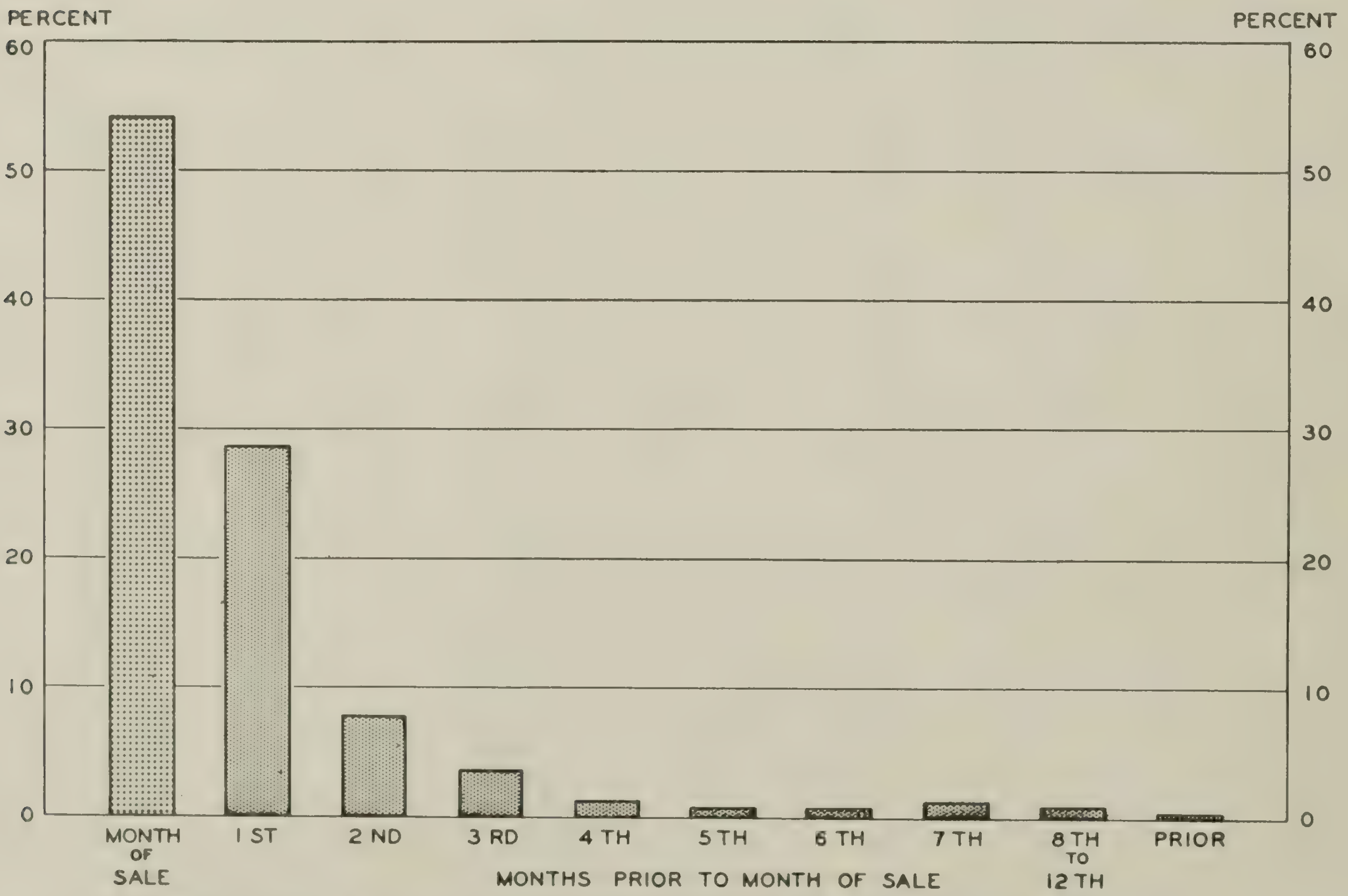

Figure 8.—Average percentage distribution of monthly sales of used passenger cars by dealers to consumers, by month in which title was transferred to dealer.

purchaser) were tabulated against month of purchase by the dealer, and the size of the dealers' inventories, or cars on hand, at the end of each month was obtained by deducting cumulative cars sold from cumulative cars purchased.

Dealers' inventories of used cars as obtained in this manner do not include cars destined to be sold to junkers rather than to consumers, or cars destined to be sold outside the District of Columbia, as for example, in the neighboring States of Maryland and Virginia. For this reason, the total given by expansion of the sample value of cars on hand would probably be materially less than the value given by a physical inventory of used cars in the hands of District of Columbia dealers. The quantity does have a definite and important significance, however—it may be defined as the effective used-car inventory of District of Columbia dealers with respect to the District of Columbia consumers' market.

The curve of dealers' inventories, or cars on hand, appears to follow a normal trend, having a pronounced maximum at the close of the registration year (March 31), and showing the next highest value on April 30, just preceding the month of maximum sales. It was impossible to carry this curve beyond the end of July, because of the absence of data regarding sales after December 31, 1941.

In order to develop an index of the rate of turn-over of used cars, the value of dealers' inventories, or cars on hand, was expressed in terms of days' supply on hand by referring to the average daily sales in the subsequent month. It was found that days' supply, computed in this manner, varied from 22 to 28 days.

The rate of turn-over of used cars in the District of Columbia was approximated by another means. Figure 8 gives the average percentage distribution of monthly sales of used cars by month in which the car was purchased. It will be observed that the vast majority of cars were sold either in the month in which they were purchased or in the first month thereafter. On the other hand, 5.3 percent of the 532 cars reported in the sample were sold after remaining four or more months in the hands of the dealer. The weighted average number of days in dealers' hands was 34.9. This quantity is comparable to days' supply, which was found to vary from 22 to 28 days. That the weighted average is materially greater than days' supply is due to the weighting computation, which magnifies the effect of the small number of cars that remained in the dealers' hands for several months. It is probable that the rate of turn-over of used cars in the District of Columbia, shown in this study to be in the neighborhood of 30 days, is materially shorter than in the average State, because of the effect of more leisurely ways of doing business in small cities and rural areas.

These examples are sufficient to illustrate the wealth of information regarding the characteristics of motor-vehicle ownership and the motor-vehicle market to be found in the files of certificates of title. Such material is perhaps of more consequence to the industry than to highway research, although it is believed that a knowledge of the dynamics of the motor-vehicle market is a valuable asset in highway research and planning, particularly with respect to the forecasting of highway revenue and of fluctuations in the volume of travel.

