HIGHWAY RESEARCH BOARD

Bulletin 160

Bituminous Paving Mixtures

National Academy of Sciences—
National Research Council
publication 499

HIGHWAY RESEARCH BOARD

Officers and Members of the Executive Committee

1957

OFFICERS

REX M. WHITTON, *Chairman* C. H. SCHOLER, *First Vice Chairman*

HARMER E. DAVIS, *Second Vice Chairman*

FRED BURGGRAF, *Director* ELMER M. WARD, *Assistant Director*

Executive Committee

C. D. CURTISS, *Commissioner, Bureau of Public Roads*

A. E. JOHNSON, *Executive Secretary, American Association of State Highway Officials*

LOUIS JORDAN, *Executive Secretary, Division of Engineering and Industrial Research, National Research Council*

R. R. BARTELSMEYER, *Chief Highway Engineer, Illinois Division of Highways*

J. E. BUCHANAN, *President, The Asphalt Institute*

W. A. BUGGE, *Director of Highways, Washington State Highway Commission*

HARMER E. DAVIS, *Director, Institute of Transportation and Traffic Engineering, University of California*

DUKE W. DUNBAR, *Attorney General of Colorado*

FRANCIS V. DU PONT, *Consulting Engineer, Washington, D. C.*

PYKE JOHNSON, *Consultant, Automotive Safety Foundation*

KEITH F. JONES, *County Engineer, Jefferson County, Washington*

G. DONALD KENNEDY, *President, Portland Cement Association*

BURTON W. MARSH, *Director, Traffic Engineering and Safety Department, American Automobile Association*

GLENN C. RICHARDS, *Commissioner, Detroit Department of Public Works*

C. H. SCHOLER, *Head, Applied Mechanics Department, Kansas State College*

WILBUR S. SMITH, *Wilbur Smith and Associates, Bureau of Highway Traffic, Yale University*

REX M. WHITTON, *Chief Engineer, Missouri State Highway Department*

K. B. WOODS, *Head, School of Civil Engineering and Director, Joint Highway Research Project, Purdue University*

Editorial Staff

FRED BURGGRAF ELMER M. WARD HERBERT P. ORLAND

2101 Constitution Avenue Washington 25, D. C.

HIGHWAY RESEARCH BOARD

Bulletin 160

Bituminous Paving Mixtures

PRESENTED AT THE
Thirty-Sixth Annual Meeting
January 7-11, 1957

1957

Washington, D. C.

Department of Materials and Construction

R.R. Litehiser, Chairman
Engineer of Tests, State Highway Testing Laboratory
Ohio State University

BITUMINOUS DIVISION

H. L. Lehmann, Chairman
Testing and Research Engineer
Louisiana Department of Highways

COMMITTEE ON DESIGN OF BITUMINOUS PAVING MIXTURES

Lloyd F. Rader, Chairman
Department of Civil Engineering
University of Wisconsin

A. B. Cornthwaite, Testing Engineer, Virginia Department of Highways

Professor Ladis H. Csanyi, Civil Engineering Department, Iowa State College

R. T. Healy, Engineer of Materials, Connecticut State Highway Department

Donald I. Inghram, Nebraska Department of Roads and Irrigation

O. A. Philippi, Assistant Construction Engineer, Texas Highway Department

C. K. Preus, Engineer of Materials and Research, Minnesota Department of Highways

W. C. Ricketts, Airfields Branch, Engineering Division, Office of the Chief of Engineers, Department of the Army

B. A. Vallerga, Managing Engineer, Pacific Coast Division, The Asphalt Institute

Ellis G. Williams, District Engineer, The Asphalt Institute

E. Zube, Supervising Materials and Research Engineer, California Division of Highways

Contents

State Practices in the Use of Bituminous Concrete

W. E. CHASTAIN, SR., Engineer of Physical Research, and
JOHN E. BURKE, Assistant Engineer of Physical Research
Bureau of Research and Planning, Illinois Division of Highways

● FIFTY highway agencies cooperated in furnishing the information on bituminous concrete practice that is presented and summarized in this report. Cooperating agencies include all of the state highway departments, the District of Columbia Department of Highways, and the Ontario (Canada) Department of Highways. The contributions of all of these agencies are gratefully acknowledged.

The information that is herein compiled was assembled to serve as a basis upon which to pattern the construction of the experimental flexible pavement to be tested during the AASHO Road Test. Two separate questionnaires were sent out to and completed by the cooperating agencies in 1953. The first questionnaire was of a general nature and the second was much more detailed. Data from the two questionnaires were tabulated and the tabulations were submitted to all of the cooperating agencies for checking and for adding information to bring the tabulations up-to-date for 1954. The practice represented in this report is therefore 1954 practice.

Although the questionnaires were considered to be "bituminous concrete" questionnaires, which would include both tar and asphaltic concrete, they were definitely pointed toward asphaltic-concrete usage since there was no question but that asphaltic concrete rather than tar concrete would more truly represent national practice and be used in the Test Road construction. However, much of the information that has been compiled applies to both types of bituminous concrete.

In preparing the questionnaires it was assumed that bituminous concrete as generally used consists of a mixture of coarse aggregate, fine aggregate, mineral filler and asphalt cement. Such a material is plant-mixed, laid with a spreading and finishing machine, and immediately compacted with rollers. With one or two possible exceptions, all of the reporting agencies make some use of such a material. However, considerable variation occurs in the number of refinements that are introduced and the degree of control that is exercised. Practice is tailored generally to meet the individual needs of the constructing agencies. For example, a bituminous-concrete mixture that is to be subjected to the heavy traffic and severe moisture conditions of one area must meet much higher design standards and must be much more vigorously controlled during the construction process than a mixture that must meet only the moderate traffic demands and the favorable climatic conditions of another area.

In preparing the questionnaires it was assumed that in all probability the Road Test pavement, to represent national practice, would consist generally of two layers of bituminous concrete. The lower layer was referred to as the "binder course" and the upper layer as the "surface course." It may have been better not to have used the term "binder course," and to have used the terms "first course" and "second course," or "lower course" and "surface course." However, it is believed that no essential information was lost through the use of the term "binder course." While it was found that many agencies, even though using multi-course bituminous concrete, do not vary the mixture composition between courses, many others use a coarser-graded material and do not require the addition of mineral filler in the lower course or courses.

The questions that were asked in the questionnaires may be placed in two groups, one dealing with standard specification requirements, and the other dealing with general practice not outlined in detail in the specifications. This latter group of questions covered procedures that are not normally covered by specifications such as design procedures, and principal usage where specifications permit alternate usage or are sufficiently broad to allow important variations in usage.

For the purpose of the AASHO Road Test, the questionnaires were not intended to cover all details of bituminous-concrete practice, but were designed rather to obtain information where some variation in practice was believed to occur. Therefore, the reader will find that in a few instances the report may seem to underemphasize certain important phases of bituminous-concrete construction, and in other instances overemphasize less important phases. However, it is believed that the report will prove particularly useful to engineers already practicing bituminous-concrete construction in comparing their practices with the practices of others, and in improving their practices on the basis of the experience of others. With a proper consideration of the background for the report, the information presented should be of value also to engineers less experienced in the detailed phases of bituminous-concrete design and construction.

BITUMINOUS-CONCRETE MATERIALS

FINE AGGREGATE

While some of the reporting agencies distinguish between and apply separate specification requirements to the fine aggregate and the coarse aggregate to be used in bituminous concrete mixtures, others of those reporting apply requirements to only the total aggregate. For example, in the matter of gradation requirements, of the 50 reporting agencies only 20 specify gradation limits for binder-course fine aggregate, and 22 specify limits for surface-course fine aggregate; only 17 specify gradation limits for binder-course coarse aggregate, and 18 specify limits for surface-course coarse aggregate.

Kinds of Material

Natural sand is reported as being used as fine aggregate either optionally or exclusively by all but one of the 50 reporting highway agencies. Seven report an exclusive use of natural sand. The single agency not using sand (Delaware) permits only the use of stone screenings. Thirty-one agencies report an optional use of stone screenings, and 14 report an optional use of stone sand. Several other materials are used less extensively. Table 1-a[1] lists all of the materials that were reported as being used as fine aggregate in bituminous concrete mixtures, and indicates the number of agencies using each.

TABLE 1-a

MATERIALS USED EITHER OPTIONALLY OR EXCLUSIVELY AS FINE AGGREGATE

Kind of Material	Number of Agencies
Natural sand	49
Stone screenings	31
Stone sand	14
Natural sand and screenings	11
Slag screenings	9
Crushed gravel screenings	8
Chat	3
Mine tailings	2
Volcanic cinders	1
Total agencies reporting	50

Particle Shape

Only five agencies report having specifications concerning the proportion of angular or rounded particles in the fine aggregate. The small number of agencies reporting such a requirement, and the variability of the answers that were received from them, seem to indicate that this requirement is essentially of local significance. The following descriptions were received from those answering affirmatively to the question of whether the proportion of rounded or angular particles in the fine aggregate was controlled: "fine aggregate shall consist of sand or a mixture of a minimum of 50 percent sand and a maximum of 50 percent screenings;" "specify crushed stone screenings exclusively;" "at least 50 percent passing No. 10 must be natural sand;" "fine aggregate may be 100 percent glacial sand or mixture of sand and stone screenings—50 percent maximum screenings," "not less than 50 percent or 75 percent to have one fractured face."

[1]The summary tables included in the text are identified by letters preceded by the number of the appendix table (Appendix 3) that contains the detailed data that have been summarized.

Three agencies not specifying the proportion of angular or rounded particles in the fine aggregate volunteered the information that the fine-aggregate material that usually is used contains from 30 to 50 percent angular particles.

Deleterious Substances

Substances that the reporting agencies consider deleterious in fine aggregate, and the methods used to prevent the inclusion of what are considered to be harmful quantities, appear to be something of a local or regional matter and undoubtedly depend largely on experience with the aggregates at hand. Most of the reporting agencies (40 of 50) consider that their specifications recognize specifically at least one type of deleterious material. Of the 10 that do not, several report that they believe their other requirements, such as those pertaining to soundness, automatically limit the quantity of deleterious material that can be included in the fine aggregate. Others, though not volunteering the information, are undoubtedly of the same opinion.

TABLE 1-b

LIMITATION OF DELETERIOUS MATERIALS IN FINE AGGREGATE

Material	Number of Agencies Specifically Limiting Material	Number of Agencies Allowing No Amount	Number of Agencies Having Percentage Limitation	Range of Percentage Limitations (>0)
Clay, loam	20	11	5	0.25-15
Organic, vegetable, roots, etc.	14	11	3	0.1-1
Clay lumps	14	5	8	0.2-1
Shale	9	1	5	0.5-2 1/
Finer than No. 200 sieve; or decanted	8	0	8	1-12
Soft	6	1	3	3-5
Coal, lignite	6	0	4	0.5-1
Cemented	2	1	1	1
Other (mica, alkali, shells, cinders, salt, elongated)	5	1 2/	2 3/	0.5-1
Undifferentiated	14	11	1	3
No specific limitation	10 agencies			
Total reporting	50 agencies			

1/ One state allows up to 12 percent shale in total mixture.

2/ One state requires freedom from mica and salt.

3/ One state allows up to 0.5 percent cinders and clinkers, and up to 1 percent mica and alkali; one state allows up to 1 percent mica.

TABLE 1-c

SOUNDNESS REQUIREMENTS FOR FINE AGGREGATE

Test (AASHO Standard)	Cycles	Max. Allowable Weight Loss (percent)	Number of Agencies	Remarks
Sodium sulfate	5	10	7	
	5	12	3	
	5	15	2	
	5	8	1	
	10	7	1	Stone for sand 1/
	10	8	1	Natural sand 1/
Magnesium sulfate	5	12	1	
	5	16	1	
	5	8	1 2/	
	10	12	1	Stone for sand 1/
	10	22	1	Natural sand 1/
Freeze-thaw	15	8	1 2/	
	16	25	1	Test of parent material
		Non-standard freeze-thaw	1	
Not specified			30	
Total agencies			50	

1/ One agency reports four separate requirements

2/ One agency reports two separate requirements

Table 1-b shows the various substances that are considered deleterious by the reporting agencies, the number of agencies that consider each as being deleterious, and the amounts of these materials that are allowed in the fine aggregate. Heading the list of materials most frequently mentioned as being deleterious are clay and loam, followed by organic materials, clay lumps, minus No. 200 or decanted, soft particles, coal and lignite, and others to a lesser extent.

Twenty of the reporting agencies place a percentage limitation on at least one specifically mentioned deleterious substance. Sixteen agencies permit the inclusion of no material that they consider to be deleterious. Two agencies place a percentage limitation on the total amount of deleterious material that may be contained in fine aggregate, without applying a specific limitation to any single substance. One agency states that the fine aggregate shall be free of an "injurious quantity of deleterious material," and another states that the quantity shall be "negligible."

Four agencies placing percentage limitations on more than one type of deleterious material place a limitation on the total that is less than the sum of the percentages for the individual types. The range of percentage limitations of this nature on the total material varies from 1. 25 to 5 percent. Two agencies list more than one material as being considered deleterious, but place a percentage limitation only on the total (2 and 3 percent). Two other agencies place percentage limitations on only a portion of the individual materials that they list as being deleterious, but also place a percentage limitation (both use 5 percent) on the total.

A check of the specifications of many of the agencies limiting the quantity of "clay" and "loam" in fine aggregate indicates that few actually define these materials. It is suspected that the term "clay" usually refers to material that can be decanted, or that passes the No. 200 sieve; and that "loam" refers to topsoil of perhaps similar particle size.

Soundness

As shown in Table 1-c, 20 agencies report having soundness requirements in their specifications for fine aggregate for bituminous-concrete construction. Thirteen base their requirements on the sodium sulfate test, and one uses the sodium sulfate test in combination with the magnesium sulfate test. Three use the magnesium sulfate test exclusively, one uses the magnesium sulfate test in combination with the freeze-thaw test, and as previously mentioned, one uses the sodium sulfate test and magnesium sulfate test in combination. One agency bases its requirement on a freeze-thaw of the fine-aggregate parent material, and one has its own version of the freeze-thaw test.

For those agencies basing their requirements on the sodium sulfate test, at 5 cycles of testing, 7 permit up to 10 percent loss of weight, 3 permit 12 percent loss, 2 permit 15 percent, and one permits 8 percent. The three agencies reporting requirements based on the magnesium sulfate test, at 5 cycles of testing, permit 8, 12 and 16 percent weight loss respectively.

Gradation

Twenty agencies report having gradation specifications for fine aggregate for use in binder-course mixtures. Twenty-two agencies have such specifications for fine aggregate for surface-course mixtures. All 20 of the agencies specifying gradation requirements for binder-course mixtures are among the 22 specifying fine-aggregate gradations for surface-course mixtures. Eleven of the agencies use the same fine-aggregate gradation requirements for both binder and surface mixtures.

Seven of the 20 agencies reporting gradation specifications for fine aggregate for binder-course mixtures specify percentages of material by weight passing one sieve and retained on the next. Eleven of the remainder specify percentages by weight passing a series of sieves, and two specify percentages retained. Ten agencies use the passing-and-retained basis for fine aggregate for surface-course mixtures, while 10 of the remainder specify percentages passing. Two specify percentages retained.

Not all agencies use the same separating size between fine and coarse aggregates. If it is assumed that some agencies permit as much as 10 percent oversize material to be retained on what is considered to be the nominal maximum-size sieve, (and an inspection of the data indicates that this assumption is not unreasonable, as explained later in the paper) the distribution of agencies according to nominal maximum size of fine aggregate is as follows:

	Number of Agencies	
Nominal Maximum Sieve Size	Binder-Course Fine Aggregate	Surface-Course Fine Aggregate
No. 4	11	11
No. 10	6	7
No. 8	2	3
⅜ in.	1	1
Total agencies	20	22

In order to compare the fine-aggregate gradation requirements of the reporting agencies, it was necessary that these requirements be placed on a uniform basis. The "percentage passing" basis was chosen for this particular presentation because of the ease with which the limits may be plotted for visualizing the nature of the aggregate meeting the specified requirements. A method reported in Public Roads, Volume 27, No. 7, April 1953, was used to convert "passing and retained" requirements to "percentage passing." Conversion of "percentage retained" to "percentage passing" is a common procedure of a simple nature.

After the conversion of all gradation requirements to a "percentage passing" basis, the envelope describing the upper and lower percentage limits for the various sieve combinations for each of the agencies was drawn on semi-logarithmic cross-section paper with the percentage scale on the vertical axis and the sieve sizes on the logarithmic horizontal axis. Straight lines were drawn to connect the percentage limits for the sieves in the series used by each of the agencies.

Using the envelopes that were prepared to describe the sieve-size limits of the reporting agencies, the limiting values for individual sieves were investigated. Limiting values for only the more commonly used sieves were considered in this investigation. For the agencies not having specifications based on the particular sieves chosen for study, the gradation limits that would be likely to apply were estimated from the envelope curves that had been constructed from the sieve data furnished by these agencies.

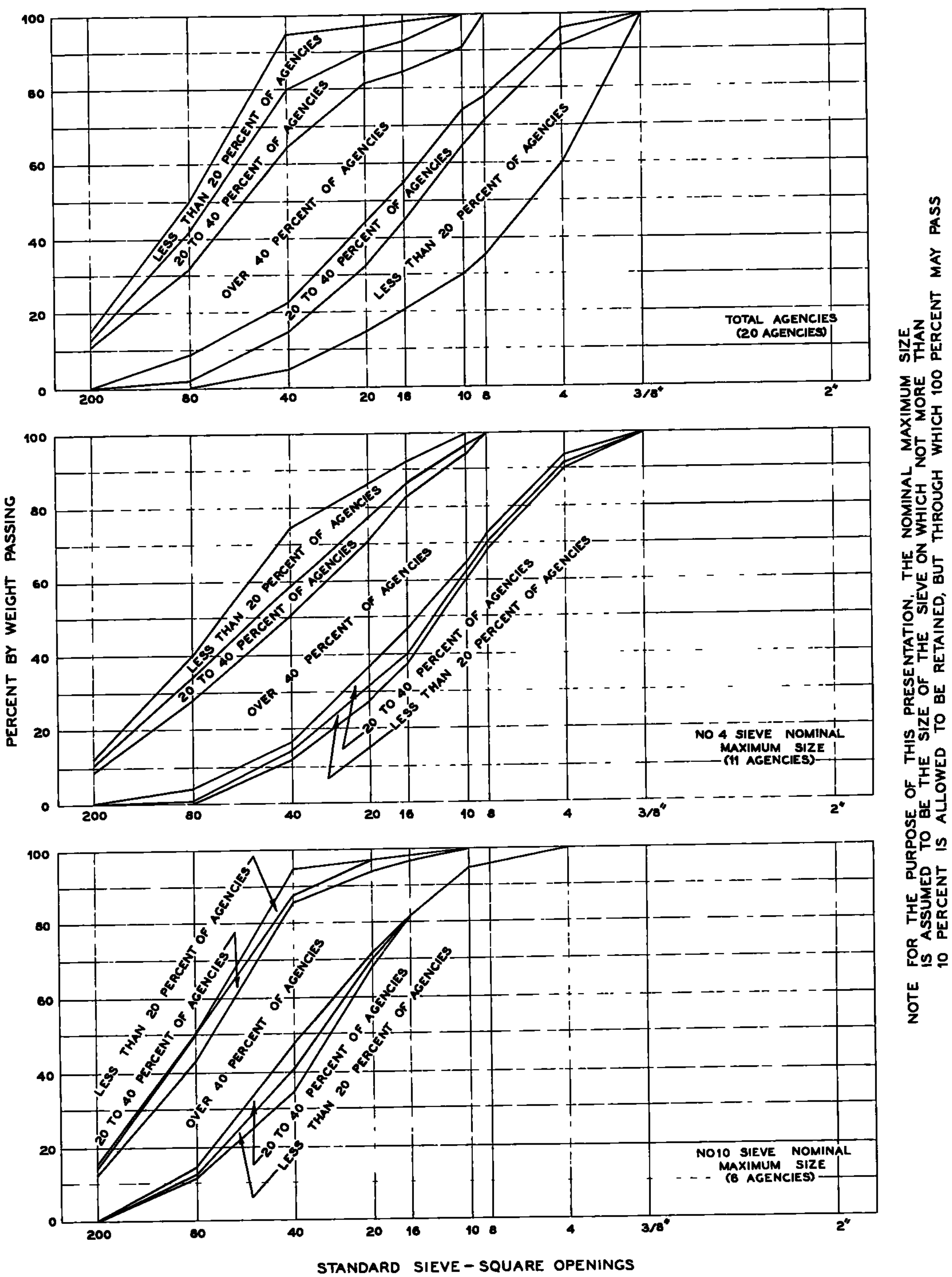


Figure 1. General acceptability with respect to gradation of fine aggregate for binder-course mixtures.

For each sieve, curves of frequency of acceptance were prepared in the same manner as that employed in examining mixture gradations, as described later.

From the frequency-of-acceptance curves were determined the usage envelopes of

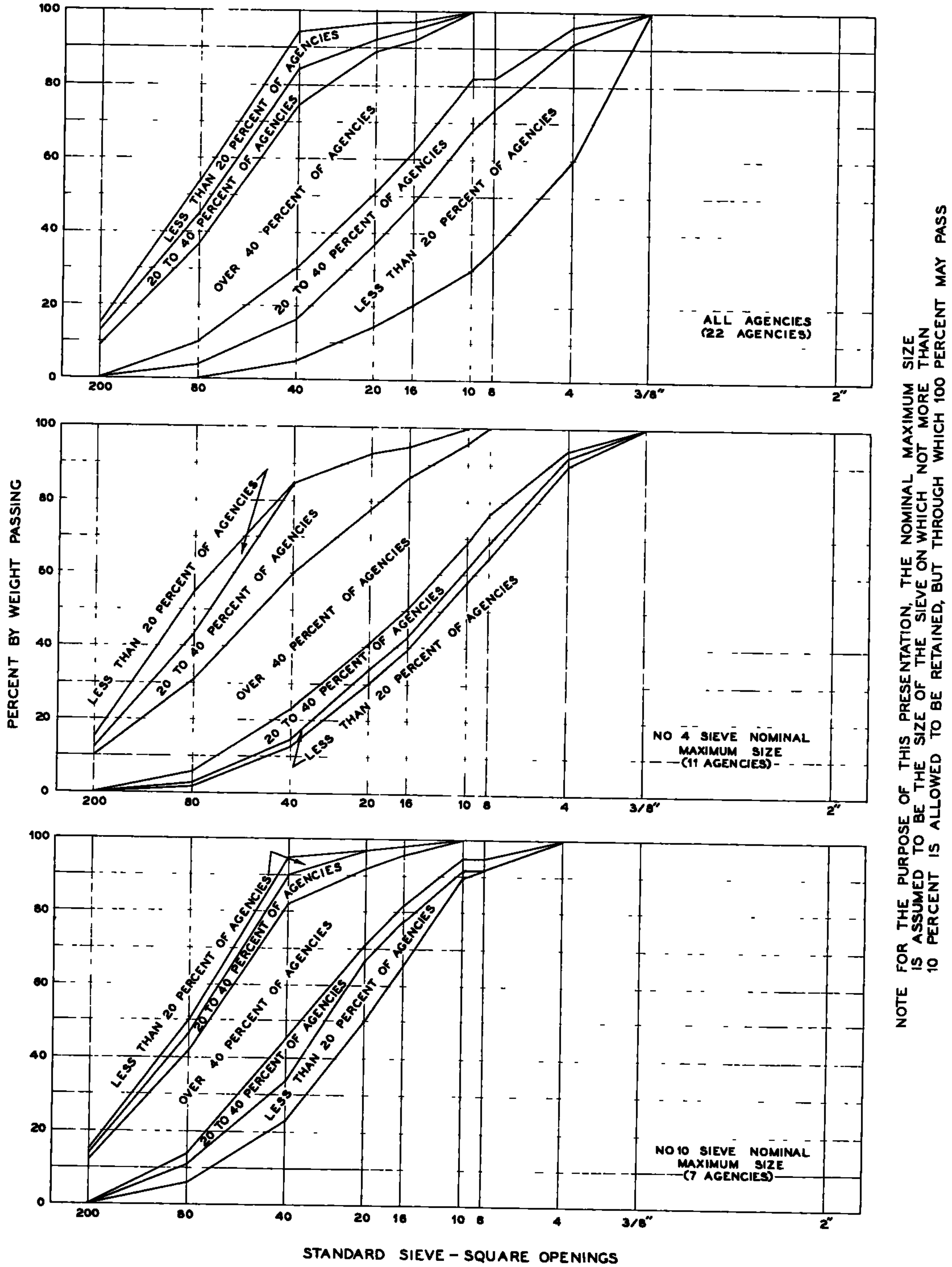


Figure 2. General acceptability with respect to gradation of fine aggregate for surface-course mixtures.

Figure 1 for binder-course fine aggregate and Figure 2 for surface-course fine aggregate. The envelopes of these figures have been prepared to show: (1) limits acceptable to over 40 percent of the reporting agencies; (2) limits acceptable to 20 to 40 percent of the reporting agencies; and (3) limits acceptable to less than 20 percent of the reporting agencies. One set of envelopes was prepared for all agencies, another set for those reporting the No. 4 sieve size as the nominal maximum size for fine aggregate, and another set for the agencies reporting the No. 10 sieve size as the nominal maximum size for fine aggregate. As would be expected, the envelopes show a much better agreement among agencies when the maximum size of material is taken into consideration.

The percentage-of-agencies separations of over 40 percent, 20 to 40 percent, and less than 20 percent were chosen arbitrarily after a visual inspection of the data indicated that such a grouping would present observable separations. This same grouping has been used also for the analysis of coarse-aggregate gradations and for the analysis of total-mixture gradations.

COARSE AGGREGATE

Kinds of Material

All but one of the 50 agencies replying to the questionnaires report that crushed stone is used to at least some extent as coarse aggregate for bituminous-concrete mixtures. Crushed gravel is used by 39 agencies, and crushed slag, uncrushed gravel, and other materials to a lesser extent. A complete tabulation of usage is shown in Table 2-a.

TABLE 2-a

MATERIALS USED EITHER OPTIONALLY OR EXCLUSIVELY AS COARSE AGGREGATE

Kind of Material	Number of Agencies
Crushed stone	49
Crushed gravel	39
Crushed slag	18
Gravel	14
Mine chats	3
Volcanic cinders	2
Crushed boulders	1
Lava	1
Total agencies	50

With reference to crushed and uncrushed material, 21 agencies indicate that they require all coarse aggregate to be crushed or fractured; 17 agencies permit part of the coarse aggregate to be uncrushed; and 12 agencies permit all of the coarse aggregate contained in the mixture to be uncrushed. For the 17 agencies permitting a portion of the coarse aggregate to be uncrushed, specified percentage limitations are as shown in Table 2-b.

TABLE 2-b

PERCENTAGE LIMITATIONS ON UNCRUSHED COARSE AGGREGATE PARTICLES

Maximum Percent of Uncrushed Particles Permitted in Coarse Aggregate	Number of Agencies
25	3
30	2
40	3
50	6
60	1
40 (based on total aggregate)	1
50 (based on total aggregate)	1
Total agencies	17

Wear Requirements

Wear requirements for coarse aggregates used in bituminous-concrete mixtures are specified by 48 of the 50 reporting agencies. Forty-two of these base their requirements on the Los Angeles Abrasion Test, and the remaining six use the Deval Abrasion Test. Specified maximum percentages of loss by the Los Angeles method (500 revolutions) range between 30 and 60. Nineteen agencies specify a maximum percentage loss of 40, 7 specify a maximum percentage loss of 35, and no more than 4 agencies specify any one other percentage value. A complete summary tabulation of the wear requirements for those agencies using the Los Angeles method of test appears in Table 2-c.

For the six agencies basing wear requirements on the Deval method of test, maxi-

TABLE 2-c

WEAR REQUIREMENTS FOR COARSE AGGREGATE BASED ON LOS ANGELES METHOD OF TEST

Maximum Percent Loss Allowed	Number of Agencies
60	2
55	1
50	4
48	1
45	4
40	19
37	1
35	7
32	1
30	2
Total agencies	42

mum allowable percentage loss values ranged from 3. 5 to 7 for stone, and between 15 and 16 for gravel.

Soundness

Twenty-four agencies report having a soundness requirement in their specifications concerning coarse aggregate for bituminous concrete. As will be seen from Table 2-d, most of these report basing their requirements on the AASHO standard sodium sulfate or magnesium sulfate tests. Three use the standard freeze-thaw test, one of these in combination with the sodium sulfate test and another in combination with the magnesium sulfate test. Two agencies report using a non-standard freeze-thaw test. Twenty-one agencies report that they do not have a specific soundness requirement for the coarse aggregate, and five agencies did not reply to the question or furnished an imcomplete reply.

For those agencies basing their requirements on the sodium sulfate test, at five cycles of testing, 8 agencies permit a weight loss of up to 12 percent, 3 allow a loss of up to 15 percent, 2 allow up to 10 percent, one allows up to 8 percent, and one allows up to 20 percent. For the agencies using the magnesium sulfate test, at five cycles of testing, 4 allow a loss up to 12 percent, and one allows up to an 8 percent loss.

Deleterious Substances

As was the case with fine aggregate, the substances that are mentioned in specifications as being deleterious in coarse aggregate, and the limitations that are placed thereon are generally a matter of experience with the aggregates at hand.

Forty agencies report specific references to deleterious materials in their specifications. Nine other agencies report that they have no requirement referring directly to deleterious materials. However, some of these voluntarily stated that they believe other properties that are specified automatically limit the amount of harmful material that can be contained in the coarse aggregate. Undoubtedly others are of the same opinion.

Table 2-e summarizes information concerning the substances that are most frequently regarded as being deleterious in coarse aggregate, and indicates the range of percentage limitations that are placed on them. Organic materials, fine materials including clay and loam, clay lumps, soft particles, coal, lignite, shale, and elongated pieces are among the materials which are most frequently limited.

