PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

VOL. 21, NO. 1 ▽ MARCH 1940

SECTION OF BITUMINOUS ROAD IN YELLOWSTONE NATIONAL PARK

For sale by the Superintendent of Documents, Washington, D. C. - - - - - - - - - - - - - - See page 2 of cover for prices

PUBLIC ROADS ▸ ▸ ▸ *A Journal of Highway Research*

Issued by the

FEDERAL WORKS AGENCY

PUBLIC ROADS ADMINISTRATION

D. M. BEACH, *Editor*

Volume 21, No. 1 March 1940

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

In This Issue

THE PUBLIC ROADS ADMINISTRATION - - - - - - - Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS - - - - - - - - - - - - - - - Federal Building, Civic Center, San Francisco, Calif.

▼

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Federal Building, Civic Center, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
254 New Customhouse, Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
907 Post Office Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
711 U. S. Courthouse, Kansas City, Mo

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
Room 502, United States Courthouse, Fort Worth, Tex.

DISTRICT No. 7. Illinois, Indiana, Kentucky, and Michigan.
South Chicago Post Office Building, Chicago, Ill.

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, and Tennessee.
Post Office Building, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
505 Post Office Building, Albany, N. Y.

DISTRICT No. 10. Delaware, Maryland, Ohio, Pennsylvania, and District of Columbia.
Willard Building, Washington, D. C.

DISTRICT No. 11. Alaska.
Room 419, Federal and Territorial Building, Juneau, Alaska.

DISTRICT No. 12. Idaho and Utah.
Federal Building, Ogden, Utah.

DISTRICT No. 14. North Carolina, South Carolina, Virginia, and West Virginia.
Montgomery Building, Spartanburg, S. C.

Because of the necessarily limited edition of this publication it is impossible to distribute it free to any person or institution other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. At the present time additions to the free mailing list can be made only as vacancies occur. Those desiring to obtain PUBLIC ROADS can do so by sending $1 per year (foreign subscription $1.50), or 10 cents per single copy, to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

THE PHYSICAL AND CHEMICAL PROPERTIES OF PETROLEUM ASPHALTS OF THE 50–60 AND 85–100 PENETRATION GRADES[1]

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by R. H. LEWIS, Chemist, and J. Y. WELBORN, Junior Highway Engineer

FOR MANY YEARS semisolid asphalts used in the construction of the higher type bituminous pavements were produced from relatively few base petroleums by refining processes that were practically standard. More recently new sources of crude petroleums have been used and various refining methods, some of which were designed primarily to increase the yield of distillates, have been developed. Standard specifications that were thought to control adequately the quality and serviceability of these earlier asphaltic cements have been subjected to considerable questioning since the advent of these materials produced from different base petroleums and with newer refining processes. As a result, there have been changes in specification requirements by the resurrection of old tests, or the development of new tests, in an effort to obtain more satisfactory and more durable materials.

In the United States there have been three major specifications for asphalt cements around which the various State highway departments have developed their test requirements for this type of bituminous material. These are as follows:

1. Federal Specifications. These are specifications that have been adopted by the Federal Specifications Executive Committee for use by the various agencies of the Federal Government.
2. A. S. T. M. Specifications. These are specifications that were adopted as tentative some years ago by the American Society for Testing Materials but have recently been withdrawn.
3. A. A. S. H. O. Specifications. These are specifications that have been adopted by the American Association of State Highway Officials.

REQUIREMENTS OF VARIOUS SPECIFICATIONS COMPARED

The specifications for the various grades of asphalt cement in general use in road construction, as proposed or adopted by the above agencies, are given in table 1. This table includes requirements for the physical and chemical properties of the 40–50, 50–60, 60–70, 85–100, 100–120, and 120–150 penetration grades, together with their designations and the use for which they are intended. In addition to the above grades, the American Society for Testing Materials has had tentative specifications for 25–30 and 30–40 penetration asphalts, but these specifications have been omitted from table 1 since they are seldom used in road construction. The specification for the 30–40 penetration grade adopted by the American Association of State Highway Officials has likewise been omitted and for the same reason.

As shown by the last number in the grade designation, the Federal specification was initially adopted in 1925, and, after a change in the form but not in test requirements, was approved for promulgation in 1931. The A. S. T. M. specifications for 40–50, 50–60, and 60–70 penetration grades were first issued as tentative specifications in 1921 and were revised in 1922, 1923, and 1926. Specifications for the 85–100 and 100–120 grades were issued as tentative in 1921 and revised in 1922, 1923, and 1924, while that for the 120–150 grade was issued in 1922 and revised in 1923. The designations, as given in table 1, show the date ot final revision for each grade followed by the letter T, to indicate a tentative standard. The term "tentative," as stated by the A. S. T. M., applies to a proposed standard published for 1 or more years with a view of eliciting criticism before it is formally adopted as standard by the Society. It is significant to note that some of these A. S. T. M. specifications remained as tentative standards for 16 years after their last revision.

Because of inability to obtain the adoption of these tentative specifications, they were withdrawn as tentative at the 1939 meeting of the A. S. T. M. The society at the present time has, therefore, no specifications for asphalt cements for use in road construction. A. A. S. H. O. specification M–20 was adopted in 1924 and revised in 1926. It is the policy of this association to adopt where possible the existing standards of the A. S. T. M. and the provisions of M–20 vary but slightly from those of the tentative standards of the A. S. T. M.

The specifications from these three sources contain general requirements that apply to the various grades as a whole. The Federal specification requires that the asphalts shall be prepared by the distillation of asphaltic petroleums. The A. A. S. H. O. specification states that the asphalts shall be prepared from petroleum while the A. S. T. M. specifications simply declare that the asphalt cement shall meet certain test requirements. All specifications require that the asphalt shall be homogeneous and free from water, and the Federal and A. A. S. H. O. specifications contain a requirement that the asphalt shall not foam when heated to 175° C. (347° F).

The Federal specification stipulates that only those asphalts that have been demonstrated by service tests as satisfactory for the intended use will be accepted. This specification also regulates the uniformity of supply of the asphalt for any given contract by controlling the specific gravity and softening point within certain limits. The A. A. S. H. O. specification states that the exact penetration grade to be used depends on the type of road, climatic conditions, and the kind and nature of the traffic; while the Federal and A. S. T. M. specifications recommend certain types of construction for each particular grade. The Federal specification also indicates the climatic conditions and amount of traffic for which each penetration grade is especially suited.

---

[1] Paper presented at the meeting of the Association of Asphalt Paving Technologists, Chicago, Ill., January 30-31, 1940.

TABLE 1.—*Summary of specifications for petroleum asphalt cements used in road construction*

Specification	Designation	Penetration grade	Intended use	Physical and chemical properties									
				Specific gravity at 77°/77° F.	Flash point	Penetration 100 gm. 5 sec. at 77° F.	Softening point	Ductility 5 cm. per minute, at 77° F.	Loss at 325° F., 5 hours	Penetration of residue as a percentage of original	CS₂ solubility		Bitumen soluble in CCl₄
											Bitumen soluble	Organic matter insoluble	
					°F.		*°F.*	*Cm.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Federal	AP-1-25 [1]	120-150	Bituminous macadam, northern United States, comparatively light traffic.	1.000+	347+	120-150	95-131		1.0−	60.0+	99.5+	0.2−	
A. S. T. M.	D135-23T [2]	120-150	Asphalt macadam		347+	120-150		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	120-150	Depends on type of road, climate, and traffic.		347+	120-150		30+	1.0−	60.0+	99.5+		99.0+
Federal	AP-2-25 [1]	100-120	Bituminous macadam, middle United States or northern United States, comparatively heavy traffic.	1.000+	347+	100-120	95-131		1.0−	60.0+	99.5+	.2−	
A. S. T. M.	D103-24T [2]	100-120	Asphalt macadam		347+	100-120		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	100-120	Depends on type of road, climate, and traffic.		347+	100-120		30+	1.0−	60.0+	99.5+		99.0+
Federal	AP-3-25 [1]	85-100	Bituminous macadam, southern United States.	1.000+	347+	85-100	104-140		1.0−	60.0+	99.5+	.2−	
A. S. T. M.	D102-24T [2]	85-100	Asphalt macadam		347+	85-100		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	85-100	Depends on type of road, climate, and traffic.		347+	85-100		30+	1.0−	60.0+	99.5+		99.0+
Federal	AP-5-25 [1]	60-70	Graded bituminous concrete, northern United States, light or moderate traffic.	1.010+	347+	60-70	104-140	40+	1.0−	60.0+	99.5+	.2−	
A. S. T. M.	D101-26T [2]	60-70	Sheet asphalt, asphaltic concrete, asphalt macadam.		347+	60-70		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	60-70	Depends on type of road, climate, and traffic.		347+	60-70		30+	1.0−	60.0+	99.5+		99.0+
Federal	AP-6-25 [1]	50-60	Graded bituminous concrete, southern United States or northern United States, heavy traffic. Sheet asphalt, northern United States, light or moderate traffic.	1.010+	347+	50-60	104-140	40+	1.0−	60.0+	99.5+	.2−	
A. S. T. M.	D100-26T [2]	50-60	Sheet asphalt, asphaltic concrete		347+	50-60		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	50-60	Depends on type of road, climate, and traffic.		347+	50-60		30+	1.0−	60.0+	99.5+		99.0+
Federal	AP-7-25 [1]	40-50	Sheet asphalt, southern United States or northern United States, heavy traffic.	1.010+	347+	40-50	113-149	40+	1.0−	60.0+	99.5+	.2−	
A. S. T. M.	D99-26T [2]	40-50	Sheet asphalt, asphaltic concrete		347+	40-50		30+	2.0−	60.0+	(3)		99.0+
A. A. S. H. O.	M-20 [4]	40-50	Depends on type of road, climate, and traffic.		347+	40-50		30+	1.0−	60.0+	99.5+		99.0+

[1] Special requirements:
C-1. The materials supplied under this specification shall be asphalts prepared by the distillation of asphaltic petroleum.
C-2. Those materials only, which have been demonstrated by service tests as satisfactory for the intended use, will be acceptable under this specification.
D-1. The asphalt shall be homogeneous, free from water, and shall not foam when heated to 175° C. (347° F.).
E-2. Uniformity. The material furnished under this specification for a given contract, type, and grade shall be uniform in character and shall not vary more than 10° C. (18° F.) in softening point from the test limits specified, nor more than 0.02 in specific gravity.

[2] The asphalt shall be homogeneous and free from water.

[3] When less than 99.0 percent of the asphalt cement is soluble in carbon tetrachloride, the percentage of bitumen (soluble in carbon disulfide) shall be reported.

[4] Specification M-20 was adopted in 1924, revised in 1926. The asphalt shall be prepared from petroleum. The asphalt shall be homogeneous, free from water, and shall not foam when heated to 175° C. (347° F.).

ASPHALTS TESTED REPRESENTATIVE OF THOSE IN GENERAL USE

As shown in table 1, the physical and chemical requirements of the A. S. T. M. and A. A. S. H. O. specifications are the same except for the maximum limit of loss at 325° F. and the determination of bitumen soluble in carbon disulphide. In contrast to the A. S. T. M. and A. A. S. H. O. specifications, the Federal specification contains additional requirements for specific gravity, softening point, and organic matter insoluble in carbon disulphide, but it does not require that the solubility in carbon tetrachloride be determined. In the Federal specification the limits for the flash point and the consistency of the residue from the oven-loss test are the same as the A. S. T. M. and A. A. S. H. O. specifications, and the requirements for the percentage of loss at 325° F. and the percentage of bitumen soluble in carbon disulphide are the same as the A. A. S. H. O. specification. The Federal specification does not require a ductility test on those asphalt cements softer than the 60-70 penetration grade; and for the other grades, the ductility must be more than 40 centimeters as compared to the minimum requirement of 30 centimeters for the A. S. T. M. and A. A. S. H. O. specifications.

In order to determine how the asphalts being produced today would meet these major standard specifications, as well as other test requirements that have been used by other agencies for the control of this type of bituminous material, the Public Roads Administration requested the leading producers in the United States to submit samples of their materials corresponding to the various grades of the Federal specifications. In response to this request 30 producers submitted 42 sets of petroleum asphalt cements, of which all except one represented two or more of the penetration grades covered by the Federal specification. Several producers furnished two or more sets of asphalts differing as to the source of the base petroleum or in the method of refining. In all, 245 samples of petroleum asphalt were received, distributed among the various penetration grades as indicated in table 2.

Obviously it would take considerable time to make a detailed study of all the samples submitted. Therefore, as the asphalt cements of 50-60 and 85-100 penetration are used more generally than the other grades, and, as shown in table 2, most of the producers submitted these two grades, it was decided to confine this study more particularly to the asphalts of these grades. Twenty-seven producers furnished 39 samples of 50-60 asphalt and 28 producers furnished 40 samples of 85-100 penetration asphalt. There were two sets of asphalt samples that did not have material of either the 50-60 or 85–100 penetration grade. One of these was an asphalt from a southern California field containing a base petroleum not duplicated by any product received, and the other, an asphalt from an Oklahoma field which was duplicated in this investigation by materials of a similar type. The producer of the California asphalt submitted samples representing only the 40–50, 60–70, and 100–120 grades and the other producer did not manufacture asphalt cements harder than the 150–180 penetration grade.

TABLE 2.—*Classification of samples received from various producers*

Federal specification designation	Penetration grade	Total number of samples	Producers represented
	180–200	1	1
	150–180	2	2
AP-1-25	120–150	30	24
AP-2-25	100–120	33	22
AP-3-25	85–100	40	28
	70–80	4	3
AP-5-25	60–70	33	25
AP-6-25	50–60	39	27
AP-7-25	40–50	34	25
	30–40	28	20
	20–30	1	1

The source of the base petroleum and the method of refining the 50–60 and 85–100 penetration asphalt cements studied in this investigation, together with their laboratory identification and producer identification numbers, are shown in table 3. The samples of the 50–60 and 85–100 penetration asphalt of each set were produced from the same base petroleum and by the same method of refining, and they were given the same identification number. Throughout this report, these numbers, together with the designated penetration grade, will be used as the identification of the various asphalt cements.

The producers' identification numbers with the added letters A, B, or C indicate that the same producer submitted more than one set of asphalt cements which differ either as to the source of the base petroleum, the location of the refinery, or the method of refining. Producer 6 submitted samples 6, 12, and 17, representing asphalt cements refined from Colombian, Mexican, and Venezuelan petroleums, and these have been given the producers' identification numbers 6A, 6B, and 6C, respectively. Producer 7 submitted asphalts refined from Mexican and Venezuelan petroleums, while producers 13 and 24 each submitted two asphalts prepared from the same base petroleum by different refining processes. Although table 3 does not indicate any difference in the base petroleum or refining of samples 24, 25, and 26 submitted by producer 19, and samples 27 and 28 submitted by producer 20, the test results indicate differences that may be due to variations in processing. Samples 35 and 36 submitted by producer 25 were from different refineries. Samples 37 and 38 submitted by producer 26 were from the same base petroleum, but were prepared at different refineries.

ASPHALTS MET REQUIREMENTS OF A. A. S. H. O. AND A. S. T. M. SPECIFICATIONS

For all asphalts, except where noted, information as to the source of the base petroleum was furnished by the producers submitting the samples. The source of the base petroleum used in samples 27 and 28 was determined from a consideration of the producer and interpretation of the test data. The producer of samples 35 and 36 is known to refine crude petroleum from several sources; and whether these samples are products from one petroleum or blends cannot be ascertained readily from the test data only.

The principal petroleum fields that furnish the crudes for the production of asphalt cements used in the United

TABLE 3.—*Source and method of refining asphalt cements*

Identification No.	Producer identification	Source of base petroleum	Method of refining
1	1	California, Coalinga field	Vacuum distillation.
2	2	California, San Joaquin Valley field	Reduction and steam distillation.
3	3	do	Do.
4	4	do	Steam distillation in continuous tube still.
5	5	California, Elk Hills field	Vacuum distillation.
6	6-A	Colombia	Vacuum distillation with pipe still.
7	7-A	Mexico, Ebano field	Straight steam distillation.
8	8	Mexico	
9	9	Mexico, Panuco field	Steam distillation in Trumble (pipe) still.
10	10	do	
11	11	do	Vacuum distillation in pipe still.
12	6-B	Mexico	Do.
13	12	Venezuela	Fire and steam distillation.
14	13-A	Venezuela, Mene Grande field	Continuous distillation under sub-atmospheric pressure with steam.
15	13-B	do	Distilled in batch stills at atmospheric pressure with steam.
16	7-B	Venezuela	Straight steam distillation.
17	6-C	do	Vacuum distillation in pipe still.
18	14	do	Steam distillation.
19	15	Arkansas, Smackover field	Vacuum distillation at a low temperature.
20	16-A	do	Vacuum distillation, 89 m. p. flux.
21	16-B	do	Vacuum distillation, 101 m. p. flux.
22	17	Arkansas, Nevada County	Pipe still distillation unit and vacuum bubble tower.
23	18	Oklahoma, Cement and Walters field	
24	19-A	Oklahoma	Vacuum distillation in pipe still, partially oxidized.
25	19-B	do	Do.
26	19-C	do	Do.
27	20-A	do.[1]	
28	20-B	do	
29	21	Oklahoma, Healdton and Graham	
30	22	Kentucky and Illinois	Fire and steam distillation, possibly blown.
31	23	Mexican-duo-sol-residuum from Oklahoma crude	Steam distillation and air conversion in batch shell stills.
32	24-A	Kansas	Straight run, steam refined, vacuum process.
33	24-B	do	Produced from Winkler-Koch Shell still.
34	25-A	Wyoming	Fire and steam distillation.
35	25-B	Unknown	Do.
36	25-C	do	Do.
37	26-A	Mexico and Domestic Gulf Coast	
38	26-B	do	
39	27	Texas, Westbrook field	
40	28	Kentucky	Dubbs cracking process.

[1] Source assumed because of the producer and from the interpretation of test results.

States are listed in table 4. As shown in table 3, all of these sources are represented in this investigation by one or more asphalts, with the exception of the Lima, Ind., the southern California, and the Trinidad fields. Petroleums from the Illinois and gulf-coastal fields are present in blends; the Illinois petroleum has been processed with Kentucky petroleum and gulf-coastal petroleum with Mexican.

The laboratory study of these selected asphalt cements included tests to show their conformity to the Federal, A. S. T. M., and A. A. S. H. O. specifications. Other tests that have been used, or are now used by various States and municipalities as specification requirements, have also been made. Additional tests which, although not usually made as control tests for asphalt cements, might develop information of value relative to their physical and chemical properties, were also made.

Where the test methods employed in this investigation have not been standardized, the essential details will be described. The A. S. T. M. and A. A. S. H. O. designations of the usual methods of test are given in table 5.

TABLE 4.—*Principal petroleum fields supplying asphalt cements to the United States* [1]

Country	Name of field	Area included	Type of oil
United States	Appalachian	New York, Pennsylvania, West Virginia, eastern Ohio, Kentucky, Tennessee.	Nonasphaltic.
	Lima, Ind	Michigan, northwestern Ohio, Indiana.	Do.
	Illinois	Southeastern Illinois	Semiasphaltic.
	Midcontinent	Kansas; Oklahoma; northern, western, and central Texas; northern Louisiana; southern Arkansas.	Asphaltic. Semiasphaltic. Nonasphaltic.
	Gulf-coastal	Coast of Texas and Louisiana	Asphaltic.
	Rocky Mountain	Colorado, Wyoming, Montana, Utah, and New Mexico.	Do. Semiasphaltic. Nonasphaltic.
	Northern California.	San Joaquin Valley	Asphaltic.
	Southern California.	Los Angeles Basin and coastal.	Do.
Mexico	Tampico-Tuxpan	Northern Vera Cruz (including Panuco), southern Tamaulipas.	Do.
	Tehuantepec	From southern Vera Cruz to eastern limit of Tabasco.	Do.
Venezuela	Laqunillas, La Rosa, Mene Grande.	Along eastern shore of Lake Maracaibo.	Do.
Colombia	De Barco	Region of Barranca-Bermeja	Do.
Trinidad	Trinidad	Southern portion of island	Do.

[1] Data taken from Asphalts and Allied Substances, by Abraham, 4th edition.

TABLE 5.—*Test methods used in the asphalt cement investigations*

Test	Method of test
Specific gravity	A. S. T. M. D 70-27.
Flash point	A. S. T. M. D 92-33.
Penetration	A. S. T. M. D 5-25.
Softening point	A. S. T. M. D 36-26.
Ductility	A. S. T. M. D 113-35.
Loss on heating	A. S. T. M. D 6-33.
Penetration of residue	A. S. T. M. D 5-25.
Saybolt Furol viscosity	A. S. T. M. D 88-36.
Float test	A. S. T. M. D 139-27.
Bitumen soluble in CS_2	A. S. T. M. D 4-27.
Bitumen soluble in CCl_4	A. S. T. M. D 165-27.
Fixed carbon	A. S. T. M. D 168-30.
Sulphur	A. S. T. M. D 129-34.
Insoluble in 86° B. naphtha	A. A. S. H. O. T-46-35.
Insoluble in ether	Do.
Oliensis test	A. A. S. H. O. T-102-38.
Film test	Kansas Highway Commission.
Toughness test	New York Department of Highways.

The results of the physical and chemical tests that show the conformity of the 50–60 and 85–100 penetration asphalts to the Federal, A. S. T. M., and A. A. S. H. O. specifications are given in tables 6 and 7. Excluding the slight lack of compliance in the penetration values, the results that fail to meet the governing specification requirement have been indicated. Seven of the asphalts of the 50–60 grade and six of the 85–100 grade did not meet one or more of the test requirements of the Federal specification. One of each grade did not meet all the test requirements specified by the A. A. S. H. O. One 50–60 penetration asphalt did not meet the requirements of the tentative A. S. T. M. specifications. In all other particulars, these materials were in substantial compliance with the specifications of these agencies.

Graphical presentations of the data tabulated in tables 6 and 7 are shown in figures 1 and 2. These figures show the range of each specification requirement and the range and average of the corresponding test values. For convenience, minimum, maximum, and average values for the laboratory tests showing conformity to the requirements of the Federal, A. S. T. M. and A. A. S. H. O. specifications have been summarized in table 8.

Since the specific gravity of an asphalt is largely dependent on the source of the base petroleum used in its manufacture, the average test value, because of the many sources represented, is of little significance. The specific gravities of the asphalts from the midcontinent fields differ widely; but the materials in this investigation which had the lowest specific gravities were from this area. Sample 30 prepared from Illinois and Kentucky petroleums also had a low gravity. The specific gravity of the Colombian asphalt, sample 6, also was low. Following, in order of increasing density as a group, were the California, Arkansas, Venezuelan, and Mexican asphalts. The materials from Texas and Wyoming also had a relatively high gravity. Samples 23, 33, and 40 were asphalts produced by cracking processes and their specific gravities were also high. The minimum requirement for specific gravity as provided for in the Federal specification would prevent the acceptance of four materials of both the 50–60 and 85–100 penetration grades.

The flash point requirement is used in specifications to enable the user to judge the fire hazard attached to the use of the asphaltic material under particular conditions of heating and applying. For the grade of asphalt cements under investigation, the minimum requirement is approximately 100° F. below the lowest flash point of any 50–60 or 85–100 penetration material and over 200° F. below the average test value for each grade. The factor of safety is, therefore, well above that required by the specifications.