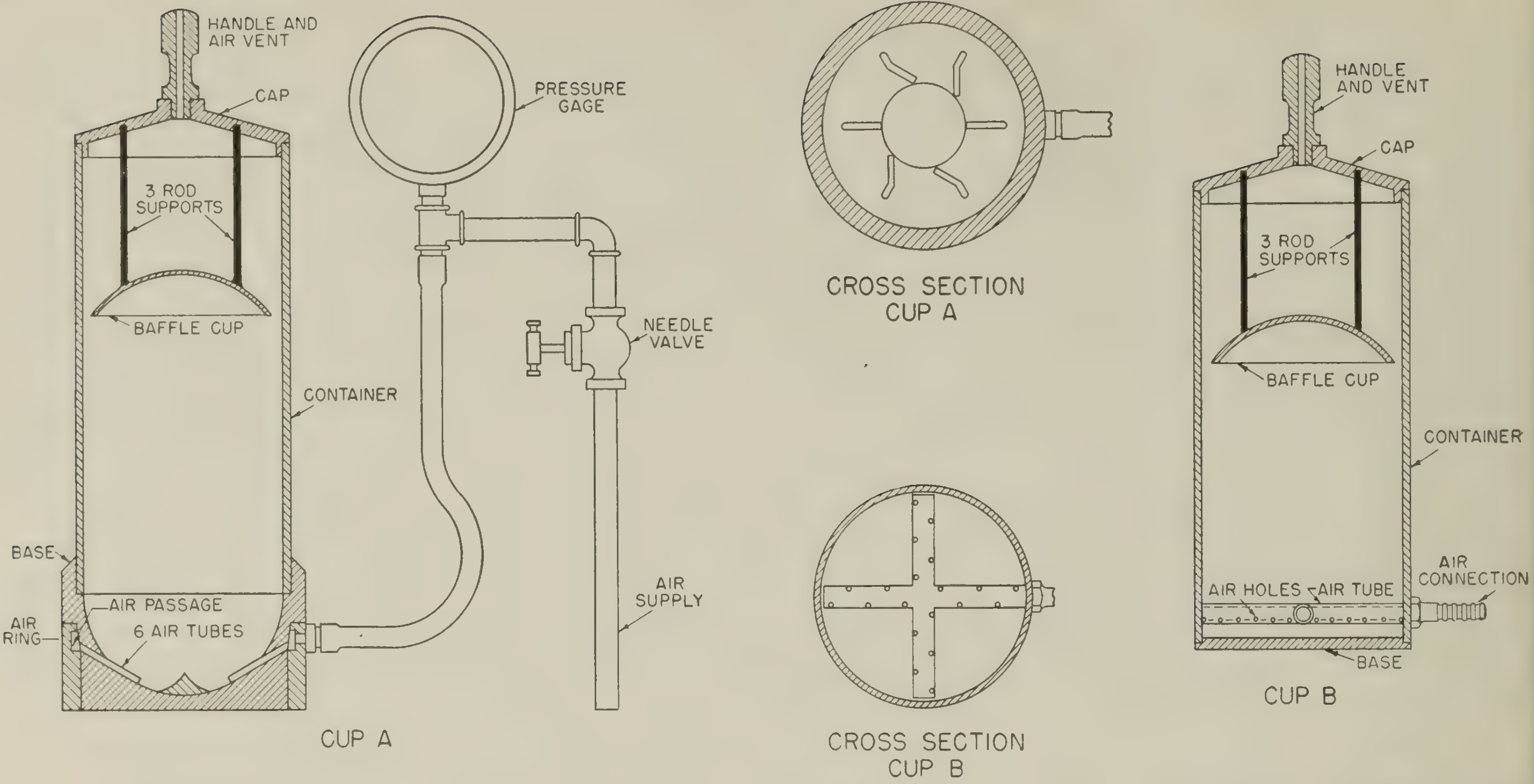

Figure 1.—The Wintermyer soil-dispersion cups.

A New Soil-Dispersing Apparatus For Mechanical Analysis of Soils

BY THE DIVISION OF PHYSICAL RESEARCH PUBLIC ROADS ADMINISTRATION

Reported by A. M. WINTERMYER, Highway Engineer

The complete mechanical analysis of soils includes the hydrometer analysis of the fine-particle fraction of the sample, suspended in water. In the present standard method of preparing this suspension a mechanical stirring device is used to disperse the soil particles. This report describes a new apparatus utilizing air jets to stir the soil-water mixture. The air-jet cup provides more complete dispersion of the clay portion of plastic soils, yet its degrading action is no greater than that of the present standard stirrer. The new device can thus permit analysis more nearly representative of the actual gradations of the soils being tested.

THE ORIGINAL hydrometer method of mechanical analysis of soils was developed by Bouyoucos [1] in 1927. In this method of test a hydrometer is used to determine the percentage, by weight, of a sample of soil remaining in suspension in water after any given period of sedimentation. Since the velocity of sedimentation of soil particles of different sizes varies in accordance with Stokes' law, it is possible to compute the maximum grain size in suspension at the time any hydrometer reading is made. A series of such readings makes possible the determination of the gradation of the fraction of soil passing about the No. 200 sieve, which cannot be determined accurately by dry sieving methods. These data, combined with the sieve analysis of the washed material retained on the No. 200 sieve, provide complete mechanical analysis of the soil.

A modification of the original Bouyoucos method was described in PUBLIC ROADS [2] in 1931. That modification, with some revisions, was adopted by the American Association of State Highway Officials as the standard method of mechanical analysis of soils.[3]

[1] *The hydrometer as a new and rapid method for determining the colloidal content of soils,* and *The hydrometer as a new method for the mechanical analysis of soils,* by G. J. Bouyoucos; Soil Science, vol. 23, No. 4, April 1927, p. 319 and vol. 23, No. 5, May 1927, p. 343.

[2] *Procedures for testing soils for the determination of the subgrade soil constants,* by A. M. Wintermyer, E. A. Willis, and R. C. Thoreen; and *Graphical solution of the data furnished by the hydrometer method of analysis,* by E. A. Willis, F. A. Robeson, and C. M. Johnston; PUBLIC ROADS, vol. 12, No. 8, October 1931.

[3] A. A. S. H. O. standard test method T 88–42, mechanical analysis of soils.

In the combined sieve and hydrometer method of mechanical analysis, it is necessary to use a mechanical device to disperse the soil thoroughly in water. The standard A. A. S. H. O. method specifies a high-speed stirring device with a metal paddle and a dispersion cup with metal baffles on its walls, similar in appearance to an electric milk-shaker. Various investigators have criticized the use of this apparatus on the ground that the agitation was of such a nature as to produce degradation [4] of the coarser soil particles. In fact, this criticism was responsible for the reduction of the dispersing time from 15 minutes as originally proposed to 1 minute as now specified by the standard A. A. S. H. O. test method. However, this modification has resulted in decreased efficiency for the dispersion of the clay fraction, especially in the more cohesive soils.

This report describes a new type of dispersing apparatus, utilizing the turbulence created by air jets to stir the soil-water mixtures, which has been developed to overcome the faults of the high-speed stirring device.

CONCLUSIONS

Comparative tests of a large number of soil samples, using the standard A. A. S. H. O. high-speed stirring apparatus and the new air-jet dispersing cup, are the basis for the following conclusions:

1. The degrading action of the air-jet dispersing cup with dispersing periods up to 20 minutes is no greater than that of the high-speed stirring device with a 1-minute dispersing period.

2. The use of the air-jet dispersing cup results in more efficient dispersion of the clay fraction of plastic soil samples than is obtained with the high-speed stirrer.

3. The air-jet dispersing cup, when used in accordance with the tentative procedure described in this report, will result in mechanical analyses more nearly representative of the actual gradations than those obtained by using the stirring device specified in the A. A. S. H. O. test method T 88–42.

DEVELOPMENT OF THE AIR-JET DISPERSING APPARATUS

Preliminary studies were conducted to determine the feasibility of using air jets for dispersing soil in water, the most effective shape for the dispersion cup, the effect of using a baffle plate, and the influence of such variables as air pressure, time of dispersion, volume of mixture to be dispersed, and method of treatment before dispersion. As a result of this exploratory work, an air-jet dispersing cup was designed which was believed to be suitable for the preparation of the soil-water suspensions required for the mechanical analysis of soils by the combined sieve and hydrometer method. A diagrammatic sketch of this apparatus, identified as cup *A*,[5] is shown in figure 1.

[4] As used in this article, degradation means the wearing down or breaking of soil particles into smaller sizes.

[5] Working drawings of the air-jet dispersion cups *A* and *B* described in this article may be obtained from the Public Roads Administration.

Table 1.—*Comparison of mechanical analyses using different methods of dispersion*

Sample No.	Plasticity index	Liquid limit	Dispersion method	Percentage of particles smaller than—					
				2.0 mm.	0.42 mm.	0.074 mm.	0.050 mm.	0.005 mm.	0.001 mm.
5	3	48	A. A. S. H. O.[1]	100	100	71	62	22	11
			Cup *A* [2]	100	95	68	57	21	11
6	62	88	A. A. S. H. O	100	94	84	81	61	44
			Cup *A*	100	94	84	82	63	48
7	36	70	A. A. S. H. O	100	99	95	94	62	26
			Cup *A*	100	99	95	95	60	27
8	7	46	A. A. S. H. O	100	100	81	74	21	6
			Cup *A*	100	100	80	70	18	11
9	11	30	A. A. S. H. O	100	100	88	82	40	23
			Cup *A*	100	99	86	81	38	21
10	11	28	A. A. S. H. O	100	89	35	32	12	6
			Cup *A*	100	78	30	26	11	5
11	NP [3]	37	A. A. S. H. O	100	98	68	54	6	2
			Cup *A*	100	90	50	40	8	5
12	40	67	A. A. S. H. O	100	99	95	93	66	45
			Cup *A*	100	98	95	94	72	46
13	23	54	A. A. S. H. O	100	100	84	75	48	21
			Cup *A*	100	100	79	71	41	26

[1] Tested in accordance with A. A. S. H. O. test method T 88–42.