Twenty-two of the 37 agencies that refer specifically to one or more of the various deleterious materials (most of which are listed in Table 2-e) place a percentage limitation on at least one of them. Fourteen agencies permit no amount of material that they consider to be deleterious. Two agencies have a percentage limitation on total deleterious material without specifically limiting individual kinds, one agency states that the coarse aggregate shall be free of an "injurious quantity of deleterious material," another states that "the quantity shall be negligible," and another bases its limitations on total aggregate.

Gradation

Insofar as gradation is concerned, the term "coarse aggregate" as applied herein

TABLE 2-d

SOUNDNESS REQUIREMENTS FOR COARSE AGGREGATE

Test (AASHO Standard)	Cycles	Maximum Allowable Weight Loss (percent)	Number of Agencies
Sodium sulfate	5	12	8
	5	15	3 1/
	5	10	2
	5	8	1
	5	20	1
	10	7	1 2/
Magnesium sulfate	5	12	4
	5	8	1 3/
	10	12	1 2/
Freeze-thaw	16	10	1
	50	15	1 1/
	15	8	1 3/
	Non-standard freeze-thaw		2
Not specified			21
No reply or incomplete reply			5
Total agencies			50

1/ Sodium sulfate and freeze-thaw alternate combination, one agency.

2/ Sodium sulfate and magnesium sulfate alternate combination, one agency.

3/ Magnesium sulfate and freeze-thaw alternate combination, one agency.

denotes the coarsest of a combination of two or more aggregates used to form the total aggregate portion of the bituminous concrete mixture. Two agencies reported their total aggregate gradation under coarse aggregate, but in the interest of uniformity, their reported gradations have been tabulated only as total aggregate. For the agencies listing separate gradation requirements for coarse and fine aggregates, the No. 4, No. 8 and No. 10 sieves are most frequently considered to be the separating sieves between the two sizes.

Seventeen of the 50 reporting agencies include gradation limits in their specifications for the coarse aggregate that is used in binder-course mixtures. Two of the 50 reporting agencies state that a binder course is not used, and the remainder report that they do not specify gradation limits for coarse aggregate. Eighteen agencies, including all of the 17 that specify gradation limits for binder-course coarse aggregate, specify gradation limits for surface-course coarse aggregate. Four of the 17 agencies specifying gradation limits for both binder- and surface-course coarse aggregates specify the same limits for both. The others specify generally coarser materials for use in the binder course.

TABLE 2-e

LIMITATION OF DELETERIOUS MATERIALS IN COARSE AGGREGATE

Material	Number of Agencies Specifically Limiting Material	Number of Agencies Allowing No Amount	Number of Agencies Having Percentage Limitation	Range of Percentage Limitations (>0)
Organic, vegetable, roots, etc.	11	7	4	0.03-1
Clay, loam	13	9	2	1
Clay lumps	18	3	15	0.05-2
Finer than No. 200 sieve; or decanted	13	0	11	0.05-4
Soft	16	1	13	2-10
Coal, lignite	9	0	8	0.25-1
Shale	16	1	11	0.5-12 1/
Elongated	10	5	4	2-15
Other (cinders, shells, schist, etc.)	7			
Undifferentiated	14	8	2	2-5
No specific limitation	9 agencies			
Total reporting	48 agencies			

1/ 12 percent of total mixture

All but three of the agencies specifying coarse-aggregate gradation limits specify percentages by weight passing a series of sieves. The remaining three specify percentages retained.

Assuming that some agencies permit as much as 10 percent oversize material to be retained on what is considered to be the nominal maximum-size sieve, the distribution of agencies according to specified nominal maximum size of coarse aggregate is as shown in Table 2-f. It will be seen from the table that, on this basis, the nominal maximum size of coarse aggregate most frequently specified for binder-course mixtures are the 1-in. size (7 agencies), and the ¾-in. size (6 agencies). For surface-course mixtures,

TABLE 2-f

NOMINAL MAXIMUM SIZE OF COARSE AGGREGATE SPECIFIED

Nominal Maximum Sieve Size (inches)	Number of Agencies Binder-Course Coarse Aggregate	Number of Agencies Surface-Course Coarse Aggregate
1 1/2	1	
1 1/4	1	
1	7	1
7/8	1	
3/4	6	3
5/8	1	3
1/2		10
3/8		1
Total agencies	17	18

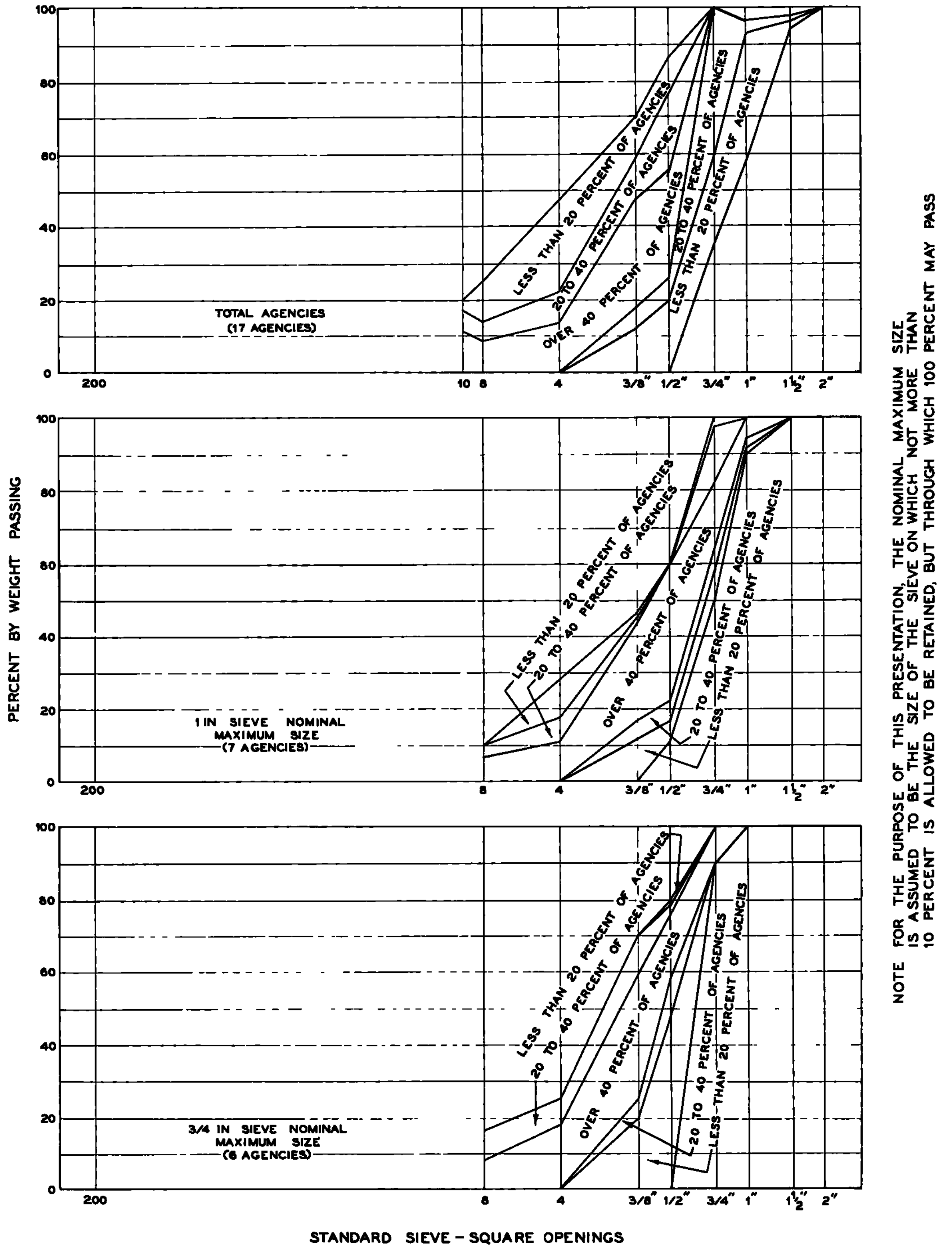


Figure 3. General acceptability with respect to gradation of coarse aggregate for binder-course mixtures.

the nominal maximum sizes of coarse aggregate most frequently specified are the ½-in. size (10 agencies), and the ¾-in. and ⅝-in. sizes (each by 3 agencies).

Gradation-limit envelopes for the coarse aggregates were prepared in the same

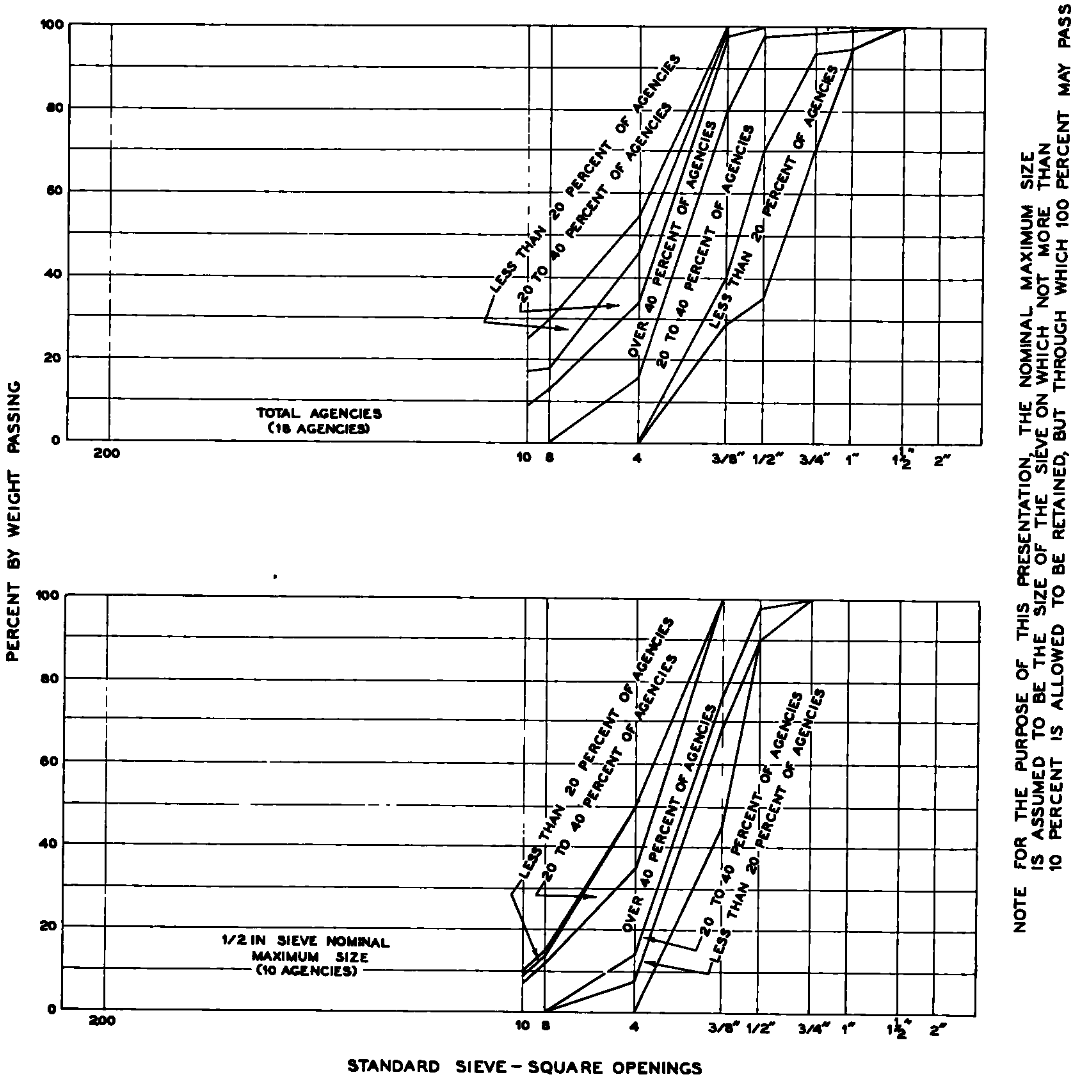


Figure 4. General acceptability with respect to gradation of coarse aggregate for surface-course mixtures.

manner as that previously described for the fine aggregate. Frequency-of-acceptance curves were also prepared in the same manner as that previously described. The usage envelopes that were then developed are shown in Figure 3 for binder-course coarse aggregate and in Figure 4 for surface-course coarse aggregate. The separation of agencies into groups of less than 20 percent accepting, 20 to 40 percent accepting, and over 40 percent accepting is that which was also used for the fine aggregates and has been discussed previously.

For binder-course coarse aggregate, usage envelopes were prepared for the entire group of reporting agencies, for the agencies indicating a nominal maximum size of 1 in. for coarse aggregate, and for the agencies indicating a coarse-aggregate nominal maximum size of ¾ in. (Fig. 3). For the surface-course coarse aggregate, usage envelopes were prepared for all of the agencies grouped together, and for the group of agencies indicating the use of a nominal maximum size of ½ in. for coarse aggregate (see Figure 4). It will be seen from the usage envelopes that there is a reasonably good agreement among agencies in the matter of gradation of the coarse aggregates. The agreement is particularly good when the nominal maximum size of coarse aggregate is taken into consideration.

Other Requirements

A few agencies listed requirements in addition to those concerning which information was specifically sought. Some of the requirements upon which information was volunteered appear to apply more directly to total aggregate rather than to coarse aggregate alone. The diversity of these miscellaneous requirements is so great as to render summarization impractical. They are listed individually in Appendix Table 2.

MINERAL FILLER

Kinds of Material

Forty-four of the 50 reporting agencies list one or more specific materials that their specifications permit for use as mineral filler. Though not stated specifically, the mineral-filler requirements listed by four additional agencies indicate that their filler would be soil fines or the fine fraction usually present in their granular mixtures. Two agencies state that they require no mineral filler.

The filler materials that are most frequently specified, and the number of agencies specifying them, are listed in Table 3-a. It will be noted that limestone dust and portland cement are the most frequently specified of the mineral-filler materials, followed by mineral dust, stone dust and "inert mineral matter." Seven of the agencies listing mineral dust or stone dust do not list limestone dust, so it may be presumed that their more general terms of "stone dust" and "mineral dust" would not preclude the use of limestone dust.

Other materials specifically mentioned by more than one agency as receiving use as mineral filler include hydrated lime, flyash, natural soil, basalt rock dust and shell dust. No more than four agencies mention any one of these materials.

Gradation

Forty-three of the 50 agencies report specifying gradation limitations for the mineral filler. Fourteen of these have requirements identical to those listed in AASHO Specification M 17-42. One of the 14 has additional requirements in the subsieve area as well. The gradation requirements of AASHO Specification M 17-42 are as follows:

Passing No. 30 sieve	100 percent
Total passing No. 80 sieve, not less than	95 percent
Total passing No. 200 sieve, not less than	65 percent

The gradation specifications of all but four of the remaining 29 agencies define material generally similar to that defined by the AASHO specification. The most frequent variations from the standard specifications lie at the No. 80 and No. 200 sieves. Twenty-two of these latter agencies have either eliminated the requirements at the No. 80 sieve or have changed the requirements in such a way as to permit a somewhat greater amount of material (about 5 percent) to be retained on this sieve. Thirteen agencies have reduced the allowable amount to be retained on the No. 200 sieve by raising the lower limit on this sieve from 2 to 15

TABLE 3-a

MATERIALS SPECIFIED FOR USE AS MINERAL FILLER

Material	Number of Agencies
Limestone dust	36
Portland cement	37
Mineral dust	11
Stone dust	10
Inert mineral matter	10
Other	12
Total agencies	44

percentage points above the AASHO specification of not less than 65 percent required to pass the No. 200 sieve.

Seven agencies, including one with the M 17-42 gradation requirement, have placed limitations on size fractions finer than the No. 200 sieve, including both sieve and sub-sieve sizes.

Other Requirements

Only a few specified requirements in addition to those concerning the kind and gradation of material to be used as mineral filler were mentioned by the reporting agencies. A few (4) mention requirements dealing with the plasticity of the material, particularly where natural soil or the aggregate fines are considered as mineral filler. One agency specifies that the filler be non-plastic and non-hydrophilic.

ASPHALT CEMENT

All of the reporting agencies indicate that the asphalt cements (prepared from petroleum) used in their bituminous-concrete mixtures are controlled almost entirely through the use of standard AASHO tests. The specification requirements covering the asphalt cements are also very similar or identical to those of the AASHO standard specifications (Designation: M 20-42).

TABLE 4-a

PENETRATION GRADES OF ASPHALT CEMENT REPORTED SPECIFIED FOR BITUMINOUS-CONCRETE MIXTURES

Penetration Grade or Grades	Number of Agencies
61-70	1
60-70, 70-85	1
60-70; 70-85; 85-100	1
60-70; 85-100	4
60-70, 85-100, 100-120	1
70-85	3
70-80, 85-100	2
70-85; 85-100	3
71-80, 85-100, 150-200	1
85-100	23 1/
85-100, 100-120	2
85-120	1
85-100; 100-120, 120-150	1
85-100; 121-150	1
100-120; 120-150	1
120-150	2 2/
120-150, 150-200	1
150-200	1
Total agencies	50

1/ Includes two agencies reporting 86-100 penetration

2/ Includes one agency reporting 121-150 penetration

Penetration Grades

The AASHO penetration grade, or the various combination of AASHO grades, reported as specified for asphalt cement for bituminous-concrete mixtures are shown in Table 4-a. The data are further summarized in Table 4-b.

Referring to Table 4-a, it will be noted that for the agencies reporting usage of a single penetration grade, far more use the 85-100 grade than any other single grade. Twenty-three agencies report the 85-100 penetration as the grade they use, while no more than three agencies indicate that usage is confined to any other single penetration grade. The lowest

TABLE 4-b

SUMMARY OF USE OF PENETRATION GRADES OF ASPHALT CEMENT IN BITUMINOUS-CONCRETE MIXTURES

Penetration Grade	Number of Agencies
60-70 (or 61-70)	8
70-80 (or 71-80)	3
70-85	8
85-100 (or 86-100)	40
100-120	6
120-150 (or 121-150)	6
150-200	3
Total Agencies	50

grade reported used was 60-70 penetration, and the highest was 150-200 penetration.

Of the 20 agencies that consider their use of more than one penetration grade of asphalt to be sufficient to justify mention, 12 indicate that the grade selected for use is based on the anticipated traffic. Traffic was usually described as light and heavy, or light, medium and heavy. The lower penetration grades are reported to be used when traffic is expected to be heavy. Only one agency provided information in the form of definite traffic figures that determine the penetration grade to be used. This particular agency uses 70-80 penetration-grade asphalt cement where over 5,000 vehicles per day are expected, and 85-100 penetration where a lesser volume is expected.

Considering the number of agencies giving at least some usage to the various penetration grades, it will be seen from the summary of Table 4-b that more agencies make at least some use of 85-100 penetration-grade asphalt cement than of all the other grades combined.

Total Bitumen

Thirty-three of the 50 reporting agencies require a total bitumen content (soluble in carbon disulfide) for asphalt cement of not less than 99. 5 percent. This is the AASHO standard requirement. Four agencies have a total bitumen requirement of 99. 0 percent by this test, and 13 have no requirement based on this test. All of the latter group have a requirement based on the test for the proportion of bitumen soluble in carbon tetrachloride.

Bitumen Soluble in Carbon Tetrachloride

Only 20 ot the 50 reporting agencies have a requirement based on the AASHO standard test for the proportion of bitumen soluble in carbon tetrachloride. As previously stated, 13 of these do not have a requirement based on the standard test for total bitumen (soluble in carbon disulfide). Of the 20 using the carbon tetrachloride procedure, 10 require a proportion of bitumen soluble in carbon tetrachloride of not less than 99. 0 percent (the AASHO standard), 9 require the proportion to be not less than 99. 5 percent, and one agency has a requirement of not less than 99. 65 percent.

Ductility

The AASHO standard specifications for ductility for asphalt cement require a ductility by the standard test of not less than 100 cm for grades 85-100 and higher, and of not less than the numerical value of the penetration for grades of 70-85 and lower.

All of the reporting agencies have ductility requirements based on the standard test. Of the 45 agencies listing requirements for penetration grades of asphalt of 85-100 and higher, all but two use the standard ductility requirement of not less than 100 cm. One of the latter two has a requirement of not less than 60 cm (for 85-120 penetration), and the other has a requirement of not less than 90 cm (for 85-100 penetration). Of the 14 agencies listing ductility requirements for penetration grades of 70-85 and lower, 11 show a required ductility of not less than 100 cm, only two require the ductility that is specified by the AASHO standard, and one requires a ductility of not less than 70 for 61-70 penetration.

Flash Point

Twenty-four of the 50 reporting agencies require a flash point of not less than 347 F, as required by the AASHO standare specifications. The remaining 26 agencies specify higher flash points. Deviations from the standard AASHO requirements were in some instances of

TABLE 4-c

FLASH POINT SPECIFIED FOR ASPHALT CEMENT

Flash Point	Number of Agencies 1/
Not less than 347°F. (AASHO standard)	24
Not less than 350°F.	2
Not less than 400°F.	5
Not less than 425°F.	3
Not less than 450°F.	15
Others (ranging from 374°F. to 500°F.)	5
Total agencies	50

1/ Three agencies vary flash point according to penetration grade.

TABLE 4-d

REQUIREMENTS FOR
PENETRATION OF RESIDUE FROM EVAPORATION
LOSS COMPARED TO PENETRATION BEFORE HEATING

Penetration Grade	Penetration Relationship (not less than, percent) 1/	Number of Agencies	AASHO Standard Requirement
60-70 (or 61-70)	70	2	
	75	3	
	80	1	
70-80	60	1	Not less than 75 percent
	65	1	
70-85	60	1	
	70	4	
	75	3	
85-100 (or 86-100)	50	2	
	60	4	
	65	14	
	70	6	
	75	9	
	80	2	
	80.25	1	
100-120	60	2	Not less than 65 percent
	65	1	
	70	1	
	75	1	
	80.25	1	
120-150 (or 121-150)	60	1	
	65	2	
	70	2	
	80.25	1	
150-200	65	2	
Total agencies		49	

1/ Penetration of residue from evaporation loss compared to penetration before heating.

considerable magnitude. Fifteen agencies specify a flash point of not less than 450 F, and the requirements of one agency go as high as 500 F. A complete summary of general flash-point usage appears in Table 4-c.

Among the 40 agencies reporting the use of 85-100 penetration grade asphalt cement, 19 reported a flash-point requirement of not less than 347 F, and 12 report a requirement of not less than 450 F for this particular grade.

Loss on Heating

Forty-two of the 50 reporting agencies specify the AASHO standard loss-on-heating requirement of not more than 1.0 percent. One of these agencies specifies this requirement for 85-100 penetration grade, and specifies a loss of not more than 2.0 percent for 121-150 penetration-grade asphalt. Three other agencies specify a loss on heating of not more than 2.0 percent, two specify not more than 0.75 percent, and one each specify the loss on heating to be not more than 0.2, 0.5, and 3.0 percent.

Penetration of Residue

The AASHO standard specifications require that the penetration of residue from evaporation loss, compared to penetration before heating, be not less than 65 percent for grades of 85-100 and higher, and not less than 75 percent for grades of 70-85 and lower (using standard tests). While all but one of the reporting agencies report a specification concerning the penetration loss, the permissible values vary considerably, and departures from the AASHO standard are frequent. This will be seen from an inspection of Table 4-d where the information received concerning the requirement is summarized. Six of 16 reported requirements for penetration grades of 70-85 and lower are the AASHO standard requirement. Nineteen of 52 reported requirements for penetration grades of 85-100 and higher are the standard requirement. For agencies using requirements other than standard, the trend appears to be toward lower-than-standard percentage values where standard minimum is 75 percent, and toward higher-than-standard percentage values where standard minimum is 65 percent.

Spot Test

The use of the spot test is listed as optional in the AASHO standard specifications (M 20-42) for asphalt cement. When specifications based on the spot test are to be included, the standard specifications require that the type of solvent to be used be stated (standard naphtha, naphtha xylene, or heptane xylene), and for the xylene solvents, the percent of xylene to be used. A negative spot condition is required under all three conditions of testing.

Thirty-six of the 49 agencies that answered the questions regarding the spot test requirements indicate that a requirement based on one of the three tests and following AASHO standard requirements is included in their specifications. Reported usage of the spot test is shown in Table 4-e. It will be noted from the table that specifications

TABLE 4-e

ASPHALT CEMENT REQUIREMENTS BASED ON THE STANDARD SPOT TEST

Test	Requirement	Percent Xylene	Number of Agencies
Standard naphtha	Negative		25
Naphtha xylene	Negative	10	2
Naphtha xylene	Negative	15	3
Heptane xylene	Negative	35	6
No requirement specified			13
Not reported			1
Total agencies			50

TABLE 4-f

SPECIFIED REQUIREMENTS BASED ON TESTS OF ASPHALT RECOVERED FROM BITUMINOUS CONCRETE MIXTURES

Asphalt recovered by:	Agency A ASTM D 762-47T	Agency B ASTM D 762-49	Agency C Abson Method	Agency D 1/
Penetration, percent of original not less than	50	65	50 2/ 60 3/	65
Ductility, cm., not less than	40 4/	60 4/	50 4/	100 4/
Ash, percent, less than		1.0		
Flash point, °F., not less than				400
Loss on heating, percent, not more than				1.0
Penetration of residue from evaporation loss, compared to penetration before heating, percent, not less than				65
Total bitumen (soluble in carbon disulfide), percent, not less than				99.0
Spot test, naptha xylene solvent, 15 percent xylene				Neg.

1/ Extraction by method of AASHO T 58-30

2/ For penetration grade 75-100

3/ For penetration grades 40-75

4/ Ductility of original asphalt required to be not less than 100 cm.

are based much more frequently on the standard naphtha solvent than on the other two solvents.

Specific Gravity

Seven agencies report a specification requirement concerning a minimum specific gravity for asphalt cement. All but one of the other agencies answering the question concerning specific gravity (42 agencies) report having no requirement. The one additional agency with a requirement concerning specific gravity requires that there be no variations greater than plus or minus 0.02.

For the seven agencies that have a minimum specific-gravity requirement, four require that the specific gravity of the asphalt cement be at least 1.01. One of these agencies limits the 1.01 minimum to 85-100 penetration-grade asphalt, and reduces the minimum to 1.00 for 60-70 penetration-grade asphalt. One other agency has a minimum specific gravity requirement of 1.01 (85-100 penetration), another has a minimum requirement of 1. 004, (85-100 penetration) and another requires that the specific gravity lie between 1. 00 and 1. 04 (85-120 penetration).

An inquiry was made as to the specific gravity of the asphalt cement normally used. Forty-five of the agencies replied to this inquiry. However, the manner in which the question was worded brought a variety of answers that were not subject to precise summarization. Generally speaking, the replies appear to indicate that most of the asphalts being used have specific gravities between 1. 00 and 1. 03. A specific gravity of about 1. 02 appears to be an approximate central value. Only two or three agencies indicate that their specific gravities fall below 1. 00 (a low of 0. 98 was reported), and only nine agencies report values higher than 1. 03 (with a top of 1. 05).

Recovered Asphalt

Four agencies report that they have set up specification requirements based on tests of asphalts recovered from bituminous-concrete mixtures. Two of these agencies indicate that the asphalt is recovered by the Modified Abson Method of ASTM D 762 (one stated, D 762-49, and the other D 762-47T), and one agency simply reports using the "Abson Method." The fourth agency indicates that extraction is made by the method of AASHO T 58-30, but does not indicate the method of recovery.

The tests that are conducted on the recovered asphalt, and the specified limiting values placed on the characteristics measured by the four agencies, are shown in Table 4-f. It appears that the most important of the tests are the penetration and ductility tests. For the four agencies reporting, the penetration of the recovered asphalt is not permitted to be less than from 50 to 65 percent of the penetration of the asphalt as originally tested. Three of the agencies indicate that they will permit the ductility to fall to from 40 to 60 cm (the ductility requirement for the original material being not less than 100 cm). The fourth agency requires the ductility value to be not less than 100 cm both before and after recovery.

The questions that were asked regarding the general practice in recovering and testing recovered asphalt were unfortunately not well worded, and the tabulations may not entirely reflect actual practice. For example, it was asked: "Do you regularly measure the characteristics of recovered asphalt from bituminous mixture samples?" Seven agencies replied affirmatively, and ten, though indicating that they did not test recovered asphalt regularly, volunteered the information that they did do a limited amount of testing. Thirty-one agencies replied negatively to the question, but volunteered no information as to whether a limited amount of testing is done. It is suspected that there are among the 31 several that do a limited amount of testing of the characteristics of recovered asphalt.

The question concerning the method used to extract and recover the asphalt from bituminous-concrete mixtures was apparently equally confusing. Eighteen agencies referred to ASTM Designation D 762, four referred to ASTM Designation D 1097 (two of these referring to D 762 also), and 15 referred to AASHO Designation T 58 (with four of these stating that the test was used for extraction only). Other methods mentioned, none by more than one or two agencies, were the Abson, the Oliensis, the Bessow, and modifications of ASTM D 762 and AASHO T 58. It appears from the answers that some of the agencies, though not so stating, intended their answers to refer only to extraction methods.

Other Specification Requirements

A few agencies volunteered information on asphalt-cement requirements in addition to those previously discussed. Several mentioned the requirement contained in the AASHO standard specifications to the effect that the asphalt shall be free of foam when heated to 347 F. Others undoubtedly have the same requirement but did not furnish the information since no specific question was asked concerning this requirement. Five agencies reported a softening point requirement. One agency reported a requirement that the ductility at 39. 2 F shall not be less than 10 percent of the penetration, and another reported a requirement that the ductility at 39. 2 F shall not be less than 30 percent of the penetration value.

In answer to the question of whether the thin-film oven test was required by specification, all agencies answered in the negative.

COMPOSITION OF BITUMINOUS-CONCRETE MIXTURES

All of the agencies that replied to the questionnaires (50) indicate that they use mixtures of a composition that they term "bituminous concrete." One agency reports that it confines its use of bituminous concrete to the surface course only. Three agencies indicate that their composition limits for binder-course and surface-course mixtures are the same. There appears to be reasonable agreement among agencies as to the sort of a mixture that should be termed "bituminous concrete." In general, the prescribed gradation limits provide for a mineral aggregate that is continuously graded from coarse to fine. All of the agencies use asphalt cement, though of various penetrations, as the binding medium. The reported asphalt-cement contents of the mixtures do not differ widely.