ONLY TWO SAMPLES FAILED TO MEET DUCTILITY REQUIREMENTS

While a few samples had penetrations slightly higher or lower than the ranges specified for the two grades, the average test value for both the 50–60 and 85–100 penetration asphalts was approximately in the middle of the specified limits. It is believed that a satisfactory comparison of the other test characteristics of these asphalts can be made even though some of them failed to meet absolutely the penetration requirements of their particular grade.

The limits for softening point, as provided by the Federal specification, are from 104° F. to 140° F., or a range of 36° for both the 50–60 and 85–100 grades.

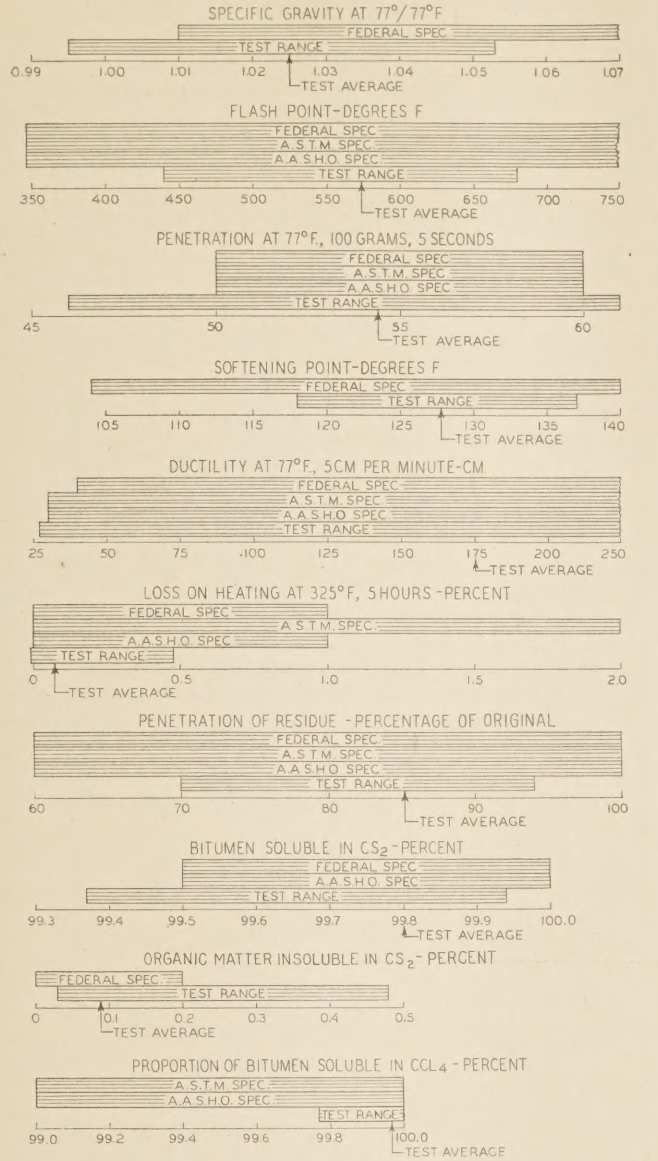

Figure 1.—Specifications and Test Data for the 50–60 Penetration Asphalts, Showing the Range of Each Specification Requirement and the Range and Average for Corresponding Laboratory Tests.

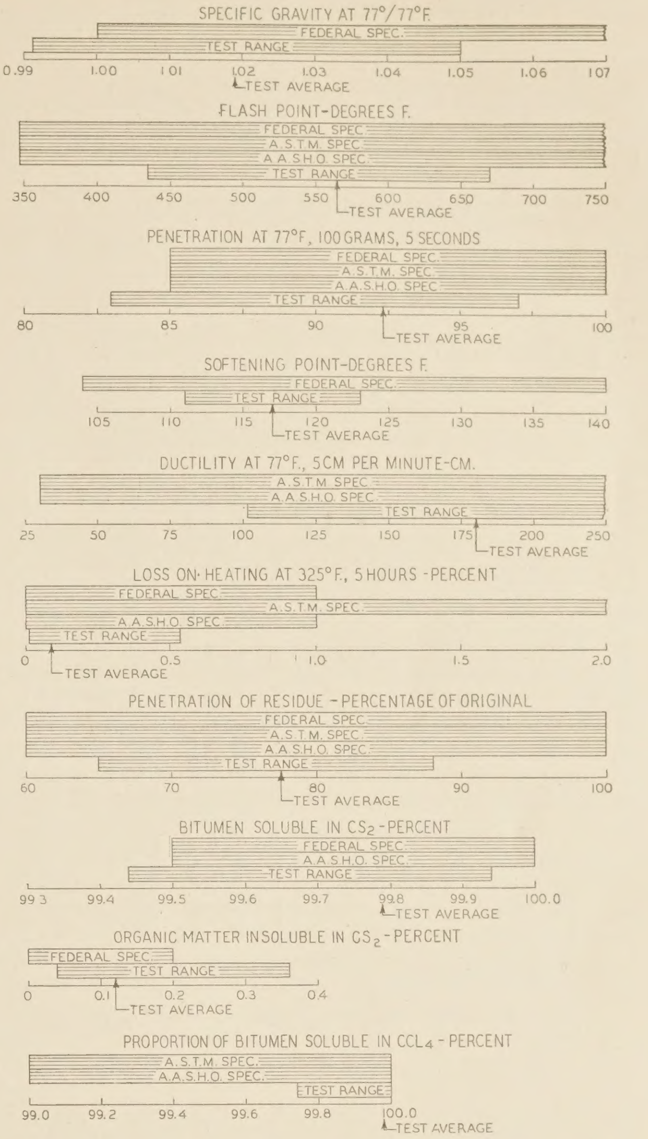

Figure 2.—Specifications and Test Data for the 85–100 Penetration Asphalts, Showing the Range of Each Specification Requirement and the Range and Average for Corresponding Laboratory Tests.

The softening points of the 50–60 asphalts varied from 118° to 137° F., a range of 19°; and the 85–100 asphalts varied from 111° to 123° F., a range of 12°. Eighteen 85–100 penetration asphalts and eight 50–60 penetration asphalts had softening points ranging from 118° to 123° F., inclusive. The average test value for each grade was approximately in the middle of the test range. While the softening point of an asphalt is dependent on the source of the base petroleum and the processing, the specification limits for the particular grade are far wider than necessary to permit the asphalts of this investigation to meet the Federal specification requirement.

The minimum ductility requirements of 40 centimeters for the Federal specification and 30 centimeters for the specifications of the A. S. T. M. and A. A. S. H. O. are very low as compared to the values obtained on the majority of asphalts tested. There were only two materials, samples 20 and 33 of the 50–60 grade, that failed to meet the requirement of the Federal specification. Sample 33 also did not meet the ductility requirement of 30 centimeters of the other two specifications. Sample 31, 50–60 grade, had a ductility very close to the minimum requirement of the Federal specification. Including these three samples, there were only eight samples of the 50–60 grade and none of the 85–100 grade that did not have a ductility greater than 100 centimeters.

Although the ductility machine used in the Public Roads Administration laboratory can measure a pull of 250 centimeters, there were many asphalts that failed to break in this distance; and these results have been reported as 250 centimeters plus. In calculating the average test values, the ductilities of 250 centimeters plus were taken as 250 centimeters. The average test values for the 50–60 and 85–100 penetration asphalts were 176 and 180 centimeters, respectively, which indicate that the ductility of the bulk of the asphalt produced is far greater than the specifications require.

Sample 40 was the only asphalt of either the 50–60

TABLE 6.—*Results of laboratory tests on 50–60 penetration asphalts, showing conformity to present specifications*

Identification No.	Producer number	Specific gravity at 77°/77° F.	Flash point	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per minute	Loss on heating at 325° F., 50 gm., 5 hours	Penetration of residue compared to penetration before heating	CS_2 solubility			Bitumen soluble in CCl_4
									Bitumen soluble	Organic matter insoluble	Inorganic matter insoluble	
			°F.		*°F.*	*Cm.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Federal specification	----------	1.010+	347+	50–60	104–140	40+	1.0−	60.0+	99.5+	0.2−	----------	----------
A. S. T. M. specification	----------	----------	347+	50–60	----------	30+	2.0−	60.0+	----------	----------	----------	99.0+
A. A. S. H. O. specification	----------	----------	347+	50–60	----------	30+	1.0−	60.0+	99.5+	----------	----------	99.0+
1	1	1.021	540	57	119	250+	0.13	84	99.88	0.03	0.09	100.00
2	2	1.013	580	61	118	250+	.05	82	99.86	.06	.08	99.96
3	3	1.013	580	61	118	250+	.05	82	99.87	.05	.08	100.00
4	4	1.016	555	60	118	250+	.06	83	99.83	.06	.11	99.96
5	5	1.016	585	58	120	250+	.07	79	99.86	.05	.09	99.98
6	6–A	1.011	630	52	126	250+	.06	88	99.87	.05	.08	99.98
7	7–A	1.041	535	58	132	197	.07	84	99.93	.04	.03	100.00
8	8	1.043	550	56	130	68	.11	82	99.87	.08	.05	99.98
9	9	1.040	545	53	132	218	.08	87	99.89	.06	.05	100.00
10	10	1.047	535	56	131	215	.12	80	99.89	.08	.03	100.00
11	11	1.045	540	54	132	180	.11	81	99.87	.06	.07	99.96
12	6–B	1.041	550	55	132	250+	.06	84	99.91	.04	.05	100.00
13	12	1.034	535	51	132	140	.11	86	99.92	.08	.00	100.00
14	13–A	1.025	600	52	126	250+	+.01	88	99.90	.09	.01	99.99
15	13–B	1.035	545	52	126	181	.02	90	99.75	.14	.11	100.00
16	7–B	1.033	560	48	132	57	.03	85	99.85	.08	.07	99.96
17	6–C	1.024	600	48	128	250+	.02	90	99.89	.08	.03	100.00
18	14	1.030	595	51	129	250+	.05	90	99.92	.06	.02	100.00
19	15	1.025	680	57	125	220	.00	86	99.83	.04	.13	99.98
20	16–A	1.017	520	58	137	[1] 36	.12	91	99.84	.08	.08	100.00
21	16–B	1.021	635	57	130	232	.02	88	99.83	.07	.10	99.97
22	17	1.017	585	57	137	96	.04	84	99.81	.06	.13	99.99
23	18	1.042	550	60	120	202	.10	70	99.72	.08	.20	99.94
24	19–A	[1] .998	----------	54	131	84	.04	89	99.61	.18	.21	99.97
25	19–B	[1] .995	645	58	127	116	.07	84	99.67	.10	.23	99.87
26	19–C	1.017	520	53	129	78	.09	83	99.69	.15	.16	99.98
27	20–A	[1] 1.002	635	49	131	226	.03	88	99.83	.06	.11	99.92
28	20–B	1.021	525	58	126	244	.12	78	99.63	[1] .21	.16	99.97
30	22	[1] 1.008	620	48	131	170	.03	94	99.79	.10	.11	100.00
31	23	1.027	495	59	133	41	.08	86	99.91	.05	.04	99.95
32	24–A	1.015	675	49	128	159	.05	90	99.69	.14	.17	99.97
33	24–B	1.037	600	46	127	[1] 27	.04	87	[1] 99.37	[1] .48	.15	99.77
34	25–A	1.039	555	58	128	112	.05	79	99.94	.04	.02	99.98
35	25–B	1.014	650	57	123	219	.06	91	99.53	.04	.43	99.99
36	25–C	1.011	655	55	125	190	.07	91	99.66	.05	.29	100.00
37	26–A	1.020	525	52	132	137	.06	85	99.83	.08	.09	99.96
38	26–B	1.014	520	55	132	120	.08	84	99.81	.12	.07	100.00
39	27	1.040	620	47	129	121	.05	94	99.72	.14	.14	99.99
40	28	1.053	440	50	123	250+	.48	74	99.80	.10	.10	99.78

[1] Material fails to conform.

TABLE 7.—*Results of laboratory tests on 85–100 penetration asphalts, showing conformity to present specifications*

Identification No.	Producer number	Specific gravity at 77°/77° F.	Flash point	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per minute	Loss on heating at 325° F., 50 gm., 5 hours	Penetration of residue compared to penetration before heating	CS_2 solubility			Bitumen soluble in CCl_4
									Bitumen soluble	Organic matter insoluble	Inorganic matter insoluble	
			°F.		*°F.*	*Cm.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Federal specification	----------	1.000+	347+	85–100	104–140	----------	1.0−	60.0+	99.5+	0.2−	----------	----------
A. S. T. M. specification	----------	----------	347+	85–100	----------	30+	2.0−	60.0+	----------	----------	----------	99.0+
A. A. S. H. O. specification	----------	----------	347+	85–100	----------	30+	1.0−	60.0+	99.5+	----------	----------	99.0+
1	1	1.019	530	85	113	223	0.16	81	99.85	0.07	0.08	100.00
2	2	1.010	540	96	111	193	.07	82	99.90	.10	.00	100.00
3	3	1.010	545	95	112	204	.07	84	99.89	.11	.00	100.00
4	4	1.013	----------	92	112	227	.08	82	99.73	.15	.12	100.00
5	5	1.016	----------	91	113	197	.08	81	99.81	.08	.11	100.00
6	6–A	1.004	650	92	117	185	.05	79	99.88	.12	.00	100.00
7	7–A	1.039	490	96	120	220	.10	79	99.94	.06	.00	100.00
8	8	1.038	510	96	121	102	.21	69	99.93	.07	.00	100.00
9	9	1.038	490	96	121	230	.13	78	99.86	.08	.06	100.00
10	10	1.038	485	95	121	192	.19	74	99.92	.04	.04	99.96
11	11	1.038	----------	97	119	209	.12	77	99.91	.08	.01	100.00
12	6–B	1.039	500	97	119	242	.13	76	99.92	.05	.03	100.00
13	12	1.025	540	94	117	192	.05	74	99.84	.08	.08	99.98
14	13–A	1.020	580	95	115	192	.01	77	99.93	.06	.01	100.00
15	13–B	1.029	550	92	115	187	.04	77	99.77	.11	.12	100.00
16	7–B	1.024	565	94	117	107	.03	77	99.80	.14	.06	100.00
17	6–C	1.018	560	92	118	191	.04	78	99.82	.09	.09	100.00
18	14	1.035	500	85	123	196	.17	76	99.82	.11	.07	100.00
19	15	1.021	670	90	116	179	.02	82	99.80	.14	.06	100.00
20	16–A	1.014	500	90	121	139	.15	88	99.84	.13	.03	100.00
21	16–B	1.020	630	97	115	178	.05	80	99.74	.19	.07	100.00
22	17	1.017	585	96	117	211	.03	82	99.85	.13	.02	99.96
23	18	1.030	580	91	112	223	.04	68	99.69	.20	.11	100.00
24	19–A	[1] .995	----------	94	118	162	.04	79	99.59	.18	.23	99.97
25	19–B	[1] .991	665	94	118	152	.08	81	99.64	.19	.17	99.90
26	19–C	1.005	560	84	119	172	.08	77	99.75	.17	.08	99.95
27	20–A	[1] .999	670	93	116	164	.02	81	99.75	.14	.11	100.00
28	20–B	1.011	590	92	115	184	.06	79	99.79	.15	.06	100.00
29	21	1.031	580	92	113	200	.10	65	99.53	[1] .21	.26	100.00

[1] Material fails to conform.

TABLE 7.—*Results of laboratory tests on 85–100 penetration asphalts, showing conformity to present specifications*—Continued

Identification No.	Producer number	Specific gravity at 77°/77° F.	Flash point	Penetration at 77° F., 100 gm., 5 sec.	Softening point	Ductility at 77° F., 5 cm. per minute	Loss on heating at 325° F., 50 gm., 5 hours	Penetration of residue compared to penetration before heating	CS₂ solubility: Bitumen soluble	CS₂ solubility: Organic matter insoluble	CS₂ solubility: Inorganic matter insoluble	Bitumen soluble in CCl₄
			°F.		*°F.*	*Cm.*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
30	22	1.001	640	90	116	163	0.03	86	99.79	0.08	0.13	100.00
31	23	1.020	505	93	120	101	.08	75	99.88	.08	.04	100.00
32	24–A	1.010	665	85	119	173	.02	75	99.67	.11	.22	100.00
33	24–B	1.028	595	83	119	125	04	65	[1] 99.44	[1] .36	.20	99.94
34	25–A	1.034	560	94	116	170	.02	72	99.95	.05	.00	100.00
35	25–B	1.007	560	96	116	186	.07	83	99.64	.08	.28	99.90
36	25–C	[1] .999	655	92	121	115	.03	80	99.75	.13	.12	99.97
37	26–A	1.011	530	96	118	193	.07	78	99.85	.08	.07	100.00
38	26–B	1.002	505	95	121	120	.13	80	99.82	.08	.10	100.00
39	27	1.028	590	86	116	141	.14	76	99.64	.15	.21	100.00
40	28	1.050	435	87	113	250+	.53	70	99.67	.12	.21	99.74

[1] Material fails to conform.

or 85–100 grade that had a relatively high loss on heating at 325° F. for 5 hours. The loss for both grades of this asphalt was approximately one-half the maximum allowable loss permitted by the Federal and A. A. S. H. O. specifications and one-fourth of that provided for in the A. S. T. M. specifications. The loss on heating for the two grades of sample 40 was much higher than the average test values, which are 0.07 percent for the 50–60 asphalts and 0.09 percent for the 85–100 grade. Thus it would seem that the maximum allowable loss permitted by these specifications, especially by the A. S. T. M. specifications, is far greater than necessary.

TABLE 8.—*The range and average of results of tests used as requirements in the standard specifications*

Test	50–60 grade			85–100 grade		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Specific gravity at 77°/77° F.	0.995	1.053	1.025	0.991	1.050	1.019
Flash point, ° F.	440	680	574	435	670	564
Penetration at 77° F., 100 gm., 5 sec.	46	61	54.4	83	97	92.3
Softening point, ° F.	118	137	127.8	111	123	117
Ductility at 77° F., cm.	27	250+	175.5	101	250+	179.8
Loss on heating at 325° F., percent	+0.01	0.48	0.074	0.01	0.53	0.089
Penetration of residue, percentage of original	70	94	85.2	65	88	77.6
Bitumen soluble in CS₂, percent	99.37	99.94	99.80	99.44	99.94	99.79
Organic matter insoluble in CS₂, percent	0.03	0.48	0.09	0.04	0.36	0.12
Bitumen soluble in CCl₄, percent	99.77	100	99.97	99.74	100	99.98

FEDERAL SPECIFICATIONS FOR ASPHALT CEMENTS MOST RESTRICTIVE

The Federal, A. S. T. M. and A. A. S. H. O. specifications require that the penetration of the residue from the loss on heating shall be at least 60 percent of its original penetration before heating. The percentage of original penetration retained by the residues of the 50–60 asphalt varied from 70 to 94, with an average of 85 percent. For the 85–100 asphalts the range was from 65 to 88, with an average of 78 percent. Although all the test results were well over the minimum permitted by the specifications, there were differences among the various asphalts of each grade in the degree of hardening during the 5-hour oven test. The ranges and averages for the percentage of original penetration retained by the residues of the asphalts indicate that the 85–100 penetration asphalts harden to a greater degree than do the 50–60 penetration asphalts.

Only one 50–60 asphalt and one 85–100 penetration asphalt failed to meet the minimum requirement of the Federal and A. A. S. H. O. specifications of 99.5 percent bitumen soluble in carbon disulphide. The test average for both grades was approximately 99.8 percent. The test ranges of both the 50–60 and 85–100 penetration asphalts, as shown in figures 1 and 2, extended well beyond the limit of the Federal specification for the amount of organic matter insoluble in carbon disulphide because of the relatively high insolubility of sample 33 of each grade. All of the other materials except sample 28 of the 50–60 grade and sample 29 of the 85–100 grade met this specification requirement, and the average percentage of organic matter insoluble in carbon disulphide was approximately 0.1 for the asphalts of both penetration grades.

The minimum requirement of the A. S. T. M. and A. A. S. H. O. specifications of 99.0 percent bitumen soluble in carbon tetrachloride is far lower than any test value obtained on the asphalts of either grade. The minimum test value for each grade was approximately 99.75 percent and the average test value was 99.98 percent for the 85–100 materials and 99.97 percent for the 50–60 asphalts.

Careful study of the data that show the conformity of these asphalts to the A. S. T. M. and A. A. S. H. O. specifications furnishes no information that can be used to indicate definitely the source of the base petroleum or the refining process.

A requirement for ductility of not less than 30 centimeters as designated in these specifications may eliminate products from those petroleums that do not develop ductile residues, and this requirement may restrict to some extent the amount of blowing that can be employed in the refining process. However, with only the test data required by these specifications, it is impossible to determine the distinguishing characteristics of asphalts from various sources and refining processes. Accordingly, the uniformity of supply cannot be controlled, and no pertinent information is available to indicate what measures should be employed in the use of the particular asphalt to insure the prevention of deterioration during the mixing and construction processes and under service conditions.

The test data obtained to show compliance with the Federal specification furnish additional information that is helpful in this respect although not entirely satisfactory. The minimum specific gravity requirement serves to eliminate to some extent those asphalts prepared from petroleums of paraffinic base. The slightly higher minimum ductility requirement of this

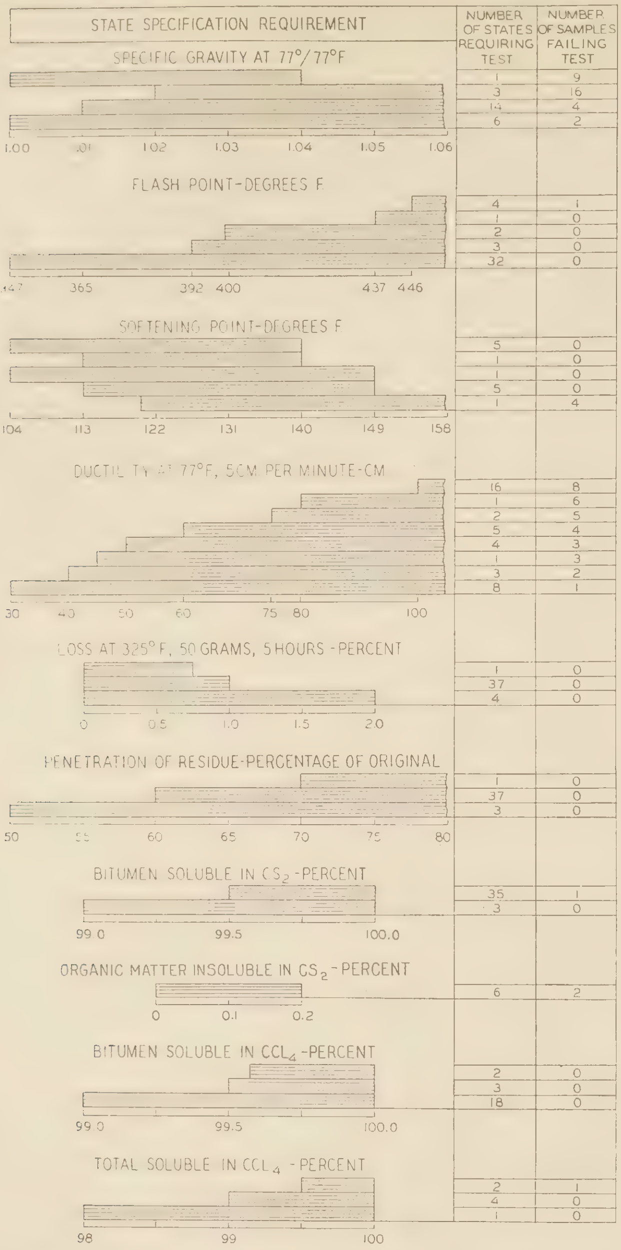

Figure 3.—State Specifications for 50–60 Penetration Asphalts, Showing the Test Requirements, the Number of States Using Each Limit and the Number of 50–60 Penetration Asphalts Investigated Failing Each Requirement.

specification, together with the softening point limits, offers some control over the processing of certain petroleums.