[2] Average results obtained from tests in which soil was dispersed in cup *A* using pressures ranging from 2 to 20 psi, mixing time from 1 to 15 minutes, and various methods of pretreatment.

[3] Nonplastic.

Compressed air, after passing through a needle valve and pressure gage, enters an air ring encircling the base of the apparatus. Six radial tubes connected to the ring direct the compressed air against the specially shaped center of the bottom of the cup, vigorously agitating the soil-water mixture. After bubbling through the liquid, the air escapes through a vent in the handle of the cap which fits tightly over the top of the cup. A baffle suspended below the cap prevents the liquid from being thrown against the vent and blown out of the cup.

The simplified air-jet dispersion cup *B* was subsequently designed, and is also shown diagrammatically in figure 1. It differs from cup *A* primarily in the manner in which the compressed air is introduced. Cup *B* has four radial air tubes, parallel to and raised somewhat above the flat bottom of the cup. Compressed air is introduced at the outer end of one tube and, since the tubes are interconnected at the center, passes into the other three. Small apertures in the sides of the tubes jet the compressed air downward into the liquid. Cup *B* is much simpler to construct and, as will be shown later, is practically as efficient in dispersing soils as cup *A*.

Preliminary studies were made, using cup *A*, to establish a satisfactory procedure for using the air-jet device and to determine whether this apparatus would give results equal to or better than the standard A. A. S. H. O. high-speed stirrer. The results of tests on a group of representative soils having a wide range in physical properties are summarized in table 1. The values shown for the A. A. S. H. O. method of dispersion were obtained after dispersing the soil in accordance with A. A. S. H. O. method T88–42; those shown for cup *A* are average values for a number of tests in which the agitating air pressure was varied from 2 to 20 pounds per square inch, the mixing time was varied from 1 to 15 minutes, and various methods of pretreatment were employed.

The results of these preliminary tests gave the following indications:

1. The percentages of particles smaller than 0.42 mm. (No. 40 sieve) and 0.074 mm. (No. 200 sieve) obtained in the mechanical analyses using cup *A* were equal to or less than the corresponding percentages obtained by the A. A. S. H. O. method, indicating greater breakage and abrasion of the sand particles in the high-speed stirring device. This was more apparent in some soils than in others (see data for soil samples *5*, *10*, *11*, and *13* in table 1).

2. The degrading action of the stirring device was indicated in most cases by the increased percentages of material smaller than 0.05 mm. (silt and clay) although a reversal of this trend, caused by the more efficient dispersion of the clay and colloidal fractions in the air-jet device, began to be apparent in the analyses of some soils such as samples *6*, *7*, and *12*.

3. The percentages of particles smaller than 0.001 mm. obtained in the analyses using cup *A* were approximately equal to or greater than the corresponding percentages obtained by the A. A. S. H. O. method, indicating that greater dispersion was being obtained with the air-jet device for some soils and that the dispersing action of this new device was equal to that of the high-speed stirring apparatus for all soils tested.

These exploratory tests also showed that air pressure between 2 and 20 pounds per square inch could be used without appreciably affecting the particle-size distribution of the soils. In all tests subsequently reported, an air pressure of 20 pounds per square inch was used.

ABRASION CHARACTERISTICS

In order to obtain more conclusive data on the abrasion and dispersing characteristics of the two types of dispersing apparatus, an additional series of tests was run.

A quartz sand (Potomac River sand) and a commercial limestone sand were selected for the study of the abrasion characteristics of the two types of dispersing apparatus. Three samples were prepared from each sand, having maximum-size particles of 2.0 mm., 0.42 mm., and 0.074 mm., respectively. In this way, it was possible to study the effect on abrasion loss of maximum-particle size as well as the character of the sand grains.

The samples were quartered into 100-gram

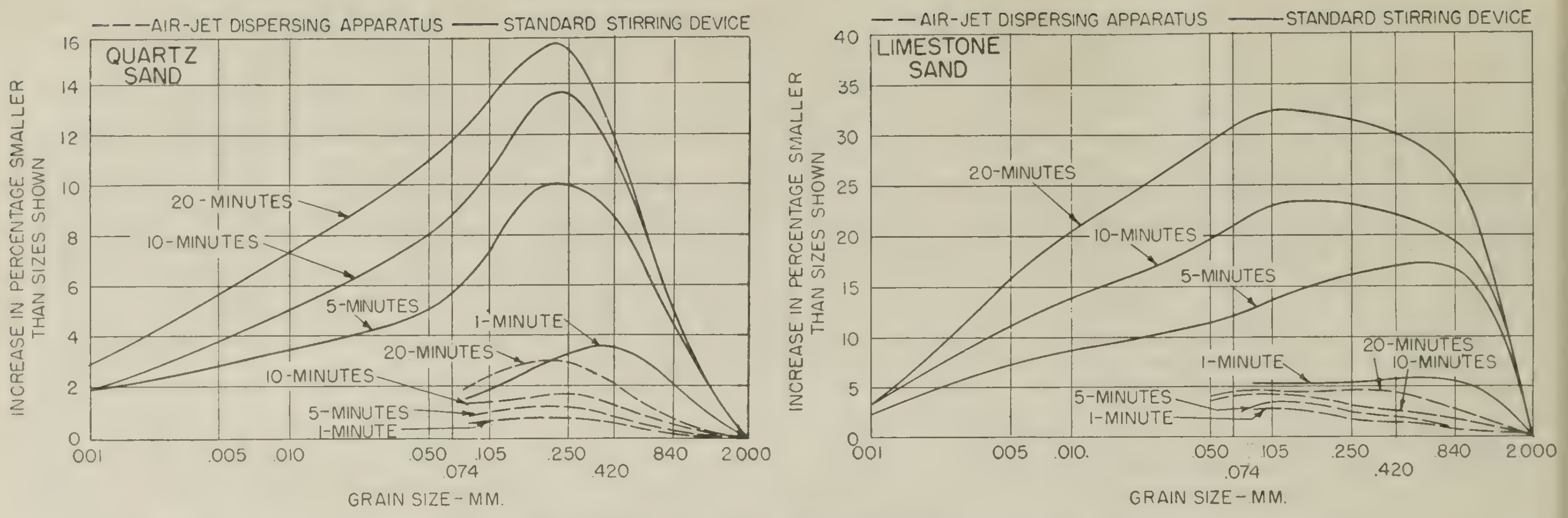

Figure 2.—Change in particle-size distribution due to abrasion of soil particles (maximum size 2.0 mm.).

individual test samples which were dispersed in each type of apparatus for 1, 5, 10, and 20 minutes. All tests were made in triplicate. The average test results are shown in table 2. An increase in abrasion of the mineral soil particles is indicated by a decrease in coarse sizes with a corresponding increase in fine sizes.