Gradation of Mineral Aggregate

Specifications outlining the general limits of particle-size distribution are expressed in one of three forms: (1) maximum and minimum percents by weight of material to pass each of a given series of sieves; (2) maximum and minimum percents by weight of material to be retained on each of a given series of sieves; and (3) maximum and minimum percents by weight of material to pass each and to be retained on the next finer of a series of sieves. For binder-course material, 48 agencies reporting, 33 use the percent-passing method, 12 use the passing-and-retained method, and 3 use the percent-retained method. For surface-course material, 50 agencies reporting, 32 use the percent-passing method, 15 use the passing-and-retained method, and 3 use the percent-retained method.

All of the agencies that specify the sieve gradation limits for aggregate for mixtures on a "percent passing" or "percent retained" basis base the percentage requirements on the total weight of aggregate. With two exceptions, the agencies that specify the sieve gradation limits on a "passing-and-retained" basis base the aggregate percentage requirements on the total weight of the mixture, inclusive of the bitumen. The other two use the total-aggregate basis.

All but five of the reporting agencies specify the bitumen content of mixtures as a percentage of the total mixture. The remaining five, all of which use either the "percent-passing" or "percent-retained" methods in specifying the aggregate, specify the bitumen content of mixtures as a percentage of the total aggregate.

Any of the three methods is satisfactory for outlining the general limits of gradation for mineral aggregates. The range between the maximum and minimum limits for any sieve, or between consecutive sieves if the passing-and-retained method is used, can be broadened or narrowed depending on the general range of gradations that, if met, will produce a satisfactory mix.

The degree of general control is further influenced by the number of sieves that are used to specify the grading of the aggregate. The greater the number of sieves, the greater will be the degree of control that can be exercised over the material through the entire range of gradation. For the reporting agencies, 12 use a total of 7 sieves to specify binder-course materials, and 24 use 7 sieves to specify surface-course materials. Other numbers of sieves used with considerable frequency for specifying binder-course materials are 9 (by 8 agencies), and 5 (by 7 agencies). Twelve agencies use 8 sieves for specifying surface-course materials. The number of sieves reported in use for specifying binder-course materials ranged from 2 to 13, and for surface course mixtures from 3 to 10.

For surface-course mixtures, a small amount of mineral dust passing a No. 200 sieve is almost always required. Only two of 49 agencies reporting requirements on the No. 200 sieve for their highest type of asphaltic-concrete surface-course mixtures indicate that a mixture with no particles passing the No. 200 sieve would be acceptable. One agency does not include in its specifications a sieve finer than the No. 100. However, this agency requires a certain amoung of the material to pass the No. 100 sieve.

For binder-course mixtures, a small amount of dust passing the No. 200 sieve is always permitted, but not always required. Twenty-four of 48 agencies reporting on binder-course requirements do specify that a small amount of material must pass the No. 200 sieve.

Considerable variation occurs in the maximum size of the mineral aggregate that is permitted in asphaltic concrete by the reporting agencies. As would be expected, most of the agencies use a smaller size aggregate in surface-course mixtures than in binder-course mixtures. Usage with respect to the maximum size of aggregate is shown

TABLE 5-6-a

FREQUENCY OF USE OF VARIOUS MAXIMUM SIZES FOR MINERAL AGGREGATE

Sieve Size (inches)	Number of Agencies		
	100 Percent to Pass 1/	95 Percent or More to Pass	90 Percent or More to Pass
	Binder-Course Aggregate (48 agencies)		
2	2	-	-
1 3/4	1	2	1
1 1/2	5	4	5
1 1/4	12	9	2
1	14	13	16
7/8	2	2	2
3/4	10	15	18
5/8	1	1	1
1/2	1	2	3
	Surface-Course Aggregate (50 agencies)		
1 1/4	2	-	-
1	11	6	4
3/4	13	14	13
5/8	4	4	4
1/2	20	24	26
3/8	-	2	3

1/ Agencies not stating a 100-percent-passing requirement are placed in the sieve-opening group next above the maximum size listed in specifications.

in Table 5-6-a. For the purpose of this discussion, three separate groupings are shown in the table. The first grouping is based on the maximum size of sieve that all aggregate is required to pass. For those agencies that do not set a top size that all material must pass, the next largest standard sieve size above the top size mentioned in their specifications is assumed as the sieve through which all material must pass. As an example, an agency requiring that 95-100 percent of aggregate must pass a 1-in. sieve, but having no requirement based on a sieve with larger openings, would be placed in the 1¼-in. top-size group. The second grouping is based on the assumption that any agency specifying that at least 95 percent pass a sieve, but accepting up to 100 percent passing considers that sieve opening to be the nominal top size of the material they use, and permits up to 5 percent oversize material. The third grouping is similar to the second grouping except that the assumption is made that any agency requiring at least 90 percent to pass a specified sieve, but accepting up to100 percent passing the sieve, considers the openings of that particular sieve to be the nominal top size of the aggregate. It will be noted from Table 5-6-a that, for binder-course materials, the most frequently specified top sizes by the first method of grouping are the 1¼-in., 1-in., and ¾-in. sizes. For the second and third methods of grouping, the 1-in. and ¾-in. sizes predominate. For surface course mixtures, the ¾-in. and ½-in. top sizes predominate regardless of the method of grouping, although by the first method of grouping a considerable number of agencies are also shown to use a 1-in. size group.

As was indicated earlier in the report in the sections concerning the fine and coarse aggregates, the comparisons involving the maximum size of aggregate that are made in the gradation analyses in this report are made with the assumption that the nominal maximum size is the sieve size through which at least 90 percent of the material is required to pass, but through which up to 100 percent is allowed to pass. In other words, it is assumed that some agencies are specifying that material containing up to 10 percent of particles larger than the nominal size is acceptable. This assumption is not based on specific information that was received from the reporting agencies. However, grouping of gradation limits based on this assumption provided the best showing of uniformity of practice among agencies.

The size of the mineral-aggregate particles and the distribution of sizes from coarse to fine are recognized by all to have an important bearing on the performance of bituminous concrete. A continuous grading in sizes of particles from coarse to fine, with no great concentration at any one particle size and with no absence of particles at any size, is generally considered productive of the best bituminous concrete. Because of the influence of angularity, roundness, and probably other considerations, there is apparently no ideal gradation that is suitable for all aggregates. And if there were, practical considerations would require that a certain amount of deviation from the ideal be permitted to keep costs within reason.

Each agency exercises a control of gradation and uniformity that it considers consistent with its needs and ability to financially fulfill these needs. This brings about a certain amount of variation in the degree of control that is exercised over the gradation of the mineral aggregate.

All of the reporting agencies include in their general specifications prescribed sieve-size limits for the mineral aggregates to be contained in bituminous-concrete surface-course mixtures. All but one of the agencies using bituminous-concrete binder-course mixtures include prescribed sieve-size gradation limits for the binder-course aggregate in their general specifications. The single exception reports that special provisions regarding sieve-size limits are written to fit aggregates available in the area of construction projects where the binder-course mixture is to be used.

Besides controlling the gradation of the mineral aggregate, it is considered desirable by most agencies to also control the uniformity of grading of the aggregate from coarse to fine. Two different methods are generally used to accomplish this purpose. The first of these is to use the passing-and-retained method of specifying gradation limits. By this method considerable assurance is offered that there will not be an excess or deficiency of particles between successive sieves. As stated previously, 12 agencies use the passing-and-retained method of specifying mineral aggregate for binder-course mixtures, and 15 use the passing-and-retained method for surface-course mixtures. One of these agencies requires, in addition, a prescribed total percentage of material to pass the No. 10 sieve for both binder- and surface-course mixtures. Another requires a prescribed percentage to pass a No. 6 sieve for surface-course mixtures.

For the agencies specifying gradation limits by the percent-passing method, a few (six) attain increased uniformity by specifying a certain minimum percentage of material to be retained between successive sieves. Four of these require that at least four percent of the material be retained between successive sieves. The other two require that at least five percent be retained between successive sieves smaller than the ⅜-in. sieve.

Additional uniformity obtained through the use of job-mix formulas and tolerated variations therefrom will be discussed later.

Of considerable interest is comparison of the gradations of the mineral aggregates specified by the reporting agencies. To make such a comparison, it is first necessary to place all of the prescribed gradations on a common basis. As explained earlier in the report the percent-passing basis has been chosen for making this comparison because of the more common use of this method, and also because of the greater ease with which gradations prescribed by this method may be plotted for visual examination. As is usually done, charts on semilogarithmic paper with a percentage scale on the vertical axis and the sieve sizes in logarithmic scale on the horizontal axis have been used for the comparisons.

Percent-retained limits were converted to percent-passing limits by simple sub-

TABLE 5-b

SIEVE-SIZE GRADATION LIMITS FOR ALL AGENCIES
CONVERTED TO COMMON BASIS - BINDER-COURSE MIXTURES

Agency	Indicated Limiting Percentages by Weight of Total Aggregate Permitted to Pass Sieve															
	2 in	1 3/4 in	1 1/2 in	1 1/4 in	1 in	7/8 in	3/4 in	5/8 in	1/2 in	3/8 in	No 4	No 10	No 20	No 40	No 80	No 200
Ala					100		75-100		55-95	47-87	35-57	24-50	17-36	12-30	4-15	2-6
Ariz							Variable									
Ark					100		80-95		60-80	54-72	40-55	25-40	17-32	10-25	5-15	0-5
Calif					100		95-100		75-90	0-75	40-55	[illegible]	17-27	11-19	7-13	3-5
Colo				100	90-100		75-92		60-80	[illegible]	32-43	25-34	21-29	15-24	-17	1-5
Conn				100	90-100		72-90		45-75	41-60	29-44	15-35	-	-	-	-
Del				100	90-100		70-100		50-80	40-65	25-45	20-35	15-25	10-20	-15	5-10
D C					100		90-100		60-83	40-60	20-40	15-35	11-27	6-21	4-13	0-5
Fla			100	94-100	86-100		80-100		[illegible]	60-80	40-60	15-35	-	-	-	-
Ga					100		95-100		63-85	40-75	30-57	16-38	13-30	7-23	2-12	0-5
Idaho							100		80-100	57-82	43-54	30-46	23-32	17-25	10-17	3-9
Ill				100	95-100		75-89		48-73	44-63	34-54	21-36	-	-	-	-
Ind					100		79-100		48-95	37-85	10-53	9-49	-34	4-23	1-10	0-3
Iowa					100		90-100		80-92	67-77	47-[illegible]	35-53	24-39	1-30	-20	3-10
Kans					100		85-100		72-92	55-85	40-75	23-50	6-27	2-14	2-11	2-7
Ky					100		90-100		59-[illegible]	55-80	35-50	10-33	10-25	4-18	0-11	0-5
La				100	90-100		75-100		55-80	49-74	35-50	25-40	16-33	15-30	6-16	2-
Maine							100		78-100	[illegible]	25-40	13-38	15-35	-25	-	-
Md				10	93-10		-95		71-[illegible]	1-77	40-54	22-35	13-25	6-18	5-13	2-8
Mass					100		100		4-	-53	27-52	14-41	11-32	7-1	3-11	1-4
Mich				100	94-100		5-100		72-	3-	41-1	14-3	-	-	-	-
Minn							100		5-93	71-83	40-60	25-	18-31	[illegible]	7-14	0-
Miss					100		85-100		-90	62-85	45-67	40-53	31-47	-4-3	10-22	-10
Mo			100	97-100	95-100		71-100		33-59	2-	17-79	11-	[illegible]	7-46	4-4	2-9
Mont									100	77-100	25-75	1-	11-4	-34	-19	0-5
Nebr					10		-100		1-97	70-95	[illegible]	[illegible]	10-34	14-2	-17	5-10
Nev				10	-100		0-		-70	[illegible]	7-0	-3	19-31	15-25	-1	2-
N H							100		0-90	0-60	30-55	22-42	11-32	10-27	-	-
N J				100	-100		-100		30-7	-3	-1	-5	-38	5-31	-1	0-5
N Mex							100		-100	[illegible]	30-0	20-4	1-3	1-9	7-21	3-12
N Y				100	95-100		70-		32-63	3-3	7-30	3-13	0	0	0	0
N C					100		90-100		52-84	4-7	33-63	1-4	12-35	8-20	4-16	0-5
N Dak							100		90-100	83-93	60-77	[illegible]	10-47	13-3	6-20	0-6
Ohio							Binder course not used									
Okla			100	9-100	90-100		0-92		5-0	57-73	40-5	30-4	24-37	20-30	10-20	1-7
Oreg							100		4-100	72-7	45-57	23-45	16-33	10-23	-15	3-
Pa			100	9-100	90-100		70-90		40-75	34-	20-45	14-32	7-23	4-7	2-11	0-5
R I				100	94-100		85-100		71-87	52-78	39-57	12-31	-	-	-	-
S C							100		97-100	0-95	30-6	15-30	-	-	-	-
S Dak					100		90-100		75-90	4-33	47-70	35-55	27-41	20-30	13-20	-10
Tenn			100	-100	2-100		9-5		62-76	5-70	43-5	13-43	22-30	14-21	4-10	-
Tex	100	97-100	64-95	7-9	[illegible]		43-70		23-8	1-4	11-6	7-52	7-49	7-43	4-27	1-11
Utah		100	9-100	-1	75-100		0-90		46-75	35-65	25-50	0-40	14-34	10-30	5-20	3-8
Vt							100		65-90	53-6	22-64	17-55	15-51	13-46	8-23	4-7
Va					100		95-100		74-88	60-80	40-0	0-40	14-28	9-21	3-10	-
Wash								100	90-100	70-89	40-	-40	17-35	11-32	4-20	1-
W Va	100	-100	95-100	7-94	74-86		60-75		43-60	30-50	20-40	1-31	6-21	4-14	2-8	0-4
Wis				100	95-100		63-3		65-90	55-0	40-5	-50	17-3	10-30	7-	3-12
Wyo							100		75-100	0-0	45-	-45	20-3	15-26	9-19	3-10
Ontario						100	75-94		54-80	40-68	30-50	1-4	9-37	5-25	2-11	0-5

TABLE 6-b

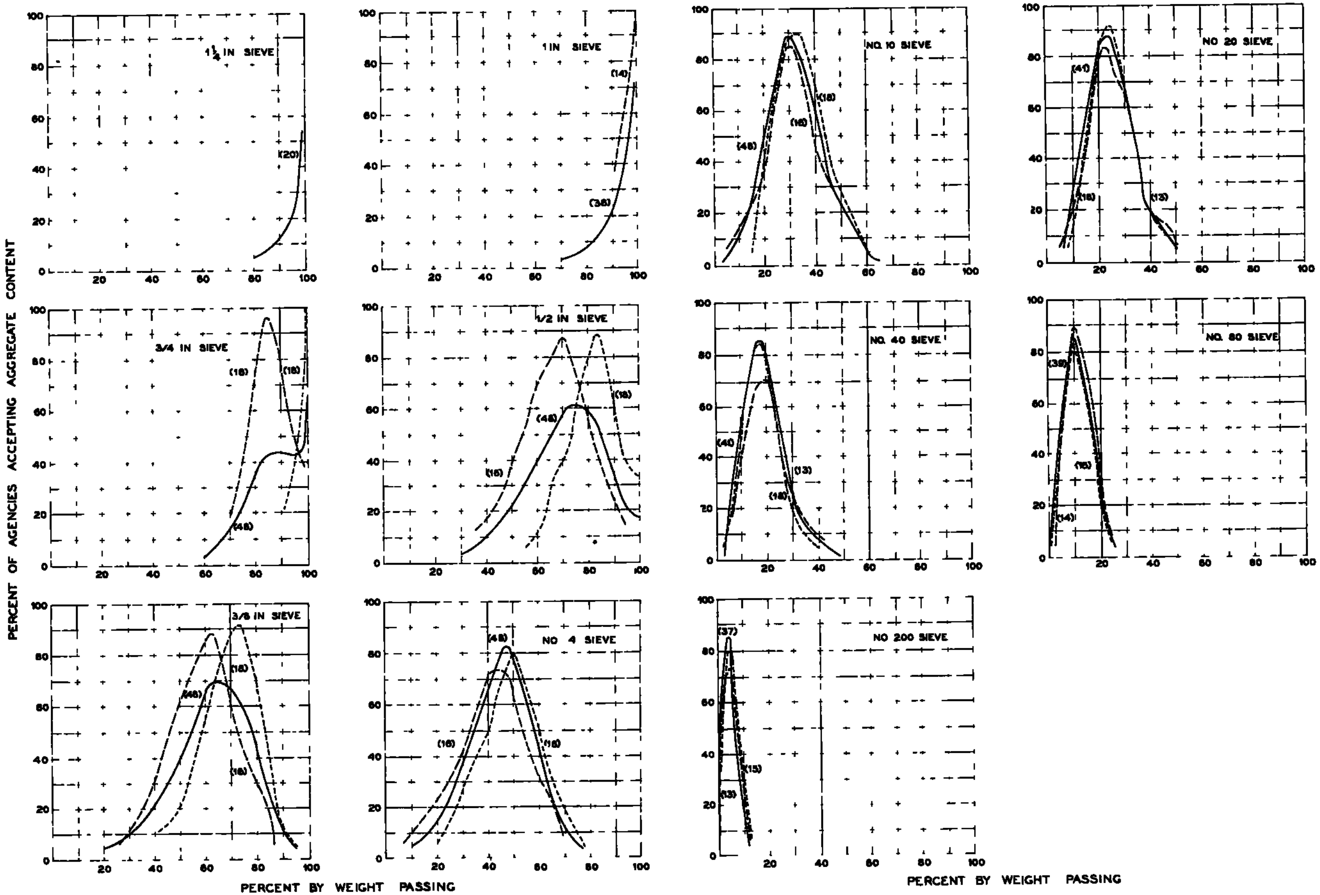
SIEVE-SIZE GRADATION LIMITS FOR ALL AGENCIES CONVERTED TO COMMON BASIS - SURFACE-COURSE MIXTURES

Agency	Indicated Limiting Percentages By Weight of Total Aggregate Permitted to Pass Sieve											
	1 1/4 in.	1 in.	3/4 in.	5/8 in.	1/2 in.	3/8 in.	No. 4	No. 10	No. 20	No. 40	No. 80	No. 200
Ala.		100	95-100		75-88	60-80	40-60	20-40	14-32	10-25	5-15	2-8
Ariz.		100	85-90		62-80	45-65	37-57	25-45	19-34	15-25	8-17	2-10
Ark.			100		87-100	77-88	55-75	40-55	26-41	15-30	9-20	4-10
Calif.		100	95-100		75-85	60-75	40-55	28-38	17-26	11-19	7-13	3-6
Colo.		100	90-100		70-85	61-75	40-52	29-38	24-33	19-27	13-21	4-8
Conn.	100	95-100	82-100		60-100	51-86	28-55	22-44	17-37	12-31	8-18	4-8
Del.				100	91-100	80-100	50-65	30-45	20-30	15-25	10-20	5-10
D. C.					100	80-100	55-80	40-75	23-50	10-30	3-15	2-8
Fla.					100	61-92	33-84	24-75	22-63	19-53	10-26	5-8
Ga.					100	95-100	60-80	44-61	30-46	20-38	11-23	5-10
Idaho				100	88-100	72-87	45-65	30-50	24-40	18-32	12-22	5-12
Ill.			100		95-100	78-92	42-73	27-62	25-57	22-46	15-23	4-9
Ind.					100	85-98	32-76	21-72	14-54	8-40	4-18	3-9
Iowa		100	98-100		80-92	67-87	47-61	34-53	23-40	17-30	8-20	3-10
Kans.		100	95-100		78-93	65-88	53-77	37-61	24-43	17-29	11-15	6-12
Ky.					100	85-100	50-70	31-48	15-34	6-24	1-12	0-5
La.			100		85-100	78-95	60-80	40-60	29-51	20-35	12-25	4-10
Maine					100	80-100	35-75	30-55	24-45	12-40	7-19	3-8
Md.		100	88-100		76-88	66-80	48-62	32-44	18-31	10-20	6-14	2-8
Mass.					100	87-100	58-73	31-57	21-52	15-34	9-17	4-6
Mich.				100	93-100	83-100	61-76	32-47	25-37	19-28	12-19	5-9
Minn.			100	98-100	87-93	70-85	50-65	35-50	24-38	15-30	8-16	4-8
Miss.					100	95-100	80-95	55-75	40-57	28-42	12-24	6-10
Mo.			100		97-100	71-100	29-78	22-71	18-60	15-52	9-30	4-11
Mont.			100		76-100	58-84	34-73	25-64	19-54	15-47	9-25	4-9
Nebr.		100	96-100		81-97	70-95	45-65	25-45	19-34	14-26	8-17	5-10
Nev.	100	95-100	81-92		60-80	52-69	37-51	28-38	24-32	20-27	13-20	5-11
N. H.					100	80-95	45-75	30-50	17-37	10-30	5-20	3-8
N. J.			100		85-100	74-100	26-78	19-73	18-67	14-54	7-26	4-9
N. Mex.			100		90-100	55-85	40-65	30-50	22-38	15-30	8-20	4-10
N. Y.		100	98-100		95-100	82-93	46-74	17-52	8-34	6-24	3-13	2-6
N. C.			100		95-100	79-90	42-68	22-57	17-50	14-44	6-22	2-9
N. Dak.			100		82-100	68-93	44-78	25-60	18-47	13-34	7-20	2-8
Ohio		100	95-100		74-93	43-86	24-75	23-67	13-47	7-30	2-16	0-5
Okla.			100		90-100	79-94	55-80	40-55	29-44	20-37	10-25	4-8
Oreg.			100		85-100	73-88	48-60	27-43	17-32	9-23	6-14	3-7
Pa.					100	80-100	45-72	28-52	16-34	9-24	3-13	2-8
R. I.					100	84-100	28-73	27-72	19-56	12-34	9-17	5-9
S. C.					100	75-97	58-75	42-60	36-52	25-35	15-25	5-12
S. Dak.		100	90-100		75-90	64-83	47-70	35-55	27-41	20-30	13-20	6-10
Tenn.					100	89-100	64-76	46-56	31-40	19-27	7-14	
Tex.				100	97-100	75-88	37-69	12-57	12-57	12-57	7-38	2-11
Utah					100	90-100	70-100	60-90	43-79	30-70	10-40	5-12
Vt.					100	61-92	46-84	24-75	22-63	19-53	10-26	5-8
Va.					100	80-100	50-70	35-50	21-36	10-25	3-15	2-10
Wash.				100	90-100	69-87	35-62	20-40	15-33	10-28	3-18	1-6
W. Va.					100	85-100	60-80	37-57	21-38	11-26	5-14	1-5
Wis.			100		95-100	75-100	45-85	30-55	22-44	15-35	10-25	5-12
Wyo.					100	84-100	50-70	30-50	23-39	18-31	12-20	5-10
Ontario					100	75-88	50-60	37-58	23-48	16-34	7-15	3-8

traction. Passing-and-retained limits were converted to percent-passing limits by the method described in the article "Plotting Aggregate Gradation Specifications for Bituminous Concrete," (Public Roads, April 1953).

In instances where the specified percentages are based on the total mixture, these were converted to percentage limits based on the total aggregate. All but two of the agencies using the passing-and-retained method of specifying the mineral aggregate base the gradation limits on the total mixture. All other agencies base the percentage limits on the total aggregate.

Two agencies base their specifications on sieves with round openings for sizes of 1/4-in. and greater. All of the other agencies use sieves with square openings. The



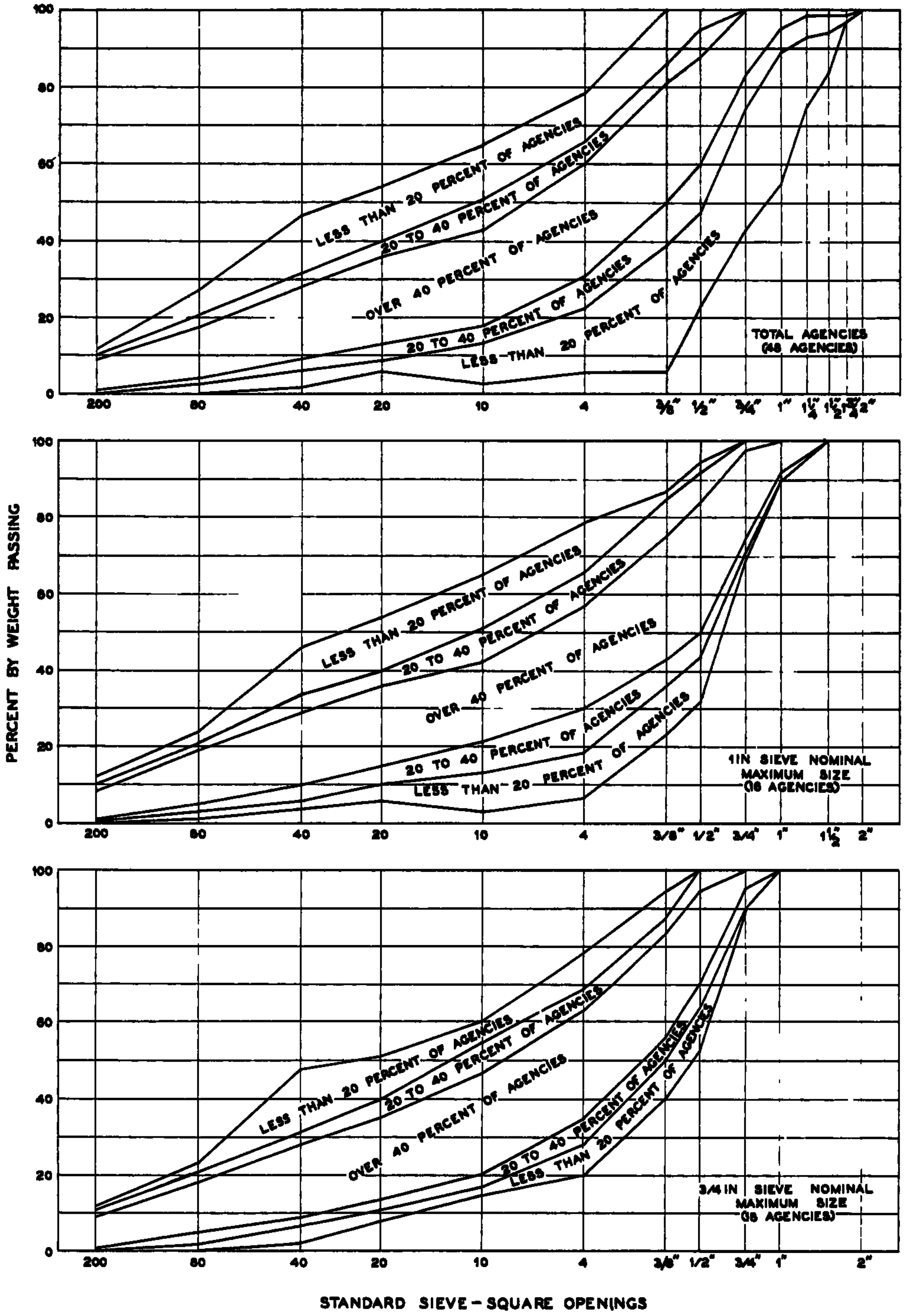
INCLUDES ALL AGENCIES FOR WHICH LIMITING FIGURES COULD BE DETERMINED FOR THE SIEVE INVOLVED

INCLUDES ONLY THE AGENCIES INDICATING THE USE OF A 1 INCH NOMINAL MAXIMUM SIZE OF AGGREGATE, AND FOR WHICH LIMITING FIGURES COULD BE DETERMINED FOR THE SIEVE INVOLVED

INCLUDES ONLY THE AGENCIES INDICATING THE USE OF A 3/4 INCH NOMINAL MAXIMUM SIZE OF AGGREGATE AND FOR WHICH LIMITING FIGURES COULD BE DETERMINED FOR THE SIEVE INVOLVED

(48) NUMBERS IN PARENTHESES INDICATE THE TOTAL NUMBER OF AGENCIES UPON WHICH PERCENT OF AGENCY FIGURES ARE BASED FOR THE PARTICULAR SIEVE INVOLVED

Figure 5. Frequency of acceptance of percentages of aggregate passing various sieves - binder-course mixtures.