The uniformity of supply for a particular job is controlled in the Federal specification by the following special requirement:

> The material furnished under this specification for a given contract, type, and grade shall be uniform in character and shall not vary more than 18° F. in softening point from the test limits specified nor more than 0.020 in specific gravity * * *.

The intent of this somewhat ambiguous requirement is to provide that shipments of material for a particular job shall be within the test limits specified for the grade and in addition shall have softening points within 18° F. and specific gravities within 0.02 of values obtained for the asphalt originally accepted.

A study of the test data in tables 6 and 7 will show, however, that this provision does not insure the desired uniformity. The ranges in specific gravity values for 50–60 and 85–100 penetration asphalt were 0.995 to 1.053 and 0.991 to 1.050, respectively. If the material initially submitted had a specific gravity of 1.025, the above requirement would permit the subsequent acceptance of asphalts having specific gravities of 1.005 to 1.045. Only five 50–60 asphalts and seven 85–100 asphalts included in this investigation could not be substituted in this specific case.

The range in values of the softening point for the 50–60 asphalts was 19° F. and for the asphalts of 85–100 penetration was 12° F. It is apparent, therefore, that in both grades many of the asphalts represented by materials in this investigation could be substituted for another without violating the provisions of this special requirement for permissible variation in the softening points of subsequent shipments of asphalt for the same project and without indicating to the user that a different base petroleum or a different refining process had been substituted.

STANDARD SPECIFICATIONS CONSIDERABLY MODIFIED BY SOME STATES

The specifications of the various States for asphalt cement indicate that there is a decided tendency to modify the specifications as adopted or proposed by the Federal Specifications Executive Committee, the American Association of State Highway Officials, and the American Society for Testing Materials. A majority of the States have specifications for asphalt cements of one or more of the usual penetration grades. A study of the specifications available showed that 40 States and the District of Columbia specify 50–60 penetration asphalts. Three States do not have specifications for 50–60 but do have specifications for 60–70 penetration asphalts and these will be included in the following summary of the 50–60 grade. A majority of these specifications were adopted after 1935.

A summary of the State specifications shows that only two States use the Federal specification, two the A. A. S. H. O. specification, and one the A. S. T. M. specification, with their present test requirements. Some of the States use the same physical and chemical tests as required in one of the above-named specifications, but they have changed the limits of one or more of these requirements. Other States have changed the test limits of the Federal, A. S. T M., or A. A. S. H. O. specifications and also have added special test requirements.

In order to show how the States have modified their specifications, the physical and chemical tests of the Federal, A. S. T. M., and A. A. S. H. O. specifications with the various test limits as adopted by the different States and the District of Columbia are shown graphically in figure 3. This figure also shows the number of States using the different limits for the specification tests and the number of asphalt cements of the 50–60 penetration grade, given in table 6, that failed to meet each specification requirement.

A discussion of the data plotted in this figure will show how the limits of the various State specifications vary from those of the Federal, A. S. T. M., or A. A. S. H. O. specifications.

Twenty-four States require a test for specific gravity at 77°/77° F. and 10 of these have test limits that differ from the requirement of the Federal specification.

Three States specify a higher minimum requirement and 6 States a lower minimum requirement. One State has both a maximum and minimum limit. In general, the higher the minimum limit, the greater the number of 50–60 asphalts that fail to meet the specification requirement. It is interesting to note that if the test requirement for specific gravity of not less than 1 or more than 1.04 were to be rigidly enforced, 5 out of 6 Mexican asphalts examined in this investigation would be excluded from use. In setting this limit it is believed that it was not the intention of this particular specification to eliminate this material.

Thirty-two of the forty-two States using the flash point test have the same requirements as the Federal, A. S. T. M., and A. A. S. H. O. specifications, while the other 10 States specify higher minimum limits ranging from 392° to 446° F. Only one 50–60 asphalt has a flash point lower than 446° F.

Only 13 States have a specification requirement for softening point and 5 of these use the same limits as the Federal specification. Of the other States, 5 use limits of 113° to 149° F., 1 uses 113° to 140° F., 1 uses 104° to 149° F., and 1 State specifies only a minimum requirement of 120° F. The 50–60 penetration asphalts meet all these limits except the last. Four of the five California asphalts tested in this investigation had softening points below 120° F.

The requirements of the States for ductility show the greatest variations from the limits of the Federal, A. S. T. M., or A. A. S. H. O. specifications. Of the 40 States requiring a ductility test at 77° F., 8 use the limit of the A. S. T. M. and A. A. S. H. O. specifications, and 3 use the limit of the Federal specification. All the remaining States have higher minimum requirements ranging from 45 centimeters up to 100 centimeters with 16 States using the highest limit. With a minimum ductility of 100 centimeters, however, only 8 of the 50–60 asphalts failed to pass this test requirement. Four asphalts, samples 16, 20, 31, and 33, had ductilities below 60 centimeters, and 3 of these, samples 20, 31, and 33, had ductilities below 45 centimeters.

Thirty-seven States have the same maximum limits for loss on heating at 325° F. as the Federal and A. A. S. H. O. specifications. Four use the A. S. T. M. requirement of not more than 2 percent and one permits a maximum loss of 0.75 percent. All of the asphalts tested had losses much lower than the 0.75 percent limit.

Thirty-seven States use the same minimum requirement of 60 for penetration of the residue from loss on heating at 325° F. expressed as the percentage of the penetration before heating. Three States specify a minimum of 50 percent and one State a minimum of 70 percent. All the asphalts met these requirements.

CERTAIN REQUIREMENTS FOUND TO BE DEFINITELY RESTRICTIVE

Thirty-five out of thirty-eight States have the same limit of 99.5 percent of bitumen soluble in carbon disulphide as the Federal and A. A. S. H. O. specifications. One sample failed to meet this requirement. Only six States require a determination of organic matter insoluble in carbon disulphide and these States use the same limit as required by the Federal specification. Two asphalts failed to meet this requirement. Twenty-three States require a determination of the proportion of bitumen soluble in carbon tetrachloride and seven States require a determination of total solubility in carbon tetrachloride. Eighteen of the twenty-three States specifying the percentage of bitumen soluble in carbon tetrachloride have the same limit as the A. S. T. M. and A. A. S. H. O. specifications. All the asphalts passed the requirements for percentage of bitumen soluble in carbon tetrachloride. Only one asphalt failed to meet the highest specification requirement for total solubility in carbon tetrachloride.

On the basis of the test data shown in table 6, seven of the 50–60 asphalts failed to pass the test requirements of the Federal specification, while but one asphalt failed to meet the test requirements of the A. S. T. M. or A. A. S. H. O. specifications. With the same control tests but with changes in the specification requirements, the limits imposed by various States, if rigidly enforced, would result in the rejection of 28 of these asphalts, leaving only 11 materials that would not be excluded by some one of the modifications. Table 9 shows the samples that failed to meet the various requirements of the States. The failure of such a large proportion of the asphalts, some of which are representative of materials which have given satisfactory service performance, indicates that certain requirements are definitely restrictive.

In addition to the routine tests that were made to determine the conformity of the 50–60 and 85–100 penetration asphalts to the Federal, A. S. T. M., and A. A. S. H. O. specifications, modifications of these routine tests and a number of other tests that have been used or are proposed for use by various agencies were also made. The data will be discussed and, where the particular test has been used as a specification requirement, the effect of the particular limits on the acceptance or rejection of materials similar to the asphalts of this study will be considered.

In table 10, the essential data for the calculation of various factors that have been used in specification requirements for controlling the susceptibility of asphalts to changes in temperature are given. Various combinations of requirements for softening point, ductility, and penetration at 32° and 115° F., together with consistency at normal temperature, 77° F., have been employed in some instances to insure a material having a satisfactory range in consistency for particular climatic conditions. In many cases various consistency tests are used to devise empirical susceptibility factors that become essential requirements in the specifications for asphaltic cements. The susceptibility factors that have been derived from the data shown in this table are given in table 11.

Since the penetration test was first adopted as a specification requirement, it has been used as a means of controlling the susceptibility of asphalts to changes in temperature. Various penetration relationships have been used for this purpose. One of the oldest methods for controlling the susceptibility of asphalt cements is the one generally used in the specifications for materials such as those intended for waterproofing and as fillers. Besides providing for a given penetration range at 77° F., these specifications require a minimum limit at 32° F., 200 grams, 60 seconds and a maximum limit at 115° F., 50 grams, 5 seconds.

SUSCEPTIBILITY FACTORS SOMETIMES ADVANCED AS SPECIFICATION REQUIREMENTS

A State specification of a few years ago employed the values obtained at these three temperatures to set up the factor:

TABLE 9.—*Identification*[1] *of the 50–60 penetration asphalts which fail to meet the test limits of the standard* [2] *specifications as modified by the States*

Test	Specific gravity at 77°/77° F.				Flash point	Softening point	Ductility at 77° F., 5 cm. per minute								Bitumen soluble in CS₂	Organic matter insoluble in CS₂	Total soluble in CCl₄
Test requirement	1.00–1.04	1.02+	1.01+	1.00+	446+ °F.	120+ °F.	100+ cm.	80+ cm.	75+ cm.	60+ cm.	50+ cm.	45+ cm.	40+ cm.	30+ cm.	99.5+ percent	0.20– percent	99.5+ percent
Sample number:																	
1	---	---	---	---	---	x	---	---	---	---	---	---	---	---	---	---	---
2	---	x	---	---	---	x	---	---	---	---	---	---	---	---	---	---	---
3	---	x	---	---	---	x	---	---	---	---	---	---	---	---	---	---	---
4	---	x	---	---	---	x	---	---	---	---	---	---	---	---	---	---	---
5	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
6	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
7	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
8	x	---	---	---	---	---	x	x	x	---	---	---	---	---	---	---	---
9	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
10	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
11	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
12	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
13	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
14	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
15	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
16	---	---	---	---	---	---	x	x	x	x	---	---	---	---	---	---	---
17	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
18	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
19	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
20	---	x	---	---	---	---	x	x	x	x	x	x	x	---	---	---	---
21	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
22	---	x	---	---	---	---	x	---	---	---	---	---	---	---	---	---	---
23	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
24	x	x	x	x	---	---	x	---	---	---	---	---	---	---	---	---	---
25	x	x	x	x	---	---	---	---	---	---	---	---	---	---	---	---	---
26	---	x	---	---	---	---	x	x	---	---	---	---	---	---	---	---	---
27	---	x	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---
28	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	x	---
30	---	x	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---
31	---	---	---	---	---	---	x	x	x	x	x	x	---	---	---	---	---
32	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
33	---	---	---	---	---	---	x	x	x	x	x	x	x	x	x	x	x
34	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
35	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
36	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
37	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
38	---	x	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
39	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
40	x	---	---	---	x	---	---	---	---	---	---	---	---	---	---	---	---
Number of samples failing each test requirement	9	16	4	2	1	4	8	6	5	4	3	3	2	1	1	2	1

[1] Samples marked (x) fail to meet test requirement.

[2] Includes the Federal, A. S. T. M. and A. A. S. H. O. specifications.

TABLE 10.—*Consistency determinations of the 50–60 and 85–100 penetration asphalts*

Identification No.	50–60 penetration asphalts														85–100 penetration asphalts											
	Penetration												Saybolt-Furol viscosity at 275° F.	Float test at 176° F.	Penetration										Saybolt-Furol viscosity at 275° F.	Float test at 176° F.
	200 grams, 60 seconds		100 grams, 5 seconds									50 grams, 5 seconds at 115° F.			200 grams, 60 seconds		100 grams, 5 seconds									
	At 32° F.	At 39.2° F.	At 32° F.	At 41° F.	At 50° F.	At 59° F.	At 68° F.	At 77° F.	At 86° F.	At 95° F.	At 104° F.				At 32° F.	At 39.2° F.	At 32° F.	At 41° F.	At 50° F.	At 59° F.	At 68° F.	At 77° F.	At 86° F.	At 95° F.		
													Seconds	*Seconds*											*Seconds*	*Seconds*
1	9	15	1	5	9	15	27	57	105	190	----	----	105	106	15	22	2	6	11	21	43	85	160	266	82	90
2	9	17	1	5	9	16	30	61	113	200	----	----	127	109	16	29	3	7	13	24	51	96	177	290	94	91
3	9	16	1	5	9	15	29	61	112	198	----	----	124	108	15	27	4	6	13	25	51	95	176	283	93	90
4	9	16	1	5	9	15	30	60	115	202	----	----	114	107	16	23	2	6	12	23	49	92	173	277	95	98
5	9	18	1	5	9	15	29	58	104	186	----	----	131	119	14	23	4	7	13	24	49	91	175	278	110	100
6	10	20	3	7	11	17	30	52	88	143	226	279	251	135	18	31	5	10	16	29	53	92	157	265	178	106
7	18	27	5	10	14	23	34	58	91	140	225	268	475	173	27	44	9	15	23	38	59	96	147	224	294	139
8	21	31	7	11	17	25	36	56	82	123	210	279	260	153	31	43	10	18	24	37	57	96	138	215	152	115
9	17	26	4	9	12	21	33	53	81	126	206	247	537	183	27	42	9	16	22	37	57	96	144	219	316	132
10	17	26	5	10	14	23	34	56	85	133	208	257	483	174	27	41	9	15	22	36	58	95	141	216	313	134
11	20	25	5	9	14	22	34	54	82	130	202	243	490	184	25	44	8	16	22	37	58	97	148	227	288	134
12	17	25	5	9	14	20	33	55	85	136	211	248	555	176	28	40	10	15	22	38	59	97	148	230	281	128
13	19	28	6	10	16	23	35	51	74	108	168	196	274	160	28	41	9	13	22	38	61	94	145	238	166	118
14	11	24	3	6	12	19	31	52	84	137	236	----	260	131	21	35	5	10	17	32	57	95	153	258	152	109
15	15	25	4	7	13	21	33	52	84	135	225	273	274	135	22	33	5	10	17	32	57	92	152	258	147	109
16	15	25	5	8	13	21	30	48	72	106	169	205	288	160	25	37	8	13	20	37	59	94	153	250	167	113
17	14	22	5	8	13	19	30	48	78	122	196	246	337	152	25	33	6	12	19	33	55	92	151	244	197	112
18	14	26	4	7	13	21	32	51	79	123	208	248	337	147	25	37	7	11	18	33	53	85	132	214	267	135
19	12	20	5	7	12	20	36	57	96	162	265	----	304	133	20	32	6	13	21	34	54	90	145	236	217	113
20	24	38	8	14	20	29	40	58	81	116	170	188	425	199	37	48	13	21	26	43	61	90	132	200	234	126
21	16	27	4	9	16	23	36	57	91	145	225	270	340	144	23	34	7	15	19	37	58	97	156	250	217	109
22	25	32	8	14	20	26	40	57	78	113	169	198	415	180	31	41	11	19	26	40	64	96	149	230	227	117
23	11	20	4	6	12	18	32	60	111	194	----	----	82	100	14	24	5	9	12	29	50	91	162	271	84	89
24	17	23	5	10	15	24	37	54	84	129	197	235	337	152	23	----	9	14	23	37	58	94	150	230	195	103
25	14	24	5	8	16	23	35	58	96	156	248	----	311	132	20	31	8	12	22	36	56	94	150	237	203	106
26	15	22	4	8	15	21	35	53	88	141	213	280	215	144	21	30	8	11	20	33	51	84	138	218	173	107
27	12	21	3	7	13	19	30	49	79	125	195	248	362	156	18	27	6	10	18	31	54	93	158	249	182	103
28	12	20	4	8	14	20	35	58	90	150	253	----	196	130	15	24	5	9	14	30	51	92	157	259	148	101
29	----	----	----	----	----	----	----	----	----	----	----	----	----	----	15	25	4	10	16	26	49	92	163	263	102	99

TABLE 10.—*Consistency determinations of the 50–60 and 85–100 penetration asphalts*—Continued

Identification No.	50–60 penetration asphalts														85–100 penetration asphalts											
	Penetration												Saybolt-Furol viscosity at 275° F.	Float test at 176° F.	Penetration										Saybolt-Furol viscosity at 275° F.	Float test at 176° F.
	200 grams, 60 seconds		100 grams, 5 seconds									50 grams, 5 seconds at 115° F.			200 grams, 60 seconds		100 grams, 5 seconds									
	At 32° F.	At 39.2° F.	At 32° F.	At 41° F.	At 50° F.	At 59° F.	At 68° F.	At 77° F.	At 86° F.	At 95° F.	At 104° F.				At 32° F.	At 39.2° F.	At 32° F.	At 41° F.	At 50° F.	At 59° F.	At 68° F.	At 77° F.	At 86° F.	At 95° F.		
													Seconds	*Seconds*											*Seconds*	*Seconds*
30	15	21	4	9	13	20	32	48	76	112	170	203	515	167	18	32	7	12	19	31	54	90	143	223	185	112
31	19	29	6	12	16	25	39	59	88	136	198	224	393	193	28	44	10	18	26	41	58	93	141	213	215	128
32	13	22	3	8	11	17	31	49	79	126	187	232	285	146	18	28	5	13	20	30	48	85	131	207	195	115
33	13	21	3	8	11	18	30	46	76	121	186	234	113	123	17	29	5	11	19	32	50	83	125	200	98	104
34	19	27	5	10	16	23	36	58	86	138	211	252	204	144	25	38	8	14	24	36	56	94	147	232	132	104
35	17	27	6	10	14	22	36	57	90	147	239	------	210	129	25	40	9	16	25	38	58	96	150	248	163	109
36	16	25	4	9	13	22	36	55	87	134	212	263	254	141	26	37	10	17	27	39	60	92	136	200	172	109
37	19	29	5	10	16	24	33	52	77	116	174	206	369	180	32	47	9	17	28	42	63	96	143	223	195	122
38	21	33	7	11	17	25	37	55	81	120	176	204	324	173	42	49	14	21	29	43	65	95	138	205	195	135
39	8	14	2	6	8	13	26	47	82	134	227	276	209	139	15	23	4	9	16	25	45	86	159	265	132	103
40	13	21	3	7	12	19	31	50	82	136	220	------	120	129	18	36	6	10	18	31	52	87	151	259	76	96

TABLE 11.—*Susceptibility factors of the 50–60 and 85–100 penetration asphalts*

Identification No.	Pen. 77° F. / Pen. 32° F. (1)		(Pen. 115° F.−Pen. 32° F.) / Pen. 77° F. (1) (2)	Pen. 100° F. / Pen. 77° F. (1)		Pen. 39.2° F. / Pen. 77° F. (1)		*P T S* [3] calculated by Pfeiffer and Van Doormal method		Slope of the log penetration-temperature curve		Penetration index				Float test index		Fluidity factor	
												Calculated from *P T S* [3]		Calculated from slope of log penetration temperature curve					
	50–60 grade	85–100 grade	50–60 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade	50–60 grade	85–100 grade
						Percent	*Percent*												
1	6.3	5.7	(4)	4.7	5.3	26	26	0.0276	0.0272	0.0295	0.0323	−1.39	−1.29	−1.79	−2.32	77.7	87.4	27.4	−2.6
2	6.8	6.0	(4)	4.8	5.1	28	30	.0270	.0268	.0307	.0314	−1.25	−1.20	−2.02	−2.16	81.6	93.4	40.3	−1.9
3	6.8	6.3	(4)	4.8	5.4	26	28	.0271	.0268	.0297	.0324	−1.28	−1.20	−1.83	−2.34	81.2	92.5	38.4	−1.9
4	6.7	5.8	(4)	4.9	5.2	27	25	.0272	.0272	.0307	.0315	−1.29	−1.29	−2.02	−2.18	80.2	95.0	32.4	−2.8
5	6.4	6.5	(4)	4.4	5.3	31	25	.0266	.0262	.0287	.0313	−1.15	−1.07	−1.63	−2.14	83.1	95.4	42.3	8.2
6	5.2	5.1	5.2	3.7	4.1	38	34	.0242	.0237	.0252	.0267	−.57	−.44	−.83	−1.19	83.8	98.8	103.5	79.1
7	3.2	3.6	4.3	3.2	3.1	47	46	.0209	.0213	.0217	.0219	+.42	+.25	+.17	+.10	100.1	115.5	241.9	190.1
8	2.7	3.1	4.6	2.8	2.8	55	45	.0209	.0207	.0192	.0211	+.42	+.47	+.99	+.32	92.6	105.1	114.2	53.8
9	3.1	3.6	4.3	3.2	2.9	49	44	.0216	.0211	.0226	.0217	+.20	+.32	−.12	+.15	98.5	112.5	256.5	211.2
10	3.3	3.5	4.3	3.0	3.1	46	43	.0208	.0210	.0216	.0220	+.43	+.38	+.19	+.07	98.7	112.8	239.1	207.1
11	2.7	3.9	4.1	3.1	3.1	46	45	.0212	.0217	.0216	.0219	+.33	+.17	+.19	+.10	99.6	114.0	235.4	185.3
12	3.2	3.5	4.2	3.2	3.1	45	41	.0210	.0218	.0222	.0219	+.38	+.14	------	+.10	98.4	111.5	275.0	178.5
13	2.7	3.4	3.5	2.7	3.2	55	44	.0219	.0231	.0185	.0221	+.08	−.24	+1.26	+.03	90.4	105.3	113.7	67.7
14	4.7	4.5	(4)	3.5	3.7	46	37	.0242	.0243	.0238	.0248	−.57	−.58	−.45	−.71	82.6	101.7	108.2	54.2
15	3.5	4.2	5.0	3.3	3.8	48	36	.0244	.0246	.0224	.0248	−.63	−.67	−.05	−.71	83.8	100.1	115.4	50.6
16	3.2	3.8	4.0	2.9	3.5	52	39	.0221	.0235	.0202	.0236	+.05	−.37	+.64	−.40	87.6	103.1	115.2	68.6
17	3.4	3.7	4.8	3.3	3.7	46	36	.0241	.0229	.0224	.0246	−.52	−.20	−.05	−.67	85.4	101.5	138.7	96.6
18	3.6	3.4	4.6	3.1	3.3	51	44	.0228	.0202	.0215	.0226	−.18	+.68	+.22	−.12	86.6	107.0	145.9	154.7
19	4.8	4.5	(4)	3.7	3.4	35	36	.0238	.0246	.0249	.0235	−.45	−.67	−.74	−.37	87.0	100.8	140.8	114.3
20	2.4	2.4	2.8	2.5	2.7	66	53	.0189	.0217	.0172	.0189	+1.09	+.17	+1.76	+1.11	107.5	106.5	212.9	129.6
21	3.6	4.2	4.5	3.3	3.4	47	35	.0216	.0241	.0223	.0230	+.20	−.54	−.02	−.21	90.6	102.7	161.3	116.4
22	2.3	3.1	3.0	2.5	3.1	56	43	.0191	.0229	.0174	.0214	+1.05	−.19	+1.70	+.26	101.3	106.0	204.1	125.8
23	5.5	6.5	(4)	4.7	4.3	33	26	.0263	.0271	.0292	.0277	−1.08	−1.26	−1.74	−1.42	77.4	90.0	13.2	−6.4
24	3.2	4.1	4.0	3.0	3.2	43	------	.0216	.0228	.0207	.0226	+.19	−.16	+.47	−.12	90.6	98.4	152.8	94.9
25	4.1	4.7	(4)	3.5	3.3	41	33	.0228	.0224	.0231	.0228	−.16	−.07	−.26	−.16	87.2	99.8	146.7	102.5
26	3.5	4.0	5.0	3.5	3.4	42	36	.0226	.0231	.0227	.0231	−.10	−.24	−.15	−.26	87.4	94.8	85.9	74.8
27	4.1	5.2	(4)	3.4	3.9	41	29	.0223	.0241	.0236	.0256	−.03	−.53	−.40	−.92	87.4	97.9	80.0	82.8
28	4.8	6.1	4.8	3.4	4.1	36	26	.0234	.0245	.0228	.0272	−.35	−.65	−.16	−1.30	86.8	96.4	153.4	51.5
29	------	6.1	------	------	3.9	------	27	------	.0258	------	.0266	------	−.98	------	−1.16	------	95.5	------	9.2
30	3.2	4.8	3.9	3.0	3.6	44	37	.0226	.0241	.0203	.0245	−.10	−.53	+.62	−.63	89.6	100.4	224.2	85.1
31	3.1	3.3	3.5	2.8	2.9	49	47	.0202	.0214	.0195	.0205	+.64	+.26	+.89	+.54	106.6	109.1	197.1	113.5
32	3.8	4.7	4.5	3.3	3.2	45	33	.0240	.0221	.0227	.0225	−.51	+.05	−.15	−.08	84.6	98.8	115.6	93.5
33	3.5	5.0	4.8	3.3	3.0	46	34	.0248	.0234	.0227	.0219	−.71	−.34	−.15	+.10	75.2	92.9	30.8	11.1
34	3.1	3.8	4.0	3.1	3.3	47	40	.0221	.0236	.0215	.0227	+.03	−.40	+.22	−.15	91.4	98.9	84.7	35.7
35	3.4	3.8	(4)	3.4	3.2	47	42	.0247	.0234	.0229	.0224	−.68	−.34	−.20	−.05	85.8	102.3	87.2	64.3
36	3.4	3.6	4.5	3.2	2.7	45	40	.0240	.0212	.0215	.0192	−.51	+.31	+.22	+.99	88.1	100.1	109.5	73.5
37	2.7	3.0	3.6	2.8	2.9	56	49	.0214	.0222	.0194	.0200	+.26	------	+.93	+.71	96.8	108.2	164.8	95.0
38	2.8	2.2	3.3	2.7	2.7	60	53	.0212	.0210	.0198	.0188	+.33	+.38	+.79	+1.15	97.6	113.2	148.0	94.9
39	5.9	5.7	5.7	3.8	4.1	30	27	.0247	.0247	.0248	.0277	−.68	−.68	−.71	−1.42	80.8	94.2	76.1	39.6
40	3.8	4.8	(4)	3.6	4.0	42	41	.0262	.0268	.0240	.0261	−1.07	−1.20	−.52	−1.04	80.3	91.4	19.0	−9.6

[1] Penetrations at various temperatures as follows:
32° F., 200 gm., 60 sec.
39.2° F., 200 gm., 60 sec.
77° F., 100 gm., 5 sec.
100° F., 100 gm., 5 sec.
115° F., 50 gm., 5 sec.