Table 2.—*Mechanical analyses of sands after various periods of dispersion*

Dispersion time and method	Percentage of particles smaller than—								
	2.0 mm.	0.84 mm.	0.42 mm.	0.25 mm.	0.105 mm.	0.074 mm.	0.050 mm.	0.005 mm.	0.001 mm.
QUARTZ SAND									
Undispersed	100	76	37	9	0	0	0	0	0
1 minute: A. A. S. H. O	100	78	41	12	2	2	----	----	----
Cup *A*	100	76	38	10	1	1	----	----	----
5 minutes: A. A. S. H. O	100	80	46	19	8	6	5	3	2
Cup *A*	100	76	38	10	1	1	----	----	----
10 minutes: A. A. S. H. O	100	81	48	23	11	9	8	4	2
Cup *A*	100	76	38	11	2	1	----	----	----
20 minutes: A A. S. H. O	100	81	49	24	14	12	11	6	3
Cup *A*	100	77	39	12	3	2	----	----	----
Undispersed	----	----	100	75	17	0	0	0	0
1 minute: A. A. S. H. O	----	----	100	75	18	2	----	----	----
Cup *A*	----	----	100	75	17	2	----	----	----
5 minutes: A. A. S. H. O	----	----	100	76	19	3	3	2	2
Cup *A*	----	----	100	75	18	2	2	2	2
10 minutes: A. A. S. H. O	----	----	100	76	19	4	4	3	2
Cup *A*	----	----	100	75	18	3	2	2	2
20 minutes: A. A. S. H. O	----	----	100	77	21	5	5	3	2
Cup *A*	----	----	100	76	19	4	3	3	2
1 minute: A. A. S. H. O	----	----	----	----	----	100	76	14	6
Cup *A*	----	----	----	----	----	100	75	14	5
5 minutes: A. A. S. H. O	----	----	----	----	----	100	76	15	6
Cup *A*	----	----	----	----	----	100	76	14	6
10 minutes: A. A. S. H. O	----	----	----	----	----	100	77	16	7
Cup *A*	----	----	----	----	----	100	77	15	7
20 minutes: A. A S. H. O	----	----	----	----	----	100	76	15	6
Cup *A*	----	----	----	----	----	100	74	16	6
LIMESTONE SAND									
Undispersed	100	48	23	15	5	0	0	0	0
1 minute: A. A. S. H. O	100	53	29	20	10	5	----	----	----
Cup *A*	100	48	24	17	8	3	----	----	----
5 minutes: A. A. S. H. O	100	65	40	30	19	13	11	7	2
Cup *A*	100	49	25	17	8	3	----	----	----
10 minutes: A. A. S. H. O	100	67	45	37	28	22	19	11	3
Cup *A*	100	49	26	18	9	4	----	----	----
20 minutes: A. A. S. H. O	100	73	53	46	37	33	29	16	3
Cup *A*	100	51	27	19	9	5	4	----	----
Undispersed	----	----	100	55	18	0	0	0	0
1 minute: A. A. S. H. O	----	----	100	63	24	6	----	----	----
Cup *A*	----	----	100	61	23	5	----	----	----
5 minutes: A. A. S. H. O	----	----	100	66	29	10	9	7	3
Cup *A*	----	----	100	63	25	6	6	4	3
10 minutes: A. A. S. H. O	----	----	100	69	32	13	12	9	3
Cup *A*	----	----	100	63	26	7	7	5	3
20 minutes: A. A. S. H. O	----	----	100	72	37	18	17	9	3
Cup *A*	----	----	100	65	28	9	8	7	3
1 minute: A. A. S. H. O	----	----	----	----	----	100	72	7	1
Cup *A*	----	----	----	----	----	100	71	7	2
5 minutes: A. A. S. H. O	----	----	----	----	----	100	79	8	3
Cup *A*	----	----	----	----	----	100	79	9	3
10 minutes: A. A. S. H. O	----	----	----	----	----	100	80	9	3
Cup *A*	----	----	----	----	----	100	80	9	3
20 minutes: A. A. S. H. O	----	----	----	----	----	100	80	9	4
Cup *A*	----	----	----	----	----	100	80	10	4

Figures 2 and 3 show graphically the results of the study of abrasion characteristics of the two types of dispersing apparatus. In these figures the increases in the percentage smaller than any given size (differences between the results of the analyses before and after dispersion) are plotted against the respective grain sizes produced by the two types of apparatus in 1-, 5-, 10-, and 20-minute dispersing periods.

A study of these comparative test data shows that:

1. The abrasion losses are greater for samples dispersed in the standard high-speed stirring device than for similar samples dispersed for an equal length of time in the air-jet dispersion cup.

2. Degradation of the sand particles increases with increased time of dispersion in both types of apparatus. The increase in degradation with dispersion time is much greater in the stirring device than in the air-jet cup.

3. The abrasion losses in the standard stirrer are much greater in samples containing particles having a maximum grain size of 2.0 mm. than in samples having maximum grain sizes of 0.42 mm. or 0.074 mm.

4. The degradation of the sand samples containing particles with a maximum size of 2.0 mm. when dispersed for 20 minutes in cup *A* was less than that which occurred when duplicate samples were dispersed for 1 minute in the standard stirring device.

5. The amount of abrasion occurring in the samples having a maximum particle size of 0.074 mm. was negligible.

6. The mineral composition of the sand grains appears to be a factor influencing the degradation. In the tests reported here, the quartz sand was more resistant to fracture and abrasion than the limestone sand. However, it is not known to what extent the shape and hardness of the mineral particles affect the abrasion loss, since these factors were not studied separately during this investigation.

It appears then, that for sandy soils the use of the air-jet type of dispersion cup will result in lower abrasion losses than those which are to be expected when the standard A. A. S. H. O. dispersing procedure is fol-

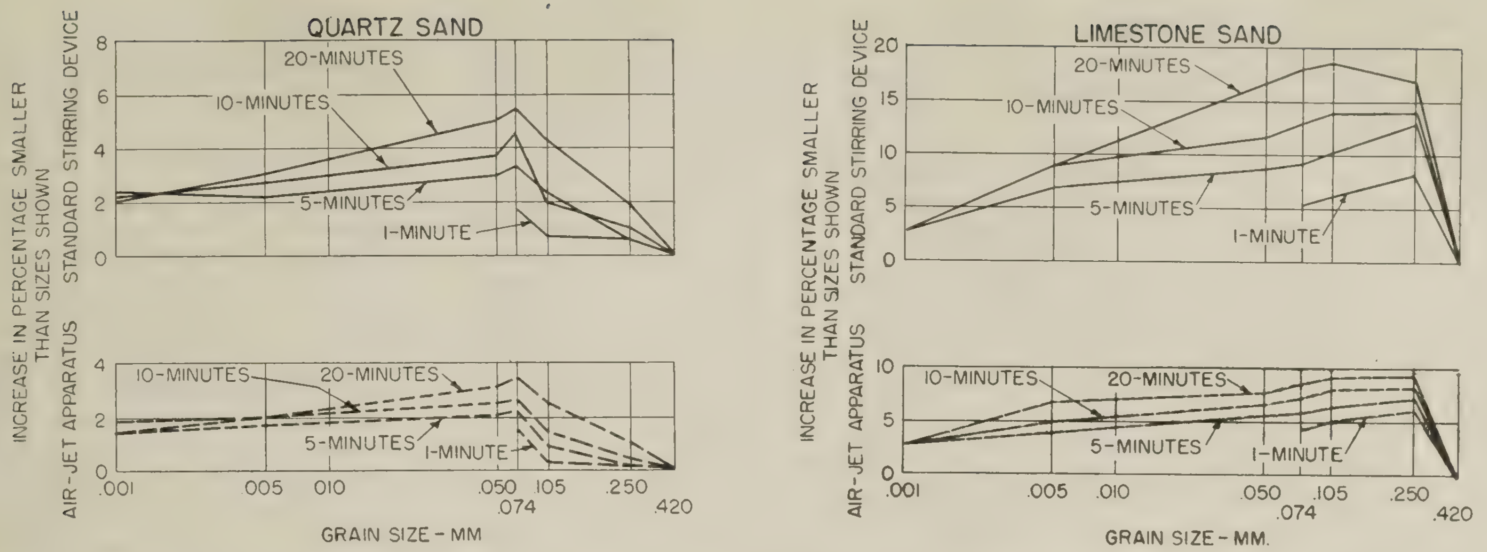

Figure 3.—Change in particle-size distribution due to abrasion of soil particles (maximum size 0.42 mm.).

lowed. In this connection, it was indicated that degradation could be materially reduced if the standard procedure required that the combined sieve and hydrometer analysis be made on the fraction passing the No. 40 sieve (0.42 mm.) instead of on the fraction passing the No. 10 sieve (2.0 mm.).

DISPERSING CHARACTERISTICS

Two clay soils were selected to study the dispersing characteristics of the two types of agitating devices. Test samples were prepared in a manner similar to that used for the two sands except that 50-gram instead of 100-gram individual test samples were used. Tests were made in each device for dispersing time intervals of 1, 5, 10, and 20 minutes and for test samples having maximum particle sizes of 2.0 mm., 0.42 mm., and 0.074 mm. In all tests in this series, the samples were soaked in water for 18 hours prior to dispersion. The results of tests are shown in table 3. Each value is the average of the results obtained on three samples.

A study of the test data for the Coastal Plain clay soil shows that for samples having maximum particle sizes of 2.0 mm. and 0.42 mm. there is very little difference in the dispersing characteristics of the two types of dispersing devices as measured by the percentages smaller than 0.005 mm. and 0.001 mm. About the same degree of dispersion was obtained in both devices with the 1-minute mixing period as with the 20-minute period. For the samples passing the No. 200 sieve, however, the percentage of colloidal material increased very considerably with increased time of dispersion. The air-jet dispersion was more effective at all dispersion periods.