NOTE FOR THE PURPOSE OF THIS PRESENTATION, THE NOMINAL MAXIMUM SIZE IS ASSUMED TO BE THE SIZE OF THE SIEVE ON WHICH NOT MORE THAN 10 PERCENT IS ALLOWED TO BE RETAINED, BUT THROUGH WHICH 100 PERCENT MAY PASS

Figure 6. General acceptability with respect to gradation of total aggregate for binder-course mixtures.

requirements of the two agencies using the round openings were converted to square openings on the basis of the following table which was found in the New Jersey specifications:

Conversion from Round to Square Openings

Round Openings	3½ in.	3 in.	2¼ in.	1¼ in.	¾ in.	½ in.	¼ in.	10	30	200
Square Openings	3 in.	2½ in.	1⅞ in.	1 in.	⅝ in.	⅜ in.	No. 4	10	30	200

Following the conversion of all gradation specification limits to a common basis, the limits of each agency were plotted on semilogarithmic paper to form the familiar gradation envelope. The envelopes were formed by connecting the plotted points with straight lines. In instances where agencies did not specify a maximum size, the lower line of the envelope was extended to the 100-percent point on the next commonly-used sieve above that which is specified by the agency. In a few instances where a 100-percent-passing figure was listed, followed by specified limits on a much smaller sieve, an unrealistically narrow upper portion of the envelope would result if the upper boundary of the envelope were formed by connecting the 100-percent point to the upper-limit point for the first sieve listed below the top-size sieve. In these few cases this

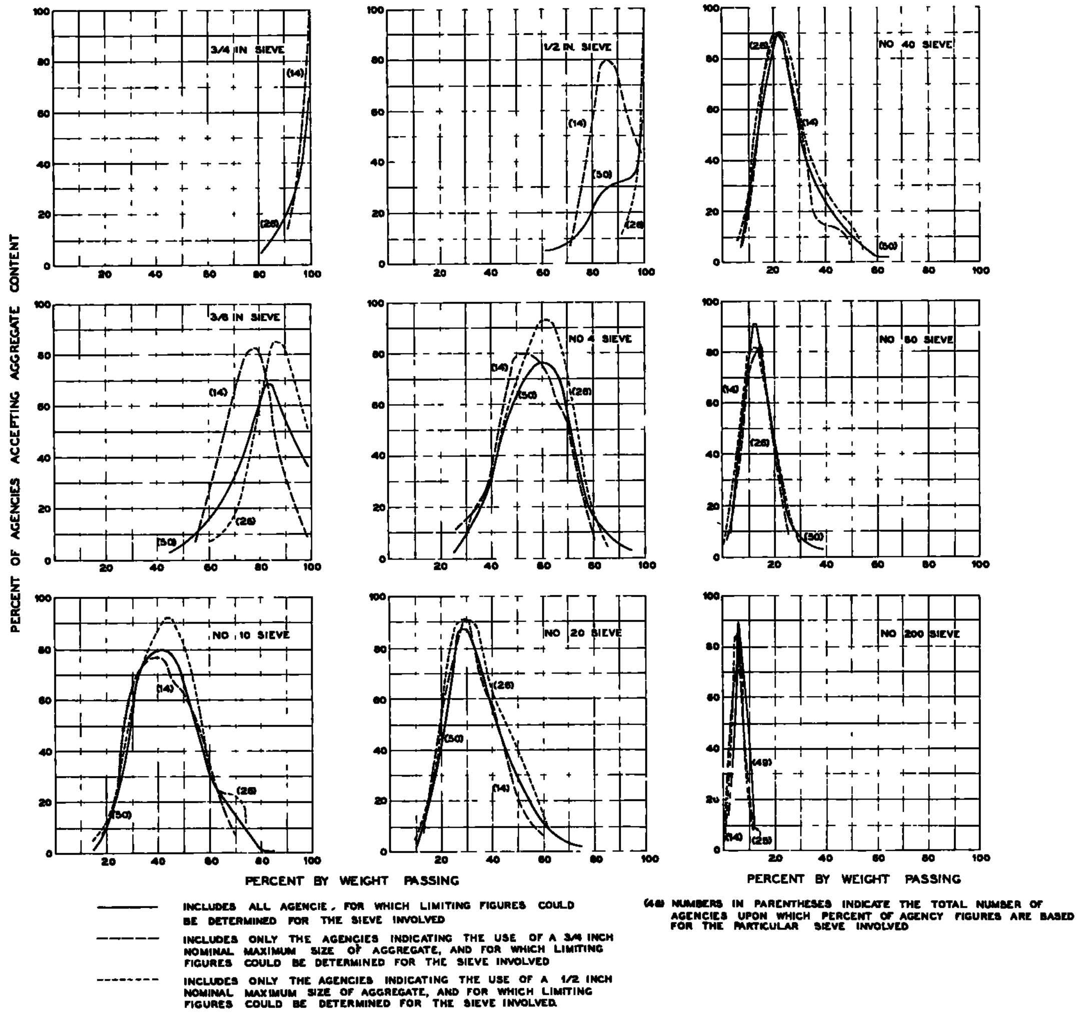


Figure 7. Frequency of acceptance of percentages of aggregate passing various sieves - surface-course mixtures.

portion of the envelope was determined by arbitrarily drawing the line to the 100-percent point on a sieve one or two sizes smaller than the maximum specified.

After all envelopes had been plotted, the percentage values were determined for all

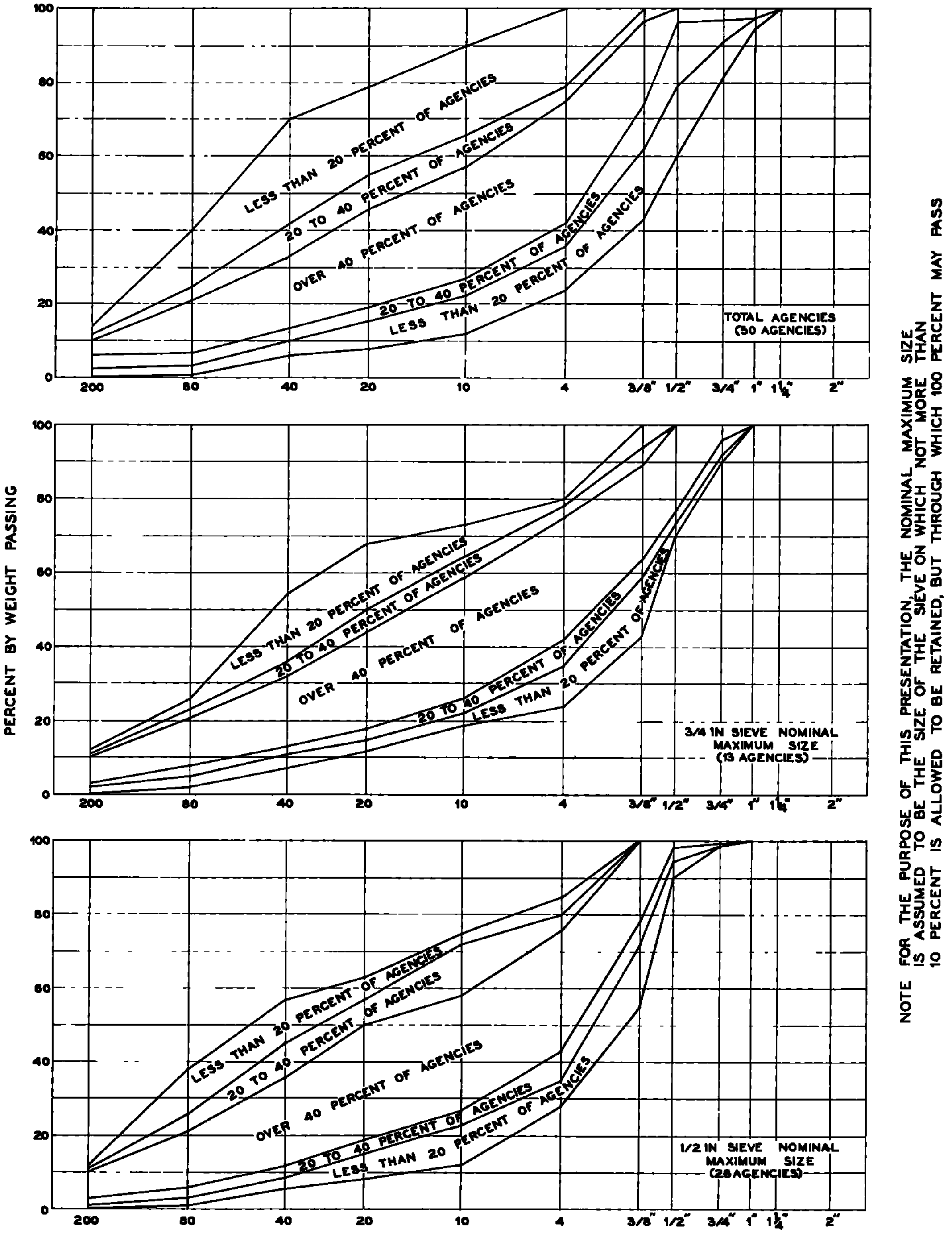


Figure 8. General acceptability with respect to gradation of total aggregate for surface-course mixtures.

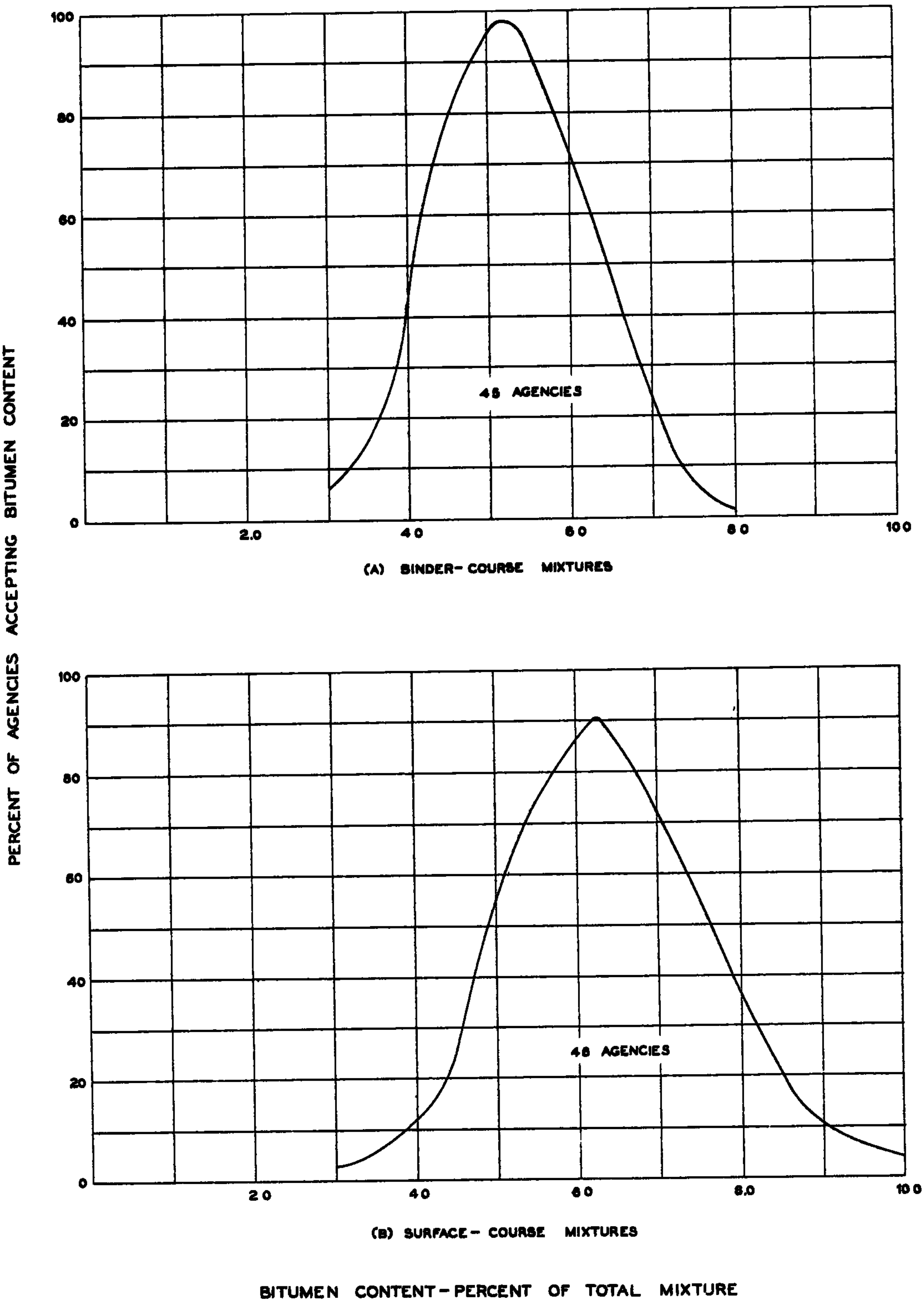


Figure 9. Frequency of acceptance of percents of bitumen in total mixture.

of the points at which the straight lines intersected the vertical lines of the semilogarithmic chart representing the more commonly used sieves. The tabulation of these values for binder-course mixtures is shown in Table 5-b, and for surface-course mixtures in Table 6-b.

Binder Course. From the values given in Table 5-b, the frequency of acceptance of the various percentage values passing each of the selected sieves was determined and plotted for all agencies. The frequency-of-acceptance curves for all agencies were then drawn as shown in Figure 5. It will be noted from these frequency-of-acceptance curves that, although the complete range of percentage limits for any one

TABLE 7-8-a

SPECIFIED TOLERANCES FROM JOB-MIX FORMULAS

Sieve Size or Number	Number of Agencies 1/	Average of Reported Tolerance Figures % (±)	Number of Agencies Within ± One Percentage Point of Average	Range of Tolerances Reported % (±)
		Binder-Course Mixtures		
3/4"	26	6	18	3-10
1/2"	29	6	21	3-10
3/8"	27	6	13	3-12
No. 4	36	5	23	2-10
No. 10	29	4	23	2-10
No. 20	12	4	12	3-5
No. 40	22	4	18	2-10
No. 80	17	3	13	2-5
No. 200	31	2	26	0.5-4
Asphalt	38	0.4	34 2/	0.2-1.0
		Surface Course Mixtures		
1/2"	27	6	18	2-10
3/8"	34	6	23	2-10
No. 4	37	5	29	2-10
No. 10	36	4	31	2-10
No. 20	26	4	24	2-5
No. 40	32	4	27	2-8
No. 80	29	3	25	2-5
No. 200	41	2	34	0.5-5
Asphalt	39	0.4	33 2/	0.2-1.0

1/ Total of 42 agencies reporting

2/ Within ± 0.1 percentage point of average sieve is relatively great, there is still a definite tendency toward concentration of acceptance within a relatively narrow range. This is further demonstrated in Figure 6 where are shown various concentrations of agencies with respect to acceptance of percentages of mineral aggregate passing the entire range of sieves. The method of developing these envelopes is the same as that previously described for the development of the envelopes for fine aggregate.

It is generally accepted that, for optimum performance, the grading of a mineral aggregate from coarse to fine must vary somewhat in relation to the maximum size of aggregate. The practices of the agencies grouped according to top-size of aggregate for the more frequently used top sizes were examined in a manner similar to that previously described for the agencies as a whole. For binder-course aggregates, the most frequently used top sizes (based on 90 percent of material passing, as shown in Table 5-b), are the 1-in. and ¾-in. top sizes. The results of this examination are also shown in Figures 5 and 6. It will be noted from the figures that grouping of the agencies by top sizes of aggregate produced a greater degree of concentration with respect to acceptance of percentages of material passing all sieves.

Surface Course. Surface-course-aggregate gradation limits were examined in the same manner as were the binder-course-aggregate limits. The results of the plottings are shown in Figures 7 and 8. It will be seen from these figures that similar results were obtained.

Asphalt Content. Forty-six of the 50 reporting agencies indicate that maximum and minimum asphalt contents are specified for binder-course mixtures. All but five of the agencies use the total mixture as a basis for specifying asphalt content. The remaining five specify asphalt content as a percentage of the total aggregate.

For the agencies reporting (converting the limits for the agencies using the total-aggregate basis to a total-mixture basis), the specified percentages range from a low of 2.9 percent to a high of 8.0 percent for binder-course mixtures, and from a low of 2.9 percent to a high of 10 percent for surface-course mixtures. Frequency-distribution curves for acceptance of various asphalt contents are shown in Figure 9(a) for binder course materials, and in Figure 9(b) for surface-course materials. Average values for the lower and upper limits for asphalt content of binder-course mixtures are 4.1 percent and 6.4 percent respectively, and average values for the lower and upper limits for surface-course mixtures are 5.0 percent and 7.5 percent respectively.

Job-Mix Formula

In addition to the controls previously discussed, most agencies require that a single combination of aggregate and asphaltic material, known as the "Job-Mix Formula," be determined for each project. The job-mix formula must of course be within the limits of the specifications. Small tolerances from the job-mix formula are specified. The job-mix formula is usually determined from trial mixes or from previous experience with the aggregates at hand.

Forty-two agencies indicate the use of job-mix formulas and specified tolerances therefrom for binder-course mixtures, and the same number also for surface-course mixtures. Summary information concerning tolerances for the more commonly used sieves, and for asphalt content is presented in Table 7-8-a. It will be noted that practice is reasonably consistent.

TABLE 9-a

USAGE OF STABILITY TESTS IN DESIGNING BITUMINOUS-CONCRETE MIXTURES

Stability Test	Number of Agencies	Tests Used in Addition to Those Listed in First Column	Number of Agencies
Marshall	20	Hubbard-Field Hveem Triaxial Compression	3 1 1
Hveem	12	Marshall	1
Hubbard-Field	11	Marshall Immersion-Compression	3 1
Unconfined Compression	2	Immersion-Compression and Vibrating Table	1
Triaxial Compression	2	Marshall	1
Immersion-Compression	2	Hubbard-Field Unconfined Compression and Vibrating Table	1 1
Vibrating Table	2	Unconfined Compression and Immersion-Compression	1
Direct Compression	1		
Practical experience - no specific test	5		

Total of 45 agencies reporting

MIXTURE DESIGN

Stability Tests

Most of the reporting agencies use at least one of the special tests that are available as guides in designing for stability in bituminous-concrete mixtures. Of 49 agencies reporting, only five indicate that no method other than trial and error is used in at least the preliminary determination of proper mixture composition with respect to stability. The usage of the various stability tests is summarized in Table 9-a. It will be noted that the most popular stability tests are the Marshall (20 agencies), the Hveem (12 agencies), and the Hubbard-Field (11 agencies).

Stability Test Figures

The ranges in test figures that are considered by the reporting agencies to be indicative of satisfactory mixtures are shown in Table 9-b for the tests receiving major usage. The ranges are listed without regard to the characteristics of the aggregates and bituminous materials contained in the mixtures to which they have been applied. They must therefore not be considered to have universal application.

TABLE 9-b

LIMITING STABILITY TEST FIGURES USED IN THE DESIGN AND CONTROL OF BITUMINOUS CONCRETE MIXTURES
(For Tests Receiving Major Usage)

Test	Traffic Undiff	Number of Agencies	For Medium Traffic	Number of Agencies	For Heavy Traffic	Number of Agencies
		Marshall Method 1/				
Stability, lbs	500+	3	500+	2	1500+	5
	1000+	2	600+	1	2000+	1
	1000 to 1500	1	1000+	3		
	1500+	1	1200+	1		
Flow, 0 01 in	12	1	12-20	1	8-18	1
	15-	1				
	16-	3				
	20-	4				
	8-18	1				
	10-15	1				
	12-18	1				
	12-20	1				
Density, pct of theoretical 2/3/	90 B	1				
	92-96 B	1				
	96 B	1				
	94-96 B	1				
	94-98 B	1				
	95-97 B	3				
	93-97 A	1				
	94-98 A	1				
	94-97 E	1				
	94-98 E	1				
	94-97 V	1				
Voids Filled with Asphalt, percent 2/	65-85 E	1				
	75-85 E	1				
	75-85 B	2				
	93-97 A	1				
		Hveem Stabilometer Method 1/				
Stabilometer Value, pct	30+	1				
	35+	4				
	40+	1				
	35-50	2				
Cohesiometer Value	50+	1				
Density, pct. of theoretical 2/3/	94-98	1				
	92+B	1				
	94-98 A,B	1				
		Hubbard-Field Method 1/				
Stability, lbs	1500	1	1200	1	2000	1
	3000+	1	1500	1	2500	1
			3000 to 4500	1	3000	1
Density, pct of theoretical 2/3/	94-97 A,B	1				
	95-98 S	1				
	90 B	1				

1/ Figures are not included for agencies indicating modified testing methods
2/ Specific gravities used in determining theoretical densities and void contents
B = Bulk; A = Apparent; E = "Effective"; V = "Vacuum saturated"; S = Bulk, surface dry basis
3/ For agencies reporting voids limitations rather than density limitations, the complementary density limitations have been tabulated to facilitate comparison

Specifications Based on Stability Tests

Eleven of the reporting agencies state that they include in their specifications requirements that are based on stability tests. Nine of these state that their specified values are based on standard tests and test procedures. The limiting figures specified by these nine agencies are tabulated in Table 9-c. It will be seen from the table that these particular specifications are far from standardized, with no two agencies specifying identical groups of limiting figures.

Specific Gravity in Mixture Design

Experience has shown that bituminous-concrete mixtures perform best at a relatively narrow range of densities below a given voidless maximum. The maximum density to which compacted mixtures are usually referenced is a theoretical voidless density calculated through the use of specific gravity figures for the individual constituents of the mixture.

If aggregate absorbed no asphalt, or if the voids within the aggregate particles became completely filled with asphalt, the choice of specific-gravity figures for use in theoretical calculations would be a simple matter. However, it is most common for the voids in the aggregate particles to become partially filled with asphalt. Therefore, the specific-gravity figures that are used for the aggregates are frequently a compromise, although some effort has been directed toward the determination of specific-gravities that more accurately represent actual conditions. Usage among the reporting agencies with regard to specific gravities assumed for aggregates in theoretical-density calculations is shown on the following page.

Specific Gravity	Number of Agencies
Bulk (ASTM)	19
Apparent (ASTM)	14
Bulk and Apparent	5
Bulk, Surface Dry Basis (ASTM)	3
"Effective"	2
"Vacuum Saturated"	1

CONSTRUCTION REQUIREMENTS

As mentioned previously, the questionnaires were for the most part designed to obtain information on items where some choice was likely to be involved insofar as the preparation of the construction specifications for the AASHO Test Road was concerned. Questions were usually not asked about detailed specification requirements and practices which were recognized as intrinsic in the control of bituminous-concrete construction and as being common to all agencies practicing bituminous-concrete construction. The absence of information on these details occurs perhaps with greatest frequency in the portions of the report dealing with construction and equipment requirements. This should be borne in mind by anyone making use of the information which is herein presented.

TABLE 9-c

LIMITING STABILITY TEST FIGURES USED IN BITUMINOUS-CONCRETE SPECIFICATIONS
(For Agencies Using Standard Test Procedures)

Stability Test		Specified Limiting Test Figures: Stability Figures	Flow (0.01 in.)	Density 1/ 2/ (pct. theoretical)
Marshall	(La.)	1000+	8-18	92-96 B
	(S.C.)	600+ med. traffic; 2000+ heavy "		
Hveem	(Okla.)	35+		94-98 A,B
	(Cal.)	35+		
	(Me.)	35-50		
Hubbard-Field	(Mo.)	3000+		94-97 A,B
	(Mont.)	-		95-98 S
	(Fla.)	1200 med. traffic; 3000 heavy "		95-98 (Asphalt Institute)B
	(Va.)	1500 med. traffic; 2000 heavy "		90 B

1/ For agencies reporting voids limitations rather than density limitations, the complementary density limitations have been tabulated to facilitate comparison.

2/ Specific gravities used in determining theoretical density:

A = Apparent

B = Bulk

S = Bulk, surface dry basis

PREPARATION OF MATERIALS

Mineral Aggregates

Storage. Forty-four of the reporting agencies state that their specifications require that when different sizes of aggregate are furnished separately for bituminous-concrete mixtures, each size that is furnished is to be maintained in a separate stockpile. The six remaining agencies have no such requirement, presumably because aggregates are not furnished in separate size fractions.

Twenty-seven agencies report specification statements requiring a general absence of segregation, degradation and intermixing of materials. Eleven agencies report having no such statement, and 12 agencies did not report.

Only 13 agencies report having specification requirements covering the construction of stockpiles. Four require that stockpiles be constructed in lifts 3 ft or less in thickness, 4 others require that lifts be 4 ft or less in thickness, one requires that the lifts be 5 ft or less, and 4 require only that the stockpiles be constructed in lifts.

Heating and Drying. Forty-six agencies reported on temperatures specified for the heating of the aggregate. One agency reports only that its requirements vary with conditions, one agency reports having no specification requirement, and two agencies did not report. Thirty-two specify temperature ranges, and 14 specify maximum limitations only. Reference to Part a of Table 10-a will show that there is considerable variation in the temperature ranges or maximum limiting temperatures that are specified for aggregate. Twenty-five different ranges or maximum limitations are reported. The greatest number of agencies specifying any one range is five; these specifying a range of 250 F to 325 F. The greatest number of agencies specifying the same maximum limitation is nine; these specifying a limitation of 325 F.

TABLE 10-a

SPECIFIED TEMPERATURES FOR HEATING AND DRYING MINERAL AGGREGATES

a. Agencies grouped according to specified temperature range

Specified Temperature Range °F.	Number of Agencies	Specified Temperature Range °F.	Number of Agencies
225-275	1	300-350	1
225-300	1	300-375	2
225-325	2	300-385	1
225-350	2(1-B)1/	300-400	1
250-300	1	300 max	1
250-320	1	325 max.	9
250-325	5	350 max	2
250-340	1	375 max.	1
250-350	3(1-B)	400 max	(1-B)
250-375	2	425 max	(1-S)
250-400	2	Varies	1
275-325	1	Not specified	1
275-335	1	Not reported	2
275-350	2		
275-375	(2-S)	Total agencies	50

b Agencies grouped according to specified upper temperature limit and according to specified lower temperature limit

Specified Lower Limit °F	Number of Agencies	Specified Upper Limit °F	Number of Agencies
225	6(1-B)1/	300	3
250	15(1-B)	325	17
275	4 (2-S)	350	10(2-B)
300	5	375	5(2-S)
		400	3(1-B)
		Other	5(1-S)

1/ Three additional agencies report specifying different temperature ranges for binder-course and surface-course aggregates The numerals within parentheses indicate the number of agencies, the letter "B" indicates binder-course aggregate, the letter "S" indicates surface-course aggregate

TABLE 10-b

SPECIFIED LIMITATIONS ON AMOUNT OF MOISTURE TO BE CONTAINED IN MINERAL AGGREGATE AT TIME OF MIXING

Specified Maximum Moisture Content	Number of Agencies
Percent of dry weight	
0.0	1
0 2	1
0.5	2
1.0	9
1.25	1
2.0	1
"Dry"	8
"Trace"	1
"No foaming"	3
Not specified	20
Not reported	3
Total agencies	50

Considering specified maximum and minimum limitations rather than ranges, practice appears more consistent. As will be seen from Part b of Table 10-a, only four different minimum limits are specified. A minimum of 250 F, specified by 15 agencies, is used most frequently. There will be seen to be a somewhat greater diversity of practice in maximum limits specified, although 17 agencies specify a 325 F maximum and 10 specify a 350 F maximum.

Three agencies have differing temperature requirements for binder-course and surface-course mixtures, as will be seen from Table 10-a.

Moisture Retention. Only 15 agencies report specifying a maximum percentage limitation on the amount of moisture allowed to be contained in mineral aggregate at the time of mixing. As will be seen from Table 10-b, percentage limitations that were reported vary from 0. 0 percent to 2. 0 percent, with 9 agencies specifying a maximum moisture content of 1. 0 percent. Eight agencies report that they require the aggregate to be "dry," one permits a "trace" of moisture, and three require that the moisture content be such that there will be "no foaming." Twenty agencies report having no specification requirement covering moisture retention.

Asphalt Cement

Eighteen different temperature specifications for heating asphalt cement were reported by forty-three agencies. Thirty-seven of these agencies specify a range of temperature to within which the asphalt must be heated, five specify a maximum limitation only, and one specifies a minimum limitation only. Practice concerning the specified limitations is summarized in Table 10-c. It will be seen from Part a of Table 10-c that the greatest number of agencies specifying any single range is the ten that specify a range of 250 F to 350 F. No more than seven specify any other range, or single maximum or minimum limitation.

From Part b of Table 10-c it will be seen that when maximum and minimum limitations are considered rather than ranges, only five different figures were reported for each. Of these, a 250 F limitation is specified as a minimum most frequently (21 agencies), and 350 F limitation is specified as a maximum most frequently (15 agencies).

PREPARATION OF MIXTURES

Batch-Type Mixing Plants

Mixing Period

Data regarding required mixing periods for batch-type mixers are summarized in Table 10-d.

Twenty-six agencies report that a minimum number of seconds of dry mixing are required. The specified minimums range from 5 to 20 seconds, with 19 agencies specifying a 15-second minimum dry-mix period. One additional agency specifies a minimum dry-mix period of 15 seconds for surface-course mixtures and 5 seconds for binder-course mixtures. Twelve agencies require only that mixing of the dry material shall be "thorough."

Forty-seven agencies reported on specified minimum wet-mix periods. Specified minimums range from 20 to 55 seconds. Twenty-one agencies specify a minimum of 30 seconds, and 19 specify a minimum of 45 seconds. One other agency specifies a minimum wet-mix period of 45 seconds for surface-course mixtures and a minimum of 35 seconds for binder-course mixtures.

Forty-one agencies report that a minimum total-mix period is specified in seconds. The minimum periods that are specified range from 30 seconds to 90 seconds. Thirteen specify a minimum total-mix period of 45 seconds, and 10 specify a minimum period of 60 seconds. One additional agency specifies a minimum total-mix period of 60 seconds for surface-course mixtures and 45 seconds for binder-course mixtures. Another agency specifies 45 seconds for surface-course mixtures and 35 seconds for binder-course mixtures.

TABLE 10-c

SPECIFIED TEMPERATURES FOR HEATING ASPHALT CEMENT

a. Agencies grouped according to specified temperature range

Specified Temperature Range °F	Number of Agencies	Specified Temperature Range °F	Number of Agencies
180-350	1	250-300	2
200-300	1	250-325	7
200-325	1	250-340	1
200-400	1	250-350	10
225-275	1	250-400	1
225-300	3	255-295	1
225-325	2	275 min.	1
		275 max	1
		275-325	1
		275-350	4
		300 max	4
		Varies	1
		Not specified	2
		Not reported	4
		Total agencies	50

b Agencies grouped according to specified upper temperature limit and according to specified lower temperature limit.

Specified Lower Limit °F	Number of Agencies	Specified Upper Limit °F.	Number of Agencies
180	1	275	2
200	3	300	10
225	6	325	11
250	21	350	15
275	6	400	2

Continuous-Type Mixing Plants

Mixing Period

Specified minimum mixing periods for

TABLE 10-d

SPECIFIED MINIMUM MIXING PERIODS FOR MIXTURES PREPARED IN BATCH-TYPE MIXING PLANTS

Dry Mix		Wet Mix		Total Mix	
Specified Minimum Mixing Period seconds	Number of Agencies	Specified Minimum Mixing Period seconds	Number of Agencies	Specified Minimum Mixing Period seconds	Number of Agencies
5	2(1-B)[1/]	20	1	30	3
10	3	25	2	35	4(1-B)[1/]
15	19(1-S)	30	21	40	5
20	1	35	(2-B)[1/]	42	1
		40	1	45	13(1-B, 1-S)
"Thorough"	12	45	19(1-S)	50	1
Not specified	4	50	(1-S)	60	10(1-S)
Not reported	8	55	1	70	1
		Not reported	3	90	1
Total agencies	50	Total agencies	50	"Thorough"	1
				Not specified	3
				Not reported	5
				Total agencies	50

1/ Two agencies report specifying different mixing periods for binder-course and surface-course mixtures. The numerals within parentheses indicate the number of agencies; the letter "B" indicates binder-course mixture; the letter "S" indicates surface-course mixture.

continuous mixing were reported by only 22 agencies. Since the mixing period in continuous mixing cannot be determined directly, these agencies use the following formula to determine the mixing period:

$$\text{Mixing period (sec)} = \frac{\text{Pugmill dead capacity (lb)}}{\text{Pugmill output (lb/sec)}}$$

Reported specified minimum periods vary from 30 seconds to 60 seconds. As will be seen from Table 10-e, there is no great concentration of agencies specifying any single minimum mixing period. Six agencies specify a minimum period of 45 seconds as determined by formula, 5 agencies specify a minimum period of 35 seconds, and an additional agency specifies a minimum period of 45 seconds for surface-course mixtures and 35 seconds for binder-course mixtures.