[2] All 85–100 penetration asphalts too soft for penetration at 115° F. in standard container.

[3] Penetration-temperature susceptibility factor.

[4] Material too soft for penetration at 115° F.

$$\text{Susceptibility factor}=\frac{\text{penetration } 115^\circ \text{ F., 50 gm., 5 sec.}-\text{penetration } 32^\circ \text{ F., 200 gm., 60 sec.}}{\text{penetration } 77^\circ \text{ F., 100 gm., 5 sec.}}$$

and required that it should not be more than 4.2 for asphalts of 40–70 penetration. The use of this factor for asphalts of normal construction grade is limited by the fact that the material may be too soft for a penetration test at the temperature of 115° F. As indicated in table 11, all of the 85–100 penetration asphalts were too soft for a penetration test at this temperature, while of the 50–60 asphalts, only 27 of the 39 materials could be tested. Of these 27 samples, there were 15 that would not meet the requirement for a maximum susceptibility factor of 4.2. The other 50–60 penetration materials, too soft for penetration at 115° F., would also fail, so that a total of only 12 out of the 39 asphalts tested would meet the requirement.

Two other susceptibility factors have been suggested that are based on the following relationships:

$$\text{a.—S. F.}=\frac{\text{penetration } 77^\circ \text{ F., } 100 \text{ gm., } 5 \text{ sec.}}{\text{penetration } 32^\circ \text{ F., } 200 \text{ gm., } 60 \text{ sec.}}$$

$$\text{b.—S. F.}=\frac{\text{penetration } 100^\circ \text{ F., } 100 \text{ gm., } 5 \text{ sec.}}{\text{penetration } 77^\circ \text{ F., } 100 \text{ gm., } 5 \text{ sec.}}$$

Limits for these factors have not been proposed for specification requirements, and the values in table 11 are shown for comparative purposes only.

However, one State has recently adopted a susceptibility factor based on the ratio of the penetration at 39.2° F., 200 grams, 60 seconds to the penetration at 77° F., 100 grams, 5 seconds. The requirement states that the penetration at 39.2° F. must be greater than 30 percent of the penetration at 77° F. For the 50–60 grade, this limit would cause the rejection of four out of five California asphalts. For the 85–100 grade, four out of five California asphalts together with four asphalts from Oklahoma and one from Texas would also fail to meet this requirement.

Penetration-temperature relationship.—The results of the penetration tests made under a load of 100 grams for 5 seconds at temperature intervals of 9° F. (5° C.) from a minimum temperature of 32° F. to a maximum of 104° F. for the 50–60 asphalts and to a maximum of 95° F. for the 85–100 asphalts, are shown in table 10. These tests were made in the standard 3-ounce container and the depth did not permit higher test temperatures to be used. Some materials of the 50–60 grade were too soft to obtain a penetration even at the temperature of 104° F.

It was found that when the values are plotted to scale there is a straight-line relation between the temperature of test and the logarithm of the corresponding penetration. A few typical examples of this relation are shown in figure 4.

Penetration index.—J. Ph. Pfeiffer and P. M. Van Doormal [2] [3] have described a method of classifying asphalts by means of a "penetration index." In calculating this penetration index, the assumption is made that the penetration at the softening point is 800 for all asphalts. This value is used in an equation for calculating the penetration-temperature susceptibility factor as follows:

$$P\ T\ S=\frac{\log 800-\log p}{t-77}$$

where $P\ T\ S$=penetration-temperature susceptibility factor

p=penetration at 77° F., 100 gm., 5 sec.
t=softening point, °F.

This equation is the slope of the log-penetration-temperature line for the assumed penetration value of 800 and penetration, p, at the temperatures t and 77° F. respectively. The $P\ T\ S$ value is then used in calculating the penetration index by the equation

$$PI=\frac{30}{1+90(P\ T\ S)}-10$$

Values of the penetration-temperature susceptibility factor ($P\ T\ S$) and penetration index calculated in this manner are given in table 11.

For a given penetration at 77° F. the softening point is the only variable in the equation for the value of the $P\ T\ S$, as determined by Pfeiffer and Van Doormal, and thus, for asphalts of the same penetration, the value of the penetration index is dependent only on the softening point.

Since the log-penetration-temperature curves of the 50–60 and 85–100 penetration asphalts had been made, the penetration at the temperature of the softening point of each material could be found by extending the straight line up to a temperature equal to the softening point, as shown in figure 4. It was found that these values ranged from approximately 540 to 1,060 for the 50–60 grade and from approximately 620 to 1,300 for the 85–100 grade. The calculated values for the penetration at the temperature of the softening point were partially checked for the 85–100 penetration asphalts by determining the penetration of samples 14, 19, and 39, at 115° F. In determining these values, a special needle 6 inches long but otherwise conforming to the specification of the standard needle was used. Large samples of the selected asphalts were carefully prepared and held in the water bath at 115° F. until the thermometer immersed at the center of the sample came to test temperature. The values obtained are shown in figure 5.

Since the log-penetration-temperature curves of the 50–60 and 85–100 penetration asphalts assume the form of straight lines, a true indication of their susceptibility to change of temperature is found in the slope of the lines. The slope can be calculated as follows:

$$\text{Slope}=M=\frac{\log p_2-\log p_1}{t_2-t_1}$$

where p_2 and p_1 are penetrations at the two temperatures t_2 and t_1, respectively. The slope can be calculated readily from the penetration-temperature curves by finding the temperatures of the asphalt at penetrations of 10 and 100. Then

$$\text{Slope}=\frac{\log 100-\log 10}{t_2-t_1}=\frac{2-1}{t_2-t_1}=\frac{1}{t_2-t_1}$$

Where t_2=temperature, °F., corresponding to a penetration of 100
t_1=temperature, °F., corresponding to a penetration of 10.

The values of the slope for the 50-60 and 85–100 penetration asphalts are given in table 11.

MAJORITY OF SAMPLES FAILED TO MEET FLUIDITY FACTOR REQUIREMENTS

With these values of slope, which are also the true values of the penetration-temperature susceptibility factor, the exact values of the penetration index can be calculated. In general, the exact penetration index values, also given in table 11, show a wider range than those calculated on the basis of an assumed penetration

---

[2] Journal Institute Petroleum Technologists 1936, 22, 414.

[3] Classifying Asphalts by Means of Penetration Index. Reprint from National Petroleum News. Refining Technology. February 1938.

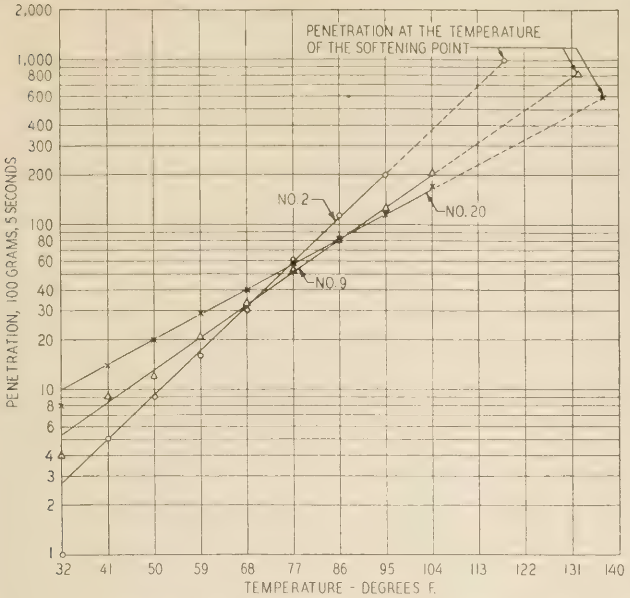

Figure 4.—Penetration-Temperature Curves for 50–60 Penetration Asphalts.

of 800 at the softening point temperature. Although the penetration indexes using the true values for the penetration-temperature susceptibility factor provide sharper differentiation among the asphalts used in this report, it is believed that the penetration-temperature susceptibility as determined by the slope of the log-penetration-temperature curve, is a true measure of susceptibility. The penetration index, whether based on the assumption of Pfeiffer and Van Doormal or on the true value of the penetration-temperature susceptibility factor, is an empirical equation that distorts the results and is not a true measure of susceptibility.

Fluidity factor: According to Joseph Zapata,[4] the fluidity factor was first proposed as a means for identifying the source of the crude from which the asphaltic material was refined. Early investigators found that asphalt cements from various sources were represented by typical viscosity temperature curves and that the maximum deviation in viscosity for these curves occurred at 135° C. (275° F.). With this as a basis the penetration at 77° F. and the factor $\frac{P}{100}$ were introduced to give an empirical formula:

$$\text{Fluidity factor} = (V - P) \times \frac{P}{100}$$

where V=Furol viscosity at 135° C. (275° F.)
P=penetration at 25° C. (77° F.).

Tests limits for fluidity factor when inserted in specifications may be considered, therefore, a means of controlling the source of an asphalt by its susceptibility to change in temperature. While the Furol viscosity of the asphalt at high temperatures may be of value for governing the temperatures of the mixing operation, a susceptibility factor based on the viscosity at this high temperature might not give an adequate indication of the change in consistency of the material over the temperature range of the pavement in service. Furthermore, as indicated by Zapata[5] in 1937, the initial purpose of the test can be voided by blending and blowing oils to meet the established limits for fluidity factors.

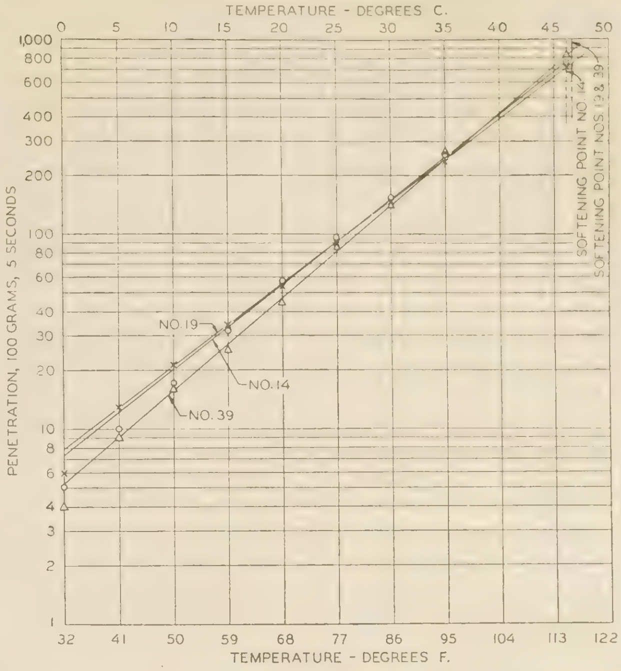

Figure 5.—Penetration-Temperature Curves Showing the Actual Penetration at the Temperature of the Softening Point; 85–100 Penetration Asphalts.

Furol viscosities of all the 50–60 and 85–100 asphalts at 275° F. were determined and the fluidity factors calculated. The Furol viscosities are given in table 10 and the fluidity factors in table 11.

A minimum limit of 140 for the fluidity factor has been included in certain specifications for asphalt cements having penetrations between 40 and 100. Of the 50–60 penetration grade, 22 asphalts out of 39 failed to meet this requirement. Those having fluidity factors below 140 include all of the California asphalts, one Mexican asphalt, the Colombian asphalt, 5 out of 6 Venezuelan asphalts, 3 of the 6 Oklahoma asphalts, and the Kansas, Texas, and Kentucky asphalts. Those asphalts having fluidity factors greater than 140 are the other Mexican, the Mexican and domestic blends, Arkansas, and a few other Mid-continent asphalts. There were 34 out of 40 samples of the 85–100 penetration grade that did not meet this minimum requirement of 140. Those meeting the requirement were 5 of the 6 Mexican asphalts and 1 of the 6 Venezuelan asphalts.

It is apparent, because of the large number of asphalts of the 85–100 grade that were lower than the specified minimum requirement, that the fluidity factor is materially affected by the consistency of the material even within the penetration limits of 40 to 100. In order to determine the effect of penetration on the fluidity factor, a set of Mexican asphalts received from producer 10 and a set of Texas asphalts received from producer 27 were tested for penetration at 77° F. and Furol viscosity at 275° F. and the fluidity factors were determined. These values are shown graphically in figure 6. The fluidity factors for the Mexican asphalts were fairly constant between the 40–100 penetration range and then the values decreased rapidly. Although the fluidity factors of all the Texas asphalts were below 140, there is a relatively wide range in these values between the penetration limits of 40 to 100.

---

[4] The Fluidity Factor Test, Proceedings Association of Asphalt Paving Technologists. January 30, 1935.

[5] A Study of Bituminous Material Weathering Tests. Proceedings Association of Asphalt Paving Technologists, January 1937.

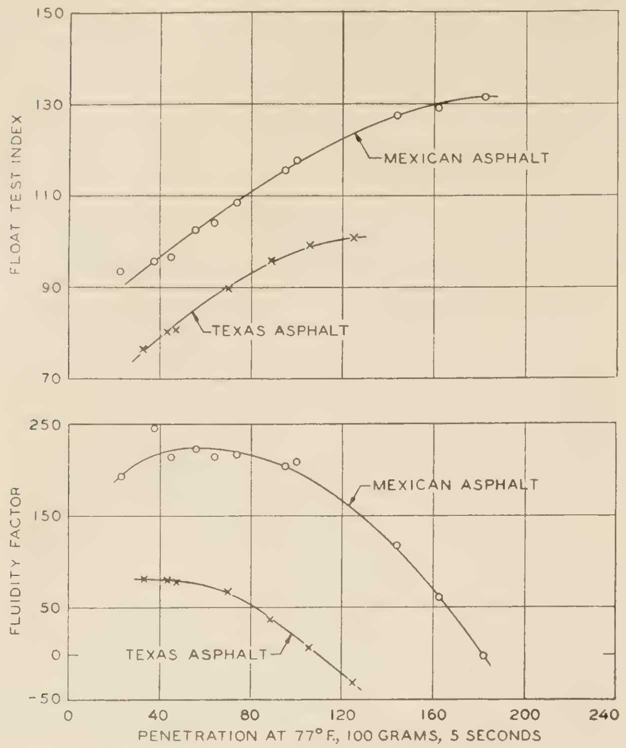

Figure 6.—Relations Between Penetration and Fluidity-Factor and Between Penetration and Float-Test Index of Asphalts of Different Penetrations From the Same Sources.

FLUIDITY FACTOR AND FLOAT TEST REQUIREMENTS HIGHLY RESTRICTIVE

Float test index.—The values for the float test, shown in table 10, were used to determine the float test index of the asphalts of both grades and the results are shown in table 11. The float test index is determined by the following formula:

$$\text{Float test index} = \sqrt{F \times P}$$

where F=Float test at 176° F. (80° C.) in seconds.

P=Penetration at 77° F. (25° C.) 100 grams, 5 seconds.

This index is used, like the fluidity factor, in an attempt to measure the susceptibility of an asphalt to change in temperature. Certain specifications have required that the float test index shall not be less than 90. This requirement applies to asphalts of 40–70 penetration but the indexes for the asphalts of both grades used in this study have been calculated for comparative purposes.

As shown in table 11 there were 24 asphalts of the 50–60 grade that did not meet the float test index requirement of 90 plus. All but 8 of the 24 asphalts were the same as those failing to meet a minimum fluidity factor of 140. Five of the twenty-four failing to pass the float test index requirement, however, did pass the fluidity factor requirement. In contrast to the fluidity factor, which is more restrictive for the softer grades of asphalts, a float test index of 90 is more favorable to the asphalts of higher penetration, since only one 85–100 penetration asphalt failed to meet the requirement. This, however, might be expected since the limit of 90 was specified for asphalts of 40–70 penetration only. This is further indicated by the float test index values for the same series of Mexican and Texas asphalts referred to in the discussion of the fluidity factor. These values are shown also in figure 6. For each series of asphalts, the difference in float test index for materials of 40 penetration and materials of 100 penetration was approximately 20. Although all the Mexican asphalts had float test indexes greater than 90, the grades of Texas asphalts harder than 70 penetration failed to meet this requirement.

The various susceptibility factors, including the penetration index as determined by Pfeiffer and Van Doormal, as given in table 11, except the one involving penetration at 115° F., have been plotted in figures 7 and 8. In these figures, the slope of the log-penetration-temperature curve, which is a true index of susceptibility, has been plotted against the other susceptibility factors. It is apparent from these charts that none of the empirical factors is more than an approximate measure of susceptibility.

While these various susceptibility factors might be used to advantage in controlling the uniformity of supply for particular jobs, a study of table 11 will indicate that they can be used for the identification of sources of the base petroleums. In many cases by special processing, which may be injurious to some asphalts, materials could undoubtedly be produced to meet any of the requirements that have been proposed for these different factors. However, since materials representing the most susceptible asphalts in this investigation have had satisfactory service behavior under climatic conditions as adverse as those to which the less susceptible materials have been exposed, it is felt that a designated limit for a susceptibility factor that restricts the use of such materials is not a rational requirement.

With the few exceptions already mentioned, all of the asphalts had much higher ductilities than were required by the standard specifications. However, the ductility test, as made under normal testing conditions, furnishes little comparative information on the ductile characteristics of different asphalts.

In order to make a more comprehensive study of the ductility test, a special ductility machine was designed and built. The bath has approximately twice the length of the ordinary bath, and the temperature of the bath at both high and low temperatures can be controlled adequately. A wide range in the speed of pull has been provided. In this machine five tests may be made at the same time and ductilities up to 250 centimeters may be measured. The design is such that there is little shock in starting and a uniform speed may be maintained during the test.

DUCTILITIES OF ASPHALTS DETERMINED FOR SEVERAL TEMPERATURES

In making the ductility tests in this investigation, A. S. T. M. Method D113–35 was followed, and the precautions as to time of cooling, and the minimum and maximum times at test temperatures were carefully observed. At test temperatures of 59° F. and higher, it was necessary to control the gravity of the bath within 0.005 of the specific gravity of the asphalt in order to keep the thread of asphalt in a horizontal plane. The lower test temperatures were maintained by ice, and at 32° F. both ice and salt were used. The large capacity of the bath made it possible to control its temperature within ±0.9° F. at the test temperatures of 32°, 39.2°, and 41° F. without disturbing the thread of asphalt by any movement of the ice.

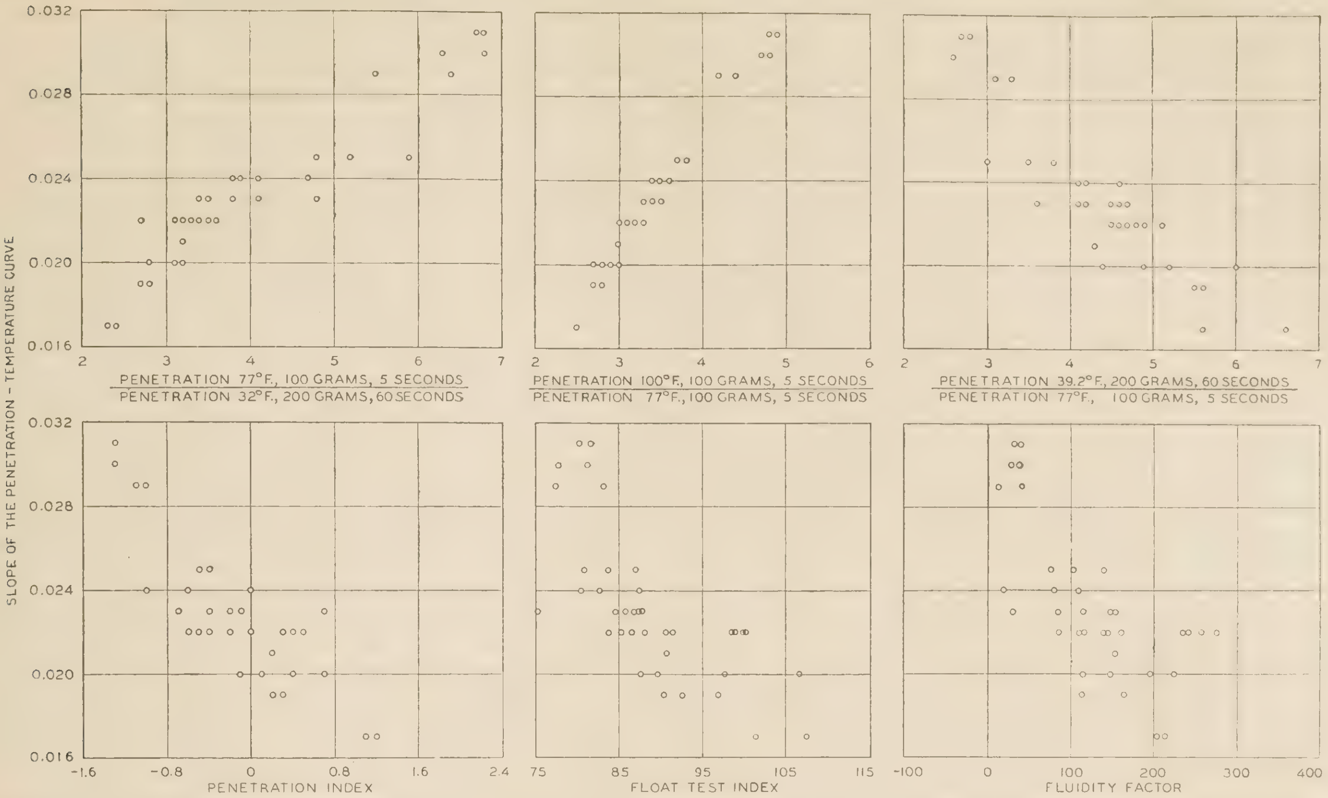

Figure 7.—Comparison of the Slope of the Penetration-Temperature Curves to Various Other Susceptibility Factors for the 50–60 Penetration Asphalts.