The study of the test data for the Piedmont Plateau region clay soil indicates that the dispersing time is an important factor to be considered for this type of cohesive soil. The percentage of particles smaller than 0.001 mm. increased with an increase in the time of dispersion. The greatest change occurred between the 1- and 5-minute periods. Also, there was a marked difference in the dispersing characteristics of the two types of dispersion cups. The degree of dispersion at the end of 5 minutes for the air-jet device was greater than that found at the end of 20 minutes for the standard stirring apparatus.

It appears from the study of these data that the dispersing time for cohesive soils should be increased over the 1-minute period specified in the A. A. S. H. O. method in order

Table 3.—*Mechanical analyses of clay soils after various periods of dispersion*

Dispersion time and method	Percentage of particles smaller than—					
	2.0 mm.	0.42 mm.	0.074 mm.	0.050 mm.	0.005 mm.	0.001 mm.
COASTAL PLAIN SOIL [1]						
1 minute: A. A. S. H. O	100	96	67	63	42	31
Cup *A*	100	96	67	63	41	32
5 minutes: A. A. S. H. O	100	96	68	64	44	31
Cup *A*	100	96	68	64	44	32
10 minutes: A. A. S. H. O	100	96	69	64	42	32
Cup *A*	100	96	67	63	43	32
20 minutes: A. A. S. H. O	100	96	69	64	44	32
Cup *A*	100	96	68	65	45	34
1 minute: A. A. S. H. O	--------	100	66	62	42	30
Cup *A*	--------	100	66	62	42	30
5 minutes: A. A. S. H. O	--------	100	66	62	42	31
Cup *A*	--------	100	67	62	42	30
10 minutes: A. A. S. H. O	--------	100	67	62	42	31
Cup *A*	--------	100	66	62	42	32
20 minutes: A. A. S. H. O	--------	100	67	62	42	31
Cup *A*	--------	100	67	62	42	32
1 minute: A. A. S. H. O	--------	--------	100	94	54	31
Cup *A*	--------	--------	100	94	58	36
5 minutes: A. A. S. H. O	--------	--------	100	94	60	38
Cup *A*	--------	--------	100	95	61	42
10 minutes: A. A. S. H. O	--------	--------	100	94	60	40
Cup *A*	--------	--------	100	94	62	44
20 minutes: A. A. S. H. O	--------	--------	100	94	61	42
Cup *A*	--------	--------	100	92	61	45
PIEDMONT PLATEAU SOIL [2]						
1 minute: A. A. S. H. O	100	91	82	79	59	30
Cup *A*	100	91	81	79	57	34
5 minutes: A. A. S. H. O	100	93	83	80	62	42
Cup *A*	100	91	82	79	63	50
10 minutes: A. A. S. H. O	100	92	84	82	63	43
Cup *A*	100	92	82	81	64	53
20 minutes: A. A. S. H. O	100	94	85	83	64	48
Cup *A*	100	92	83	80	65	55
1 minute: A. A. S. H. O	--------	100	87	85	60	30
Cup *A*	--------	100	87	84	59	32
5 minutes: A. A. S. H. O	--------	100	88	85	65	41
Cup *A*	--------	100	87	84	66	50
10 minutes: A. A. S. H. O	--------	100	88	85	65	44
Cup *A*	--------	100	88	86	68	54
20 minutes: A. A. S. H. O	--------	100	88	85	66	46
Cup *A*	--------	100	88	86	67	54
1 minute: A. A. S. H. O	--------	--------	100	96	64	34
Cup *A*	--------	--------	100	95	68	37
5 minutes: A. A. S. H. O	--------	--------	100	96	67	43
Cup *A*	--------	--------	100	96	68	52
10 minutes: A. A. S. H. O	--------	--------	100	96	67	46
Cup *A*	--------	--------	100	96	68	53
20 minutes: A. A. S. H. O	--------	--------	100	96	66	50
Cup *A*	--------	--------	100	96	66	57

[1] A reddish-brown heavy clay soil derived from the weathering of unconsolidated sediments of the Coastal Plain region, with liquid limit of 50, plasticity index of 28, and specific gravity of 2.73.

[2] A yellow tenaceous residual clay derived from the weathering of diabasic rocks of the Piedmont Plateau region, with liquid limit of 76, plasticity index of 49, and specific gravity of 2.79.

TENTATIVE PROCEDURE FOR USING AIR-JET DISPERSION APPARATUS

The representative soil sample, prepared according to the A. A. S. H. O. standard method T 87–42, shall be weighed and placed in a 250-ml. beaker. Then about 150 ml. of distilled water shall be added and the soil–water mixture stirred until the soil is thoroughly wetted. This mixture shall be allowed to soak for at least 1 hour. It is recommended that plastic clay soils difficult to disperse be permitted to soak overnight, to facilitate the dispersion of the soil colloids.

The air-jet dispersion apparatus shall be assembled without the cover cap in place. The needle valve controlling the line pressure shall be opened until the pressure gage indicates 1 pound per square inch air pressure. This initial air pressure is required to prevent the soil–water mixture from entering the air-jet tubes when the mixture is transferred to the dispersion cup. After the apparatus is adjusted, the soil–water mixture shall be transferred from the beaker to the dispersion cup, using a wash bottle to assist in the transfer operation. The deflocculating agent as specified in A. A. S. H. O. method T 88–42 shall then be added.

The volume of the soil–water mixture in the dispersion cup shall not exceed 250 ml. The cover and affixed baffle plate shall be placed upon the dispersion cup and the needle valve opened until the pressure gage reads 20 pounds per square inch. The soil–water mixture shall be dispersed for 5, 10, or 15 minutes depending upon the plasticity index of the soil: Soils with a plasticity index of 5 or less shall be dispersed for 5 minutes; soils with a plasticity index between 6 and 20 for 10 minutes; and soils with a plasticity index greater than 20 for 15 minutes. Soils containing large percentages of mica need be dispersed for 1 minute only.

At the end of the dispersion period, the needle valve shall be closed until the pressure gage indicates 1 pound per square inch. The cover shall be removed and all adhering soil particles washed back into the dispersion cup. The soil–water suspension shall then be washed into the 1,000-ml. glass graduate and the needle valve closed. The remainder of the test procedure follows A. A. S. H. O. method T 88–42 for the mechanical analysis of soils.

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to insure adequate dispersion of the clay fraction. Since the cohesion is related to the plasticity, the time of dispersion should logically be varied with the plasticity index of the soil; that is, a short dispersion period should be used for soils with low plasticity indexes, an intermediate period for soils with moderate plasticity indexes, and longer dispersion periods for soils having high plasticity indexes.

USING THE AIR-JET APPARATUS

A tentative method of preparing soil-water suspensions for the mechanical analysis of soils by the hydrometer method using the new type of air-jet dispersion cup has been prepared, based on the comparative testing of a large number of soils. The results of tests on a few of the more representative soils are used in this report to indicate the relative performance of the air-jet dispersion cup as compared with the standard stirring device.

The method for the preparation of soils for test and the determination of particle-size distribution from the soil-water suspension by the soil hydrometer is the same as that designated in the A. A. S. H. O. standard methods T 87–42 and T 88–42. The only changes in the procedure are those required for using the air-jet dispersing cup instead of the standard high-speed stirrer and the use of different dispersion-time periods based upon the plasticity index of the soils. The tentative procedure for using the air-jet dispersion cup is presented elsewhere on this page.

DISPERSION CHARACTERISTICS OF REPRESENTATIVE SOILS

A series of representative soils were tested using the standard stirrer and the two air-jet dispersing cups (*A* and *B*) for the preparation of the soil–water suspensions. The soil samples dispersed by the standard stirring device were tested in accordance with the standard A. A. S. H. O. method T 88–42. The samples dispersed by the two types of air-jet dispersing cup were tested in accordance with the tentative procedure except that all soils were soaked for 18 hours prior to dispersion. The results of tests on this series of representative soils are given in table 4.