Twenty-one agencies did not report concerning specifications for a minimum mixing period for continuous mixing, four agencies reported that no minimum period is

TABLE 10-e

SPECIFIED MINIMUM MIXING PERIODS FOR MIXTURES PREPARED IN CONTINUOUS-TYPE MIXING PLANTS

Specified Minimum Mixing Period 1/	Number of Agencies
seconds	
30	4
35	5(1-B) 2/
40	2
45	6(1-S)
50	2
60	2
Not reported	21
Not specified	3
Type not permitted	4

1/ Calculated by formula Seconds = Pugmill Dead Capacity (lb.) / Pugmill Output (lb./sec.)

2/ One additional agency reports specifying different mixing periods for binder-course and surface-course mixtures. The letter "B" indicates binder-course mixture, the letter "S" indicates surface-course mixture.

specified, and four agencies do not permit the use of a continuous-type mixer.

Both Types of Mixing Plant

Mixture Temperature at Discharge

All but 4 of the 50 reporting agencies have specifications covering temperatures for material at discharge from the mixer. Thirty-seven of these specify minimum and maximum temperatures between which the temperature of the material must range. Nine specify only a maximum temperature which is not to be exceeded. As will be seen from Part a of Table 10-f, practice is quite varied as to specified ranges. The only single range that is specified by more than 3 agencies is the 250 F - 350 F range that is specified by 6 agencies. Grouping of agencies by minimum and maximum temperatures specified produces less variation. As will be seen from Part b of Table 10-f, four minimum temperatures are principally specified. Among these, a 250 F minimum is specified by 16 agencies (one agency for gravel aggregate only), and a 225 F minimum by 9 agencies. Also from Part b of the table, it will be seen that 5 maximum temperatures are principally specified. Fourteen agencies specify a maximum temperature of 325 F, one of which specifies this temperature only when stone is used. One additional agency specifies this maximum temperature for binder-course material only, and specifies a maximum of 350 F for surface-course material. Eleven other agencies specify a maximum temperature of 350 F.

PLACING MIXTURES

Air Temperature

Forty-six of the agencies reported on air temperatures that are specified as minimums for the placing of bituminous-concrete mixtures. Three agencies reported that they do not specify a minimum air temperature at which mixtures are to be placed, and one agency made no report.

As will be seen from Table 10-g, minimum temperatures specified for placing vary from 32 F to 60 F. The single agency specifying the 32 F minimum qualifies this by stating that the temperature must be rising. If the temperature is falling, this agency specifies a minimum of 38 F. Only one other agency specifies one minimum for use when the temperature is rising and another for use when the temperature is falling. A total of 28 agencies specify a minimum air temperature of 40 F, and another specifies 40 F when the temperature is falling. Six agencies specify 35 F as a minimum, and one specifies 35 F when the temperature is rising. Six others specify a minimum

TABLE 10-f

SPECIFIED TEMPERATURES FOR MIXTURE AT DISCHARGE FROM MIXER

a Agencies grouped according to specified temperature range

Specified Temperature Range °F.	Number of Agencies	Specified Temperature Range °F	Number of Agencies
200-300	1(1-gravel) 1/	265-325	1
200-350	1	275-325	2
225 min	1	275-350	2
225-275	2	280-375	1
225-300	2	300-350	1
225-325	3	300 max	1
225-350	1	310 max	1
235-275	1	325 max	5(1-B) 2/
250-275	1	350 max	(1-S)
250-280	1	375 max	1
250-300	3	Not specified	4
250-325	3(1-stone) 1/		
250-340	1		
250-350	6		
255-295	1		
260-375	1		

b Agencies grouped according to specified upper temperature limit and according to specified lower temperature limit

Specified Lower Limit °F	Number of Agencies	Specified Upper Limit °F	Number of Agencies
200	2(1-gravel) 1/	275	4
225	9	300	7(1-gravel) 1/
250	15(1-stone) 1/	325	14(1-B) 2/ (1-stone) 1/
275	4	350	11(1-S)
Other	6	375	3
		Other	4

1/ One additional agency reports specifying one temperature range for mixtures containing stone, and another for mixtures containing gravel The numerals within parentheses indicate the number of agencies

2/ One additional agency reports specifying different temperature ranges for binder-course and surface-course mixtures The numeral within parentheses indicates the number of agencies, the letter "B" indicates binder-course mixture, the letter "S" indicates surface-course mixture air temperature of 50 F for placing.

TABLE 10-g

SPECIFIED MINIMUM AIR TEMPERATURES AT WHICH MIXTURES MAY BE PLACED

Specified Minimum Air Temperature °F.	Number of Agencies
32	(1-rising)[1/]
35	6(1-rising)
36	1
38	(1-falling)
40	28(1-falling)
45	2
50	6
60	1
Not specified	3
Not reported	1
Total agencies	50

1/ Two additional agencies report specifying two minimum air temperatures for placing mixtures, one minimum temperature when the temperature is rising and another when the temperature is falling The numeral within parentheses indicates the number of agencies

Mixture Temperature at Placing

Forty-three agencies reported on specifications for mixture temperature at the time of placing. Thirty-six of these specify maximum and minimum temperatures within which the temperature of the mixture must range. Included are three agencies that specify differing limits for binder-course and surface-course material, and one agency that specifies one set of limits for gravel aggregate and another set for stone aggregate. Three agencies specify only minimum limits, and three others specify only maximum limits. Five agencies report no specification, and two agencies did not report.

As was true for the specifications concerning mixture temperatures at discharge, few agencies specify any single specific range (see Table 10-h, Part a). The greatest number of agencies specifying any single range is the four that specify the 225 F to 325 F range. Two additional agencies specify this range for binder-course mixtures only.

As was also true for specified temperatures at discharge, grouping of agencies by specified minimum and maximum temperatures produced less variation. As will be seen from Part b of Table 10-h, four minimum temperatures and five maximum temperatures are principally specified. A 225 F minimum is specified by 14 agencies and a 250 F minimum by 12 agencies. In addition, two agencies specify the 225 F minimum for binder-course mixtures, and one specifies this minimum for use only with stone aggregate. Also, one agency specifies the 250 F minimum for binder-course mixtures only, and three specify the minimum for surface-course mixtures only. Twelve agencies specify a 325 F maximum and nine specify a 300 F maximum. Three additional agencies specify the 325 F maximum for binder-course mixtures alone, and one additional agency specifies the 300 F maximum when crushed-stone aggregate is used.

Daily Tolerance in Temperature

Specifications controlling the maximum daily variations in mixture temperature were reported by 33 agencies. Thirteen agencies report having no such specification, and four agencies did not report. The information on tolerances is summarized in Table 10-i. It will be seen from the table that specified tolerances ranged from ± 10 F to ± 30 F. Seventeen of the agencies specify a tolerance of ± 20 F, and 8 agencies specify a tolerance of ± 25 F.

Spreading and Finishing Machine Speed

Operating speeds for spreading and finishing machines are reported to be specified by 20 of the reporting agencies. Eleven report having no specification regarding speed, and the remaining 19 either did not report, or reported a general statement which has the effect of indirectly controlling speed. Some, or all, of those reporting that a speed is not specified probably also have some form of indirect control.

Twelve of the 20 agencies with speed regulations specify a speed range within which the machine must operate. Eight specify a maximum speed which is not to be exceeded. One of these 8 specifies one maximum speed for binder-course mixtures and another for surface-course mixtures. As will be seen from Table 10-j, no single range, or maximum value when only a maximum speed is specified, is specified by a large

TABLE 10-h

SPECIFIED TEMPERATURES FOR MIXTURE AT PLACING

a. Agencies grouped according to specified temperature range

Specified Temperature Range °F	Number of Agencies	Specified Temperature Range °F	Number of Agencies
175-275	(1-gravel)1/	250-350	2(3-S)
200-300	2	250-375	1
200-350	1	255-305	1
225 min.	1	265-325	1
225-255	1	275 max.	1
225-275	2	275-325	3
225-300	3(1-stone)	280-375	1
225-325	4(2-B)2/	300 max.	1
225-350	3	325 max.	1
240 min.	1	Not specified	5
250 min.	1	Not reported	2
250-275	1		
250-300	3		
250-325	3(1-B)		
250-340	1		

b. Agencies grouped according to specified upper temperature limit and according to specified lower temperature limit

Specified Lower Limit °F	Number of Agencies	Specified Upper Limit °F	Number of Agencies
200	3	275	4
225	14(1-stone)1/ (2-B)2/	300	9(1-stone)
250	12(1-B)(3-S)	325	12(3-B)
275	3	350	6(3-S)
Other	4	375	2
		Other	3

1/ One agency reports specifying different temperature ranges for stone and gravel in the bituminous mixture. The numerals within parentheses indicate the number of agencies; "stone" and "gravel" indicates the aggregate used.

2/ Three agencies report specifying different placing temperature ranges for binder-course and surface-course mixtures. The numeral within parentheses indicates the number of agencies; the letter "B" indicates binder-course mixtures; the letter "S" indicates surface-course mixtures.

group of agencies. The greatest number specifying any single range is the four that specify that the operating speed of the spreading and finishing machine be between 10 and 30 ft per min. Of the agencies specifying maximum speed only, the greatest number specifying a single value is the three that specify a maximum of 30 ft per min. One additional agency that specifies one maximum speed for surface-course mixtures and another for binder-course mixtures specifies a maximum of 30 ft per min for binder-course mixtures.

Lift Thickness

Information concerning lift thicknesses that are specified and lift thicknesses that are normally placed was obtained from the questionnaires and is summarized in Table 10-k. Thirty agencies report that a maximum lift thickness is specified for the binder course, and 35 agencies report that a maximum thickness is specified for the surface

TABLE 10-i

SPECIFIED MAXIMUM DAILY TOLERANCES FROM ESTABLISHED TEMPERATURE FOR MIXTURE AT PLACING

Specified Daily Temperature Tolerance ± °F.	Number of Agencies
10	2
15	3
20	17
25	8
30	3
Not specified	13
Not reported	4
Total agencies	50

course. One agency controls thickness by specifying a maximum lb per sq yd of material that may be placed. Specified maximum thicknesses for binder courses range between 1 in. and 3 in. Twelve agencies specify 2 in., 8 agencies specify 3 in., and 6 agencies specify 1½ in. Specified maximum thicknesses for surface courses range between 1 in. and 3½ in. Fourteen agencies specify 2 in., 9 agencies specify 1½ in. and 4 agencies specify 1 in.

Lift thickness of binder courses normally placed was reported by 34 agencies, and for surface courses by 39 agencies. Normally-placed thicknesses of binder course range between 1 in. and 3 in., with more agencies placing 1½-in. courses (15), and 2-in. courses (6), than any other thicknesses. Normally-placed thicknesses of surface course range between 1 in. and 2½ in., with more agencies placing 1½-in. courses (14), and 1-in. courses (8), than any other thicknesses.

Rolling Requirements

Type and Number of Rollers. Data regarding the type and number of rollers that are required are summarized in Table 10-l and Table 10-m. In Table 10-l are summarized requirements for roller type. Tandem, three-wheel, and pneumatic rollers are all used to some extent. Of 49 agencies reporting that they specify the type of roller to be used, 16 specify that either tandem or three-wheel rollers may be used, another 16 specify that a minimum of one tandem roller and one three-wheel roller is to be used, and 11 specify that tandem rollers alone may be used. Other combinations of the three types of rollers are used much less extensively. Only six agencies permit a pneumatic roller to be used.

From Table 10-m it will be seen that two agencies specify that a minimum of three rollers are to be used (for each spreading and finishing machine), and 25 agencies specify that a minimum of two rollers are to be used. The remaining 23 reporting agencies apparently do not specify a minimum number of rollers to be used. It will be further noted that the most frequently required combination is a minimum of one tandem roller and one three-wheel roller (by 14 agencies).

Tonnage and Roller Speed. Thirty-two agencies set a specific maximum amount of material that may be placed per hour for each roller that is used. Twenty-seven of these state the amount of material on a ton-per-roller-hour basis, and five use a square-yard-per-roller-hour basis. Maximum-tonnage values, as will be seen from Table 10-n, range from 25 tons per roller-hour to 150 tons per roller-hour. The most frequently specified maximum tonnages per roller-hour that are specified are 40 (6 agencies), 30 (5 agencies) and 50 (4 agencies).

TABLE 10-j

SPECIFIED OPERATING SPEEDS FOR SPREADING AND FINISHING MACHINE

Specified Operating Speed ft. per min	Number of Agencies
5-20	1
5-30	1
5-50	1
7-28	1
10-20	4
10-30	2
10-50	1
20 max.	2(1-S)[1/]
20-25	1
25 max	1
30 max	3(1-B)
35 max.	1
As required	1
Avoid tearing	2
Not specified	11
Not reported	16
Total agencies	50

1/ One additional agency reports specifying different maximum speeds for binder-course and surface-course mixtures. The numeral within parentheses indicates the number of agencies, the letter "B" indicates binder-course mixture, the letter "S" indicates surface-course mixture

TABLE 10-k

LIFT THICKNESSES - MAXIMUM SPECIFIED AND THICKNESS NORMALLY USED

Specified Maximum Thickness				Thickness Normally Placed			
Binder Course inches	Number of Agencies	Surface Course inches	Number of Agencies	Binder Course inches	Number of Agencies	Surface Course inches	Number of Agencies
1	1	1	4	1	1	1	8
1 1/4	1	1 1/4	1	1-1 1/2	1	1-1 1/2	2
1 1/2	6	1 1/2	9	1-2	1	1-2	2
2	12	2	14	1-3	1	1 1/4	5
2 1/2	2	2 1/2	4	1 1/4	2	1 1/2	14
3	8	3	2	1 1/2	15	1 1/2-2	2
170 lbs. 1/	1	3 1/2	1	1 1/2-2	1	1 1/2-2 1/2	1
Var.	1	130 lbs. 1/	1	1 1/2-2 1/2	1	2	3
N.R. 2/	17	Var.	1	1 3/4	1	2 1/2	2
Not used	1	N.R.	13	2	6	100 lbs. 1/	1
Total agencies	50	Total	50	2-3	3	N.R.	10
				2 1/2	1	Total	50
				Not used	1		
				N.R.	15		
				Total	50		

1/ Lbs. per sq. yd.

2/ Not reported.

Only 24 agencies report specifying a maximum roller speed. Seven agencies report a requirement to the effect that the speed is to be such that displacement under the roller will be avoided. It is possible that some of the agencies reporting no requirement may have a requirement similar to that which was reported by these seven agencies. Reported maximum allowable speeds (see Table 10-o) range from 1.5 mph to 3 mph, with most agencies (15) specifying 3 mph.

Compacted Density

The questions that were asked con-

TABLE 10-1

TYPES OF ROLLERS REQUIRED

Roller Type	Number of Agencies
Tandem or three-wheel	16
Tandem and three-wheel, minimum	16
Tandem only	11
Tandem, three-wheel, or pneumatic	2
Tandem or pneumatic	1
Tandem, three-wheel, and pneumatic	3
Not specified	1
Total agencies	50

TABLE 10-m
MINIMUM NUMBER OF ROLLERS REQUIRED

Minimum Requirement	Number of Agencies
Three rollers	
(a) Two tandem or three-wheel and one pneumatic	1
(b) One 3-axle tandem, others tandem, three-wheel or pneumatic	1
Total agencies	2
Two rollers	
(a) One tandem and one three-wheel	14
(b) Tandem or three-wheel	5
(c) Tandem only	4
(d) Two tandem, or one tandem and one three-wheel	2
Total agencies	25
Minimum not specified	
(a) Tandem or three-wheel	9
(b) Tandem only	8
(c) Tandem, three-wheel or pneumatic	1
(d) Tandem, three-wheel and pneumatic	1
(e) Tandem and three-wheel	2
(f) Tandem or pneumatic	1
(g) Type not specified	1
Total agencies	23

TABLE 10-n
MAXIMUM TONNAGE SPECIFIED PER ROLLER-HOUR

Specified Maximum Tonnage Per Roller-Hour	Number of Agencies
25	3
30	5
35	2
37½	1
40	6
50	4
75	2
80	1
100	2
150	1
Sq. yd requirement[1/]	6
Not specified	5
Not reported	12
Total agencies	50

1/ Six agencies have a requirement based on square yards placed per hour rather than on tonnage These requirements vary from 200 to 500 sq. yds maximum placement per roller-hour

TABLE 10-o
SPECIFIED ROLLER SPEEDS

Specified Maximum Speed	Number of Agencies
1.5 mph	2
1.7 mph	1
1.8 mph	1
2 mph	1
2.5 mph	1
3 mph	15
Avoid displacement	7
Not specified	19
Not reported	3
Total agencies	50

cerning density specifications and criteria were unfortunately not sufficiently specific to indicate the amount of information that was needed to completely compare and analyze practice with regard to layer density. Many of the replies that were received were therefore not sufficiently complete to permit a detailed examination of them. Such summarization as was possible is presented in Table 10-p. It will be noted from the table that, while the general range of density that is sought is, with a few exceptions, relatively narrow, the actual limiting figures that are listed are quite varied. Several different bases are also used in arriving at standard densities to which the compacted-layer densities are compared.

For binder courses, 21 agencies report that they specify relative-density requirements. An additional 8 agencies report relative densities that they attempt to meet, but which they do not specify. Of this total of 29 agencies, 11 relate the compacted density to a voidless density calculated through the use of the apparent specific gravity (ASTM) of the aggregates, 6 relate the compacted density to a voidless density calculated through the use of the bulk specific gravity (ASTM) of the aggregates, one uses density obtained by the Hubbard-Field laboratory procedure as a standard, and 3 use a density obtained by the Marshall procedure as a standard. Among the remaining 8 are 2 that report using other specific gravities of aggregates in determining voidless density (surface dry and vacuum saturated), and 6 that did not report in such a way that their standard could be classified.

For surface courses, 25 agencies report specifying relative-density requirements. Eight others report having relative densities that they attempt to meet but do not specify. Of this total of 33 agencies, 13 relate compacted density to voidless density based on the apparent specific gravity of the aggregates, 7 relate compacted density to voidless density based on the bulk specific gravity of the aggregates, 2 use a Hubbard-Field density as standard, and 3 use a Marshall density as standard. Two others report calculating voidless densities from other specific gravities of aggregates (surface dry and vacuum saturated), and 6 could not be classified.

TABLE 10-p

DENSITY REQUIREMENTS FOR COMPACTED LAYERS

Relative Density Requirement			
Binder Course Percent	Number of Agencies	Surface Course Percent	Number of Agencies
	Based on Voidless Density Using Apparent Specific Gravity of Materials		
85+	1 (1) 1/ 2/	85+	(1) 1/ 2/
90+	1 (1) 2/	90+	3 (1) 2/
91-96	(1)	91-96	(1)
92+	3	92+	3
94-98	1	92-96	1
95+	1 (1)	94-98	1
97+	(1)	95+	1 (1)
		97+	(1)
	Based on Voidless Density Using Bulk Specific Gravity of Materials		
88+	1	90+	1
91-92	(1)	90-95	1
92+	1	91-92	(1)
95+	3	92+	1
		95+	3
	Based on Hubbard-Field Laboratory Density		
95+	1	94+	1
		95+	1
	Based on Marshall Laboratory Density		
95-99	1	95-99	1
98	1	98	1
Vary with job	1	Vary with job	1
	Miscellaneous, or Basis Not Reported		
	8		8
	Not Specified		
	14		13
	Not Reported		
	7		4

1/ Numbers in parentheses indicate number of additional agencies reporting that they desire, but do not specify, the indicated figures.

2/ One agency desires the 85+ percent for bituminous concrete placed on flexible base, and 90+ percent for bituminous concrete placed on rigid base.

TABLE 10-q

REQUIREMENTS FOR SURFACE SMOOTHNESS

Binder Course		Surface Course	
Maximum Variation	No. of Agencies	Maximum Variation	No. of Agencies
1/10 in. in 10 ft.	1	1/10 in. in 10 ft.	1
1/8 in. in 16 ft.1/	1	1/8 in. in 16 ft.1/	2
1/8 in. in 10 ft.	4	1/8 in. in 10 ft.	14
1/16 in. per ft.	1	3/16 in. in 10 ft.	11
3/16 in. in 10 ft.	3	1/4 in. in 20 ft.	1
1/4 in. in 16 ft.	4	1/4 in. in 16 ft.	5
1/4 in. in 12 ft.	1	1/4 in. in 12 ft.	2
1/4 in. in 10 ft.	13	1/4 in. in 10 ft.	11
3/8 in. in 10 ft.	2	Not reported	3
1/2 in. in 20 ft.	1		
1/2 in. in 10 ft.	1		
Not specified	11		
Not reported	7		

1/ One agency specifies this degree of surface smoothness for bituminous concrete placed on rigid base, but permits up to 1/4-in. variation in 16 ft. for bituminous concrete placed on flexible base.

Surface Smoothness

Thirty-two agencies reported on surface-smoothness requirements for binder courses, and 47 reported on surface-smoothness requirements for surface courses. The requirements are summarized in Table 10-q. For binder courses, maximum allowable variations range from 1/10 in. in 10 ft to 1/2 in. in 10 ft. For surface courses, maximum allowable variations range from 1/10 in. in 10 ft. to 1/4 in. in 10 ft. A 1/4-in. maximum permissible variation in 10 ft is reported most frequently for binder courses (13 agencies), followed by 1/8 in. in 10 ft (4 agencies), and 1/4 in. in 16 ft (4 agencies). A maximum-variation requirement of 1/8 in. in 10 ft is reported most frequently for surface courses (14 agencies). Other requirements receiving frequent usage for surface courses are 3/16 in. in 10 ft (11 agencies), 1/4 in. in 10 ft (11 agencies), and 1/4 in. in 16 ft (5 agencies).

EQUIPMENT REQUIREMENTS

The questions that were asked concerning equipment requirements were for the most part limited to items where differences in practice were believed to exist. The information that is reported is therefore not a detailed description of equipment used in preparing and placing bituminous-concrete mixtures.

PREPARATION OF MATERIALS

Cold-Aggregate Bins

Thirty-five agencies reported on equipment generally used to convey aggregates to the cold bins. Of the agencies using cranes and reporting on the specific type of bucket used, 16 reported using a clamshell bucket and 2 reported using a dragline bucket. Twelve agencies use conveyor belts or elevators. Other pieces of specific equipment mentioned were bulldozers (2 agencies) and trucks (1 agency).

Reported requirements for cold-aggregate bins are outlined in Table 11-a. Fifteen agencies reported on the minimum number of bin compartments specified where more than one compartment is required. Nine of these specify 2 compartments and 6 specify 3 compartments. Eight agencies report specifying a minimum of one compartment for each aggregate size, and it is presumed that the other agencies have a similar requirement though it may not be stated specifically.

Requirements for cold-bin capacity, when included in specifications, are stated in general terms (see Table 11-a). Of 16 agencies reporting a definite requirement, 12 require that the capacity be sufficient to supply the full capacity of the mixer or the operating rate of the plant, 3 require that the bin capacity be not less than 3 times the dead-load capacity of the mixer, and one requires that the bin capacity be in excess of the mixer capacity.

Aggregate Feeders

Forty-three of the reporting agencies require the use of mechanical feeders for conveying cold aggregate to the driers, and seven do not. However, at least two of those that do not have such a requirement indicate that mechanical feeders are used to some extent. Compartment feeders are normally used by 27 agencies, combination feeders by 10 agencies, individual feeders by 7 agencies, and reciprocating-gate feeders by 2 agencies. Four agencies did not report.

Forty agencies report that their feeders are adjustable for proportional feed, two reported that they are not adjustable, and eight agencies did not report. Thirty-six report that their feeders are adjustable for total feed, one reports the feeder not to be adjustable for total feed, and 13 agencies did not report.

Thirty-six agencies report having a general requirement that the feeder be such that adequate control can be exercised, 7 agencies report having no specific requirement of this nature, and the remaining 7 agencies did not report.

Aggregate Screens

Twenty-nine agencies reported on scalping-screen openings as related to the maximum size of aggregate. Three agencies report that they do not use scalping screens, and 18 agencies did not report. Summarized information on this item appears in Table 11-b. Screen openings will be seen to vary from aggregate size to ½ in. larger than aggregate size. Twelve agencies report that the screen

TABLE 11-a

REQUIREMENTS FOR COLD-AGGREGATE BINS

Minimum Number of Compartments	Number of Agencies	Bin Capacity	Number of Agencies
2	9	Supply full capacity of mixer or plant rate	12
3	6	Not less than 3 times dead load of mixer	3
On each aggregate size	8		
Varies	1	In excess of mixer capacity	1
Not specified	10	Not specified	7
Not reported	16	Not reported	27

TABLE 11-b

SCALPING-SCREEN USAGE

Screen Opening Related to Maximum Size of Aggregate	Number of Agencies
1/2-in. larger	2
1/4-in. larger	7
1/8-in. larger	12
1/16 in. larger	1
Same size	2
1/8 - 1/4-in. larger	1
1/16 - 1/4-in. larger	2
1/16 - 1/8-in. larger	2
Not used	3
Not reported	18

TABLE 11-c
REQUIREMENTS CONCERNING SCREENING EFFICIENCY WHERE OVERSIZE AND UNDERSIZE MATERIALS ARE CONSIDERED SEPARATELY

	Small Aggregate 1/	⟶					Large Aggregate
	Bin No. 1 1/	Bin No. 2		Bin No. 3		Bin No. 4	
Agency	Maximum Oversize 2/ percent	Maximum Undersize 2/ percent	Maximum Oversize percent	Maximum Undersize percent	Maximum Oversize percent	Maximum Undersize percent	Maximum Oversize percent
1	5	20	5	10	5		
2	10	15	5	15	5		
3	5	10	5	20	5		
4	5	5	5	10	5	15	5
5	5	15	10	25	5	25	0
6	10	15	15	15	0		
7	10	10	10	10	10		

1/ The usual practice of designating as Bin No. 1 the bin containing the smallest size of aggregate exclusive of mineral filler has been followed.

2/ Oversize and undersize determinations are based on tests with laboratory sieves.

openings are ⅛ in. larger than maximum aggregate size, and 7 agencies report that the openings are ¼ in. larger. No other single figures were reported as frequently.

Seventeen agencies have established definite requirements concerning screening systems in an effort to control the size-separations of aggregate in the hot-bin compartments (sometimes called "screening efficiency"). Three different types of requirement are used in attaining this control. These are:

1. Separate limitations on the amounts of material larger than and smaller than the established nominal maximum and minimum sizes that will be permitted in a size-group.

2. A limitation on the combined amounts of material larger than and smaller than the established nominal maximum and minimum sizes that will be permitted in a size-group.

3. A limitation on only the amount of material that is smaller than the established minimum size that will be permitted in a size-group (sometimes referred to as "carry-over").

Table 11-c summarizes the requirements that have been established by the seven agencies using the first type of requirement. As will be seen from the table, the maximum amount of oversize permitted in the various size-groups is either 5 or 10 percent of the total material in the size-group for most agencies, with one agency permitting as high as 15 percent for one size-group and two agencies permitting no oversize material in their coarsest size-groups.

Since the finest size-group contains the finest aggregate permitted under the general gradation specifications (assuming that the gradation specifications are met), there is no reason to place a limitation on undersize material to be contained in this size-group. Undersize limitations for the other size-groups range from 5 to 25 percent of the total material in the size-groups, with most agencies specifying either 10 or 15 percent.

Five agencies used the second-named method; that of limiting the combined amount of oversize and undersize material to be contained in any size-group. Four of these require that at least 85 percent of the material in a size-group must meet the established minimum and maximum sizes for the group, when tested with laboratory sieves (85 percent efficient). One of these has a further requirement that at least 90 percent of the material in the fine-size bin must pass the No. 10 sieve. The fifth agency requires that 90 percent of the material in a size-group must meet the nominal size requirements for the group, except that at least 95 percent of the material in the fine-size bin must pass the No. 10 sieve.

TABLE 11-d

REQUIREMENTS FOR HOT-AGGREGATE BINS

Minimum Number of Compartments Required	Number of Agencies Binder Course	Number of Agencies Surface Course	Bin Capacity Required	Number of Agencies
2	7	8	Supply plant-rate	12
3	33	34	Supply full capacity of mixer	7
4	4	4		
One for each aggregate size	1	1	Not less than three times dead-load capacity of mixer	5
Not reported	5	3	Not less than ten times dead-load capacity of mixer	1
			Six-ton minimum capacity	1
			No requirement	10
			Not reported	14

Four of the five agencies that limit only the undersize material in a size-group separate their aggregates into only two sizes, and place a limitation on the amount of fine material that may be carried into the coarse-size bin. One of the four reports that no carryover is allowed, one allows up to 8-percent carryover, and two allow up to 10-percent carryover. The fifth agency allows up to 10 percent undersize in the No. 2 bin (the No. 1 bin containing the finest-size aggregate), up to 15 percent undersize in the No. 3 bin, and up to 20 percent undersize in the No. 4 bin.

Hot-Aggregate Bins

Either two, three or four compartments are required for separating the hot aggregates into size groups. As will be seen from Table 11-d, 7 agencies require at least two compartments for binder-course material, 33 agencies require 3 compartments, and 4 agencies require 4 compartments. Practice with regard to surface-course material will be noted in the table to be almost identical. Six agencies did not report for binder-course material, and four agencies did not report for surface-course material.