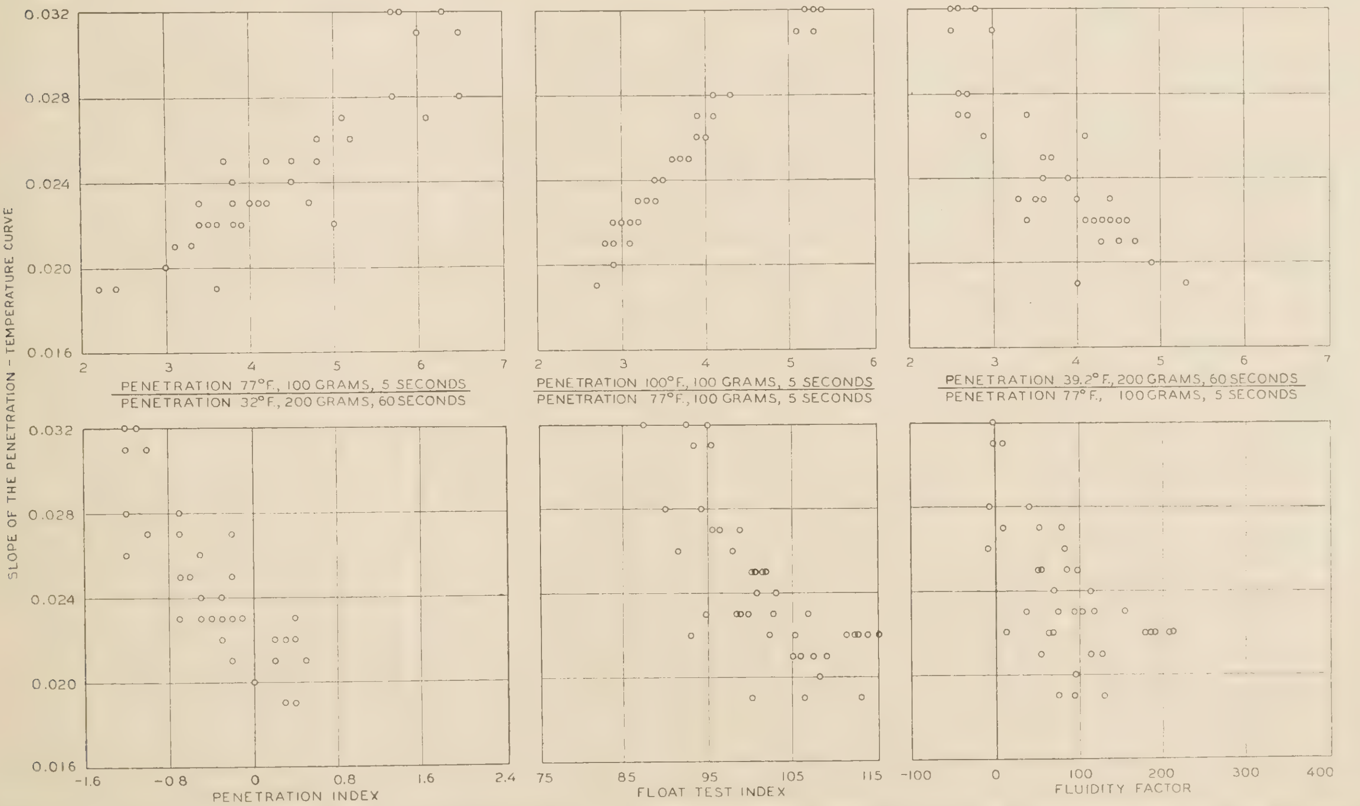

Figure 8.—Comparison of the Slope of the Penetration-Temperature Curves to Various Other Susceptibility Factors for the 85–100 Penetration Asphalts.

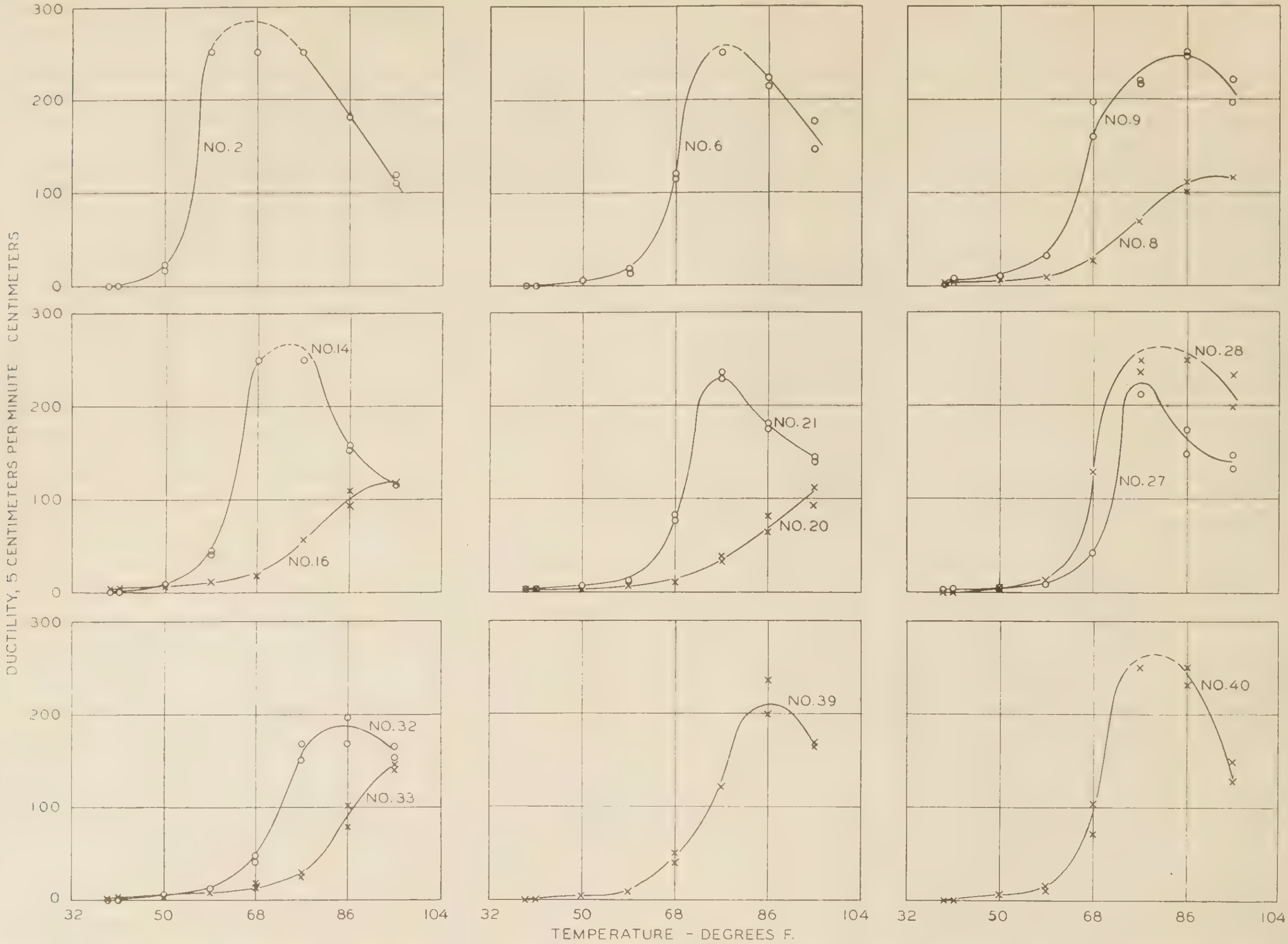

Figure 9.—Relation Between Ductility, at 5 Centimeters per Minute, and Test Temperature of Selected Samples of 50–60 Penetration Asphalts.

From the time that the ductility test was first suggested as a control test for asphalt cements, arguments have been advanced for and against the adequacy and value of the test. Even after requirements for ductility had been generally adopted for specification purposes, the differences of opinion continued and, although a test method was first proposed by the A. S. T. M. in 1921, it was not finally adopted as a standard until 1935.

For many years, the test has been made at 77° F. with a rate of pull of 5 centimeters per minute, although in recent years other temperatures have been used. In this study all the asphalts were tested at a standard temperature of 77° F., and at the low temperatures which have been most frequently proposed, 32° and 39.2° F. At 39.2° F. three rates of pull were used and two rates of pull at 32° F. The results are shown in table 12.

In order to determine the effect of temperature and rate of pull on ductility, 14 materials of the 50–60 grade were selected for special study. These asphalts, where possible, were materials of high and low ductility at 77° F. from each of the sources. The values for the ductility of these selected asphalts are given in table 13, and the data are shown graphically in figures 9 and 10.

Figure 9 shows the effect of temperature on the ductility when the rate of pull is 5 centimeters a minute. Figure 10 shows the same data except that the penetration of the asphalt at the test temperature has been plotted against the ductility of the asphalt at the same temperature.

Figure 9 shows that there is a definite temperature at which all the asphalts had a maximum ductility. Although this is indeterminable for several of the materials because their ductility exceeded 250 centimeters, in general it ranges from approximately 68° F. for sample 2 to over 95° F. for samples 16, 20, and 33. Sample 2 showed the most rapid change in ductility with increase in temperature. This material had no measurable ductility at 41° F., 19 centimeters at 50° F., and 250 centimeters plus at 59° F. At 77° F., it still had a ductility of 250 centimeters plus. The other asphalts, except samples 8, 16, 20, and 33, had a relatively low ductility up to 59° F. and then the ductility increased rapidly between 59° F. and 77° F. Asphalts 8, 16, 20, and 33 had a more gradual increase in ductility with rise in test temperature up to 95° F. With the exception of samples 8, 16, 20, and 33, the curves indicate that at temperatures higher than 95° F. the ductilities of all the asphalts decreased rapidly.

As shown in figure 10, the susceptibility of the individual asphalts to changes in temperature tended to alter somewhat the shape of the curves. It will be seen that sample 2 retained a very high ductility at a penetration much lower than any of the other asphalts. From a penetration of 16 to a penetration of 200 this material had a ductility of more than 100 centimeters. With a decrease in penetration below 16, however, this

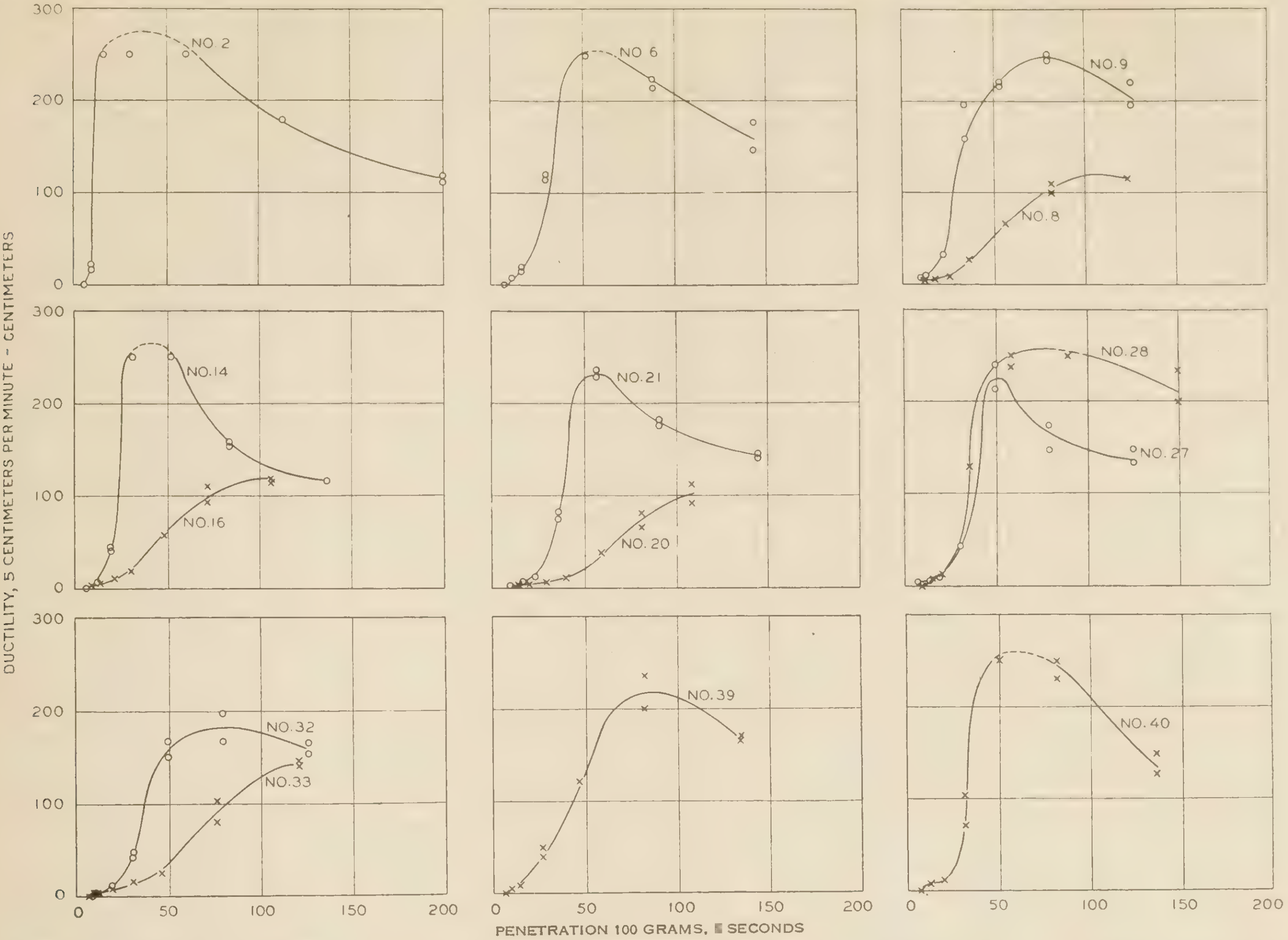

Figure 10.—Relation Between Ductility, at 5 Centimeters per Minute, and Penetration, 100 Grams, 5 Seconds, of Selected Samples of 50–60 Penetration Asphalts, Tested at Various Temperatures.

material showed an abrupt loss in ductility. These curves indicate that while asphalts may have identical ductilities when tested at one consistency, they may differ widely when tested at another consistency. The curves show that both the source and the processing have a pronounced influence on the ductility characteristics of the asphalt.

DUCTILITIES OF ASPHALTS AT LOW TEMPERATURES GREATLY INFLUENCED BY RATE OF PULL

The data shown in table 14 and plotted in figure 11 indicate that the ductility test can be used to identify the source of the base material and the uniformity of the refining process. An entire set of Mexican asphalts, of which the 50–60 and 85–100 penetration asphalts identified as sample 10 were a part, was tested for penetration and ductility at various test temperatures. The penetrations of the asphalts at the temperature of the ductility tests were measured at 59°, 77°, and 95° F., and values at 50°, 68°, and 86° F. were taken from the temperature-penetration curves. The slope of these penetration-temperature curves was the same for all the grades. The data and the curve show that the ductilities of the asphalts in this set were essentially the same when the penetrations of the materials at their respective test temperatures were the same. This figure further shows that ductility is dependent upon the consistency of the material at the test temperature.

In order to determine the effect of the rate of pull on the ductility of asphalts, a study was made of the fourteen 50–60 penetration asphalts previously mentioned. Preliminary tests indicated that a test temperature somewhat lower than 77° F. would provide a much better comparison, and the temperature of 59° F. accordingly was selected. The rates of pull were 10, 7.5, 5, 2.5, and 1 centimeters per minute. The data are given in table 13 and the results obtained on the individual materials are plotted in figure 12. Sample 2 had ductilities greater than 250 centimeters for all rates of pull. Asphalts 8, 16, 20, and 33, all of which had ductilities under 70 centimeters in the standard test at 77° F. showed relatively small increases in ductility as the rate of pull was decreased. All of the other samples had appreciably higher ductilities at rates of pull of 2.5 and 1 centimeters. Sample 14 showed the greatest increase in ductility at 5 centimeters over that at 10 centimeters, and at a rate of 2.5 centimeters this material had the highest ductility of all samples except sample 2.

The tests made on these asphalts, to show the effect of temperature and rate of pull on their ductility, indicate that there were inherent differences in these materials that were not made evident by the routine tests for ductility. Whether the ductility tests made under various temperature conditions and at different rates of pull are of any practical significance it is impos-

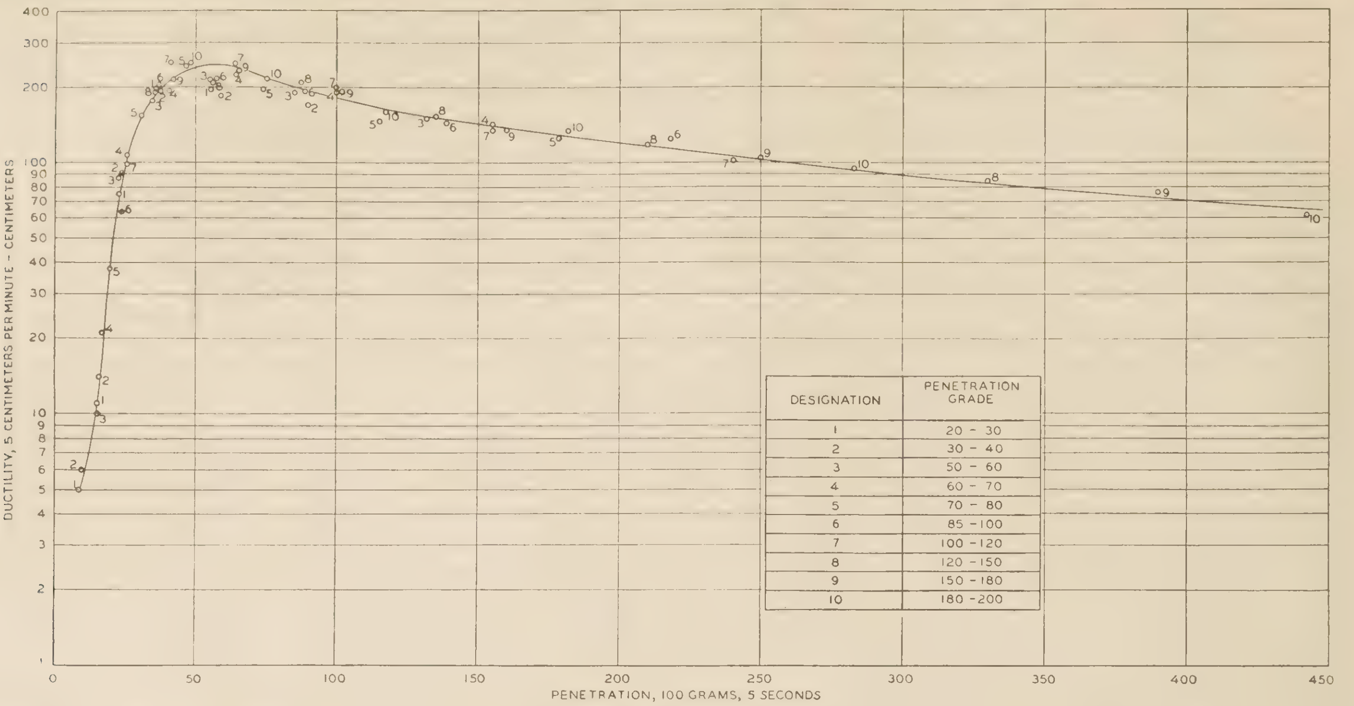

FIGURE 11.—RELATION BETWEEN PENETRATION AND DUCTILITY OF VARIOUS GRADES OF MEXICAN ASPHALT TESTED AT VARIOUS TEMPERATURES.