(*Continued on page 108*)

Table 4.—*Comparative mechanical analyses using three dispersion devices*

Soil						Dispersion method	Percentage of particles smaller than—					
Sample No.	Type	Derivation	Source	Liquid limit	Plasticity index		2.0 mm.	0.42 mm.	0.074 mm.	0.050 mm.	0.005 mm.	0.001 mm.
21	Plastic clay	Weathering of diabasic rocks.	Piedmont Plateau of Virginia.	88	62	A. A. S. H. O.	100	93	83	80	58	32
						Cup *A*	100	93	84	82	65	52
						Cup *B*	100	93	83	80	61	51
22	Clay	Unconsolidated sediments.	Coastal Plain of Virginia.	67	40	A. A. S. H. O.	100	99	95	93	70	46
						Cup *A*	100	99	96	95	75	50
						Cup *B*	100	98	95	93	70	48
23	do	Marl or chalk deposits.	Coastal Plain of Texas.	54	32	A. A. S. H. O.	100	100	79	72	35	13
						Cup *A*	100	100	79	72	44	32
						Cup *B*	100	100	79	71	42	29
24	do	Weathering of glacial till.	Minnesota	51	21	A. A. S. H. O.	100	94	76	70	16	6
						Cup *A*	100	95	83	76	33	18
						Cup *B*	100	95	73	66	30	16
25	do	Loess	Mississippi	42	17	A. A. S. H. O.	100	100	100	98	34	7
						Cup *A*	100	100	100	98	48	19
						Cup *B*	100	100	100	98	44	16
26	do	Weathering of glacial till.	Wisconsin	31	15	A. A. S. H. O.	100	93	73	68	30	10
						Cup *A*	100	93	73	70	40	22
						Cup *B*	100	93	73	68	40	21
27	Silt	Weathering of loess.	Iowa	33	7	A. A. S. H. O.	100	100	99	86	11	2
						Cup *A*	100	100	100	88	17	7
						Cup *B*	100	100	100	88	14	5
28	Muck	Tidal flats	Virginia	35	7	A. A. S. H. O.	100	99	89	80	16	5
						Cup *A*	100	100	90	82	26	9
						Cup *B*	100	99	90	81	27	9
29	Sand-clay		Coastal Plain of Alabama.	23	4	A. A. S. H. O.	100	83	22	21	18	14
						Cup *A*	100	84	25	22	19	17
						Cup *B*	100	84	23	22	19	17
30	Sand	Weathering of granitic rocks.	Piedmont Plateau of Virginia.	37	NP [1]	A. A. S. H. O.	100	98	68	54	6	2
						Cup *A*	100	95	57	47	8	6
						Cup *B*	100	94	49	41	8	4
31	do	do	do	40	NP	A. A. S. H. O.	100	94	36	28	6	2
						Cup *A*	100	80	30	25	6	3
						Cup *B*	100	82	36	29	7	5
32	Sand [2]		Coastal Plain of South Carolina.	NP	NP	A. A. S. H. O.	100	75	3	3	2	1
						Cup *A*	100	78	4	4	3	2
						Cup *B*	100	75	3	3	2	2

[1] Nonplastic.

[2] Contains some shell fragments.

The Federal-aid Highway Act of 1948

[PUBLIC LAW 834—80TH CONGRESS]

[CHAPTER 732—2D SESSION]

[H. R. 5888]

AN ACT

To amend and supplement the Federal-aid Road Act approved July 11, 1916 (39 Stat. 355), as amended and supplemented, to authorize appropriations for continuing the construction of highways, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That for the purpose of carrying out the provisions of the Federal-Aid Road Act approved July 11, 1916 (39 Stat. 355), and all Acts amendatory thereof and supplementary thereto, and for continuing the construction and reconstruction of highways in accordance with the provisions of the Federal-aid Highway Act of 1944 approved December 20, 1944 (58 Stat. 838), there is hereby authorized to be appropriated the sum of $450,000,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951.

The sum herein authorized for each fiscal year shall be available for expenditure as follows:

Forty-five per centum for projects on the Federal-aid highway system.

Thirty per centum for projects as set forth in paragraph (b) of section 3 of the Federal-aid Highway Act of 1944 (58 Stat. 838), except that for the purposes of this Act and all subsequent Acts continuing the postwar construction and reconstruction of highways in accordance with the provisions of the Federal-aid Highway Act of 1944, (1) the term "secondary and feeder roads" and the term "principal secondary and feeder roads", wherever used in the Federal-aid Highway Act of 1944, shall include county and township roads; and (2) in selecting county and township roads on which funds are to be expended, the State highway departments shall cooperate with township trustees and other appropriate local road officials; and

Twenty-five per centum for projects on the Federal-aid highway system in urban areas.

The said sums, respectively, for any fiscal year, shall be apportioned among the several States in the manner now provided by law and in accordance with the formulas set forth in section 4 of the Federal-aid Highway Act of 1944 approved December 20, 1944: *Provided,* That the authorization for the fiscal year ending 1950 shall be apportioned among the States as soon as practicable after July 1, 1948, but not later than September 1, 1948.

Any sums apportioned to any State under the provisions of this section shall be available for expenditure in that State for two fiscal years after the close of the fiscal year for which such sums are authorized, and any sums apportioned to any State under section 4 of the Federal-aid Highway Act of 1944, approved December 20, 1944, shall be available for expenditure in that State for three fiscal years after the close of the fiscal year for which such sums are authorized and any amount so apportioned remaining unexpended at the end of such period shall lapse: *Provided,* That such funds for any fiscal year, including any funds authorized to be appropriated under this Act, shall be deemed to have been expended if a sum equal to the total of the sums apportioned to the State for such fiscal year is covered by formal agreements with the Commissioner of Public Roads for the improvement of specific projects as provided by this Act.

SEC. 2. The Commissioner of Public Roads is hereby directed to cooperate with the State highway departments in a study of the status of improvement of the National System of Interstate Highways, designated in accordance with the provisions of section 7 of the Federal-aid Highway Act of 1944; to invite the cooperation and suggestions of the Secretary of Defense and the National Security Resources Board as to their indicated or potential needs for improved highways for the national defense; and to supplement, not later than April 1, 1949, the report dated February 1, 1941, entitled "Highways for the National Defense" (Seventy-seventh Congress, first session), to reflect current conditions and deficiencies.

SEC. 3. (a) For the purpose of carrying out the provisions of section 23 of the Federal Highway Act (42 Stat. 218), as amended and supplemented, there is hereby authorized to be appropriated (1) for forest highways the sum of $20,000,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951, subject to the provision of section 9 of the Federal-aid Highway Act of 1944 respecting the apportionment for forest highways in Alaska; and (2) for forest development roads and trails the sum of $17,500,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951: *Provided,* That immediately upon the passage of this Act the appropriation herein authorized for forest highways for the fiscal year ending June 30, 1950, shall be apportioned by the Federal Works Administrator for expenditure in the several States, Alaska, and Puerto Rico, according to the area and value of the land owned by the Government within the national forests therein which the Secretary of Agriculture is hereby directed to determine and certify to him from such information, sources, and departments as the Secretary of Agriculture may deem most accurate, and hereafter, on or before January 1 next preceding the commencement of each succeeding fiscal year the Federal Works Administrator shall make like apportionment of the appropriation authorized for such fiscal year: *Provided further,* That the Commissioner of Public Roads may incur obligations, approve projects, and enter into contracts under the apportionment of such authorizations, and his action in so doing shall be deemed a contractual obligation of the Federal Government for the payment of the cost thereof: *Provided further,* That the appropriations made pursuant to authorizations heretofore, herein, and hereafter enacted for forest highways shall be considered available to the Commissioner of Public Roads for the purpose of discharging the obligations created hereunder in any State or Territory: *Provided further,* That the total expenditures on account of any State or Territory shall at no time exceed its authorized apportionment: *Provided further,* That appropriations for forest highways shall be administered in conformity with regulations jointly approved by the Federal Works Administrator and the Secretary of Agriculture: *Provided further,* That the Commissioner of Public Roads shall transfer to the Chief of the Forest Service from appropriations for forest highways such amounts as may be needed to cover necessary administrative expenses of the Forest Service in connection with the forest-highway program.

(b) The authorization in section 9 of the Federal-aid Highway Act of 1944 for forest highways for the fiscal year ending June 30, 1948, is hereby canceled.

(c) Hereafter, construction work on forest-development roads and trails, pursuant to the provisions of section 23 of the Federal Highway Act of November 9, 1921, as amended and supplemented, estimated to cost $10,000 or more per mile, exclusive of bridges, shall be advertised and let to contract. If such estimated cost is less than $10,000 per mile, or if, after proper advertising, no acceptable bid is received, or the bids are deemed excessive, the work may be done by the Secretary of Agriculture on his own account.