Capacity requirements for hot bins are also summarized in Table 11-d. Twelve agencies require only that the bin capacity be sufficient to supply the plant-rate, 7 require the bin capacity to be sufficient to supply the full capacity of the mixer, five re-

TABLE 11-e

THERMOMETRIC EQUIPMENT FOR AGGREGATES

Type of Instrument Permitted	No. of Agencies	Recording and Non-recording Instruments	No. of Agencies	Minimum Number of Instrument Terminals: Single Drier	Minimum Number of Instrument Terminals: Dual Drier	No. of Agencies	Required Instrument Sensitivity and Efficiency	No. of Agencies
Pyrometer and thermometer	43	Recording instrument required	25	1	2	11	Record 10° F. change in one minute	1
Pyrometer only	5	Non-recording instrument permitted	25	1	Dual not used	11	Record 10° F. change within 15 minutes	1
Not specified	2			1	1	6	Record 25°F. change within one minute	1
				2	3	1	Record 10° F. variation	1
				3	3	1	As directed	1
				4	5	1	Not specified	22
				Not specified		13	Not reported	24
				Not reported		6		

quire that the capacity be three times the dead-load capacity of the mixer, and one requires a capacity of not less than ten times the dead-load capacity of the mixer. One agency sets six tons as a minimum capacity. Ten agencies have no requirement, and 14 did not reply.

TABLE 11-f

REQUIRED CAPACITY OF TANK FOR BITUMINOUS MATERIAL

Tank Capacity Regulation	Number of Agencies
Sufficient for one day's run	20
Sufficient for continuous operation	4
In excess of plant operation	1
Sufficient for ten-hour operation	1
500 gal.	1
4,500 gal.	1
10,000 gal.	1
Two tanks for truck delivery	1
Not reported	1
Not specified	19

Thermometric Equipment for Aggregate

The replies that were received to several questions concerning thermometric equipment for measuring the temperature of hot aggregate are summarized in Table 11-e. It will be noted that 43 agencies will permit the use of either a pyrometer or thermometer, 5 require that a pyrometer only be used, and two do not specify. Twenty-five of the 50 reporting agencies require that recording instruments be used, while the other 25 permit the instruments to be non-recording.

Twenty-eight agencies use but one terminal on thermometric instruments when single driers are used. Eleven of these require two terminals when dual driers are used, but six do not. The remaining 11 do not use dual driers. Only three agencies appear to require additional terminals to be placed in the bins. One agency requires one additional terminal, one requires two additional terminals and one requires three additional terminals. This information is also summarized in Table 11-e.

Only four agencies indicate that they regulate within specific limits the sensitivity and efficiency of the thermometric instruments. Data concerning this item are also summarized in Table 11-e.

Storage Tank for Bituminous Material

Regulations concerning the capacity of the storage tank for bituminous material are summarized in Table 11-f. Of the 30 agencies reporting on their requirement, 20 report that they require only that the capacity be sufficient for one day's run. The various requirements of the other ten may be seen by referring to Table 11-f. Nineteen agencies reported that they do not specify a capacity for the tank for bituminous material.

Thermometric Equipment for Bituminous Material

Forty-six of the reporting agencies indicate that a thermometer is used for measuring the temperature of the bituminous material. Three of these indicate the additional use of a pyrometer, and three also indicate that a recording-type instrument is used. Four agencies did not indicate the type of thermometric equipment that is used.

MIXING PLANTS

Forty-six of the reporting agencies permit the use of either batch-type or continuous-type mixers. The remaining four reporting agencies require the use of batch-type mixers. Twenty-three agencies use the batch-type mixer more frequently, and four use the continuous-type more frequently. Twenty-three agencies use both types with equal frequency. These data are tabulated in Table 11-g.

TABLE 11-g

USAGE OF BATCH-TYPE AND CONTINUOUS-TYPE MIXING PLANTS

Usage	Number of Agencies
Permit either batch-type or continuous-type mixers	46
Permit batch-type only	4
Use batch-type more frequently	23
Use continuous-type more frequently	4
Use both types with equal frequency	23

Batch-Type Mixing Plants

Aggregate Weighing Equipment

Information that was furnished by the

reporting agencies concerning aggregate-weighing equipment is tabulated in Table 11-h. As will be seen from the table, thirty-seven agencies state that they use either multiple-beam or springless-dial scales. Seven use the springless-dial scale only. Six agencies did not indicate the type used.

TABLE 11-h

AGGREGATE WEIGHING EQUIPMENT FOR BATCH-TYPE PLANTS

Type of Scale Used	Number of Agencies	Required Scale Accuracy - Maximum Tolerance	Number of Agencies
Multiple beam, springless dial	37	0 5 percent of maximum load	16
Springless dial only	7	0.5 percent of load	14
Type not indicated	6	0 4 percent of maximum load	1
		0 4 percent of load	3
		± 2 lb	1
		± 5 lb	2
		± 20 lb.	1
		± 50 lb	1
		Based on scale graduation	2
		Other	1
		Approved	2
		Not specified	4
		Not reported	2

Regarding the required accuracy of the aggregate scales (see Table 11-h), 16 agencies report that they require an accuracy within 0. 5 percent of the maximum load to be carried, and 14 report that they require an accuracy within 0. 5 percent of the load carried. Considerable variation occurs in the practice reported by other agencies, as will be seen from the table.

Measuring Equipment for Bituminous Material

Data regarding the measuring equipment for bituminous material in batch-type plants are summarized in Table 11-i. All agencies have plants operating using the weight method of measurement, and 25 have plants in which the bituminous material is metered by volume.

TABLE 11-i

MEASURING BITUMINOUS MATERIAL IN BATCH-TYPE PLANTS

Method of Measurement	No. of Agencies	Type of Scales Used	No of Agencies	Required Weigh-Bucket Capacity	No of Agencies
By weight	50	Beam or springless dial	15	10 pct of mixer capacity	4
By volume and weight	25	Springless dial	6	11 pct of mixer capacity	1
		Beam	1	12 pct of mixer capacity	2
		Spring-type	1		
		Springless dial or cylinder	1	15 pct of mixer capacity	3
		Type not reported	26	20 pct of mixer capacity	3
				25 pct. of mixer capacity	1
				10-20 pct of mixer capacity	1
				15 pct of aggregate wt	2
				20 pct of aggregate wt	3
				Sufficient, adequate, etc	7
				Not specified	16
				Not reported	7

Regarding the type of scales used, 15 report using either beam or springless-dial scales, 6 report using the springless-dial type only, one reports using a beam scale only, and two report using other types (see Table 11-i). Twenty-six agencies did not report on scale type.

Twenty agencies reported specific requirements regarding the weigh-bucket capacity for bituminous material. These requirements range from 10 percent to 25 percent of the mixer capacity, and from 10 to 20 percent of the aggregate weight. As will be seen from Table 11-i practice is well divided through these ranges. Seven agencies require that the capacity be sufficient, adequate, etc. , 16 reported that they have no specification requirement, and 7 did not report.

Batch-Type Mixers

A number of questions were asked concerning specification requirements for, and usage of, batch-type mixers. Several of the questions were concerned with detailed items which many agencies appear not to cover directly in their specifications. Such replies as were received are summarized in Table 11-j, and are discussed in the following paragraphs.

Forty-seven of the reporting agencies use twin-shaft mixers exclusively. Only two report that some use is made of rotary-drum mixers in addition to the twin-shaft mixer.

Regarding permissible minimum mixer capacity, a variety of replies were received (see table). Of 25 agencies that report having a minimum capacity requirement (that is, in pounds per batch), 16 have set a 2,000-lb minimum, 4 have a 1,500-lb minimum, 4 have a 1,000 lb minimum, and 1 agency has a 750-lb minimum. Such other capacity requirements as were reported will be seen by referring to the table. Fifteen agencies report that they do not specify a minimum capacity, and four did not report.

TABLE 11-j

USAGE AND REQUIREMENTS-BATCH-TYPE MIXERS

Type of Mixer Normally Used	Number of Agencies	Permissible Minimum Mixer Capacity	Number of Agencies	Mixer-Blade Rotation Rate rpm	Number of Agencies	Maximum Allowable Blade Clearance inches	Number of Agencies
Twin shaft	47	750 lbs.	1	40	1	1/2	1
Rotary drum or twin shaft	2	1000 lbs.	4	40-60	1	3/4	18
Not reported	1	1500 lbs.	4	56	1	1	2
		2000 lbs.	16	55-75	1	1-1 1/2	1
		300 ton/8 hrs.	1	58-60	1	2	8
		52 cu. ft.	1	60+	2	Not specified	14
		Rated capacity	2	70-90	2	Not reported	6
		1/2 rated capacity	1	Mfgr's. rate	3		
		Depends on job	1	For uniform mix, etc.	2		
		Not specified	15	Not reported	36		
		Not reported	4				

Time Lock	Number of Agencies	Specified Minimum Lock Interval seconds	Number of Agencies
Use time lock	26	2	1
Do not use time lock	24	5	10
		10	1
		15	1
		Not specified	6
		Not reported	31

TABLE 11-k

USAGE AND REQUIREMENTS-CONTINUOUS-TYPE MIXERS

Type of Mixer Normally Used	Number of Agencies	Usual Maximum Rate of Production tons per hour	Number of Agencies	Angular Adjustment Required for Paddles	Number of Agencies	Paddles Required Capable of Reverse Motion	Number of Agencies	Minimum Allowable Capacity of Discharge Hopper lbs.	Number of Agencies
Twin pugmill	41	40	1	Angular adjustment required	40	Reverse motion required	27	2000	5
Twin or single pugmill	2	50	2	Angular adjustment not required	2	Reverse motion not required	15	1000	1
Not reported	3	120	4	Not reported	4	Not reported	4	One batch	1
Type not used	4	125	1	Type not used	4	Type not used	4	Not specified	27
		160	1					Not reported	12
		80 min.	1					Type not used	4
		40-120	1						
		80-100	1						
		Not reported	34						
		Type not used	4						

Only nine agencies reported on the rotation rates of the mixer blades of the mixers used on their construction projects. Reported rates vary from 40 to 90 rpm (see table).

Thirty agencies reported on their specifications regarding mixer-blade clearance. Fourteen agencies report that they have no specifications regarding this particular item, and six did not report. Of the 30 agencies reporting a specification, 18 have established $\frac{3}{4}$ in. as a maximum clearance, and 8 have established 2 in. Maximum clearances permitted by the remaining four agencies will be seen by referring to Table 11-j.

Twenty-six of the 50 reporting agencies report that a time lock is used on their mixers. The remaining 24 do not use a time lock. Thirteen of the agencies report that they have specifications covering a minimum lock interval. Ten of these have set a minimum interval of 5 seconds, 1 requires 2 seconds, 1 requires 10 seconds, and 1 requires 15 seconds.

Continuous-Type Mixing Plants

Continuous-Type Mixers

Several questions similar to those that were asked concerning batch-type mixers were asked concerning continuous-type mixers. The replies are summarized in Table 11-k, and are discussed in the following paragraphs.

Of the 46 agencies using continuous mixers, 41 report that usage is confined to the twin-pugmill mixer. Two agencies report that they use a single-pugmill mixer in addition, and three agencies did not report.

Only twelve agencies reported on the usual maximum rate of production. Reported rates vary from 40 to 160 tons per hour. Four agencies report a maximum rate of 120 tons per hour, and, as will be seen from the table, the rates reported by the other agencies are well distributed through the range of 40 to 160.

Of 42 agencies reporting concerning a requirement for angular adjustment of the mixer paddles, 40 report that they require the paddles to be capable of angular adjustment, and two report that angular adjustment is not required.

Of 42 agencies reporting concerning a requirement that the paddles be capable of reverse motion, 27 report that this is required. The remaining 15 report that reverse motion is not required.

Only six of the 46 agencies using continuous mixers report that they specify a minimum allowable capacity for the discharge hopper of the pugmill. Five of these require a minimum capacity of 2,000 lb of mixture, and one requires a minimum capacity of 1,000 lb.

TRANSPORTATION

Forty-one of the 50 reporting agencies state that a cover for the material is required during transportation from the mixing plant to the road-site. Six additional agencies indicate that a cover is used when one is considered to be needed, particularly in cool weather. Only three agencies report that no cover is required. Of the agencies answering the question as to the type of cover specified, all indicate the use of a cloth cover. Such terms as "canvas," "waterproof canvas," and "tarpaulin" were used, but it is believed that all refer to the same type of material. One agency indicates permitting the use of heavy paper as well as canvas.

Only seven agencies indicate that they require regular use of body insulation on trucks transporting bituminous-concrete mixtures. Seven additional agencies indicate that insulation is required occasionally, particularly in cool weather or during long hauls. Only two agencies reported on the type of insulation specified; one requiring wood and the other celotex. Two agencies report requiring a $\frac{3}{4}$-in. thickness of insulation without mentioning

TABLE 11-1

SPREADING AND FINISHING MACHINE

Use of Side Forms	Number of Agencies	Use of Leveling Device	Number of Agencies	Use of Screed Heater	Number of Agencies
Not used	45	Used	31	Used	45
Required	2	Not used	15	Not required	2
Optional	2	Optional	1	Not specified	1
Not reported	1	Not reported	3	Not reported	2

type, and one agency reports requiring a ½-in. thickness without mentioning type.

SPREADING AND FINISHING MACHINE

A very limited number of questions were asked concerning spreading and finishing machines. The information that was received is summarized in Table 11-l. In reply to a question as to whether side forms are used, two report that they are required, and two report that the use of side forms is optional. Concerning the use of a leveling device to compensate for irregularities in the surface upon which the bituminous material is being placed, 31 agencies report the use of such a device, 15 report that such a device is not used, and 1 reports that the use of such a device is optional. Regarding the use of screed heaters, 45 agencies report that a screed heater is used, and 3 agencies report that the use of a screed heater is either not required or not specified.

COMPACTING ROLLERS

Requirements concerning roller types were previously discussed, and summary information was reported in Table 10-1. Information on specified weight limits for rollers, and specified compression weights, is now summarized in Table 11-m. An inspection of the table will show that, except for three-axle tandem rollers, most agencies require total weights of from 8 to 12 tons, with a scattering of agencies permitting rollers weighing as little as 5 tons and as much as 14 tons. Of two agencies specifying total weights for three-axle tandem rollers, one specifies a range of from 12 to 19 tons, and the other a range of from 16 to 21 tons. Specified compression weights of from 200 to 250 lb per in. of roller width are usually required, with a few requiring somewhat higher compression weights. One permits a compression weight of up to 400 lb per in. of roller width.

TABLE 11-m

REQUIREMENTS FOR COMPACTING ROLLERS 1/

Specified Total Weight Limit tons	Number of Agencies
Tandem	
5-8	1
5-10	2
6	1
6-10	1
7	1
7-10	4
8	2
8+	7
8-10	7
8-12	9
10	2
10+	4
10-12	1
10-14	2
Not specified	3
Not reported	1
Three Wheel	
5-10	2
7-10	1
8+	2
8-10	2
8-12	5
10	10
10+	4
10-12	5
10-14	1
Not specified	2
Not reported	1
Pneumatic	
8-10	1
10	1
10-14	2
Not specified	1
Three-Axle Tandem	
12-19	1
16-21	1

Specified Compression Weight lb per in roller width	Number of Agencies
Tandem	
200	7
200+	5
200-250	1
250	6
250+	5
250-400	1
260+	1
300+	1
325	2
330	1
Not specified	13
Not reported	6
Three Wheel	
200	7
200+	1
250	4
250+	2
250-400	1
300	1
300+	1
310-350	1
325	2
330	2
350	1
Not specified	9
Not reported	3
Pneumatic	
250	1
325	2
Not specified	4
Three-Axle Tandem	

1/ Summary information on roller-type requirements is presented in Table 10-1.

TESTS OF MIXTURES

The cooperating agencies were asked to report on the various tests that are made on samples taken from regularly-produced paving mixtures. They were also asked to indicate which tests are performed in field laboratories, and which are performed in central laboratories; and which are made on samples taken from trucks or at discharge from the mixer, and which are made on samples taken from the compacted pavement.

Of 40 agencies reporting on the frequency with which samples are taken from the compacted pavement to determine in-place density, at least eighteen indicate that they take about one sample a day minimum. One agency reports taking two per day, and another four per day. One agency reports taking one every other day. Several other agencies reporting on a tonnage or sq yd basis indicate a similar frequency of sampling. Five agencies report that samples are taken rarely, occasionally, etc., and two report that sampling frequency is at the Engineer's discretion. Only four agencies report that samples are not taken from the compacted pavement. Hand tools, core drills, air hammers, and saws are most frequently used for the removal of samples from the compacted pavement.

TESTS IN FIELD LABORATORY

The information that was received regarding tests made in field laboratories on

TABLE 12-a

TESTS PERFORMED IN FIELD LABORATORY ON SAMPLES OF PLANT-PREPARED BITUMINOUS-CONCRETE MIXTURES

Test	Total Number of Agencies Making Test in Field Laboratory	Number of Agencies Making Test in Field Laboratory on Sample of: Loose Mixture	Compacted Pavement	Undetermined
Gradation	46	38	16	1
Extraction	35	26	14	2
Density 1/	29	5	28	0
Marshall	8	5	2	1
Hubbard-Field	1	1	0	0
Thickness	2	0	2	0
Moisture Content	1	1	0	0
Compaction	1	1	0	0

1/ Many agencies calculate the theoretical void content following the determination of density of samples from the compacted pavement.

TABLE 12-b

TESTS PERFORMED IN CENTRAL LABORATORY ON SAMPLES OF PLANT-PREPARED BITUMINOUS-CONCRETE MIXTURES

Test	Total Number of Agencies Making Test in Central Laboratory	Number of Agencies Making Test in Central Laboratory on Sample of: Loose Mixture	Compacted Pavement	Undetermined
Gradation	36	30	16	0
Extraction	45	37	19	1
Density 1/	29	7	28	0
Marshall	12	9	4	0
Hveem Stabilometer	8	6	3	0
Hubbard-Field	5	3	2	0
Triaxial Compression	2	1	1	0
Unconfined Compression	2	0	0	2
Hveem Cohesiometer	2	2	1	0
Abson Recovery	4	1	4	0
Swell	2	1	1	0
Thickness	4	0	4	0
Moisture Content	1	1	0	0
Compaction	1	1	0	0

1/ Many agencies calculate the theoretical void content following the determination of density of samples from the compacted pavement.

mixture samples is summarized in Table 12-a. It will be noted from the table that tests most frequently made on samples of loose material and also on samples of the compacted pavement are gradation, extraction, and density tests. Forty-six agencies indicate that gradation tests are made in a field laboratory, 35 indicate that extraction tests are made in the field, and 29 indicate that density tests are made in the field. As would be expected, gradation and extraction tests are more frequently made on samples taken from the loose mixture rather than from the compacted pavement. Twenty-eight of the 29 agencies making density tests determine the density of specimens taken from the compacted pavement. Four of these also conduct density (or compaction) tests on samples taken from the loose mixture. One agency makes density (compaction) tests only of samples taken from the loose mixture. Additional details of practice will be seen by referring to Table 12-a.

TESTS IN CENTRAL LABORATORY

Table 12-b contains data similar to that contained in Table 12-a, except that the data relate to tests performed in the central laboratory. Fewer agencies perform gradation tests on field-obtained samples in the central laboratory than perform these tests in the field laboratory (36 as compared with 46). A greater number perform extraction tests in the central laboratory (45 as compared with 35). An equal number (29) perform density tests in the central laboratory and in the field.

The Marshall and Hubbard-Field tests are made much more frequently in the central laboratory, and the Hveem, triaxial, and unconfined compression tests are made only in the central laboratory. Details regarding the number of agencies performing these and other tests of samples obtained in the field will be found in Table 12-b.

A further comparison of practice regarding central and field laboratory testing of field-obtained samples is presented in Table 12-c for the three principal tests. It will be seen that the gradation test is used by all but one of the 50 reporting agencies, and that samples are tested in both field and central laboratories by 33 of the agencies. Thirteen of the agencies use the gradation test in the field only, and 3 use the test in the central laboratory only. It will also be seen from the table that all agencies make use of the extraction test, 30 using the test in both field and central laboratories. Five agencies use the test in the field only, and 15 use the test in the central laboratory only. Continuing to refer to Table 12-c, it will be seen that 40 of the 50 reporting agencies make use of the density test on field-obtained samples. Seventeen use the test in both field and central laboratories, 11 use the test in the field only, and 12 use the test in the central laboratory only.

Appendix I

PRIME COAT

Questionnaire returns indicate that all but two of the reporting agencies apply a coating of asphalt or tar to the base that is to receive the asphaltic concrete. The term "prime coat" is applied to this coating most frequently when a granular base is involved and some penetration is expected. The term "tack coat" is frequently used when the bituminous material is applied to a concrete base. The term "bond coat" is also sometimes used. Terminology is not consistent; and since the term "prime coat" was the only one used on the questionnaires some of those who filled in the replies may have met with some difficulty in understanding the answers that were desired. However, it is not believed that the confusion was sufficient to seriously affect the reliability of the answers.

The more important features of the returns are summarized and discussed in the paragraphs which follow. Details of the replies that were received are tabulated in Appendix Table 13.

TABLE 12-c

SUMMARY DATA REGARDING PRINCIPAL TESTS PERFORMED ON FIELD-OBTAINED SAMPLES IN FIELD AND CENTRAL LABORATORIES

	Number of Agencies Conducting Test		
	Gradation	Extraction	Density
Test made in field laboratory only	13	5	11
Test made in central laboratory only	3	15	12
Test made in both field and central laboratories	33	30	17
Test not used	1	-	10
Total agencies reporting	50	50	50

BITUMINOUS MATERIAL

The reporting agencies were asked to list the grades of asphalt and tar that they use for priming bases upon which is to be placed bituminous concrete, and to indicate the type and grade of material that is normally used on flexible base, and on rigid base. Forty-eight of the agencies make at least some use of asphalt, and 20 make at least some use of tar. Two agencies do not use a prime coat. A summary of the information that was furnished by the agencies concerning the specific types and grades of asphalts and tars normally used is presented in Table 13-a. It will be noted from the table that Type MC and Type RC asphalts are used most frequently on flexible bases (Type MC by 21 and Type RC by 7 of 30 reporting agencies). Type RC and emulsified asphalts are the types most frequently used on rigid bases (Type RC by 20 and emulsified asphalts by 9 of 27 reporting agencies). Individual grades of asphalt used most frequently are Grades MC-1 and MC-0 for flexible bases (by 12 and 8 agencies respectively), and Grades RC-1 and RC-0 for rigid bases (by 9 and 7 agencies respectively).

TABLE 13-a

TYPES AND GRADES OF BITUMINOUS MATERIAL NORMALLY USED FOR PRIME COAT OF BASE ON WHICH IS PLACED BITUMINOUS CONCRETE

Type and Grade of Bituminous Material	Number of Agencies Normally Using Type and Grade On Flexible Base	On Rigid Base
Type RC asphalt	7	20
Grade RC-0	1	7
RC-1	5	9
RC-2	2	5
RC-3	2	2
RC-4	1	1
Type MC asphalt	21	4
Grade MC-0	8	3
MC-1	12	2
MC-2	5	1
Type SC asphalt	1	
Grade SC-2	1	
Emulsified asphalt	1	9
Type AEM-1		1
AE-2		1
AE-5		1
AE-7	1	1
RS-1		5
MS-2		1
Tar	5	
Grade RT-1	2	
RT-2	3	
RT-3	3	
RT-4	1	
DHO Asphalt Primer (Ont.)1/	1	1
Total agencies reporting	30	27
Agencies reporting normal use of more than one type and grade of material	9	8

1/ Resembles Type RC

Agencies using tar as a prime-coat material confine its use almost wholly to flexible base (one exception). For agencies reporting on the grade of tar used (only five reported grade), three use RT-2, three use RT-3 and two use RT-1. All of this usage is on flexible base.

Specifications controlling the characteristics of the various grades of bituminous material are, for most of the reporting agencies, identical with specifications recommended by the AASHO. The few variations that do occur are mostly of a minor nature. Where a spot requirement is listed by the AASHO as optional, ten agencies report definitely that they do not have a spot-test requirement. Twelve agencies indicate that a negative spot is required when the test is made with standard naphtha solvent; five indicate that a negative spot is required with 35 percent heptane xylene solvent; three require a negative spot with 15 percent naphtha xylene solvent; and two require a negative spot with 10 percent nephtha xylene solvent.

CONSTRUCTION PRACTICE

Application Rate

Forty-three agencies reported on the unit quantities of bituminous material applied to flexible bases. The over-all limits of application reported range from 0.10 to 0.60 gal per sq yd. Only 14 percent of the agencies indicate that applications of less than 0.15 or more than 0.50 gal per sq yd are made.

Thirty-six agencies reported on the unit quantities of bituminous material applied to rigid bases. The over-all limits of application reported range from 0.02 to 0.50 (?) gal per sq yd. Only 19 percent of the agencies indicate that applications of less than 0.03 or more than 0.15 gal per sq yd are made.

A tachometer is used by all but one of the reporting agencies in determining the rate of application of the bituminous material. The agency not using a tachometer reports that distances through which the distributor is to travel are measured and that this measurement is used in determining the rate of application. Two of the agencies using a tachometer also report the use of a synchronizer.

Application Temperature

A question was asked concerning the temperature at which bituminous priming materials are applied, but space was not provided on the questionnaires for indicating the grades of material to which the reported application temperatures applied. The variety of answers that were received seem to indicate that the method of replying to this question was not uniform, so no summary has been made of the information that was received. Over-all, the reported material temperatures at application vary from 50 F to 225 F. About one-third of the 37 agencies reporting application temperatures indicated temperatures that can be reached in normal summer weather without heating. The remainder indicated temperatures likely to be reached only through heating. As would be expected, the agencies using the higher grades of asphalt reported the higher application temperatures.

Curing Period

Only 16 of 41 agencies specify a fixed minimum curing period. The remainder either do not specify a curing period, or include in their specifications a general statement that curing shall be continued until the prime is "properly cured," "tacky," "blotted," etc. Of the 16 agencies specifying a fixed minimum curing period, 8 specify a minimum period of 25 hr. Other minimum periods reported vary from 1 hr to 7 days.

Appendix II

THICKNESS OF PAVEMENTS SURFACED WITH BITUMINOUS CONCRETE

In an effort to assemble some information on the thicknesses of flexible pavement that the reporting agencies would be likely to use under the conditions that prevail in the area of the Test Road, they were asked to indicate the thicknesses of the various pavement components that they would be likely to use if they were to design a pavement for the area. The natural soil was listed as an A-6 soil, the average annual rainfall was stated to be 32 in., and the average annual frost penetration was listed at 28 in. Agencies were asked to indicate the method of flexible pavement design that they use, and whether or not the character of the subgrade soil is taken into consideration in their method of design. They were also asked to furnish designs for medium and heavy traffic, providing their methods took traffic into consideration.

TABLE 14-a

SUMMARY OF REPORTED METHODS OF DESIGN OF FLEXIBLE PAVEMENT THICKNESS

Design Method	Number of Agencies	Design Method	Number of Agencies
Past experience	9	HRB Group Index, traffic, rainfall, and drainage	1
HRB Soil Classification	3	Traffic, rainfall, gradation, and Atterberg limits of base and subbase material	1
CBR (modified)	3	Traffic and bearing value	1
CBR	2	Triaxial	1
Hveem Stability Test	2	Triaxial-modified Hveem	1
Volume and type of traffic	2	Traffic volume and soil type	1
California Method	1	Gradation and plate bearing tests	1
Colorado Method	1	Rational determination	1
Hveem Method	1		
Kansas Triaxial Method	1	Total	42
North Dakota Method	1		
P I of subgrade soil and amount of minus No 200 sieve material	1		
CBR and frost penetration	1		
CBR and HRB Soil Class	1		
CBR (modified) and Hveem Stability Test	1		
Ky (CBR) and Ohio (HRB) design curves	1		
HRB Soil Class, traffic, drainage and frost penetration	1		
HRB Soil Class and traffic	1		
Soil profile and estimated stability of foundation	1		

Design Methods

Since it was desired that the reporting agencies indicate the thicknesses of pavement they would be likely to use under the conditions of the area of the Test Road, it was also considered desirable to obtain general information on the method by which they arrive at pavement thickness. However, it was considered beyond the scope of the questionnaires to cover thoroughly the broad and complex subject of thickness design, and as a consequence, the information that was obtained is very limited and in some instances probably not very precise.

In Table 14-a are summarized the replies that were received concerning the method used to determine the thickness of flexible pavements. It will be seen that the replies vary widely, and that many were not sufficiently complete to indicate the over-all design procedure. For example, a number of agencies indicate only a physical test that is used as part of the design procedure. However, there is a definite indication that most agencies attempt to evaluate one or more of the conditions that must be satisfied before the pavement structure can be expected to serve adequately, and to vary the thickness accordingly.

Subgrade Character in Design

The agencies were asked to indicate the manner in which subgrade soil characteristics are taken into consideration in their designs for pavement thickness. Replies that were received are summarized in Table 14-b. It will again be seen that there was a considerable variation in the methods of replying to the question and that the information that was received is not complete. However, it is evident that almost all agencies give consideration to subgrade conditions and the character of the subgrade soil in selecting pavement thickness.

Pavement Thickness

As mentioned previously, the reporting agencies were asked to determine the total pavement thickness and also the thickness of the individual components that their design procedures would indicate to be satisfactory under the following conditions:

Subgrade soil class	A-6
Average annual rainfall	32 in.
Average annual frost penetration	28 in.

Designs were to be furnished for pavements consisting of bituminous concrete placed on both flexible (granular) and rigid bases overlying granular subbases. The agencies using design procedures that take traffic into account were asked to furnish designs for "medium" and "heavy" traffic. Twenty-seven agencies furnished complete thickness designs for heavy-traffic flexible pavement, 28 for medium-traffic, and 10 for flexible pavement without differentiating as to traffic.