TABLE 12.—*Ductility and toughness tests on the 50–60 and 85–100 penetration asphalts*

Identification No.	Ductility												Toughness test at 32° F.	
	50–60 grade						85–100 grade							
	At 77° F.	At 39.2° F.			At 32° F.		At 77° F.	At 39.2° F.			At 32° F.		50–60 grade	85–100 grade
	5 cm. per minute	5 cm. per minute	1 cm. per minute	¼ cm. per minute	1 cm. per minute	¼ cm. per minute	5 cm. per minute	5 cm. per minute	1 cm. per minute	¼ cm. per minute	1 cm. per minute	¼ cm. per minute		
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1	250+	[1] 0	8.3	160+	[1] 0	[1] 0.3	223	[1] 0	160.0	250+	[1] 0.3	250+	5.0	10.0
2	250+	[1] 0	7.5	160+	[1] 0	[1].3	193	[1] 0	188.0	250+	[1].3	250+	5.0	12.5
3	250+	[1] 0	8.5	160+	[1] 0	[1] 0	204	[1] 0	170.0	250+	[1].8	250+	5.0	12.5
4	250+	[1] 0	9.5	160+	[1] 0	[1] 0	227	[1] 0	130.0	250+	[1].3	220.0	7.5	12.5
5	250+	[1] 0	[1] 0	26.0	[1] 0	[1] 0	197	[1] 0	15.5	215.0	[1].3	8.5	7.5	12.5
6	250+	[1] 0	4.8	8.5	[2].5	4.4	185	5.5	13.3	32.0	5.0	10.8	10.0	7.5
7	197	[1] 1.0	7.9	27.5	4.9	7.1	220	9.7	47.5	100.0	9.5	24.5	15.0	22.5
8	68	3.5	4.4	6.5	2.8	3.3	102	4.5	7.8	10.0	4.5	6.0	15.0	35.0
9	218	[1] 1.0	6.5	14.5	4.0	6.5	230	9.0	35.0	123.0	8.5	32.0	12.5	20.0
10	215	[1] 1.0	6.9	18.8	4.5	6.5	192	7.2	37.0	79.0	9.0	22.8	12.5	12.5
11	180	[1].5	5.9	10.5	3.5	4.8	209	9.0	20.8	76.0	7.5	17.0	10.0	20.0
12	250+	[1].5	6.3	16.0	3.0	6.8	242	8.0	56.0	102.0	9.5	36.0	10.0	12.5
13	140	3.7	4.9	6.5	3.3	4.8	192	6.5	15.8	22.0	7.0	13.8	20.0	20.0
14	250+	[1] 0	5.5	11.5	[2].3	4.8	192	5.2	20.3	87.0	6.0	14.0	10.0	10.0
15	181	[2] 1.0	5.6	10.5	3.8	5.0	187	6.0	19.5	95.0	6.3	18.0	12.5	10.0
16	57	3.7	4.5	6.8	[2] 2.5	4.3	107	7.0	14.8	23.0	6.8	13.3	12.5	15.0
17	250+	[1].5	5.9	10.0	[2] 1.0	5.5	191	6.0	29.3	119.0	7.3	22.0	10.0	12.5
18	250+	4.0	5.5	10.0	3.9	5.3	196	6.0	15.3	47.0	6.5	9.8	10.0	12.5
19	220	[1] 0	4.8	8.8	[2].5	[1].3	179	5.2	11.0	33.5	5.0	8.5	10.0	7.5
20	36	3.6	4.0	5.0	3.1	3.9	139	5.0	7.0	10.0	5.0	6.0	22.5	17.5
21	232	3.8	4.9	7.5	4.0	4.5	178	5.2	12.8	20.5	5.3	10.8	7.5	12.5
22	96	3.7	4.8	6.8	3.8	4.5	211	5.5	13.3	26.8	6.3	12.5	20.0	15.0
23	202	[1] 0	3.1	5.0	[2].5	[2].5	223	[1].8	7.8	12.8	4.0	6.3	10.0	10.0
24	84	2.8	4.1	5.3	[2] 2.0	3.4	162	----------	5.3	7.8	3.8	4.5	7.5	10.0
25	116	3.3	5.3	8.5	3.5	4.3	152	5.3	10.5	18.5	5.0	8.3	7.5	7.5
26	78	3.2	4.3	6.3	3.3	3.9	172	4.6	10.0	12.8	4.5	7.8	12.5	10.0
27	226	3.8	4.5	6.5	[2].8	4.0	164	[2] 1.0	12.8	29.0	4.8	9.5	12.5	10.0
28	244	[1] 0	4.8	7.5	[2].8	[2] 2.9	184	[2] 1.0	18.0	25.5	5.0	11.3	10.0	5.0
29	----------	----------	----------	----------	----------	----------	200	[1].2	9.5	17.3	4.0	6.3	----------	5.0
30	170	[1] 0	4.3	6.3	3.0	3.8	163	5.0	8.3	15.5	4.8	7.0	15.0	10.0
31	41	3.2	4.0	5.8	[1].3	4.5	101	5.4	7.5	10.3	4.8	7.0	20.0	15.0
32	168	[2].8	4.3	6.3	[2] 1.3	3.4	173	4.0	7.8	11.8	4.0	6.5	10.0	10.0
33	27	[1].8	2.6	4.8	[2].3	[2] 1.0	125	3.5	5.8	7.5	3.5	5.3	10.0	10.0
34	112	[1] 0	4.5	7.0	3.4	4.0	170	5.0	11.3	20.8	5.5	7.8	20.0	10.0
35	219	4.1	5.3	8.8	3.8	4.6	186	4.5	10.8	19.8	6.0	9.8	15.0	12.5
36	190	3.7	5.3	7.8	3.8	4.5	115	4.3	6.5	7.0	4.5	5.0	15.0	10.0
37	137	3.7	5.0	7.3	3.3	4.3	193	5.8	9.8	16.0	5.5	9.0	10.0	20.0
38	120	4.0	5.1	7.3	4.0	5.1	120	5.7	9.0	11.3	5.5	8.3	15.0	22.5
39	121	[1] 0	[2] 1.5	[2] 2.0	[1] 0	[1] 0	141	[1] 0	7.0	13.5	[2].3	5.8	5.0	10.0
40	250+	[1] 0	4.5	9.5	[1].5	[1] 2.0	250+	[1] 0	14.0	28.0	6.5	15.5	10.0	15.0

[1] Test specimen broke at shoulder of mold.

[2] Test specimen broke at smallest cross section.

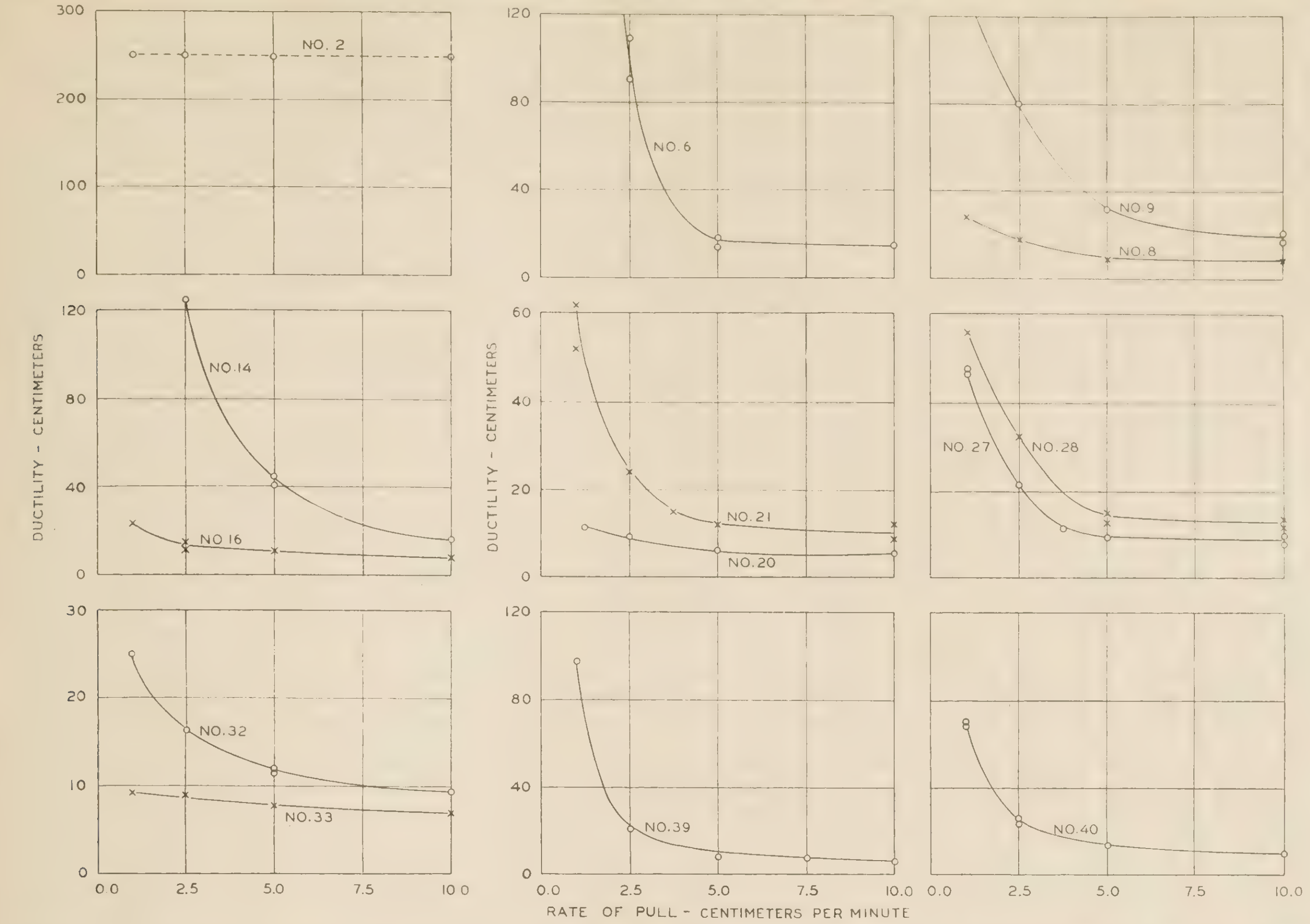

FIGURE 12.—RELATION BETWEEN DUCTILITY AND RATE OF PULL OF SELECTED SAMPLES OF 50–60 PENETRATION ASPHALTS TESTED AT 59° F. (15° C.)

TABLE 13.—*The effect of varying the temperature of test and the rate of pull on the ductility of selected samples of 50–60 penetration asphalt*

Sample No.	Ductility, 5 cm. per minute [1]								Ductility at 59° F.[1]			
	At 39.2° F.	At 41° F.	At 50° F.	At 59° F.	At 68° F.	At 77° F.	At 86° F.	At 95° F.	10 cm. per minute	5 cm. per minute	2.5 cm. per minute	1 cm. per minute
	Cm.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
2	0	0	19.0	250+	250+	250+	180	114	250+	250+	250+	250+
6	0	0	6.4	16.0	118	250+	219	161	15.0	16.0	100.0	250+
8	3.5	4.3	5.8	9.3	27	68	106	115	8.5	9.3	18.0	28.0
9	0	5.3	7.8	32.0	178	218	248	208	19.0	32.0	80.0	136.0
14	0	0	7.5	43.0	250+	250+	155	115	17.3	43.0	125.0	200+
16	3.7	4.5	6.5	11.0	20	57	102	117	8.5	11.0	14.0	23.3
20	3.6	4.0	4.5	6.5	11	36	73	102	5.8	6.5	9.5	11.5
21	3.8	4.0	6.0	12.3	79	232	178	143	10.8	12.3	24.0	57.0
27	3.8	3.8	5.7	9.7	43	226	162	141	9.5	9.7	21.5	48.0
28	0	0	6.3	14.0	130	244	250+	217	13.4	14.0	32.0	56.0
32	0	0	5.0	11.8	45	159	183	159	9.5	11.8	16.5	25.0
33	0	3.0	4.0	7.8	16	27	90	143	7.0	7.8	9.0	9.3
39	0	0	4.0	8.3	45	121	218	168	7.0	8.3	21.5	98.0
40	0	0	6.0	15.0	88	250+	240	138	10.5	15.0	25.5	70.0

[1] Results are averages of 2 or more tests.

TABLE 14.—*The ductility-penetration relationships of various grades of Mexican asphalt under variable temperature test conditions*

Penetration grade	Temperature of test											
	50° F.		59° F.		68° F.		77° F.		86° F.		95° F.	
	Penetration [1]	Ductility	Penetration	Ductility	Penetration [1]	Ductility	Penetration	Ductility	Penetration [1]	Ductility	Penetration	Ductility
		Cm.		*Cm.*		*Cm.*		*Cm.*		*Cm.*		*Cm.*
20–30	6	0	9	5	15	11	23	75	36	195	55	192
30–40	10	6	16	14	24	91	38	194	59	185	90	170
50–60	15	10	23	87	35	178	55	215	85	190	132	150
60–70	17	21	26	107	41	194	64	225	100	193	155	142
70–80	20	38	31	154	47	245	74	197	115	147	179	126
85–100	24	64	37	205	57	218	89	192	139	145	218	126
100–120	26	99	41	250+	64	250+	100	197	155	134	240	101
120–150	36	193	56	210	87	210	135	153	210	119	330	85
150–180	42	215	65	233	102	192	160	135	250	104	390	76
180–200	48	250+	75	217	117	160	182	134	283	95	442	62

[1] Penetrations taken from log-penetration-temperature curves.

sible to say, but the data and graphs indicate that the test as made under the usual standard conditions is not a good index of the ductile properties of the individual asphalts.

In 1927, W. F. Smith,[6] of the Oklahoma State Highway Commission, proposed that the ductility test be made on filler-grade asphalts to eliminate materials that were extremely brittle at low temperatures. He suggested that the test be made at a rate of pull of 5 centimeters per minute at a temperature of 32° F. Under these conditions, however, many of the test specimens were broken at the start of the test. For

---

[6] Low Temperature Ductility of Filler Grade Asphalts. A. S. T. M. Proceedings, vol. 27, pt. II. 1927.

many years the California Division of Highways specified a ductility test on 95+ road oil to be made at 34°–35° F. and at a rate of pull of 5 centimeters per minute. No difficulty in testing was experienced with this type of material since it was relatively soft at the test temperature. Tests at 34°–35° F. and at the rate of 5 centimeters a minute were made for many years on asphaltic residues of 80 and 100 penetration, but slightly lower penetrations of the residues at 77° F. often resulted in the breaking rather than in the elongation of the specimens.

In more recent years, the rate of pull of 5 centimeters per minute and temperature of test of 32° F. have been suggested for testing asphalt cements, but the failure of such a large number of materials to pull without snapping has resulted in increasing the temperature slightly, in decreasing the rate of pull, and in some cases doing both. The decrease in the rate of pull is intended to reduce the initial shock to which the specimens are subjected when the test is started.

Tests made at 39.2° F., 5 centimeters a minute, to meet the specification limit for ductility of one-tenth the penetration minus 1 or one-tenth the penetration have been criticised by W. H. Flood[7] because of the small range in values obtained, the assumed relationship between ductility and penetration, and the difficulty of maintaining a constant temperature during the test. He has suggested that a ductility test at 60° F. at a rate of pull of 5 centimeters a minute would be preferable to the low temperature test or to the normal test at 77° F. which, in most cases, gives high ductilities of little values for comparative purposes. However, the data given in table 13, and shown in figures 9 and 10, indicate that there would be considerable difficulty in designating an intermediate temperature and specifying test limits that would be adequate for evaluating the essential characteristics of asphalts intended for various uses.

Ductility at low temperatures.—All of the asphalts were tested for ductility at 39.2° F. with rates of pull of 5, 1, and ¼ centimeter per minute. Tests were also made at 32° F. with rates of pull of 1, and ¼ centimeter per minute. The results of these tests are given in table 12.

As can be seen from this table, a ductility requirement at 39.2° F., 5 centimeters per minute, of one-tenth the penetration is highly restrictive. None of the asphalts of the 50–60 grade and only one of the 85–100 penetration grade would meet this requirement. A requirement of one-tenth the penetration minus 1 would permit only three of the 85–100 penetration materials to pass and none of the 50–60 asphalts.

Although a speed of 1 centimeter per minute has had little use as a specification requirement for ductility tests made at 39.2° F. or 32° F., the ductility of both grades of asphalt at this rate of pull and at these two temperatures are reported for comparative purposes. At 32° F. and a speed of 1 centimeter per minute, a requirement of one-tenth the penetration at 77° F. would eliminate all asphalts of both grades and a requirement of one-tenth the penetration minus 1 would eliminate all but one 50–60 and three 85–100 penetration asphalts. At 39.2° F. and a speed of 1 centimeter per minute, a requirement of one-tenth the penetration at 77° F. would eliminate 26 of the 50–60 and 11 of the 85–100 grades, and for a requirement of one-tenth the penetration minus 1, nine 50–60 and eight 85–100 asphalts would fail.

DUCTILITIES DEPENDENT ON BASE PETROLEUM AND PROCESSING

A rate of pull of ¼ centimeter per minute has been used at temperatures of both 32° and 39.2° F. Requirements of one-tenth the penetration at 77° F., and one-tenth the penetration minus 1 have been used where 32° F. has been designated as the test temperature. For the test temperature of 39.2° F. a ductility requirement of one-tenth the penetration at 77° F. has been used.

Of the 50–60 penetration asphalts tested at 39.2° F., ¼ centimeter per minute, there were five that failed to meet the requirement of one-tenth the penetration at 77° F. Four of these were within 1 centimeter of the required ductility. The ductility of sample 39 was 2.7 centimeters below its required minimum. Of the 85–100 penetration asphalts, there were three materials that failed to meet this requirement. These were samples 24, 33, and 36 which were 1.6, 0.8, and 2.2 centimeters, respectively, below the calculated minimum requirements.

When the ductility is determined at 32° F., ¼ centimeter per minute, a specification requirement of either one-tenth the penetration at 77° F. or one-tenth the penetration at 77° F. minus 1 becomes highly restrictive. With a decrease of only 7.2° F. in test temperature from 39.2° to 32° F., 33 asphalts of the 50–60 grade failed to meet a requirement of one-tenth the penetration as compared to only 5 that failed when tested at 39.2° F. With the test temperature at 32° F., 22 failed to meet the requirement of one-tenth the penetration minus 1. This lower test temperature would cause the rejection of the California asphalts which showed unusually high ductility at 39.2° F. as well as a majority of the mid-continent asphalts which were slightly above the minimum test requirement for ductility at this rate of pull at the slightly higher temperature.

Of the 85–100 penetration asphalts, 18 would fail to meet a requirement of one-tenth the penetration as compared to only 3 that failed when tested at 39.2° F. For this grade, 14 materials failed to meet the requirement of one-tenth the penetration minus 1. Seventeen of the 18 asphalts of the 85–100 grade that failed to have a ductility equal to one-tenth the penetration were from the same source as the 50–60 asphalts that would not meet a similar requirement. Ten of the fourteen materials of the 85–100 grade that failed to meet a requirement of one-tenth the penetration minus 1 were also from the same source as the 50–60 asphalts failing to meet a similar requirement.

One of the most interesting points in this ductility study is the behavior of four of the five California products, samples 1, 2, 3, and 4. The samples of the 85–100 grade had extremely high ductilities at 39.2° and 32° F. at a rate of pull of ¼ centimeter per minute, and at 39.2° F. when pulled at 1 centimeter a minute. At 32° F., 1 centimeter per minute, the materials would not elongate. The 50–60 grades of the California materials had slightly higher values than any of the other samples when pulled at 1 centimeter per minute at 39.2° F., and they were many times more ductile when pulled at ¼ centimeter a minute. At 32° F., they broke when pulled at a speed of ¼ or 1 centimeter per minute. Both grades of sample 5, which had a ductility at 77° F. approximately the same as the other four California

---

[7] Ductility at Low Temperatures. Proceedings of the Association of Asphalt Paving Technologists. January 1935.

asphalts, showed a decidedly different behavior than the others when tested at ¼ and 1 centimeter a minute at 39.2° F., and the 85–100 sample showed a difference when tested at ¼ centimeter a minute at 32° F.

In these low-temperature tests there is apparently no relation between the ductility, the temperature, or the rate of pull that is common to all the asphalts or to the asphalts from a particular source. The characteristics shown by these ductility tests are probably due to the properties of the base petroleum and processing of the particular asphalts.

TOUGHNESS TEST USED TO MEASURE BRITTLENESS AT LOW TEMPERATURE

Toughness Test.—The toughness test for asphalt cements was first used by the New York Department of Public Works in 1911 as a specification requirement for the control of asphalts for asphalt-bound macadam.[8] The 1932 specifications of the department contained a clause that required 50–65 and 85–100 penetration asphalts to have a minimum toughness of 10 and 100–110 penetration asphalt to have a minimum toughness of 15. The test is now made on a cylinder of asphalt 1¾ inches in diameter and 1¾ inches high. The test procedure is as follows:

The material to be tested is melted at the lowest possible temperature and poured into a specially constructed split mold which has previously been amalgamated. The filled mold is allowed to cool to room temperature and then chilled to 32° F. (0° C.). The excess material is then cut from the top by a heated knife and the specimens removed from the mold. These are then maintained at 32° F. (0° C.) for 1 hour before testing.

The specimens are tested in a Page impact machine, which is the same as used in the Standard Method of Testing for Toughness of Rock, A. S. T. M. Specification D 3–18. A special bath is so constructed that it rests flat on the anvil of the Page impact machine and is braced by three legs that rest upon the base. The bath is of such depth that when filled with ice and water the specimen is completely covered, assuring a temperature of 32° F. (0° C.) during the test. A patch of paper approximately 1 inch square is placed between the plunger of the impact machine and the cylinder of asphalt being tested. In testing bituminous materials the 2-kilogram hammer is allowed to drop 5 centimeters onto the intervening plunger for the first blow and the drop is then increased 5 centimeters for each succeeding blow until rupture of the specimen occurs. The height from which the hammer falls when rupture occurs is the numerical value for the toughness of the material under test.

The toughness test values of the 50–60 and 85–100 penetration asphalts are given in table 12. The results shown are the average values for two tests. These values ranged from 5 to 22.5 with an average of 11.7 for the 50–60 grade and from 5 to 35 with an average of 13.1 for the 85–100 grade. Based on the minimum requirement of 10 as used in the New York State specification, there were 9 samples of the 50–60 and 5 samples of the 85–100 penetration asphalt that would not pass the test. A comparison of the results for the two penetration grades shows that 13 asphalts of the 85–100 grade had lower and 19 had higher values for toughness than asphalts from the same source in the 50–60 grade. The test was devised to identify and restrict the use of the type of asphalts that are brittle at low temperature. It may be noted that asphalts of the same consistency at the test temperature of 32° F., as measured by the penetration test, vary greatly in toughness.

In table 15, the results of tests that are essentially identification tests of source or processing are given for both grades of asphalts. Tests for solubility in 86° B. naphtha, the solubility in ethyl ether, and the fixed carbon content, while not in general use, are still required by a few specifications. The determination of the percentage of sulphur has been included in some specifications to control more definitely the source of the base petroleum. The Oliensis spot test has been used to indicate the presence of cracked materials, and the film test has been proposed as an accelerated test of the weather-resistant property of asphaltic materials. A brief discussion of these tests will be made and the effect of the proposed requirements on the rejection or acceptance of the asphalts in both grades will be noted.

SPECIAL TESTS USED TO IDENTIFY SOURCE OR PROCESSING

Solubility in 86° B. naphtha.—Many of the specifications of earlier years contained clauses limiting the percentage of bitumen insoluble in 86° B. naphtha, and the fixed carbon in asphaltic materials. These constituents are dependent on both the base petroleum and the processing. While they may have value as identification tests and in controlling uniformity of supply, the much greater number of base petroleums now in use, together with the present wide variation in refining processes, have somewhat impaired their usefulness for these purposes.

Only one State specification for 50–60 asphalt carries a requirement for the percentage of bitumen insoluble in 86° B. naphtha. The limits set by this State of 15 to 29 percent would cause the rejection of the five California asphalts that were low in asphaltenes, and five other materials that had values over the maximum limit. For the 85–100 penetration grade, the same limits would also reject the five California asphalts, the Colombian asphalt, and two mid-continent asphalts that had similar characteristics. These eight 85–100 materials had a low percentage of asphaltenes.

Fixed carbon.—Only one State has employed the fixed carbon test for the purpose of controlling asphalt cements. The requirement stipulated that the bitumen should show between 8 and 17 percent fixed carbon. Four of the five California asphalts of both grades had less than 8 percent fixed carbon and were the only materials failing to meet this specification. For asphalts from the same source, the percentage of asphaltenes tended to increase as the percentage of fixed carbon increased. As indicated by figure 13, however, there was no definite relationship between the fixed carbon and the organic matter insoluble in 86° B. naphtha for these materials as a group.

Solubility in ethyl ether.—One of the reasons for the discontinuance of the test for solubility in 86° B. naphtha was the inability to obtain a uniform supply of the naphtha. One State has substituted ethyl ether which is a definite chemical compound having uniform and unchanging properties. The requirement of this specification for solubility in ethyl ether limits the percentage of insoluble matter to a maximum of 25 percent. Table 15 shows that all of the asphalts in this study had less than 25 percent insoluble matter.

---

[8] Method of Determining the Toughness of Bituminous Materials. J. E. Meyers, Engineering Record, vol. 67, No. 3, January 18, 1913.