SEC. 4. (a) For the construction, reconstruction, improvement, and maintenance of roads and trails, inclusive of necessary bridges, in national parks, monuments, and other areas administered by the National Park Service, including areas authorized to be established as national parks and monuments, and national park and monument approach roads authorized by the Act of January 31, 1931 (46 Stat. 1053), as amended, there is hereby authorized to be appropriated the sum of $10,000,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951.

(b) For the construction and maintenance of parkways, to give access to national parks and national monuments, or to become connecting sections of a national parkway plan, over lands to which title has been transferred to the United States by the States or by private individuals, there is hereby authorized to be appropriated the sum of $10,000,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951.

(c) For the construction, improvement, and maintenance of Indian reservation roads and bridges and roads and bridges to provide access to Indian reservations and Indian lands under the provisions of the Act approved May 26, 1928 (45 Stat. 750), there is hereby authorized to be appropriated the sum of $6,000,000 for the fiscal year ending June 30, 1950, and a like sum for the fiscal year ending June 30, 1951: *Provided,* That the location, type, and design of all roads and bridges constructed shall be approved by the Public Roads Administration before any expenditures are made thereon, and all such construction shall be under the general supervision of the Public Roads Administration.

Sec. 5. All provisions of the Federal-aid Highway Act of 1944, approved December 20, 1944 (58 Stat. 838), not inconsistent with this Act, shall remain in full force and effect.

Sec. 6. The first paragraph of section 21 of the Federal Highway Act, approved November 9, 1921 (23 U. S. C. 21), is hereby amended to read as follows:

"That so much, not to exceed 3¾ per centum, of all moneys appropriated or authorized to be appropriated for expenditure under the provisions of this Act, as the Federal Works Administrator may deem necessary for administering the provisions of this Act and for carrying on necessary highway research and investigational studies independently or in cooperation with the State highway departments and other research agencies, and for publishing the results thereof, shall be deducted therefrom for such purposes when the apportionment is made and the amount so deducted shall be available until expended from appropriations made under the provisions of this Act: *Provided,* That should the apportionment of the amounts authorized for the third postwar fiscal year be made in accordance with section 4 of the Federal-aid Highway Act of 1944 before the approval of this Act, a revised apportionment may be made and the increased amount authorized by this section deducted for administration, research, and investigational studies."

Sec. 7. This Act may be cited as the "Federal-aid Highway Act of 1948".

Approved June 29, 1948.

(*Continued from page 106*)

The data presented are representative of a large number of analyses made on soils ranging from nonplastic sands through heavy plastic clays. The tests show that the use of the air-jet dispersion cup in accordance with the tentative procedure recommended does not degrade the soil sample more than the 1-minute dispersion called for in the standard A. A. S. H. O. method T 88–42, and that more efficient dispersion of the clay fraction is accomplished.

There appears to be very little difference in the dispersing efficiency of the two types of air-jet dispersing cups. Cup *A* shows slightly better dispersing characteristics than the simplified design, cup *B*, for the heavier soils shown in table 4.

In a few instances, in some of the analyses not reported in detail in this report, the degree of dispersion obtained with cup *B* was slightly less than that obtained with the standard stirring device. This was not the case with cup *A*. In every instance the degree of dispersion obtained with cup *A* was greater than that obtained with the standard disperser.

SUMMARY

The test data obtained led to the following general conclusions:

1. The use of the high-speed stirring device specified in A. A. S. H. O. method T88–42 for the preparation of soil-water suspensions for the combined sieve and hydrometer analysis of soils results in degradation of the sand particles. This action is most pronounced in the fraction between the No. 10 (2.0 mm.) and the No. 40 (0.42 mm.) sieves. The hardness of the sand grains is a factor in the amount of degradation that occurs.

2. The degrading action of the air-jet dispersing cup with dispersing periods up to 20 minutes is no greater than that of the high-speed stirring device with a 1-minute dispersing period.

3. The use of the air-jet dispersing cup results in more efficient dispersion of the clay fraction of plastic soil samples than is obtained with the high-speed stirrer.

4. The efficiency of the original air-jet dispersion apparatus, cup *A*, is slightly greater than that found for the simplified design, cup *B*. However, it is questionable whether the increased efficiency would justify the additional cost of cup *A*.

5. The maintenance costs for the air-jet type dispersion cup are considerably less than for the standard stirrer since it contains no moving parts.

6. The use of the air-jet dispersing cup, either type *A* or type *B*, in accordance with the tentative procedure contained in this report in which the dispersing time is varied with the plasticity index, will result in mechanical analyses more nearly representative of the actual gradations than those obtained by using the stirring device called for in the A. A. S. H. O. method for mechanical analysis of soils.

U. S. GOVERNMENT PRINTING OFFICE: 1948

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1933, 5 cents. 1936, 10 cents. 1939, 10 cents.

Work of the Public Roads Administration:

1940, 10 cents. 1942, 10 cents. 1947, 20 cents.
1941, 15 cents. 1946, 20 cents.

HOUSE DOCUMENT NO. 462

Part 1 . . . Nonuniformity of State Motor-Vehicle Traffic Laws. 15 cents.

Part 2 . . . Skilled Investigation at the Scene of the Accident Needed to Develop Causes. 10 cents.

Part 3 . . . Inadequacy of State Motor-Vehicle Accident Reporting. 10 cents.

Part 4 . . . Official Inspection of Vehicles. 10 cents.

Part 5 . . . Case Histories of Fatal Highway Accidents. 10 cents.

Part 6 . . . The Accident-Prone Driver. 10 cents.

MISCELLANEOUS PUBLICATIONS

No. 265T. . . . . Electrical Equipment on Movable Bridges. 40 cents.
No. 191MP . . . Roadside Improvement. 10 cents.
No. 272MP . . . Construction of Private Driveways. 10 cents.
No. 1486D . . . Highway Bridge Location. 15 cents.
Highway Accidents. 10 cents.
The Taxation of Motor Vehicles in 1932. 35 cents.
Guides to Traffic Safety. 10 cents.
An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.
Highway Bond Calculations. 10 cents.
Transition Curves for Highways. $1.25.
Highways of History. 25 cents.
Public Land Acquisition for Highway Purposes. 10 cents.
Public Control of Highway Access and Roadside Development (revision). 35 cents.
Tire Wear and Tire Failures on Various Road Surfaces. 10 cents.
Legal Aspects of Controlling Highway Access. 15 cents.
House Document No. 379. Interregional Highways. 75 cents.
Highway Statistics, Summary to 1945. 40 cents.
Highway Statistics, 1945. 35 cents.
Highway Statistics, 1946. 50 cents.
Model Traffic Ordinance. 15 cents.
Principles of Highway Construction as Applied to Airports, Flight Strips, and Other Landing Areas for Aircraft. $1.50.

Single copies of the following publications may be obtained free upon request addressed to the Public Roads Administration. They are not sold by the Superintendent of Documents.

ANNUAL REPORTS

(See also adjacent column)

Public Roads Administration Annual Reports:

1943. 1944. 1945.

MISCELLANEOUS PUBLICATIONS

No. 279MP . . . Bibliography on Highway Lighting.

No. 296MP . . . Bibliography on Highway Safety.

No. 1036Y . . . Road Work on Farm Outlets Needs Skill and Right Equipment.

Indexes to PUBLIC ROADS, volumes 17–23, inclusive.

Bibliography on Automobile Parking in the United States.

Express Highways in the United States: a Bibliography.

Bibliography on Land Acquisition for Public Roads.

REPORTS IN COOPERATION WITH UNIVERSITY OF ILLINOIS

No. 313 . . . Tests of Plaster-Model Slabs Subjected to Concentrated Loads.

No. 314 . . . Tests of Reinforced Concrete Slabs Subjected to Concentrated Loads.

No. 315 . . . Moments in Simple Span Bridge Slabs With Stiffened Edges.

No. 345 . . . Ultimate Strength of Reinforced Concrete Beams as Related to the Plasticity Ratio of Concrete.

No. 346 . . . Highway Slab-Bridges with Curbs: Laboratory Tests and Proposed Design Method.

No. 363 . . . Study of Slab and Beam Highway Bridges. Part I.