TABLE 14-b

SUMMARY OF REPORTED USE OF SUBGRADE SOIL CHARACTERISTICS IN DETERMINING THE THICKNESS OF FLEXIBLE PAVEMENTS

Characteristics Evaluated	Number of Agencies	Characteristics Evaluated	Number of Agencies
HRB Soil Class	5 (1)1/	Hveem stabilometer test value and swell pressure	1
CBR	6 (2)	CBR (modified), Hveem stabilometer test value, and frost reaction	1
Subgrade soil type	3 (2)	Past experience	1
Bearing value or ability	3		
Subgrade soil characteristics	2 (2)2/		
HRB Group Index	2	Total	40
Drainability	2		
HRB Soil Class and CBR	2		
Not evaluated	2		
PI and amount of minus No. 200 sieve material	1		
Shearing resistance and expansive characteristics	1		
CBR (modified)	1		
Hveem method	1		
Modulus of deformation from triaxial test	1		
Mechanical analysis and plate-bearing value	1		
Soil type and [illegible] cone value	1 (1)		
Stabilometer value and silt content	1		
Shear strength by triaxial test	1		

1/ Numbers in parentheses indicate the number of agencies stating that variations are made in only the subbase thickness as a result of the evaluation of subgrade soil characteristics

2/ One agency states that both base and subbase thickness are varied on the basis of the evaluation of subgrade soil characteristics

TABLE 14-c

SUMMARY OF TOTAL PAVEMENT THICKNESSES LIKELY TO BE USED BY THE REPORTING AGENCIES UNDER THE FOLLOWING CONDITIONS

Granular subbase and base, bituminous concrete surface	
Subgrade soil class	A-6
Average annual rainfall	32 in
Average annual frost penetration	28 in

Total Thickness 1/		
No Traffic Differentiation inches	Heavy-Traffic Pavement inches	Medium-Traffic Pavement inches
5-18	8-18	5-18
9½	9½	7
10¼-23½	10	7½-38½
11½	11	8¼-9
14-27	14-21	9
16	14½-23	9½ (2)
18 (2)	15	10-14
19	15½-24½	10½-15½
22½	17 (2)	11 (2)
	17½-23½	11¼-20¼
	18	14¼-21½
	18-19½	15-16½
	19-26	16
	20	16¼
	20¼	18¼
	20¼-28½	18½-23½
	21½	19 (2)
	24 (2)	19½-25½ (2)
	27	21 (2)
	27-39	21-27
	28	21-33
	28½	22
	29	28
	32-38	
	37	
Overall range 5-27 in Average 16.4 in Total agencies 10	Overall range 8-39 in Average 21.5 in Total agencies 27	Overall range 5-38½ in Average 16.9 in Total agencies 28

1/ Only a few agencies reported identical thicknesses or thickness ranges Where the same figures were reported by more than one agency, the number of agencies is indicated by the figure in parentheses following the thickness value

Only 11 agencies furnished complete thickness designs for rigid-base pavement.

Total Thickness-Flexible Base. The total-thickness figures that were reported for the flexible-base pavement are summarized in Table 14-c. It will be noted that almost as many different thickness figures were reported as there were agencies reporting. The figures for total thickness that were reported range from 5 to 27 in. for the agencies that do not make a distinction on the basis of traffic; from 8 to 39 in. for heavy-traffic pavements; and from 5 to 38½ in. for medium-traffic pavements for agencies that take traffic into consideration in their design procedures. About three-quarters of the agencies reporting thickness designs without considering traffic listed figures within the limits of 11½ and 19 in.; about three-quarters of those reporting for heavy-traffic pavements listed figures within the limits of 14 and 29 in.; and about three-quarters of those reporting for medium-traffic pavements listed figures within the limits of 9 and 25½ in.

TABLE 14-d

SUMMARY OF GRANULAR SUBBASE AND BASE THICKNESSES LIKELY TO BE USED BY THE REPORTING AGENCIES UNDER THE FOLLOWING CONDITIONS

Bituminous concrete surface	
Subgrade soil class	A-6
Average annual rainfall	32 in
Average annual frost penetration	28 in

Thickness Reported 1/				
No Traffic Differentiation	Heavy-Traffic Pavement		Medium-Traffic Pavement	
SUBBASE				
inches	inches	inches	inches	inches
0-13	0-6	9 (2)	0-10	9
4-6	0-12	10	0-12	10
4-12	0-18	10½	0-13	12 (3)
6 (2)	3-13	12 (2)	0-18	12-14
6-18	4	12-18	3	12-15
8	5+	12-20	4-6	14½
11	6-9	13	5	15
12 (2)	6-10	15	6	18
	7	17	6-9	18-24
	8	18-20	6-12	
	8-12	20	6-15	
		24	7 (2)	
		24-36	8	
			8-12	
Overall range 0-18 in Average 8 3 in Total agencies 11	Overall range 0-36 in Average 11 8 in Total agencies 26		Overall range 0-24 in Average 9 8 in Total agencies 26	
BASE				
2 (2)	2	6-10	2 (2)	6-10
2-10	3 (3)	7	3 (3)	7 (2)
3	3-6	8 (4)	4 (3)	7-10
4-8	4 (3)	9+	4-5½	7-12
4½	4½	10 (3)	4-6 (2)	8 (3)
5-6	5-6½	10-14	5-18	8-10
6 (2)	5-14	12 (2)	5½-6	9
8 (3)	5-18	12-21	6 (5)	18
	6 (3)	24		
Overall range 2-10 in Average 5 4 in Total agencies 12	Overall range 2-24 in Average 8 0 in Total agencies 30		Overall range 2-18 in Average 6 4 in Total agencies 29	

1/ Most of the thicknesses that are listed were reported by only one agency. Where more than one agency reported identical thicknesses, the number of agencies reporting appears in parentheses following the thickness figure.

It is not believed that the wide variation in thickness as determined by the different design procedures in use is attributable entirely to differences in the procedures. It is known, for example, that the information that was given concerning the subgrade soil was insufficient for many agencies (although it was all that was available at the time), and additional assumptions had to be made before many of the design procedures could be applied. Additional assumptions would be expected to cause a spread in the results. Other assumptions that were necessary, such as a more precise defining of the terms "heavy traffic" and "medium traffic," and perhaps in some instances the extrapolation in procedures not developed to cover the specified conditions of rainfall and frost, could be expected to cause further variation in results. The fact that many of the agencies chose to report ranges in thickness rather than a specific thickness is a good indication that they considered the information that was given as being insufficient for designing by their procedures.

A comparison of the ratios of the bituminous concrete surfacing to the total thickness for each agency did not indicate that the thickness of the surfacing had any consistent influence on total thickness.

Granular Subbase and Base Thickness. The granular subbase and base thicknesses determined by the reporting agencies for use with a bituminous-concrete surfacing under the conditions of soil, climate and traffic that have previously been listed are summarized in Table 14-d. It will be noted that here again the thicknesses determined by the different procedures used by the reporting agencies vary considerably. The agencies are, however, in better agreement on base thickness than on either subbase thickness or total pavement thickness.

The reported subbase thicknesses range from 0 to 18 in. and average 8. 3 in. where no differentiation is made as to traffic. For heavy-traffic pavements, the reported subbase thicknesses range from 0 to 36 in. and average 11. 8 in. For medium-traffic pavements, the reported subbase thicknesses range from 0 to 24 in. and average 9. 8 in.

Reported base thicknesses range from 2 to 10 in. and average 5. 4 where no differentiation is made as to traffic. For heavy-traffic pavements, the base thicknesses range from 2 to 24 in. and average 8. 0 in. For medium traffic pavements, reported thicknesses range from 2 to 18 in. and average 6. 4 in.

Bituminous-Concrete Thickness (Flexible Base). Much better agreement prevails among the reporting agencies as to the thickness of bituminous concrete that should be used under the conditions of soil, traffic and climate that were specified. This will be seen from an inspection of Table 14-e where the reported data are summarized.

Reported total thicknesses for the bituminous surfacing range from 2½ to 5½ in.

TABLE 14-e

SUMMARY OF BITUMINOUS CONCRETE THICKNESSES LIKELY TO BE USED BY THE REPORTING AGENCIES UNDER THE FOLLOWING CONDITIONS

Bituminous concrete surface, granular base and subbase
Subgrade soil class A-6
Average annual rainfall 32 in.
Average annual frost penetration 28 in.

Thickness Reported 1/		
No Traffic Differentiation	Heavy-Traffic Pavements	Medium-Traffic Pavements
TOTAL THICKNESS OF BITUMINOUS CONCRETE		
inches	inches	inches
2½ (3)	1	1-3
2½-3½	2 (2)	2 (5)
3 (2)	2½ (5)	2½ (9)
3½	2½-3	3 (9)
4 (4)	3 (14)	3¼
5½	3¼	3½ (2)
	3½	3½-5½
	4	
	4½	
	5	
Overall range 2½-5½ in.	Overall range 1-5 in.	Overall range 1-5½ in.
Average 3.5 in.	Average 3.0 in.	Average 2.7 in.
Total agencies 12	Total agencies 28	Total agencies 29
THICKNESS OF BINDER COURSE 2/		
1-1½	1	0-2
1¼	1¼ (2)	1 (2)
1½ (3)	1½ (9)	1¼ (3)
2 (3)	1.7	1½ (9)
2½ (2)	1 3/4	1 3/4
4	2 (6)	2 (5)
	3	2-4
	3½	
Overall range 1-4 in.	Overall range 1-3½ in.	Overall range 1-4
Average 2.0 in.	Average 1.8 in.	Average 1.6
Total agencies	Total agencies 22	Total agencies 22
THICKNESS OF SURFACE COURSE 2/		
1	1 (5)	1 (8)
1¼	1-1½	1¼ (5)
1½ (6)	1¼ (4)	1½ (9)
1½-2	1.3	
2 (2)	1½ (10)	
Overall range 1-2 in.	Overall range 1-2 in.	Overall range 1-1½ in.
Average 1.6 in.	Average 1.4 in.	Average 1.3 in.
Total agencies 11	Total agencies 22	Total agencies 22

1/ Many of the thicknesses that are listed were reported by only one agency. Where more than one agency reported identical thicknesses, the number of agencies reporting appears in parentheses following the thickness figure.

2/ The binder-course and surface-course thicknesses that are listed are for the agencies that reported thicknesses for both. Six agencies reported surface thickness only, and these are tabulated as total thickness.

and average 3.5 in. where no differentiation is made as to traffic. For heavy-traffic pavements the range is from 1 to 5 in. and the average 3.0 in.; and for medium-traffic pavements the range is from 1 to 5½ in. and the average is 2.7 in. The over-all ranges are relatively great. However, an inspection of the table will show that a majority of the agencies suggest thicknesses within the range of 2½ to 3 in., regardless of traffic considerations, and that only a scattering of agencies suggest thicknesses at or near the extreme limits of the over-all ranges.

Table 14-e also contains a summarization of recommended binder-course and surface-course thicknesses. It will be seen that here again good agreement exists, and that the pattern is very much the same as that described for the total thickness of bituminous surfacing. The averages of the reported surface-course thicknesses for the different conditions of traffic range from 0.3 to 0.4 in. less than the averages of the reported binder-course thicknesses.

Rigid-Base Pavement Thickness. Only 11 agencies furnished thickness designs for pavements consisting of bituminous concrete placed on a rigid base (and, in most of the designs furnished, including a subbase). The conditions of soils, traffic and climate that were to be considered in preparing the design are the same as those set up for the flexible-pavement design. Six of the 11 agencies furnished separate designs for heavy- and medium-traffic pavements, and two furnished designs for heavy-traffic pavements only. The other three furnished designs without differentiating as to traffic, except that one of the three indicated that subbase would be omitted from the design under conditions of medium traffic.

The proposed over-all thicknesses range from 11 in. to 23 in. for designs for heavy-traffic pavements, from 8½ in. to 22 in. for designs for medium-traffic pavements, and from 10 in. to 23 in. where no traffic differentiation was made.

Subbases were proposed for use by 7 of 8 agencies furnishing heavy-traffic designs, by 6 of 9 agencies furnishing medium-traffic designs, and by 2 of 3 agencies not differentiating as to traffic. Two of the agencies furnishing both heavy- and medium-traffic designs reduced the subbase thickness by 2½ in. for the medium-traffic design, and a third agency proposed a subbase for heavy traffic but dispensed with the subbase for medium traffic. Otherwise, there is little descernible difference in the proposed subbase thicknesses insofar as traffic conditions are concerned.

Suggested thicknesses for the rigid base range from 4 in. to 10 in. The recommendations of all but 3 of the agencies are within the range of 6 to 8 in. Two agencies that recommend an 8-in. thickness of rigid base for heavy-traffic pavements reduce the thickness to 6 in. for medium-traffic pavements. The single agency that recommends a 10-in. rigid base for heavy-traffic pavements recommends 9 in. for medium-traffic pavements. Otherwise, there is little difference in the recommended rigid-base thicknesses with respect to traffic.

Proposed thicknesses for the bituminous-concrete surfacing for use with rigid base range from 1 in. to 3 in. Six of 8 agencies furnishing a heavy-traffic design propose the 3-in. thickness. One of these would reduce the thickness to 2½ in., and another to 2 in., for medium traffic. Only one agency recommended a 1-in. thickness of bituminous concrete, but made this recommendation for both heavy and medium traffic. Thicknesses of 2½ in. and 2¼ in. were each recommended by one agency.

Only 8 agencies furnished complete thickness designs for both flexible base and rigid-base pavements. Thickness differentials ranging from 1 in. to 16 in. in favor of the rigid-base pavement were indicated in the designs of 6 of the agencies. One agency indicated the same thickness for both types of pavement, and one indicated a 1-in. differential in favor of the flexible pavement. Because of the few agencies that furnished information for this comparison, not much significance can be attached to it.

Appendix III

TABULATIONS OF DETAILED DATA

TABLE 1

FINE AGGREGATE FOR BITUMINOUS CONCRETE MIXTURES

Agency	Kinds of Material Used: Natural Sand	Stone Screenings	Cr Gravel Screenings	Stone Sand	Mine Tailings	Chat	Slag Screenings	Volcanic Cinders	Nat Sand Screenings	Angularity of Particles: In Specs	Specification
1 Ala	x								x	No	2/
2 Ariz	x			x				x		No	
3 Ark	x	x								No	
4 Calif	x	x		x						No	
5 Colo.	x									No	
6 Conn	x								x	Yes	100% rough & angular Stone screenings
7 Del.		x								Yes	
8 D.of C.	x	x								No	
9 Fla	x	x					x		x	No	
10 Ga.	x	x								No	
11 Idaho	x			x						No	
12 Ill.	x	x		x		x				No	
13 Ind.	x		x	x			x		x	No	
14 Iowa	x	x								No	
15 Kans	x	x			x					No	
16 Ky.	x			x			x			No	30-50% angular
17 La.	x	x								No	
18 Me.	x	x								No	
19 Md	x	x		x			x			No	
20 Mass.	x								x	Yes	50% max screenings
21 Mich.	x			x						No	
22 Minn	x									No	
23 Miss	x	x					x		x	No	
24 Mo.	x				x	x				No	
25 Mont.	x	x		x						Yes	50-75% Angular
26 Nebr	x									No	
27 Nev.	x			x						No	
28 N.H.	x	x								Yes	50% natura sand
29 N.J	x	x								No	
30 N.M.	x	x	x						x	No	
31 N.Y	x	x		x						No	
32 N.C.	x	x							x	No	
33 N.Dak.	x									No	
34 Ohio	x			x			x			No	
35 Okla.	x	x		x		x				No	
36 Oreg.	x	x	x							No	Moderately sharp
37 Pa.	x	x	x				x			No	
38 R.I.	x									No	
39 S.C.	x	x								No	
40 S.Dak.	x									No	
41 Tenn	x	x	x				x			No	
42 Tex.	x	x								No	
43 Utah	x	x	x							No	
44 Vt.	x								x	No	
45 Va.	x	x							x	No	
46 Wash.	x	x	x							No	
47 W. Va.	x	x		x			x			No	
48 Wisc.	x	x								No	
49 Wyo.	x									No	
50 Ontario	x	x	x						x	No	

1/ Stone for sand and screenings, 10 cycles of testing Na_2SO_4, loss not to exceed 7%, $MgSO_4$, los

2/ Minimum of 30 percent of total aggregate must be coarse, sharp concrete sand.

Note: Whenever the phrase "Not specified" is used in this and following tables, it means that the r

TABLE 1 (continued)

Limitation of Deleterious Materials											Soundness Requirements	
Organic Vegetable Roots, Etc	Clay Loam	Clay Lumps	Finer than No 200 or Decanted	Soft	Coal Lignite	Shale	Cemented	Other	Undifferentiated	Total Allowable	Method of Test	Specified Maximum Loss (percent)
			(allowable percent shown when specified)									
		0 5			0 5	1		1.0(mica, alkali)		3	$Na_2 SO_4$	10
			12		(PI 5-)			0 5 (cinders clinkers)	1	12	Not specified	
		1				x				5	Not specified	
			No specific requirement								Not specified	
			No specific requirement								L A. wear on parent mtrl - 45 m	
			No specific requirement								Not specified	
			No specific requirement								Not specified	
0	0								0	None	$Na_2 SO_4$	12
									0	None	Not specified	
	6									6	Not specified	
		Not specified for F A separately (LL 35-, PI 6-)									Not specified	
		1			1		1			3	$Na_2 SO_4$	10
		0.2			x	2				5	$Na_2 SO_4$	10
			3			2				5	Freeze-Thaw on Parent Material	(16 cycles 25
1		1		5						5	Special Freeze-Thaw	Loss Ratio 0.85-
		1	1		1					3	$Na_2 SO_4$	10
0	0	0								None	Not specified	
									0	None	Not specified	
		1			1				3	5	$Na_2 SO_4$	15
	0								0	None	Not specified	
	x		5								Not specified	
		0				0				None	Not specified	
	3	(AASHO M-79 used with slag and stone screenings)								3	Not specified	
				3						3	Not specified	
0	0	0							0	None	Not specified	
1	x			x		x		x (alkali)			$Na_2 SO_4$	15
	x								x	3	Not specified	
		Quantity of deleterious material must be negligible									Not specified	
0	0			0			0	0 (mica, salt)	0	None	Not specified	
0	0 (adobe)									None	$Mg SO_4$	12
			No specific requirement								1/	1/
0	0	0	8						0	8	Not specified	
	15(of minus No. 10 fraction)					12(of total mixture)					Not specified	
0	0									None	$Na_2 SO_4$	10
0.1		1								1.1	Not specified	
	x								x	2	Not specified	
									0	None	$Na_2 SO_4$	10
	0								0	None	$Mg SO_4$	-
			No specific requirement								Not specified	
0	0									None	L.A. wear - 45 max.	
											Swell T-101 - 13 max.	
	0 5		3	3		0.5				5	$Na_2 SO_4$ on Stone Sand	12
			No specific requirement (PI 6-)								Not specified	
				x Free of excessive quantity				x(disintegrating)			$Na_2 SO_4$	12
0									0	None	$Na_2 SO_4$	8
	0.25		1			1		1 (mica)		1.25	Freeze-Thaw	15 cycles - 8
											$Mg SO_4$	5 cycles - 8
			No specific requirement								Not specified	
		x	3		x						$Na_2 SO_4$	10
0	0	0							0	None	Not specified	
0										None	Not specified	
			No specific requirement								$Mg SO_4$	16

not to exceed 12%. Natural sand, 10 cycles of testing: $Na_2 SO_4$, loss not to exceed 8%, $Mg SO_4$, loss not to exceed 22%.

porting agency does not have a specification requirement covering the item listed

TABLE 1 (continued)

Specified Gradation Limits f

Binder Course Material

(percent by weight passing each sieve,

3/8"	No. 4	No. 8	No. 10	No 16	No. 20	No. 30	No. 40	No 50	No 80	No. 100	No. 200	3/8'
					Not specified							
					Not specified							
					Not specified							
					Not specified,							
					Same as surface course							
	95-100										0-6	
					Not specified							
					Same as surface course							100
	100										0-12	
					Not specified							
					Not specified							
	95-100	- -	0-20		Passing and retained 25-70		+		20-70		-0- 5	
					Same as surface course							
					Not specified							
					Not specified							
100	90-100	75-90						5-35			0-10	100
					Not specified							
					Same as surface course							
					Not specified							
					Same as surface course							
					Same as surface course							
100	98-100							Passing & retained 20-65			0-8	100
					Not specified							
					Not specified							
					Binder course gradation not reported							
					Same as surface course							
					Same as surface course							
					Not specified (except No. 200)						0-15	
					Same as surface course							
					No binder course used							
					Not specified							
					Not specified							
					Not specified							
					No binder course used							100
					Not specified							
					Same as surface course							
100	90-100	70-100		40-80		20-60		5-40		0-20	0-10	
	100								0-10		0-5	
					Not specified							
					Not specified							
					Not specified							
					Not specified							
					Not specified							
					Not specified							
					Not specified							
			100		20-55			15-45		10-35	4-15	
					Same as surface course							100
					Not specified							
					Not specified							
100	95-100	70-100	#14 40-90			20-70		10-40		3-15	0-7	100

TABLE 1 (continued)

1954 Practice

or Fine Aggregate

Surface Course Material

No. 4	No. 8	No. 10	No. 16	No. 20	No. 30	No. 40	No. 50	No. 80	No. 100	No. 200	Agency	
except when stated otherwise)												
				Not specified							Ala.	1
				Not specified							Ariz	2
				Not specified							Ark.	3
				Not specified							Calif.	4
	100				68-84				28-44	4-14	Colo.	5
95										8	Conn.	6
				Not specified							Del.	7
95-100			45-80				10-30		2-10		D.of C.	8
98-100	0-15			Passing and retained 15-50			30-60		15-40	0-15	Fla.	9
				Not specified							Ga.	10
				Not specified							Idaho	11
95-100	0-15			Passing and retained 15-50			20-60		15-35	0-5	Ill.	12
0	0-10	15-35		Passing and retained	25-65			5-35	1-10	0-5	Ind.	13
				Not specified							Iowa	14
				Not specified							Kans.	15
90-100	75-90		40-80				5-35		0-15	0-10	Ky.	16
				Not specified							La.	17
				Passing and retained 15-40			22-53		15-35	7-14	Me.	18
											Md.	19
		100		75-90		35-65		15-30		5-12	Mass.	20
100	0-5			Passing and retained 5-35			30-60		15-35	0-5	Mich.	21
98-100	8-25			Passing and retained 15-50			22-65		7-40	0-8	Minn.	22
				Not specified							Miss.	23
				Not specified							Mo	24
98-100	0-15			Passing and retained 15-50			30-60		15-40	0-5	Mont.	25
5-40		45-70		% retained 60-85			90-			95-	Nebr.	26
100		95-100				55-75		25-50		0-12	Nev.	27
		Not specified (except No. 200)								0-15	N.H.	28
	0-5			Passing and retained 6-30		15-42		20-40	12-35	0-5	N.J.	29
				Not specified							N.M.	30
				Not specified							N.Y.	31
				Not specified							N.C.	32
				Not specified							N.Dak.	33
90-100	65-100		40-85		20-60		7-40		0-15	0-7	Ohio	34
				Not specified							Okla.	35
0		25-40		% retained						90-100	Oreg.	36
	100		85-98		65-90		40-75		5-30	0-6	Pa.	37
100	0-10		15-40	Passing and retained	30-60			5-35	5-20	0-5	R.I.	38
				Not specified							S.C.	39
				Not specified							S.Dak	40
				Not specified							Tenn.	41
				Not specified							Tex.	42
				Not specified							Utah	43
				Not specified							Vt.	44
				Not specified							Va	45
		100		Passing & retained 30-55			20-50		10-30	5-16	Wash.	46
95-100	80-95		50-85				5-25		0-7		W. Va.	47
				Not specified							Wisc.	48
				Not specified							Wyo.	49
95-100	80-100		#14 55-90		35-70		15-40		5-15	0-5	Ontario	50

TABLE 2

COARSE AGGREGATE FOR BITUMINOUS CONCRETE MIXTURES

Agency	Kinds of Material Used: Crushed Gravel	Crushed Stone	Gravel	Crushed Slag	Volcanic Cinders	Mine Chats	Crushed Boulders	Lava	Uncrushed Gravel Particles: Permitted	Percent (of CA)	Wear Requirements: Test Method	Allowable Percent Loss	Soundness: Method 1/ of Test
1 Ala.	x	x		x					No	-	L.A.	48	Na_2 SO_4
2 Ariz.	x	x	x		x				Yes	-	L.A.	40	Not
3 Ark.	x	x							No	-	Deval	6 stone 15 gravel	Na_2 SO_4
4 Calif.	x	x	x						Yes	-	L.A.	50	Not
5 Colo.	x	x		x					Yes	50	L.A.	45	Not
6 Conn.	x	x							Yes	50	L.A.	40	-
7 Del.		x							No	-	L.A.	40	Not
8 D. of C.		x		x					No	-	L.A.	40	Na_2 SO_4
9 Fla.		x		x					No	-	L.A.	40	Na_2 SO_4
10 Ga.		x		x					No	-	L.A.	60	-
11 Idaho	x	x	x						Yes	-	L.A.	40	Not
12 Ill.	x	x		x		x			No	-	L.A.	35	Na_2 SO_4 Freeze-Thaw
13 Ind.	x	x		x					No	-	L.A.	40 to 45	Na_2 SO_4
14 Iowa	x	x							Yes	40 (Total agg.)	L.A.	40	Freeze-Thaw
15 Kans.	x	x				x			Yes	50 (Total agg.)	L.A.	45	Freeze-Thaw
16 Ky.	x	x	x	x					Rarely	-	L.A.	35	Na_2 SO_4
17 La.	x	x	x						Yes	40 (Plus No.10)	Deval	7 stone 15 gravel	Not
18 Me.	x	x							Yes	50	L.A.	40	-
19 Md.		x		x					Yes	30	L.A.	40	Na_2 SO_4
20 Mass.		x							No	-	L.A.	30 to 35	Not
21 Mich.		x					x		No	-	L.A.	32	Mg SO_4
22 Minn.	x	x							No	-	L.A.	35	-
23 Miss.	x	x	x	x					Yes	-	L.A.	40 stone&slag 35 gravel	Na_2 SO_4
24 Mo.	x	x	x			x			Yes	-	Deval	6+ (Fr. coef.)	Not
25 Mont.	x	x							Yes	25	L A.	40	Not
26 Nebr.		x	x						Yes	-	L.A.	40	Freeze-Thaw
27 Nev.	x	x							No	-	L.A.	37	-
28 N.H.	x	x							Yes	50	L.A.	40	Not
29 N.J.	x	x	x						Yes	-	Deval	3.5	Not
30 N.M.	x	x						x	Yes	50	L.A.	50	Mg SO_4
31 N.Y.		x		x					No	-	Deval	5.7	Na_2 SO_4 Mg SO_4
32 N.C.		x		x					No	-	L.A.	55	Not
33 N.Dak.	x		x						Yes	-	No specified reqm't		Not
34 Ohio	x	x		x					Yes	60	No specified reqm't		Na_2 SO_4
35 Okla.	x	x	x						Yes	-	L.A.	40	Not
36 Oreg.	x	x			x				Yes	40	L.A.	30	Not
37 Pa.	x	x		x					No	-	L.A.	10(100 rev.) 35(500 rev.)	Na_2 SO_4
38 R.I.	x	x	x						Yes	-	L.A.	40	Mg SO_4
39 S.C.	x	x	x	x					Yes	25	L.A.	60	Not
40 S.Dak.	x	x							No	-	L.A.	45	Not
41 Tenn.	x	x		x					No	-	L.A.	40	Na_2 SO_4
42 Tex.	x	x	x						Yes	-	L.A.	40	Not
43 Utah	x	x							Yes	30	L.A.	40	Na_2 SO_4
44 Vt.	x	x							No	-	Deval	5 stone 16 gravel	Na_2 SO_4
45 Va.		x		x					No	-	L.A.	[illegible] (100 rev.) 3[illegible](500 rev.)	Mg SO_4 Freeze-Thaw
46 Wash.	x	x							Yes	25	L.A.	30	Not
47 W.Va.	x	x		x					No	-	L.A.	40	Na_2 SO_4
48 Wisc.	x	x							Yes	50-	L.A.	50	Not
49 Wyo.	x	x							No	-	L.A.	50	Not
50 Ontario	x	x							Yes	40	L.A.	35	Mg SO_4

1/ Where the Na_2 SO_4 (sodium sulfate) or Mg SO_4 (magnesium sulfate) tests are indicated, a 5-cycle exposure is used except where

TABLE 2 (continued)

Requirements Specified 1/ Maximum Loss (percent)	Limitation of Deleterious Materials: Organic, Vegetable, Roots, Etc.	Clay Loam	Clay Lumps	Finer Than No.200 or Decanted	Soft	Coal Lignite	Shale	Elongated	Other
	(allowable percent shown when specified)								
10			0.25	0.5	2	0.25			
specified							No specific requirement		
12			1		x		x		
specified							No specific requirement		
specified							No specific requirement		
-							No specific requirement		
specified							No specific requirement		
12		0(dirt)							
12	0.03		0.05	1.25	10	1			0.5(cinders)
									1.0(shells)
15		1							
specified							No specific requirement		
15(5 cycles)			0.5	2.5	5	1			
15(50 cycles)									
20			0.2	1	4		2		1.0(ocher)
									1.0(shells)
10(16 cycles)			0.5	3			3		
0.85 Loss Ratio			2		5	0.5	0.5		
15		1					2	2	
specified									
-								0	
15			1		5	1	1	3	
specified									0(cr.gravel)
12					3			15	
-							0(in cr. stone)		
							3(iron oxide)(in cr.gr.)		
12		x				x	x		x(cinders)
specified	0.25		1.0(& shale)		8		x		
specified	0	0	0						
0.90 Loss Ratio	1	x		x	x		x		x(alkali)
-									
specified							Quantity of deleterious material must be negligible		
specified					2			3	
12	0	0(adobe)							
7(10 cycles)							No specific requirement		
12(10 cycles)									
specified	0	0							
specified		0					12(of total aggregate)		
12			0.25	1	3	1	2.5		
specified	0.1		1	3	5				
specified		0(dirt)						0	
10			0.25	2	2	1	1		4(glassy in slag)
									2(iron in slag)
12		0(dust)						0	
specified	0			0				0	
specified	0	0							
12			0.25	1.25	5		1		
specified				2(PI +6)					
				4(PI -6)					
12							No specific requirement		
8				x			x	x	x(schist)
8(5 cycles)			0.25	0.5					
8(15 cycles)									
specified	0								
12			0.25			1	1		
specified	0	0	0						
specified			0					0	
12							No specific requirement		

noted.