TABLE 15.—*Chemical and special tests on the 50–60 and 85–100 penetration asphalts*

Identification No.	50–60 penetration asphalts										85–100 penetration asphalts									
					Oliensis test			Film test							Oliensis test			Film test	
	Organic matter insoluble in ethyl ether	Organic matter insoluble in 86° B. naphtha	Fixed carbon	Sulphur	Character of spot	Gilsonite equivalent	Xylene equivalent	Condition after 5 hours at 325° F.	Condition after 24 hours at 325° F.	Organic matter insoluble in ethyl ether	Organic matter insoluble in 86° B. naphtha	Fixed carbon	Sulphur	Character of spot	Gilsonite equivalent	Xylene equivalent	Condition after 5 hours at 325° F.	Condition after 24 hours at 325° F.
	Pct.	*Pct.*	*Pct.*	*Pct.*						*Pct.*	*Pct.*	*Pct.*	*Pct.*					
1	3.3	10.7	7.4	1.04	Negative			Clear	Clear	3.0	10.5	7.0	0.91	Negative			Clear	Clear.
2	5.5	10.6	7.4	1.30	do			do	do	3.9	10.1	7.3	1.27	do			do	Do.
3	4.3	10.0	6.9	1.25	do			do	do	3.8	9.9	6.8	1.29	do			do	Do.
4	4.3	11.8	6.5	1.38	do			do	do	4.4	11.5	6.6	1.22	do			do	Do.
5	5.6	12.6	8.9	1.03	do			do	do	6.5	14.7	9.0	2.14	Positive	0–1	0–2	do	Do.
6	11.3	18.1	12.4	1.64	do			do	do	9.4	14.3	11.6	1.48	Negative			do	Do.
7	23.9	28.2	11.3	5.96	do			do	do	20.7	26.4	11.4	5.32	do			do	Do.
8	23.4	30.9	14.8	5.24	Positive	50–60	20–24	do	do	21.8	28.0	14.9	4.79	Positive	50–60	24–28	do	Do.
9	22.3	29.3	13.9	6.20	Negative			do	do	20.2	26.2	13.6	5.65	Negative			do	Do.
10	21.8	28.8	11.7	6.00	do			do	do	20.9	26.4	11.9	5.71	do			do	Do.
11	22.7	28.1	11.3	5.87	do			do	do	20.2	26.4	11.5	5.71	do			do	Do.
12	22.0	28.0	13.1	6.09	do			do	do	19.6	25.5	12.3	5.36	do			do	Do.
13	20.4	27.5	16.0	3.14	Positive	60–70	28–32	do	do	17.4	23.1	14.2	2.93	Positive	5–8	2–4	do	Do.
14	15.6	21.7	13.0	3.21	Negative			do	do	14.4	20.4	12.3	2.95	Negative			do	Do.
15	17.8	24.8	14.9	3.27	Positive	40–50	24–28	do	do	15.2	21.7	13.2	3.27	Positive	5–10	2–4	do	Do.
16	19.0	25.6	14.6	3.24	do	40–50	28–32	do	do	15.9	22.0	13.3	2.91	do	5–10	2–4	do	Do.
17	15.7	22.9	13.0	3.21	Negative			do	do	14.1	18.0	11.6	2.72	Negative			do	Do.
18	18.5	24.8	13.8	3.94	do			do	do	18.9	24.6	13.0	4.93	do			do	Do.
19	14.3	19.7	14.7	3.81	do			do	do	13.2	19.0	13.5	3.43	Positive	0–1	0–2	do	Do.
20	20.9	30.8	13.4	3.46	do			do	do	18.9	25.4	12.5	3.30	Negative			do	Do.
21	16.7	24.2	13.9	3.66	do			do	do	14.2	20.2	13.7	3.46	do			do	Do.
22	19.5	27.9	14.1	3.20	do			do	do	16.0	21.4	13.3	3.25	do			do	Do.
23	11.6	21.6	12.8	.84	Positive	60–70	84–88	Coagulated	Coagulated	9.4	15.9	11.7	.98	Positive	30–35	44–48	Coagulated	Coagulated.
24	13.0	20.4	11.9	1.06	Negative			Clear	Clear	10.3	16.6	10.9	1.04	Negative			Clear	Clear.
25	11.0	17.3	11.0	1.07	do			do	do	8.7	12.7	10.4	1.13	do			do	Do.
26	15.3	25.4	12.3	1.04	Positive	30–40	16–20	do	do	11.6	18.2	11.2	.89	Positive	2–4	2–4	do	Do.
27	11.6	19.3	12.3	1.10	Negative			do	do	7.7	13.2	10.7	.95	Negative			do	Do.
28	12.9	23.0	12.2	.95	Positive	40–50	32–36	do	do	8.3	15.1	11.4	.87	Positive	5–10	4–8	do	Do.
29										9.9	18.5	12.9	1.53	do	60–80	[1] 56–60	Coagulated	Coagulated.
30	15.7	23.3	12.6	.72	Negative			Clear	Clear	11.9	18.3	12.2	.54	Negative			Clear	Clear.
31	24.2	30.2	13.6	3.93	do			do	do	21.5	27.7	13.2	3.34	do			do	Do.
32	15.1	21.4	15.4	.86	do			do	do	13.8	18.9	14.3	.88	do			do	Do.
33	15.5	24.5	16.3	.74	Positive	70–80	[1] 60–64	Coagulated	Coagulated	14.4	22.5	14.9	.80	Positive	80–90	[1] 60–64	Coagulated	Coagulated.
34	20.5	28.5	16.6	3.97	do	50–60	28–32	Clear	Clear	17.0	26.3	15.8	3.81	do	15–25	12–16	Clear	Clear.
35	9.5	19.1	10.8	2.64	Negative			do	do	10.3	18.7	9.6	2.41	Negative			do	Do.
36	11.1	20.9	10.8	2.52	Positive	0.5	0–4	do	do	14.1	21.2	12.6	.94	Positive	0–2	0–2	do	Do.
37	19.3	27.0	11.3	3.18	do	0–5	0–4	do	do	16.0	24.7	10.7	2.83	Negative			do	Do.
38	18.5	25.7	11.8	2.08	do	0–5	0–4	do	do	15.9	23.6	10.9	1.69	do			do	Do.
39	12.1	23.0	14.3	3.55	do	60–70	24–28	do	do	10.7	19.9	12.8	3.31	Positive	35–40	16–20	do	Do.
40	18.6	31.9	15.0	.44	do	90+	80–84	do	Coagulated	16.5	25.8	14.5	.47	do	90+	80–84	do	Coagulated.

[1] Maximum value same as spot with 100 percent xylene.

Figure 14 indicates an approximately straight line relationship between the percentage of organic matter insoluble in ether and the percentage of organic matter insoluble in 86° B. naphtha for both grades of asphalt.

Sulphur content.—Although a number of specifications have carried a requirement that the sulphur content of asphalt cements should be more than 3 percent, no logical reason has been advanced for such a provision. Victor Nicholson [9] stated that in 1915 the Bureau of Streets of Chicago found it was possible to obtain inferior pavements with some asphalts meeting the specifications of the American Association for the Standardization of Paving Specifications. He added that the shortcomings in these specifications were overcome by altering several clauses and by the insertion of a requirement that the sulphur content should be not less than 3 percent.

In his discussion of the sulphur requirement, no direct evidence was offered by Nicholson to show the superiority of pavements containing asphalts of high sulphur content. He did attempt, however, to correlate the sulphur content with other physical properties of the materials. He concluded that the sulphur content has considerable influence on the viscosity of the asphalts as indicated by the values of the fluidity factor and float test. He stated that the consistency, as represented by the fluidity factor, did not vary directly with the sulphur content, but that asphalts having over 3 percent sulphur had fluidity factors over 130.

The fluidity factor can be altered to a considerable extent by blowing and blending, and the observations of Nicholson are only partially corroborated by the sulphur determinations made on the asphalts of this investigation, the data for which are shown in table 15.

Nineteen materials of the 50–60 grade had sulphur contents of less than 3 percent, and 5 of these had fluidity factors of more than 130. Twenty materials had more than 3 percent sulphur and 7 of these had fluidity factors of less than 130. In the 85–100 penetration grade, 25 of the materials had sulphur contents lower than 3 percent, and in no case was the fluidity factor over 130. Nine of the 15 asphalts having more than 3 percent sulphur had fluidity factors less than 130.

In 29 cases, the asphalts of the 50–60 grade had higher percentages of sulphur than the corresponding asphalts of the 85–100 grade. The 85–100 grade of samples 5 and 18 were the only materials that had appreciably higher sulphur contents than the 50–60 asphalts from the same source. Both grades of sample 35 and the 50–60 grade of sample 36, had essentially the same sulphur content, yet the 85–100 grade of sample 36 had a decidedly lower sulphur content. These asphalts were from the same producer, who used crude petroleum from several sources; and the sulphur contents, as well as the other test data, indicate that the two grades of sample 36 were refined from different base petroleums.

Nineteen of the 50–60 asphalts and 25 of the 85–100

---

[9] The Sulphur Requirement, Proceedings of Association of Asphalt Paving Technologists. January 1935.

FIGURE 13.—RELATION BETWEEN FIXED CARBON AND ORGANIC MATTER INSOLUBLE IN 86° B. NAPHTHA OF THE 50–60 AND 85–100 PENETRATION ASPHALTS.

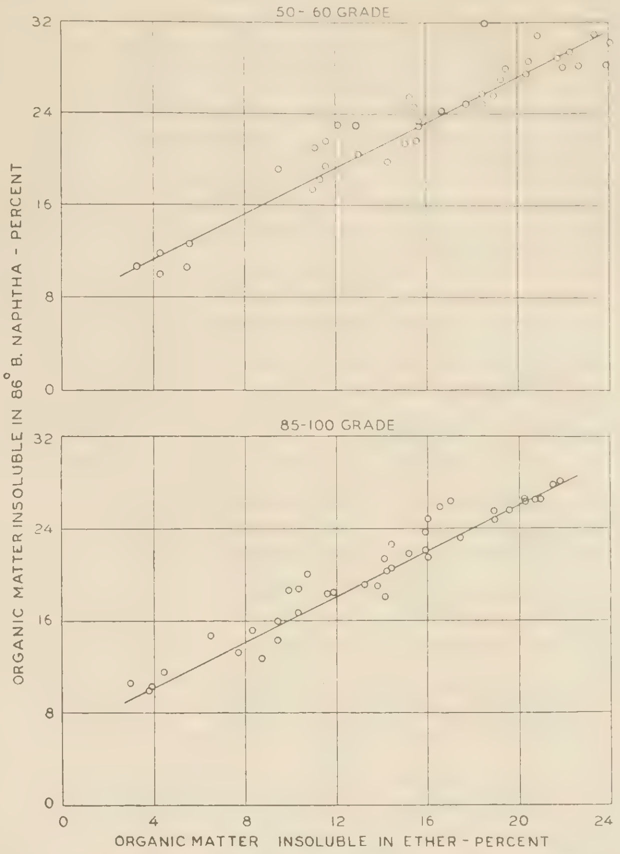

FIGURE 14.—RELATION BETWEEN ORGANIC MATTER INSOLUBLE IN ETHER AND ORGANIC MATTER INSOLUBLE IN 86° B. NAPHTHA OF THE 50–60 AND 85–100 PENETRATION ASPHALTS.

penetration asphalts would fail to meet a specification requirement of 3 percent or more. Although there are California asphalts of high sulphur contents, those represented in this study would not meet this requirement. Many mid-continent products would also be rejected. While it is generally considered that the sulphur requirement was introduced in specifications to insure the use of Mexican asphalts, a minimum limit of 3 percent will permit the use of asphalts refined from Venezuelan, Arkansas, Texas, and Wyoming petroleums. However, as shown in figure 15, a sulphur requirement is essentially an identification test of source.

SEVEN OF THE ASPHALTS HAD XYLENE EQUIVALENTS OVER 40

Reaction to Oliensis test.—The Oliensis spot test [10] has been used for several years as a means for determining if asphaltic materials have been overheated or cracked during the refining process. As initially proposed, the test served only as a means to identify overheated or cracked materials. In 1936,[11] the test was improved so that, within certain limits, a quantitative measure of the degree of heterogeneity may be determined.

Since the development of the Oliensis test several States have included a requirement for a spot test in their specifications for asphaltic materials. In order to determine the reaction of these asphalts to the Oliensis spot test, they were all tested qualitatively and those that gave positive spots were tested with both gilsonite and xylene, as homogenizers. The results of these tests for both the 50–60 and 85–100 penetration asphalts are given in table 15. This table gives the character of the spot, and the gilsonite and xylene equivalents of those samples showing a positive spot.

There were 14 asphalts of the 50–60 grade and 15 asphalts of the 85–100 grade that gave positive spots with the standard naphtha. Both grades of the asphalts from the same source gave similar spots in most instances, although the 50–60 grades of samples 37 and 38 were positive and the 85–100 grades were negative. In the two grades of samples 5 and 19, the asphalts of 85–100 grade only were positive. Sample 29 was not represented in the 50–60 asphalts.

A heterogeneous asphalt, one giving a positive spot, may be made to appear homogeneous, having a negative spot, by the use of various homogenizers.[11] As indicated in table 15, the addition of relatively small amounts of gilsonite in some instances will make the asphaltic material show a negative spot. In other cases, the quantity of gilsonite necessary to produce a blend showing a negative spot is far too great to make its use profitable. However, the addition of homogeneous asphaltic materials to mask the presence of heterogeneous materials has been noted, and such blends obviously defeat the purpose of the Oliensis test.

The solvent xylene, when used as a homogenizer in varying proportion with the standard naphtha, gives a measure of the degree of heterogeneity of asphaltic materials. The values for xylene equivalents in table 15 can be considered as indicating the relative heterogeneity of these materials.

---

[10] A Quality Test for Determining the Degree of Heterogeneity of Asphalts, by G. L. Oliensis, Proceedings, A. S. T. M., vol. 33, pt. 2, 1933.

[11] A Further Study of the Heterogeneity of Asphalt—A Quantitative Method. By G. L. Oliensis, Proceedings, A. S. T. M., vol. 36, pt. 2, 1936.

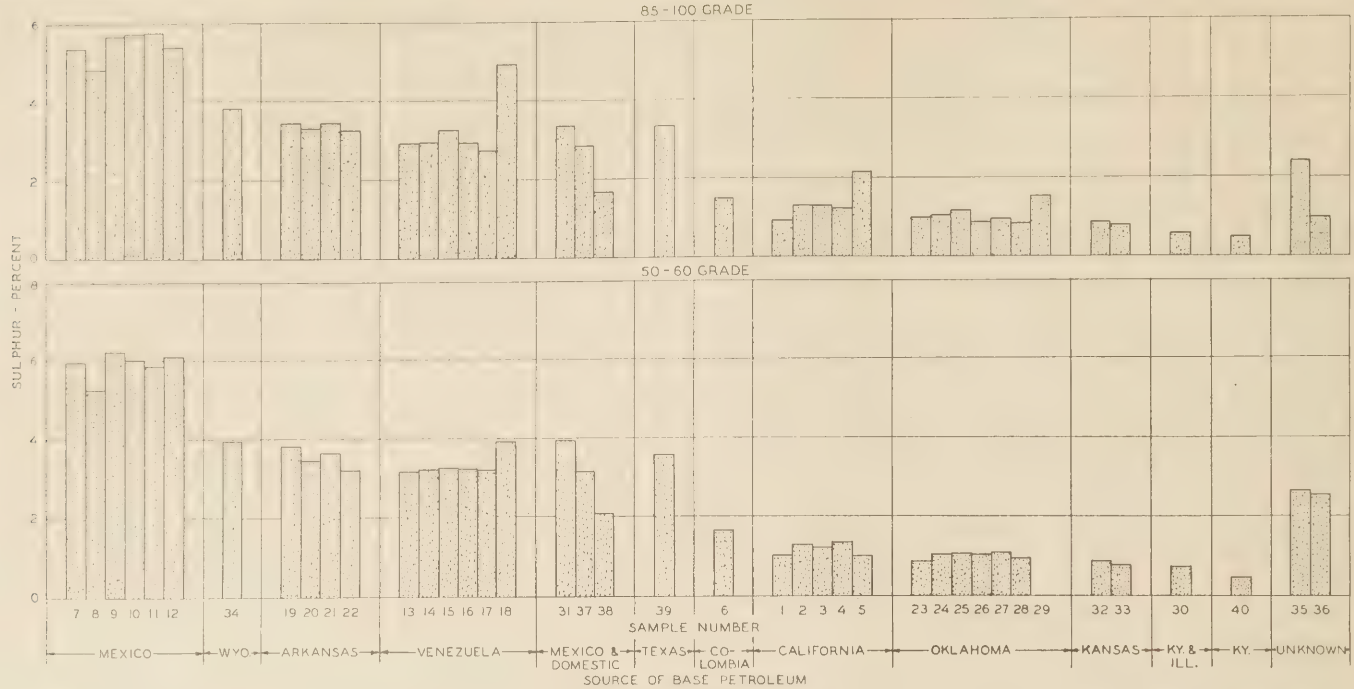

Figure 15.—The Source of the Base Petroleum in Relation to the Sulphur Content of the 50–60 and 85–100 Penetration Asphalts.

Of the 14 asphalts of the 50–60 penetration grade that were heterogeneous, 3 had xylene equivalents of less than 16 and 3 that were greater than 60. Of the 15 heterogeneous asphalts of the 85–100 penetration grade, nine had xylene equivalents of less than 16 and two were higher than 60. Samples 33 of the 50–60 grade and 29 and 33 of the 85–100 grade gave positive reactions with 100 percent xylene, but the maximum values reported are the minimum amounts of xylene in the xylene-naphtha solvent that gave a spot of the same intensity as when xylene alone was used as solvent.

A comparison of the asphalts of the two grades shows that 11 asphalts of the 50–60 grade had higher xylene equivalents than the corresponding asphalts of the 85–100 penetration grade. This would seem to indicate that under uniform refining conditions the development of heterogeneity in the residual asphalt progresses as the material becomes harder. Table 16 shows the distribution of the materials having positive spots according to the process used in manufacture.

Film test.—In 1937, J. R. Benson, of the State Highway Commission of Kansas presented two papers,[12] [13] describing the possibilities of the so-called film test as an accelerated weathering test for asphaltic materials. In these papers the author showed the reaction of translucent asphaltic films approximately 0.001 inch thick when exposed to six artificial weathering conditions. The physical changes due to the various types of exposure were determined by direct observation under the microscope. The test procedure is as follows:

The film of asphalt to be tested is spread on a 1- by 3-inch glass microscope slide by means of a special gage so constructed as to give a film approximately 0.001 inch thick. The slide is then placed horizontally in a constant-temperature oven maintained at 325° F. After 5 hours the slide is removed from the oven, cooled to room temperature, and examined under a microscope at a magnification between 200 and 360 under transmitted light. If the film is clear the slide is again placed in the oven at 325° F. and exposed for a total of 24 hours.

Table 16.—*The refining process in relation to the xylene equivalents of the heterogeneous asphalts*

Sample No.	Xylene equivalent		Refining process
	50–60 grade	85–100 grade	
5	--------	0–2	Vacuum distillation.
8	20–24	24–28	Unknown.
13	28–32	2–4	Fire and steam distillation.
15	24–28	2–4	Steam distillation.
16	28–32	2–4	Do.
19	--------	0–2	Vacuum distillation.
23	84–88	44–48	Unknown.
26	16–20	2–4	Vacuum distillation and oxidation.
28	32–36	4–8	Unknown.
29	--------	[1] 56–60	Do.
33	[1] 60–64	[1] 60–64	Cracking process.
34	28–32	12–16	Fire and steam distillation.
36	0–4	0–2	Do.
37	0–4	--------	Unknown.
38	0–4	--------	Do.
39	24–28	16–20	Do.
40	80–84	80–84	Cracking process.

[1] Maximum value same as spot with 100 percent xylene.

ONLY ASPHALTS HAVING HIGH XYLENE EQUIVALENTS FAILED TO PASS FILM TEST

The condition of the film after the 5- and 24-hour periods is determined as either clear or coagulated. A film is said to be clear when it presents a smooth surface and shows no change in condition other than hardening.

---

[12] A Study of Translucent Asphaltic Films, Proceedings, Highway Research Board, vol. 17, December 1937.

[13] Microscopic Reactions in Translucent Asphaltic Films. Proceedings of the Association of Asphalt Paving Technologists. vol. 9, December 1937.

A film is said to be coagulated when it develops a lacy or granular structure, with the asphalt often appearing to have separated into two distinct components, one light and the other dark.

Although the work done by Benson has been largely on materials of the liquid asphaltic type, it was decided to observe the behavior of the various asphalt cements of this investigation when subjected to the film test as required in the Kansas specification. The results of film test for the 50–60 and 85–100 penetration asphalts are given in table 15. Of the 50–60 grade, samples 23 and 33 showed definite coagulation at the end of the 5-hour and 24-hour periods. Of the 85–100 grade these same asphalts, together with sample 29, also showed coagulation at the end of the 5-hour and 24-hour test periods. Sample 40 in both grades showed coagulation at 24 hours but not at 5 hours. These seven asphalts showed the highest degree of heterogeneity as rated by the Oliensis test, all having xylene equivalents in excess of 44.

Table 17 shows the asphalts that failed to meet the special requirements that have been discussed. It indicates that, in general, the 85–100 penetration asphalts fail in a lesser number of tests than the 50–60 asphalts. The 85–100 asphalts could not be tested for penetration under normal test procedure at 115° F., 50 grams, 5 seconds, so that the susceptibility factor

$$\frac{\text{penetration } 115^\circ \text{ F., } 50 \text{ gm., } 5 \text{ sec.} - \text{penetration } 32^\circ \text{ F., } 200 \text{ gm., } 60 \text{ sec.}}{\text{penetration } 77^\circ \text{ F., } 100 \text{ gm., } 5 \text{ sec.}}$$

was not determined for this grade. The float-test index was specified only for asphalts having penetrations at 77° F. of from 40 to 70 and the designated specification requirement is not applicable to the 85–100 penetration asphalts.