No. 369 . . . Studies of Highway Skew Slab-Bridges with Curbs. Part I: Results of Analyses.

No. 375 . . . Studies of Slab and Beam Highway Bridges. Part II.

UNIFORM VEHICLE CODE

Act I.—Uniform Motor-Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor-Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor-Vehicle Civil Liability Act.

Act IV.—Uniform Motor-Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

STATUS OF FEDERAL-AID HIGHWAY PROGRAM

AS OF JUNE 30, 1948

(Thousand Dollars)

STATE	UNPROGRAMMED BALANCES	ACTIVE PROGRAM											
		PROGRAMMED ONLY			PLANS APPROVED, CONSTRUCTION NOT STARTED			CONSTRUCTION UNDER WAY			TOTAL		
		Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles	Total Cost	Federal Funds	Miles
Alabama	$7,951	$11,377	$5,660	308.3	$5,700	$3,421	90.6	$9,933	$4,845	334.4	$27,010	$13,926	733.3
Arizona	1,484	2,973	2,114	25.0	1,690	959	13.8	6,415	4,312	77.3	11,078	7,385	116.1
Arkansas	1,511	11,338	5,922	293.2	7,507	3,573	99.7	13,050	6,886	319.6	31,895	16,381	712.5
California	1,089	14,216	5,995	245.2	8,753	4,329	100.0	58,419	28,705	316.2	81,388	39,029	661.4
Colorado	2,681	8,021	4,711	135.0	7,149	4,261	88.1	13,012	7,584	254.4	28,182	16,556	477.5
Connecticut	1,077	11,538	5,950	22.9	3,734	1,899	6.2	6,516	3,076	27.7	21,788	10,925	56.8
Delaware	2,024	3,290	1,786	30.8	2,467	1,292	25.2	2,724	1,388	47.1	8,481	4,466	103.1
Florida	2,016	17,526	8,643	466.3	3,022	1,438	25.2	12,293	5,308	260.6	32,841	15,389	752.1
Georgia	1,879	18,412	9,148	370.0	16,064	7,110	255.2	30,291	15,714	836.3	64,767	31,972	1,461.5
Idaho	4,922	2,778	1,744	153.3	2,997	1,996	72.3	4,575	2,942	128.0	10,350	6,682	353.6
Illinois	12,125	44,876	23,827	691.3	27,818	12,622	251.8	34,712	18,113	598.0	107,406	54,562	1,541.1
Indiana	6,875	18,501	9,252	187.3	9,664	5,269	72.3	22,224	11,481	172.2	50,389	26,002	431.8
Iowa	3,983	16,220	6,762	761.7	11,971	5,255	395.8	21,770	10,779	798.4	49,961	22,796	1,955.9
Kansas	2,598	14,530	7,243	1,724.9	9,306	4,251	779.2	26,435	13,516	1,132.3	50,271	25,010	3,636.4
Kentucky	1,330	16,337	8,055	196.3	5,336	2,630	35.0	14,358	7,291	235.2	36,031	17,976	466.5
Louisiana	6,603	19,385	9,571	290.0	7,248	3,358	74.5	16,494	8,467	144.1	43,127	21,396	508.6
Maine	2,636	6,369	3,336	73.6	1,593	799	18.2	7,017	3,750	54.0	14,979	7,885	145.8
Maryland	544	11,897	5,621	62.7	6,968	3,392	20.7	7,467	3,692	52.7	26,332	12,705	136.1
Massachusetts	15,418	7,952	4,389	14.3	9,471	5,318	9.0	14,273	7,340	49.4	31,696	17,047	72.7
Michigan	3,668	19,885	9,973	430.6	18,786	8,399	243.3	34,475	16,670	269.8	73,146	35,042	943.7
Minnesota	376	19,508	9,879	903.0	9,137	4,008	362.3	25,783	12,709	853.5	54,428	26,596	2,118.8
Mississippi	2,656	7,232	3,798	285.0	5,739	2,822	178.0	23,156	11,522	662.7	36,127	18,142	1,125.7
Missouri	3,689	34,606	17,382	953.4	13,024	6,139	231.0	25,082	13,831	605.4	72,712	37,352	1,789.8
Montana	6,486	10,643	6,659	332.0	5,045	3,074	109.5	10,643	6,510	410.9	26,331	16,243	852.4
Nebraska	3,672	13,333	6,866	519.9	6,876	3,513	197.4	13,217	6,611	643.4	33,426	16,990	1,360.7
Nevada	1,057	4,958	3,988	164.5	1,116	791	71.6	4,269	3,367	148.8	10,343	8,146	384.9
New Hampshire	1,450	3,789	1,874	30.7	1,606	1,025	5.8	5,413	2,859	27.4	10,808	5,758	63.9
New Jersey	1,388	13,291	6,380	43.6	6,322	3,146	23.4	25,191	13,179	25.6	44,804	22,705	92.6
New Mexico	1,526	8,422	5,376	362.0	2,483	1,626	44.6	6,890	4,401	178.6	17,795	11,403	585.2
New York	30,833	50,450	29,349	368.1	58,691	26,983	191.1	39,502	17,633	228.3	148,643	73,965	787.5
North Carolina	3,666	18,138	9,158	457.4	6,575	2,776	150.0	27,869	13,791	674.1	52,582	25,725	1,281.5
North Dakota	3,021	10,934	5,970	1,303.9	6,314	3,538	524.5	10,896	6,026	590.5	28,144	15,534	2,418.9
Ohio	5,680	57,020	27,733	441.4	6,818	3,657	71.8	41,850	21,451	151.5	105,688	52,841	664.7
Oklahoma	6,043	19,183	10,659	1,129.1	8,073	3,959	309.2	6,288	3,248	360.4	33,544	17,866	1,798.7
Oregon	418	7,842	4,108	122.2	2,544	1,210	33.3	14,267	7,464	334.5	24,653	12,782	490.0
Pennsylvania	2,850	33,155	16,962	70.2	30,087	15,581	61.9	58,534	30,449	255.1	121,776	62,992	387.2
Rhode Island	3,211	2,476	1,346	20.1	6,300	3,116	10.2	3,785	1,850	14.4	12,561	6,312	44.7
South Carolina	1,739	8,078	3,989	150.2	3,223	1,763	101.7	11,520	5,660	300.2	22,821	11,412	552.1
South Dakota	3,400	9,092	5,476	765.0	6,176	3,738	460.1	10,820	6,353	708.3	26,088	15,567	1,933.4
Tennessee	1,984	15,258	7,386	421.0	14,134	6,938	137.8	14,822	7,899	329.5	44,214	22,223	888.3
Texas	2,911	13,476	7,613	650.0	28,306	14,041	840.7	57,749	30,629	1,493.3	99,531	52,283	2,984.0
Utah	1,300	5,343	3,968	198.0	1,185	876	44.9	4,940	3,638	193.5	11,468	8,482	436.4
Vermont	634	4,020	2,007	77.7	1,610	800	20.5	4,643	2,317	60.5	10,273	5,124	158.7
Virginia	7,832	13,958	7,095	217.6	6,615	2,917	141.3	13,273	6,611	144.9	33,846	16,623	503.8
Washington	1,551	11,794	4,959	183.4	4,488	2,243	51.1	11,776	6,156	174.9	28,058	13,358	409.4
West Virginia	2,805	10,541	5,086	208.0	2,308	1,201	43.0	8,248	4,289	93.9	21,097	10,576	344.9
Wisconsin	6,107	23,246	11,318	458.8	14,808	6,369	230.6	26,545	11,334	572.8	64,599	29,021	1,262.2
Wyoming	361	4,381	2,883	152.9	2,283	1,485	122.1	8,651	5,663	268.2	15,315	10,031	543.2
Hawaii	977	6,726	3,362	48.1	3,643	1,531	4.4	2,566	1,438	19.5	12,935	6,331	72.0
District of Columbia	52	270	135	.4	1,814	837	.1	12,617	6,137	4.0	14,701	7,109	4.5
Puerto Rico	1,953	7,771	3,627	39.5	3,270	1,177	13.7	7,717	2,810	39.8	18,758	7,614	93.0
TOTAL	194,042	726,355	376,093	17,559.8	437,857	214,451	7,463.7	894,975	459,694	16,676.1	2,059,187	1,050,238	41,699.6