TABLE 17.—*Identification [1] of the 50–60 and 85–100 penetration asphalts which fail to meet special test requirements*

Special test	Fluidity factor		Float-test index		Pen. 39.2° F. / Pen. 77° F. (2)		Pen. 115° F.—Pen. 32° F. / Pen. 77° F. (2)		Ductility at 39.2° F., ¼ cm. per minute		Ductility at 32° F., ¼ cm. per minute				Ductility at 39.2° F., 5 cm. per minute		Toughness test		Organic matter insoluble in 86° B. naphtha		Fixed carbon		Sulphur		Film test		Oliensis test		Number of tests each sample fails to pass	
Proposed test requirement	140+		90+		30+ percent		4.2−		1/10 pen. at 77° F.		1/10 pen. at 77° F. −1		1/10 pen. at 77° F.		1/10 pen. at 77° F.		10+		15–29 percent		8–17 percent		3.0+ percent		Shall not coagulate		Shall show negative spot			
Penetration grade	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100	50 to 60	85 to 100
Sample number:																														
1	x	x	x	x	x	x	x	(3)	----	----	x	----	x	----	x	x	x	----	x	x	x	x	x	x	----	----	----	----	11	7
2	x	x	x	----	x	----	x	----	----	----	x	----	x	----	x	x	x	----	x	x	x	x	x	x	----	----	----	----	11	5
3	x	x	x	----	x	x	x	----	----	----	x	----	x	----	x	x	x	----	x	x	x	x	x	x	----	----	----	----	11	6
4	x	x	x	----	x	x	x	----	----	----	x	----	x	----	x	x	x	----	x	x	x	x	x	x	----	----	----	----	11	6
5	x	x	x	----	----	x	x	----	----	----	x	----	x	x	x	x	x	----	x	x	----	----	x	x	----	----	----	x	9	7
6	x	x	x	----	----	----	x	----	----	----	----	----	x	----	x	x	----	x	----	x	----	----	x	x	----	----	----	----	6	5
7	----	----	----	----	----	----	x	----	----	----	----	----	----	----	x	----	----	----	----	----	----	----	----	----	----	----	----	----	2	0
8	x	x	----	----	----	----	x	----	----	----	x	x	x	x	x	x	----	----	x	----	----	----	----	----	----	----	x	x	7	5
9	----	----	----	----	----	----	x	----	----	----	----	----	----	----	x	x	----	----	x	----	----	----	----	----	----	----	----	----	3	1
10	----	----	----	----	----	----	x	----	----	----	----	----	----	----	x	x	----	----	----	----	----	----	----	----	----	----	----	----	2	1
11	----	----	----	----	----	----	----	----	----	----	----	----	x	----	x	x	----	----	----	----	----	----	----	----	----	----	----	----	2	1
12	----	----	----	----	----	----	----	----	----	----	----	----	----	----	x	x	----	----	----	----	----	----	----	----	----	----	----	----	1	1
13	x	x	----	----	----	----	----	----	----	----	----	----	x	----	x	x	----	----	----	----	----	----	----	x	----	----	x	x	4	4
14	x	x	x	----	----	----	x	----	----	----	----	----	x	----	x	x	----	----	----	----	----	----	----	x	----	----	----	----	5	3
15	x	x	x	----	----	----	x	----	----	----	----	----	x	----	x	x	----	----	----	----	----	----	----	----	----	----	x	x	6	3
16	x	x	x	----	----	----	----	----	----	----	----	----	x	----	x	x	----	----	----	----	----	----	----	x	----	----	x	x	5	4
17	x	x	x	----	----	----	x	----	----	----	----	----	----	----	x	x	----	----	----	----	----	----	----	x	----	----	----	----	4	3
18	----	----	x	----	----	----	x	----	----	----	----	----	----	----	x	x	----	----	----	----	----	----	----	----	----	----	----	----	3	1
19	----	x	x	----	----	----	x	----	----	----	x	----	x	x	x	x	----	x	----	----	----	----	----	----	----	----	----	x	5	5
20	----	x	----	----	----	----	----	----	x	----	x	x	x	x	x	x	----	----	x	----	----	----	----	----	----	----	----	----	5	4
21	----	x	----	----	----	----	x	----	----	----	x	----	x	----	x	x	x	----	----	----	----	----	----	----	----	----	----	----	5	2
22	----	x	----	----	----	----	----	----	----	----	x	----	x	----	x	x	----	----	----	----	----	----	----	----	----	----	----	----	3	2
23	x	x	x	----	----	x	x	----	x	----	x	x	x	x	x	x	----	----	----	----	----	----	x	x	x	x	x	x	10	8
24	----	x	----	----	----	----	----	----	x	x	x	x	x	x	x	----	x	----	----	----	----	----	x	x	----	----	----	----	6	5
25	----	x	x	----	----	----	x	----	----	----	x	x	x	x	x	x	x	x	----	x	----	----	x	x	----	----	----	----	7	7
26	x	x	x	----	----	----	x	----	----	----	x	----	x	x	x	x	----	----	----	----	----	----	x	x	----	----	x	x	8	5
27	x	x	x	----	----	x	x	----	----	----	----	----	x	----	x	x	----	----	----	x	----	----	x	x	----	----	----	----	6	5
28	----	x	x	----	----	x	x	----	----	----	x	----	x	----	x	x	----	x	----	----	----	----	x	x	----	----	x	x	7	6
29	----	x	----	----	----	x	----	----	----	----	----	x	----	x	----	x	----	x	----	----	----	----	----	x	----	x	----	x	----	9
30	----	x	x	----	----	----	----	----	----	----	----	x	x	x	x	x	----	----	----	----	----	----	x	x	----	----	----	----	4	5
31	----	x	----	----	----	----	----	----	x	----	x	x	x	x	x	x	----	----	x	----	----	----	----	----	----	----	----	----	5	4
32	x	x	x	----	----	----	x	----	----	----	x	x	x	x	x	x	----	----	----	----	----	----	x	x	----	----	----	----	7	5
33	x	x	x	----	----	----	x	----	----	x	x	x	x	x	x	x	----	----	----	----	----	----	x	x	x	x	x	x	9	8
34	x	x	----	----	----	----	----	----	----	----	x	x	x	x	x	x	----	----	----	----	----	----	----	----	----	----	x	x	5	5
35	x	x	x	----	----	----	x	----	----	----	x	----	x	----	x	x	----	----	----	----	----	----	x	x	----	----	----	----	7	3
36	x	x	x	----	----	----	x	----	----	x	----	x	x	x	x	x	----	----	----	----	----	----	x	x	----	----	x	x	7	7
37	----	x	----	----	----	----	----	----	----	----	----	----	x	x	x	x	----	----	----	----	----	----	----	x	----	----	x	----	3	4
38	----	x	----	----	----	----	----	----	----	----	----	x	x	x	x	x	----	----	----	----	----	----	x	x	----	----	x	----	4	5
39	x	x	x	----	----	x	x	----	x	----	x	x	x	x	x	x	x	----	----	----	----	----	----	----	----	----	x	x	9	6
40	x	x	x	----	----	----	x	----	----	----	x	----	x	----	x	x	----	----	x	----	----	----	x	x	x	x	x	x	10	5
Number of samples failing each test	22	34	24	1	4	9	27	----	5	3	22	14	33	18	39	38	9	5	10	8	4	4	19	25	3	4	14	15		

[1] Samples marked (x) fail to meet requirement.

[2] Penetrations at various temperatures as follows:
32° F., 200 gm., 60 sec.
39.2° F., 200 gm., 60 sec.
77° F., 100 gm., 5 sec.
115° F., 50 gm., 5 sec.

[3] Penetrations not made at 115° F. on 85–100 penetration asphalts.

Excluding these two requirements, in 6 out of 11 cases the 50–60 asphalts had a larger number of samples failing than did the 85–100 asphalts. The 85–100 asphalts showed the higher number of failures for the fluidity factor, the susceptibility factor using penetration at 77° F., 100 grams 5 seconds and 39.2° F., 200 grams 60 seconds, the sulphur content, and the reaction to the film and the Oliensis test. Both grades showed the same number of failures for the fixed carbon test.

For the 50–60 asphalts, the requirements for ductility at 39.2° F., 5 centimeters a minute, and ductility at 32° F., ¼ centimeter a minute, of one-tenth the penetration, the susceptibility factor involving tests at 3 temperatures, 115°, 77°, and 32° F., the float-test index, and the fluidity factor, in the order named, were the most restrictive. The requirements for the film test, fixed carbon, the susceptibility factor using the temperatures 39.2° and 77° F., and the ductility at 39.2° F., ¼ centimeter per minute of one-tenth the penetration, were the least restrictive.

For the 85–100 penetration asphalts the requirements for ductility at 39.2° F., 5 centimeters a minute of one-tenth the penetration, the fluidity factor, the sulphur content, and ductility at 32° F., ¼ centimeter a minute, of one-tenth the penetration, would cause the greater number of rejections. The requirements for ductility at 39.2° F., ¼ centimeter a minute, of one-tenth the penetration, the film test, and fixed carbon, would cause the least number of rejections.

The ductility requirement of one-tenth the penetration minus 1 at a speed of ¼ centimeter a minute at 32° F. is also highly restrictive for both grades. The requirement for solubility in 86° B. naphtha would cause the rejection of approximately one-fourth of the 50–60 asphalts and one-fifth of the 85–100 asphalts. The reaction to the Oliensis spot test would reject 14 of the 39 asphalts of the 50–60 grade and 15 of the 40 asphalts of the 85–100 grade.

Of these restrictive specification requirements, as a group, the California asphalts failed to pass the greatest number and the Mexican asphalts, excluding sample 8, failed to pass the least number. The Oliensis spot test indicated that sample 8 had been overheated in the refining process. Those asphalts that show high xylene equivalents generally fail to pass a larger number of these requirements than do those that are homogeneous or only slightly heterogeneous. Next to the Mexican asphalts in the number of failures were the Venezuelan asphalts with negative spots and the Arkansas products. The materials from the other fields showed considerable variation in their ability to pass these specification requirements.

Among the Mexican asphalts of the 50–60 grade, excluding sample 8, there was one sample that failed one requirement, three that failed two requirements, and one that failed three requirements. For the other materials, only sample 18, Venezuelan; sample 22, Arkansas; and sample 37, a Mexican-Texas blend, had as few failures as sample 9, which failed three requirements.

In the 85–100 grade, again excluding sample 8, one Mexican asphalt, sample 7, passed all the special requirements, and four Mexican asphalts, samples 9, 10, 11, and 12 failed to pass one requirement only. One Venezuelan asphalt, sample 18, failed to pass one requirement, and two Arkansas asphalts, samples 21 and 22, failed two requirements.

Undoubtedly the group of materials under consideration includes some asphalts representative of materials that have had unsatisfactory service records. However, there are also included materials from other sources that have had excellent behavior under most severe climatic and traffic conditions. Except for slight deviations, all of these asphalts met the specification requirements that have generally been considered as standard. The failure of such a large number of materials from sources that have been considered satisfactory, as shown in table 17, to pass many of these special requirements gives ample justification for all attempts to discourage the use of discriminatory requirements that are not true measures of quality.

It would seem from a consideration of the known service performance of similar materials and from a study of the test data presented in this report that these special tests are essentially tests that assist in the identification of source or the method of processing or that they are measures of special characteristics. There has been no definite correlation between the test data on asphalts and their performance in service to indicate that any of the tests discussed in this report are true measures of quality or durability. Specifications for asphalt cement, therefore, will remain inadequate until such correlation is provided or more satisfactory tests are developed.

AASHO APPROVES STANDARDS FOR PAVEMENT MARKINGS

The article "Marking and Signing No-Passing Zones on Two- and Three-Lane Roads," published in the December 1939, issue of PUBLIC ROADS, described the systems of marking now used by various States and discussed standards recommended by committees of the American Association of State Highway Officials.

"A Policy on Criteria for Marking and Signing No-Passing Zones on Two- and Three-Lane Roads," and "Standards for Marking and Signing No-Passing Zones," as presented in the article on pages 193 and 202, have recently been approved by the American Association of State Highway Officials.

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF FEBRUARY 29, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 6,256,760	$3,022,878	256.0	$ 4,686,781	$ 2,321,828	135.7	$1,828,891	$ 907,935	76.2	$3,866,067
Arizona	1,904,345	1,350,108	94.4	1,867,529	1,270,126	93.7				1,955,941
Arkansas	5,022,693	3,998,804	226.4	1,271,679	708,282	52.4	1,006,072	497,444	54.3	1,978,950
California	5,158,113	2,783,028	79.1	5,233,953	2,767,418	100.1	2,550,850	1,289,600	40.1	5,196,435
Colorado	3,860,230	2,134,103	89.3	1,587,936	893,102	44.6	12,516	7,054		3,647,315
Connecticut	871,263	431,585	10.0	1,448,790	722,376	15.0	1,120,441	546,721	9.4	1,459,741
Delaware	844,413	403,702	31.3	1,133,702	565,363	7.2				1,587,136
Florida	2,475,449	1,234,877	15.4	4,382,931	2,191,241	98.2	986,848	491,756	51.4	2,586,577
Georgia	4,020,849	1,935,439	222.5	4,922,376	2,461,188	252.3	3,156,303	1,578,152	106.3	7,235,807
Idaho	2,204,320	1,298,965	113.9	874,808	534,106	63.3	226,215	119,244	18.8	2,375,483
Illinois	8,733,950	4,345,913	195.7	5,476,202	2,736,112	89.0	3,554,050	1,777,025	91.3	5,500,757
Indiana	4,039,922	2,003,225	78.6	4,621,687	2,304,437	100.7	2,310,057	1,154,763	45.2	3,625,518
Iowa	3,932,852	1,826,856	190.7	3,638,250	1,616,988	107.9	1,241,130	586,800	54.6	3,048,054
Kansas	3,510,145	1,724,601	175.9	2,014,624	1,006,433	117.4	3,669,350	1,831,155	168.9	6,310,103
Kentucky	3,352,373	1,664,158	112.3	1,755,562	876,225	31.0	1,898,527	949,264	38.3	4,314,738
Louisiana	716,918	355,250	23.9	12,124,062	3,110,897	46.7	1,727,450	846,580	50.7	3,715,371
Maine	2,183,320	1,066,794	52.4	747,557	373,778	16.7	13,240	6,620	.6	1,310,922
Maryland	2,712,006	1,311,116	35.8	1,584,275	783,325	30.9	685,200	297,500	8.1	2,466,054
Massachusetts	3,134,614	1,564,618	25.1	715,245	356,778	5.7	1,569,461	781,488	12.5	3,904,093
Michigan	4,810,287	2,340,742	115.4	2,972,890	1,398,444	100.5	4,286,380	2,143,190	130.0	3,948,679
Minnesota	5,717,758	2,815,774	383.0	3,511,758	1,738,418	162.6	848,521	423,690	45.8	6,218,258
Mississippi	5,504,502	1,873,111	256.5	5,175,058	2,248,645	160.4	2,928,082	1,240,436	187.2	2,786,226
Missouri	3,270,585	1,631,445	140.7	3,365,490	1,655,176	104.2	4,175,165	1,651,907	132.1	6,837,576
Montana	3,291,920	1,861,825	189.8	2,175,159	1,233,267	108.8	1,419,970	804,779	136.3	5,099,011
Nebraska	4,516,205	2,230,935	375.0	3,392,053	1,622,632	324.8	2,615,219	1,236,622	324.0	4,289,201
Nevada	1,113,758	943,594	53.6	1,102,994	947,042	52.6	237,674	204,112	8.7	1,900,975
New Hampshire	825,547	406,051	27.2	711,819	348,783	15.5	73,301	36,650		1,497,489
New Jersey	858,420	420,086	7.1	4,963,808	2,480,954	39.1	1,300,040	650,020	11.1	2,299,140
New Mexico	2,055,830	1,232,304	143.0	1,412,907	880,817	78.1	416,857	260,160	25.3	2,312,387
New York	8,639,476	4,247,817	167.9	12,022,032	5,774,651	168.1	1,359,540	594,770	21.4	5,707,400
North Carolina	5,757,901	2,870,090	353.3	3,953,505	1,978,177	184.2	1,162,580	575,405	79.1	3,355,153
North Dakota	266,609	141,147	41.7	1,307,780	711,478	78.0	3,120,047	1,672,283	300.9	4,575,919
Ohio	5,943,593	2,912,343	84.3	8,216,372	4,084,812	61.8	8,027,351	4,013,540	88.6	6,099,060
Oklahoma	1,963,739	1,038,314	104.0	3,007,856	1,595,897	79.8	2,668,622	1,382,708	100.2	4,997,331
Oregon	2,666,441	1,595,619	108.2	3,165,892	1,701,082	106.0	635,670	371,220	40.7	2,333,075
Pennsylvania	9,655,655	4,773,516	113.7	5,493,574	2,601,802	47.7	4,077,628	1,995,224	45.1	6,637,261
Rhode Island	641,516	319,126	7.8	864,692	431,390	8.9	305,995	152,990	2.6	1,301,406
South Carolina	2,168,021	978,200	81.0	1,574,134	713,909	67.5	932,789	437,998	73.7	3,170,702
South Dakota	3,472,672	1,888,151	328.9	2,778,040	1,586,760	307.5	1,551,660	854,470	237.3	4,292,107
Tennessee	3,725,769	1,778,985	89.3	2,649,508	1,324,754	53.4	2,359,848	1,179,924	45.9	4,906,175
Texas	12,096,592	5,940,219	632.0	9,920,766	4,905,237	484.8	3,046,977	1,507,279	178.4	8,986,552
Utah	2,283,941	1,624,385	98.1	625,885	453,575	46.8	249,525	164,420	4.6	1,828,049
Vermont	732,261	351,856	18.4	711,393	355,506	22.8	122,754	61,355	4.9	861,337
Virginia	2,363,545	1,178,396	76.9	2,499,919	1,194,905	54.8	779,106	389,553	23.5	2,680,211
Washington	2,169,011	1,098,580	38.4	3,382,486	1,771,986	27.1	869,498	458,400	24.8	1,760,367
West Virginia	1,905,237	1,008,304	50.0	1,680,476	836,882	47.7	943,050	467,220	20.3	2,902,027
Wisconsin	5,189,418	2,551,264	187.9	5,021,815	2,464,880	153.2	55,948	25,805	2.4	4,438,708
Wyoming	1,501,346	911,084	141.3	1,263,852	796,581	134.8	765,542	462,676	72.0	1,461,554
District of Columbia	373,200	186,600	2.5	233,724	116,862	2.4	386,736	192,350	2.9	552,313
Hawaii	359,892	175,815	4.3	790,506	381,824	13.1	601,757	299,199	9.8	1,597,423
Puerto Rico	706,072	351,850	14.1	1,306,457	646,785	25.3	65,005	32,220	.2	904,565
TOTALS	171,481,254	88,133,548	6,464.0	161,342,549	78,583,916	4,730.8	79,945,438	39,611,676	3,206.5	178,622,699

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF FEBRUARY 29, 1940

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$ 499,424	$ 243,701	27.8	$ 937,932	$ 367,393	32.9	$ 633,000	$ 315,350	34.0	$ 611,507
Arizona	285,640	204,680	33.4	147,771	106,060	18.3	74,936	17,866	4.7	425,746
Arkansas	928,767	789,307	90.7	103,013	79,812	8.2	91,373	55,810	14.4	347,202
California	821,618	467,084	36.1	389,944	212,124	7.4	273,540	152,732	23.0	1,099,991
Colorado	897,393	473,798	31.3	217,430	99,681	5.9	30,502	4,429	1.3	280,469
Connecticut	172,310	72,417	2.9	100,760	50,197	.2	210,228	99,380	3.1	234,223
Delaware	80,623	39,067	17.5	69,537	34,768	7.8				309,475
Florida	880,547	435,557	31.3	35,029	17,515	.6	101,240	50,620	1.3	563,391
Georgia	343,588	166,234	44.2	156,859	78,430	15.1	447,483	223,742	45.5	1,302,099
Idaho	458,334	248,575	45.1	128,663	78,481	12.8				293,770
Illinois	1,281,443	628,081	78.8	998,500	443,950	56.7	975,250	472,625	39.0	728,405
Indiana	893,825	440,833	77.7	299,900	148,746	18.3	229,992	114,950	18.1	948,527
Iowa	344,063	164,873	128.5	1,098,526	523,360	120.1	1,054,397	497,075	246.4	874,732
Kansas	77,478	38,723	44.4	663,014	331,507	10.9	124,046	62,023	15.0	1,538,013
Kentucky	1,096,826	325,230	71.4	552,881	182,184	37.1	584,600	188,840	55.8	425,368
Louisiana	806,073	377,985	67.2	267,159	133,579	23.7	157,108	78,495	14.5	458,084
Maine	431,791	214,250	25.4	72,824	35,206	3.5	8,300	4,150	.5	138,607
Maryland	281,641	137,157	19.2	72,696	24,348	3.3	45,300	22,650	1.1	474,694
Massachusetts	373,212	185,203	9.2	284,559	140,915	5.9	158,713	78,674	4.2	591,071
Michigan	1,307,572	639,902	113.7	914,039	460,409	45.8	490,325	236,683	29.0	853,435
Minnesota	882,345	435,080	122.0	307,958	153,979	17.6	149,332	42,795	12.5	1,431,189
Mississippi	366,500	183,250	40.7	945,562	460,996	52.1	98,000	48,900	.5	720,893
Missouri	908,174	446,840	136.5	486,413	242,910	41.7	350,008	145,167	48.2	880,260
Montana	835,992	474,167	71.6	224,934	127,101	23.3	460,458	260,410	52.9	774,385
Nebraska	991,190	473,800	205.4	378,287	188,723	47.9	208,743	104,372	40.2	553,652
Nevada	164,206	134,299	25.0	197,591	169,920	25.5				228,342
New Hampshire	63,415	30,804	2.3	118,342	55,625	3.2	21,867	10,676	1.0	195,985
New Jersey	332,425	163,218	12.1	306,190	153,095	12.3	310,690	155,345	6.0	522,893
New Mexico	478,009	292,043	42.1	266,287	166,062	13.8	101,564	63,386	13.1	257,615
New York	1,762,199	865,669	90.9	1,666,975	802,543	45.1	549,766	204,657	12.9	783,234
North Carolina	988,610	492,157	98.5	574,933	290,078	53.6	287,020	135,679	25.4	480,966
North Dakota	115,841	61,370	8.2	62,121	34,895		150,963	80,915	3.8	1,012,290
Ohio	697,494	347,437	41.8	665,090	339,320	25.6	2,305,080	1,101,397	77.0	1,044,378
Oklahoma	260,138	133,815	10.5	534,156	284,214	40.1	340,230	181,028	25.7	1,076,856
Oregon	614,073	347,752	67.6	275,420	128,337	29.9	136,199	81,480	20.2	427,194
Pennsylvania	2,081,304	1,024,235	117.1	1,253,808	620,799	43.1	872,489	435,482	22.8	435,923
Rhode Island	93,827	46,890	2.1	81,236	40,618	.2	148,012	73,980	3.4	95,452
South Carolina	562,159	228,890	56.9	251,420	99,517	22.6	417,800	142,644	29.4	316,531
South Dakota	16,229	8,937	4.1	14,680	9,712					1,280,913
Tennessee	816,719	351,961	31.7	146,416	73,208	.7	132,927	66,463	7.9	1,006,874
Texas	2,367,888	1,166,398	261.9	1,230,763	604,983	134.5	187,720	86,655	35.3	1,399,677
Utah	230,453	126,765	38.5	121,120	76,528	8.3				297,598
Vermont	143,680	69,602	5.6	164,292	50,336	6.3	176,900	52,029	5.8	77,622
Virginia	649,933	315,482	65.5	375,010	163,055	12.8	189,020	92,878	19.1	383,337
Washington	581,930	303,948	43.1	281,527	147,657	16.9	97,856	51,200	4.8	401,162
West Virginia	145,150	72,575	8.3	331,265	165,632	18.0	144,168	72,084	8.0	444,959
Wisconsin	883,153	438,847	34.5	321,053	160,190	4.7	379,319	179,040	4.4	833,634
Wyoming	470,702	286,620	26.0	329,482	195,846	23.4	53,943	34,052	15.5	189,322
District of Columbia	98,700	49,350	1.0	17,492	8,246	.2	24,200	12,100	.3	76,554
Hawaii	89,392	44,391	3.7	376,848	188,928	11.0				159,806
Puerto Rico				224,465	109,130	12.8	105,078	51,475	4.4	109,023
TOTALS	30,953,998	15,709,249	2,671.0	20,042,172	9,860,848	1,181.7	14,089,685	6,642,383	1,051.4	30,397,328

U. S. GOVERNMENT PRINTING OFFICE: 1940

PUBLICATIONS *of the* PUBLIC ROADS ADMINISTRATION

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Agency and as the Agency does not sell publications, please send no remittance to the Federal Works Agency.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1938 10 cents.

Report of the Chief of the Bureau of Public Roads, 1939. 10 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. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP . . Roadside Improvement. 10 cents.

No. 272MP . . Construction of Private Driveways. 10 cents.

No. 279MP . . Bibliography on Highway Lighting. 5 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. 60 cents.

Highways of History. 25 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T . . . Electrical Equipment on Movable Bridges. 35 cents.

Single copies of the following publications may be obtained from the Public Roads Administration upon request. They cannot be purchased from the Superintendent of Documents.

MISCELLANEOUS PUBLICATIONS

No. 296MP . . Bibliography on Highway Safety.

House Document No. 272 . . . Toll Roads and Free Roads.

Indexes to PUBLIC ROADS, volumes 6–8 and 10–19, inclusive.

SEPARATE REPRINT FROM THE YEARBOOK

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

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

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.

Model Traffic Ordinances.

A complete list of the publications of the Public Roads Administration classified according to subject and including the more important articles in PUBLIC ROADS, may be obtained upon request addressed to Public Roads Administration, Willard Bldg., Washington, D. C.