TABLE 2 (continued)

Undifferentiated	Total Allowable	Other Requirements	2"	1-1/2"	1-1/4"	1"	7/8"	3/4"	5/8"	1/2"	3/8" (percent
								Binder Course Material			
2	3	Non - stripping						Not specified			
								Not specified			
	5							Not specified			
		Loss in wetshot rattler						Not specified			
		50 percent max. (total agg)									
								Not specified			
								Not specified			
								Not specified			
0	None			100		95-100		60-80		25-60	
	10	Washed C.A.		100		97-100				20-35	
	1					100		90-100			20-55
		Dust Ratio -65%; PI -6, LL -25						Not specified			
	5			100		95-100		80-95		30-55	
	7								Percent Retained		
						0		0-15		40-80	
	6.5							Not specified			
	5	Max. Water Abs. 4.0%						Not specified			
	5					100		90-100			30-60
0	None							Not specified			
0	None	Surface course material						Not specified			
		100 percent crushed									
	5							Not specified			
	None						100	90-100		30-50	
	18				100			45-65			0-25
x	None(cr.stone)							Same as surface course			
	3(cr.gravel)										
x	5	Minimum stability specified						Not specified			
		for each project									
x	8							Not specified			
0	None	Clean and durable						Not specified			
	Free of injurious quantity	Max. Water Abs. 3.2%						Same as surface course			
								Same as surface course			
x								Not specified			
5	10					100			20-50		0-15
	None							No binder course used			
								Not specified			
0	None							Not specified			
								Not specified			
	5							No binder course used			
	9.1							Not specified			
0	None							Same as surface course			
	2(shale, clay lumps)	Toughness -6		100		90-100				25-60	
		Deval abrasion -5									
	None					100		95-100		0-15	
	None							Not specified			
	None	1.5% Swell AASHO T-101						Not specified			
	5							Not specified			
								Not specified			
		LL 30-, PI 6-						Not specified			
	5							Not specified			
	0.75							Not specified			
	None	Breakage Factor 35-						Not specified			
			100	95-100				35-70			10-30
0	None							Not specified			
0	None							Not specified			
							100	65-88	50-75	35-60	15-35

TABLE 2 (continued)

1954 Practice

Specified Gradation Limits for Coarse Aggregate			Surface Course Material													
No. 4	No. 8	No. 10	1"	3/4"	5/8"	1/2"	3/8"	No. 4	No. 8	No. 10	No. 16	No. 20	No. 30	No.200	Agency	
by weight passing each			sieve, except when stated otherwise)													
								Not specified							1	Ala.
								Not specified							2	Ariz.
								Not specified							3	Ark
								Not specified							4	Calif
								Not specified							5	Colo.
								Not specified							6	Conn.
								Not specified							7	Del.
0-10	0-5					100	85-100	10-30	0-10	0-5					8	D of C.
		0-3		100		90-100	45-85	25-40		0-8					9	Fla
0-10	0-5					100	90-100	20-55	5-30		0-10				10	Ga.
								Not specified							11	Idaho
0-15				100		95-100		20-50		0-5					12	Ill.
							Percent Retained									
95-100	98-100					0	5-25	70-95	95-100						13	Ind.
								Not specified							14	Iowa
								Not specified							15	Kans.
5-25	0-5					100	80-100	10-30	0-5			0-3			16	Ky
								Not specified							17	La.
								Not specified							18	Me.
								Not specified							19	Md.
5-15		0				100	80-100	30-50		0					20	Mass
		0-10			100	90-100		10-25		0-10					21	Mich.
				100	95-100		40-70	0-25		0-5					22	Minn.
								Not specified							23	Miss.
								Not specified							24	Mo.
								Not specified							25	Mont.
							Percent Retained									
			0	0-10			30-65	80-100				90-100		95-100	26	Nebr.
			95-100			35-55				0-5					27	Nev.
								Not specified							28	N.H.
0-5					100		60-85	15-35		0-5			0-2		29	N.J.
								Not specified							30	N.M.
								Not specified							31	N.Y.
								Not specified							32	N.C.
								Not specified							33	N.Dak.
			100	95-100		65-90	35-65	0-15							34	Ohio
								Not specified							35	Okla.
						% Retained										
				0		25-40		90-100							36	Oreg.
0-10	0-5					100	75-100	10-30	0-10						37	Pa
						100	75-100	0-15	0-5						38	R.I.
								Not specified							39	S C.
								Not specified							40	S Dak.
								Not specified							41	Tenn.
								Not specified							42	Tex.
								Not specified							43	Utah
								Not specified							44	Vt.
								Not specified							45	Va.
								Not specified							46	Wash.
0-5						100	85-100	20-40	0-10						47	W.Va.
								Not specified							48	Wisc.
								Not specified							49	Wyo.
0-10					100	83-100	50-70	0-10							50	Ontario

TABLE 3

MINERAL FILLER FOR BITUMINOUS CONCRETE MIXTURES

Agency	Kinds of Material						Remarks	Specified Gradation Limits (percent by weight finer than each sie except when stated otherwise					
	Lime-Stone Dust	Port-land Cement	Min-eral Dust	Stone Dust	Inert Mineral Matter	Other Types		No.10	No 30	No.40	No.50	No.80	No
1 Ala.	x	x			x				100			95-100	
2 Ariz.							Nonplastic, nonhydrophilic		Not specified				
3 Ark.	x	x							100				
4 Calif.	x	x	x			Hydrated lime			100				
5 Colo.	x	x				Hydrated lime			100				
6 Conn.	x	x		x					100			95-100	
7 Del.	No mineral filler required								No mineral filler required				
8 D. of C.	x	x							100			95-100	
9 Fla.	x	x			x		Special approval for inert mineral matter		100			95-100	
10 Ga.	x	x									100		90-
11 Idaho													
12 Ill.	x						Other types on approval		100				85-
13 Ind.	x	x		x	x	Fly ash			(percent retained) 0			0-5	
14 Iowa	x	x							100			95-100	
15 Kans.	x	x				Chat sludge							
16 Ky.	x	x			x				100			95-100	
17 La.	x	x				Shell dust			100			95-100	
18 Me.		x		x					100				
19 Md.	x	x	x						100				85-
20 Mass.	x	x					Stone float or collector dust on special permission			100			
21 Mich.	x	x				Fly ash				100			
22 Minn.	x	x			x			No 20 100	95-100			80-100	
23 Miss.	x	x			x				100			95-100	
24 Mo.	x	x	x	x	x				100				
25 Mont.		x		x					100				85-
26 Nebr.	x					Natural soil					(percent retained) 0-5		
27 Nev.	x	x				Basalt rock dust			100			95-100	
28 N.H.	x	x		x					100				
29 N.J.	x		x		x	Fly ash							95-
30 N.M.							Any approved material		Not specified				
31 N.Y.	x	x				Fly ash Diatomaceous earth			100			85-100	
32 N.C.	x	x	x						100			95-100	
33 N.Dak.						Natural soil							
34 Ohio	No mineral filler required								No mineral filler required				
35 Okla.		x		x		Volanic ash			Not specified				
36 Oreg.		x	x						100			95-100	
37 Pa.		x		x							100		
38 R.I.	x	x	x						100			90-100	
39 S.C.	x	x	x						100				
40 S.Dak.				x		Silt				100			
41 Tenn.	x	x							100			95-100	
42 Tex.		x	x	x		Shell dust			100				
43 Utah	x	x	x						100			95-100	
44 Vt.	x					Talc dust	Any approved material			100			
45 Va.	x	x			x				100			95-100	
46 Wash.	x	x				Cottrell flour Basalt rock dust		100					
47 W.Va.	x	x			x				100				90-
48 Wisc.	x	x	x			Any approved material			100			85-100	
49 Wyo.						Minus No.4 sieve fraction			Not specified				
50 Ontario	x								100				

TABLE 3 (continued)

1954 Practice

No.200 size,	Remarks	Agency
65-100	AASHO M17-42 gradation	1 Ala.
		2 Ariz.
75-100		3 Ark.
75-100	Gradation continued· 0-25 percent finer than .005 mm.	4 Calif.
	Gradation continued 25-100 percent passing No 270 sieve	5 Colo.
75-100		6 Conn.
		7 Del.
65-100	AASHO M17-42 gradation	8 D.of C.
65-100	AASHO M17-42 gradation	9 Fla.
65-100		10 Ga.
	PI 6-, LL 25-; Dust Ratio less than 65 percent	11 Idaho
65-100		12 Ill.
0-35	AASHO M17-42 gradation	13 Ind.
65-100	AASHO M17-42 gradation	14 Iowa
100	Mineral filler (minus No.200) present in crushed aggregates of total mix acceptable, mineral filler in uncrushed aggregates of total mix acceptable provided this portion of filler does not exceed 50% of total.	15 Kans.
65-100	AASHO M17-42 gradation	16 Ky.
65-100	Gradation continued 60-100 percent finer than .05 mm, 30-60 percent finer than .020 mm, 10-25 percent finer than .005 mm; 2-15 percent finer than .001 mm.	17 La.
65-100		18 Me.
65-100		19 Md.
65-100		20 Mass.
75-100	Fly ash - Free carbon 7-12 percent Minus No. 200 material - 15 to 60 percent less than .01 mm. size.	21 Mich.
60-100		22 Minn.
65-100	AASHO M17-42 gradation	23 Miss.
75-100	Gradation continued, 30-100 percent passing No. 325 sieve.	24 Mo.
65-100		25 Mont.
0-20		26 Nebr
65-100	AASHO M17-42 gradation	27 Nev
65-100		28 N.H.
85-100		29 N.J.
	PI 6-, LL 25-	30 N M.
65-100		31 N.Y.
65-100	AASHO M17-42 gradation	32 N.C.
40-100	Gradation continued 0-20 percent finer than .005 mm.	33 N.Dak.
		34 Ohio
		35 Okla.
65-100	AASHO M17-42 gradation	36 Oreg.
67-100		37 Pa.
75-100		38 R.I.
70-100		39 S.C.
60-100	PI 12-; WAP 25-; Lineal Shrinkage 4-	40 S.Dak.
65-100	AASHO M17-42 gradation	41 Tenn
65-100		42 Tex.
65-100	AASHO M17-42 gradation	43 Utah
85-100		44 Vt.
65-100	AASHO M17-42 gradation	45 Va.
75-100	Gradation continued 50-100 percent finer than 025 mm, 0-35 percent finer than .005 mm. PI 2-.	46 Wash.
65-100		47 W.Va.
65-100		48 Wisc.
		49 Wyo.
80-100	Mineral litter not generally used because of low void content in mineral aggregate.	50 Ontario

TABLE 4

ASPHALT CEMENT FOR BITUMINOUS CONCRETE MIXTURES

Agency	Specification Requirements: Penetration 1/	Bitumen Soluble in 1/: Carbon Disulfide	Bitumen Soluble in 1/: Carbon Tetrachloride	Ductility 1/	Flash Point 1/ 2/	Loss on Heating 1/	Penetration Residue 1/ Before Heating	Spot Test 1/ - Negative Spot Req'd.: St'd Naphtha	Naphtha Xylene	Heptane Xylene	Specific Gravity 1/	Other Specif[ication] Requirem[ents]
				(cm)	(°F)	(percent)	(percent)		(percent xylene)			
1 Ala	60-70	99.5+		100+	450+	0.5-	70+	Neg			N S 3/	Ductility at 39.2°F not les
	85-100											
	100-120											
2 Ariz	150-200	99.5+		100+	347+	1.0-	65+			35	N S	
3 Ark	60-70		99.5+	100+	450+	1.0-	70+	Neg			N S	
	70-85											
4 Calif.	85-100	99.5+		100+	425+	2.0-	80+			35	N S.	
5 Colo	120-150	99.5+		100+	425+	2.0-	70+		10		N S	
6 Conn	85-100	99.5+		100+	347+	1.0-	60+		Not specified		N S	
7 Del	70-85	99.5+		Penetration value +	347+	1.0-	75+	Neg			N S	
8 D of C.	85-100	99.5+		100+	347+	1.0-	65+	Neg			N S	
9 Fla	85-100	99.5+	99.0+	100+	347+	1.0-	65+		Not specified		N S	
10 Ga	85-100		99.5+	100+	400+	1.0-	70+	Neg			1.004+	
11 Idaho	121-150	99.5+	99.0+	100+	400+	1.0-	65+			35	N S	
12 Ill.	70-85	99.5+		100+	500+	1.0-	70+	Neg			N S	
	85-100	99.5+		100+	450+	1.0-	70+	Neg.			N S	
13 Ind	85-100		99.0+	100+	347+	1.0-	65+	Neg			N S	Other penetration grades pe
14 Iowa	85-100	99.5+		100+	347+	1.0-	65+	Neg				
15 Kans	85-100		99.5+	100+	347+	1.0	75+	Neg			N S	Softening point 100°F -125°
16 Ky	85-100	99.5+	99.0+	100+	347+	1.0-	75+		Not specified		N S	Softening point 104°F.-140°
17 La	85-100	99.5+		100+	347+	1.0-	65+	Neg			N.S	
18 Me	85-100	99.5+		100+	450+	1.0-	50+		Not specified		1.00+	
19 Md	85-100	99.0+		100+	347+	1.0-	65+			35	N S.	
20 Mass	85-100	99.5+		100+	347+	1.0-	65+		Not specified		N S	For recovered asphalt (ASTM
												Penet 50+ pct of origina
21 Mich	60-70		99.5+	100+	347+	1.0-	75+	Neg			1.01+	For recovered asphalt (Abso
	85-100		99.5+	100+	347+	1.0-	65+				1.00+	Penet 50+ pct of origina
												pct of original 40-75 pen
22 Minn	70-85		99.0+	100+	450+	1.0-	70+	Neg			N S	
	85-100											
23 Miss	85-100	99.5+		100+	400+	1.0-	60+	Neg			1.01+	Heat to 347°F without foam
24 Mo	70-85	99.5+		100+	450+	1.0-	60+	Neg			10 02	Penetrations of 60-70 and 8
25 Mont	70-85	99.5+		100+	347+	1.0-	75+				N S	Heat to 347°F without foam
	85-100											
26 Nebr	85-100		99.5+	100+	347+	1.0-	70+		10		N S	
27 Nev.	85-100	99.5+		100+	450+	3.0-	80 25+		Not specified		N S	
	100-120											
	120-150											
28 N H	85-100		99.0+	100+	450+	1.0-	75+		Not specified		1.00+	1 Heat to 347°F without f
	100-120		99.0+	100+	450+	1.0-	75+		Not specified		1.00-	2 Penetration 85-100 used
29 N J	60-70	99.5+	99.0+	100+	410+	1.0-	50+		Not specified		N S	Heat to 347°F without foam
	70-85	99.5+	99.0+	100+	372+	1.0-	75+		Not specified		N S	ditto
	85-100	99.5+	99.0+	100+	374+	1.0-	75+		Not specified		N S	ditto
30 N M	85-100		99.5+	100+	400+	0.75-	65+		15		N S	
31 N Y	85-120	99.5+		60+	347+	1.0-	60+		Not specified		1.00-	Ratio pene at 39.2°F to
											1.04	30+ percent
32 N C	85-100	99.5+		100+	347+	1.0-	60+	Neg			N S	Heat to 347°F without foam
33 N Dak	120-150	99.5+	99.0+	100+	347+	1.0-	65+	Neg			N S	1 Use grade with penetrati
	150-200											2 For recovered asphalt (A
												Penetration 65+ percent
												Flash point 400+°F
												Loss on heating 1.0- per
												Penet, residue/before he
												Ductility 100+ cm
												Bitumen Soluble in Carbo
												Naphtha xylene, negative
34 Ohio	70-80	99.5+		100+	347+	1.0-	[illegible]	Neg			N S	Heat to 351°F without foam
												Softening point 104°F -140°
35 Okla	85-100	99.5+		100+	450+	0.2-	65+	Neg			N S	Softening point 114°F
36 Oreg	86-100	99.5+		100+	400+	1.0-	65+	Neg			N S	
37 Pa	70-80	99.5+		100+	350+	1.0-	75+	Neg			N S	
	85-100	99.5+		90+	350+	1.0-	65+	Neg			N S	
38 R I	61-70	99.0+		70+	347+	1.0-	75+		Not specified		N S	AASHO M 20
39 S C	60-70	99.0+		Penetration value +	347+	1.0-	75+		Not specified		N S	
	85-100											
40 S Dak	100-120		99.0+	100+	347+	2.0-	60+		15		N.S	
	120-150											
41 Tenn	85-100	99.5+		100+	374+	1.0-	65+	Neg			N.S	
42 Tex	85-100		99.5+	100+	450+	0.75+	50+	Neg			N S	Softening point 113°F -140
43 Utah	85-100	99.5+	99.0+	100+	347+	1.0-	65-			35	N S	AASHO M 20
44 Vt	85-100	99.5+		100+	347+	1.0-	75+		Not specified		N S	
45 Va	85-100		99.5+	100+	350+	1.0-	75+	Neg			1.00+	1. Softening point 104°F -
												2 Organic insoluble mtrl
												3 For recovered asphalt (
												Penet 65+ pct of orig
												Ash -1.0 percent.
46 Wash	86-100	99.0+	99.65+	100+	450+	1.0-	70+			35	N S.	
47 W Va	85-100	99.0+		100+	450+	1.0-	75+	Neg			N S	Heat to 347°F. without foa
48 Wisc	70-85		99.5+	100+	450+	1.0-	70+	Neg			N S.	Heat to 350°F without foa
49 Wyo	85-100	99.5+		100+	450+	1.0-	70+		15		N S	Heat to 350°F without foa
	121-150			60+	425+	2.0-						
50 Ontario	85-100	99.5+		100+	450+	1.0-			Not specified		N S	

1/ Conditions of test are AASHO standard
2/ Cleveland Open Cup (AASHO T 48-46)
3/ Not specified

TABLE 4 (continued)

1954 Practice

…on	Usage - Miscellaneous: Penetration Grade Based on Traffic	Specific Gravity of Material Normally Used	Recovered Asphalt from Mixtures: Method of Extraction and Recovery: ASTM	AASHO	Other	Recovered Asphalt Tested Regularly	Agency
…n 10 pct of penet	Lower penet grades & leaner mixes for heavier traffic	1 02-1 034			Oliensis	No	1 Ala
	Grade varies with traffic	1 0				No	2 Ariz
	60-70 penetration, heavy traffic 70-85 penetration, medium traffic	1 02				No	3 Ark
		1 02	D 762-44T			Research only	4 Calif
		1 0+			Distillation to 400°F.	Yes	5 Colo
		1 020-1 030	D 762-44			Spot checks	6 Conn
		1 015	D1097-50T	T 58-37		No	7 Del
		1 023		T 58-37		Occasionally	8 D of C
		1.02		T 58-37 (Ext only)		No	9 Fla
		1 024		T 58-37		No	10 Ga
		0 98-1 02				No	11 Idaho
		About 1 0	D 762-49			Research only	12 Ill
…ed		About 1 0					13 Ind
							14 Iowa
		1 003-1 015	D 762-49		D 762-49 modified	Yes	15 Kans
	60-70 penetration, heavy traffic	1 0+	D 762-49 D1097-50T	T 58-37		No	16 Ky
		1.0[illegible]				No	17 La
		1 05				No	18 Me
		1.02-1.03	D 762-49	T 58-37		No	19 Md
…2-47T) …ility 40+ cm			D 762-47T			Yes	20 Mass
…00 penet 50+ Ductility 50+ cm	60-70 penetration, heavy traffic 85-100 penetration medium traffic	1 015-1 040 1 010-1 035			Abson	Yes	21 Mich
	Grade varies with traffic	1 001-1 035	D 762-49			No	22 Minn
		[illegible]				No	23 Miss
…also used		1 005	D 762-49			Special test only	24 Mo
		1 03-1[illegible]	D 762-49			Yes	25 Mont
		1 00				No	26 Nebr
						No	27 Nev
… other specified		1 025 1 025				No	28 N H
	60-70 penetration, heavy traffic 85-100 penetration, medium and light traffic	1 00-1 04 1 00-1 04 1 00-1 04	D 762-49			Spot checks	29 N J
		1 015	D1097-50T	T 58-37	Original Abson	Yes	30 N M
…at 77°F =		1 02		T 58-37 (Ext only)		No	31 N Y
	60-70 penetration, severe conditions	1 0[illegible]		T 58-37		No	32 N C
…rest 150 …58-30) …nal …65+ pct …lfide 99 5+ pct …pct xylene	Lower penetration for heavy traffic	1 0[illegible]		T 58-37 (Ext only)		No	33 N Dak
	85-100 penetration, medium and light traffic	1 0	D 762-49			Occasionally	34 Ohio
		1 01	D 762-49			Occasionally	35 Okla
	86-100 penetration, all contract work	1 015-1 02	D 762-49 D1097-50T			No	36 Oreg
	70-80 penetration for traffic over 5000 v p d 85-100 penetration for traffic less than 5000 v p d	0 999-1 047 0 999-1 047				No	37 Pa
		1 020		T 58-37 (Ext only)		No	38 R I
	60-70 penetration, urban 85-100 penetration, rural	1 000+				No	39 S C
		1 000+		T 58-30		Limited number	40 S Dak
		1.025-1 030		T 58-37		No	41 Tenn
		1 020	D 762-49		Mod T 58-37 Large Ext	No	42 Tex
		1 02±		T 58-37		No	43 Utah
		1 020		T 58-37		No	44 Vt
…ercent …(762-49) …ctility 60+ cm		1 01	D 762-49			Yes	45 Va.
					Bussow Method	No	46 Wash
		1 00				No	47 W.Va.
		1 000-1 030	D 762-49			Occasionally	48 Wisc
		1 02				No	49 Wyo
	71-80 penetration, heavy traffic 85-100 penetration, medium traffic 150-200 penetration, light traffic	1 00± 005	D 762-49			No	50 Ontario

TABLE 5

MINERAL AGGREGATE GRADATION REQUIREMENTS AND BITUMEN CONTENT OF BITUMINOUS CONCRETE BINDER-COURSE MIXTURES

	Agency	Method of Specifying Sieve-Size Limits	Basis of Percentage Limits	Gradation Specifications Standard Sieve Size or Num									
				2"	1-1/2"	1-1/4"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	No.4
				(figures are perce									
1	Ala.	Percent passing	Total aggregate				100	75-100		55-95	47-87		35-67
2	Ariz.			Gradation limits specified in construction special prov									
3	Ark.	Percent retained	Total aggregate				0	5-20		20-40			45-60
4	Calif.	Percent passing	ditto				100	95-100			60-75		40-55
		ditto	"				100	95-100			65-80		45-60
5	Colo.	"	"			100	90-100			60-80			32-43
6	Conn.	"	"				90-100			45-75			
7	Del.	"	"			100	90-100	70-100		50-80	40-65		25-45
8	D.of C.	"	"				100	90-100			40-80		20-40
9	Fla	Pct. pass & ret 1/	"		k-- —	——	——	——	——	65-85	——	——	——
10	Ga.	Percent passing	"				100	95-100			40-75		
11	Idaho	ditto	"					100				48-58	
12	Ill.	Pct pass. & ret.	Total mixture		95-100 passing-		—*	—— 25-		- *----	——	20-45	—
13	Ind	ditto	ditto				k	—- 5-50		*	-- 10-60-	—	*4/
14	Iowa	Percent passing	Total aggregate				100	98-100			67-87		47-68
15	Kans.	Percent retained	ditto				0	0-5			15-45		
16	Ky.	Percent passing	"				100	90-100			55-80		35-50
17	La.	ditto	"			100	90-100	75-100		55-80			35-60
18	Me.	"	"					100					25-40
19	Md.	"	"			100	93-100	82-95		71-88	61-77		40-54
20	Mass.	Pct pass & ret	Total mixture			0		--*5/	30-50 6/	*- -		15-30	—*
21	Mich.	ditto	ditto	100 passing		- *				- 60-80			
22	Minn.	Percent passing	Total aggregate					100	95-100				40-60
23	Miss.	ditto	ditto				100	85-100		68-90	62-85		47-67
24	Mo.	Pct pass. & ret	Total mixture	100pass.	*0-5 —		—*0-20	*-	10-40	—*--	-- 10-40 -		—*-
25	Mont.	Percent passing	Total aggregate							100			25-75
26	Nebr	Percent retained	ditto				0	0-4			5-30		35-55
		ditto	"					0					
27	Nev.	Percent passing	"				95-100			58-70		28-54	
28	N H.	ditto	"					100		60-90	50-80		30-55
29	N J.	Pct pass & ret	Total mixture		3/ ←	0-35	—*—-		35-70	----*	—-0-20	*——	
30	N M.	Percent passing	Total aggregate					100		65-100			30-60
31	N.Y	Pct pass & ret	Total mixture			k0-5	-*——		35-60	-——*—	20-40	—*—	5-1
32	N.C	ditto	ditto	100 passing			—*0-10	*—	15-40	-*——		35-60	——
33	N.Dak	Percent passing	Total aggregate					100				50-83	
34	Ohio											Binder course not	
35	Okla	ditto	ditto		100		90-100			65-80			40-5
36	Oreg.	Pct pass & ret.	Total mixture		100 passing	---		*		—— 40-52			—*
37	Pa	Percent passing	Total aggregate		100		90-100			40-75			20-4
38	R.I	ditto	Total mixture			100							
39	S C.	"	Total aggregate					100		97-100	60-95		30-6
40	S.Dak.	"	ditto				100	90-100		75-90		50-75	
41	Tenn	"	'		100			69-85					43-5
		"	"		100			55-80					25-4
42	Tex.	Pct. pass & ret.	Total mixture	3/0-3*	—— 15-40		——*——		15-40	——*—	10-25	—*- ---	
43	Utah	Percent passing	Total aggregate		95-100		75-100	60-90			35-65		25-5
44	Vt	ditto	ditto					100		65-90			22-6
45	Va.	"	"				100	95-100			60-80		40-6
46	Wash.	Pct pass & ret.	" 8/						k 0-10	-*——	25-45	-*—	- 2
47	W Va.	Percent passing	"	100	95-100			60-75			30-50		20-4
48	Wisc.	ditto	"				95-100			65-90	55-80		40-6
49	Wyo.		"					100			60-85		45-6
50	Ontario	'	"				5/ 100	75-94	65-88	54-80	40-68	33-57	30-5

1/ Percent of material passing one sieve and retained on the next finer sieve.
2/ Percent of total aggregate.
3/ Round sieve-openings, 1/4 inch size and larger.
4/ Passing No. 4, retained No 6 sieve, 0-5 percent, passing No 6, retained No. 8, 0-5 percent
5/ 7/8-inch sieve
6/ Not more than 1/5 of the 7/8 to 1/2-inch fraction in the bottom course shall be retained on a 3/4-inch sieve.
7/ Percent passing
8/ Percent limitations for material finer than No. 10 based on total fraction passing No.10. Of total aggregate, 2
9/ No 14 sieve.

TABLE 5 (continued)

1954 Practice

neral Aggregate - Square Openings (by weight)										Specified Bitumen Content of Mixture (pct. by wt.)	Remarks		Agency
.8	No.10	No.16	No.20	No.30	No.40	No.50	No.80	No.100	No.200				
	24-50				12-30		4-15		2-8	5-8 2/		1	Ala.
ns for designated aggregate sources.												2	Ariz.
	60-75				75-90				95-100	3.7 - 7.7		3	Ark.
40				12-22					3-6	3.0 - 7.0 2/	Heavy traffic	4	Calif.
45				15-25					3-7	3.0 - 7.0 2/	Medium traffic		
36				19-27				7-15	1-5	4.5 - 5.5		5	Colo.
	15-35									3.5 - 6 0		6	Conn.
	20-35		15-25		10-20		8-15		5-10	4.0 - 6.0		7	Del.
	15-35								0-5	4.0 - 7.0		8	D.of C.
	*15-35									4 0 - 7.0		9	Fla
40						5-20		0-10	0-5	4 5 - 7.0		10	Ga.
	30-40								3-9	Not specified		11	Idaho
	*			20-35						4.0 - 7 0		12	Ill.
*	3-12	*		5-20		*	2-10	*0-4	*0-3	4.0 - 6.0		13	Ind.
55				19-34		13-26		6+	3-10	6.25		14	Iowa
75				85+				90+	93-98	5 0 - 7.0 2/		15	Kans.
35						0-15			0-5	4.0 - 7.0		16	Ky.
	25-40				15-30		8-18		2-6	4.0 - 6 0		17	La.
	18-38		15-35		8-25					4.0 - 6 5		18	Me.
	22-36		13-25		8-18		5-13		2-8	4.0 - 6.5		19	Md
5	*	2-8	*	4-10	*	4-10	*	2-6	*1-4	4 5 - 5.5	20-30 pct pass. No. 10	20	Mass.
	*				14-36					4.0 - 6.0		21	Mich
	25-40								0-5	4 2 - 5.0		22	Minn
	40-58				24-38		10-22		6-10	4 7 - 6.2		23	Miss
3	*		4-18		*	3-20	*	2-15	*2-8	3 5 - 6.0		24	Mo
	15-60								0-5	4.0 - 6.5		25	Mont
	55-75					78-88		85-93	90-95	4.5 - 6 0 2/	Heavy traffic	26	Nebr.
	55-75					77-87			89-95	4 5 - 6.0 2/	Medium traffic		
	25-38				15-25		8-16		2-6	3.0 - 7.0		27	Nev.
	22-42		14-32		10-27					4 0 - 6.5		28	N H.
	*		0-10	*	2-8	*2-8	*	2-12	*0-5	4.0 - 5 5		29	N.J
	20-45								3-12	-		30	N.M
.6	←	4-20 →								4.0 - 5.5	Used with sheet asphalt	31	N.Y
	*				15-40				*0-5	4.0 - 6 5		32	N.C
	25-60			15-42		10-28		5-17	0-8	3.0 - 7.0		33	N.Dak.
												34	Ohio
	30-45				20-30		10-20		1-7	4.0 - 6.5		35	Okla.
1	*		12-20		*	3-9	*	3-7	*3-7	5.0 - 7 0		36	Oreg.
5		10-25		5-20		2-15		1-10	0-5	4.3 - 7.0	5.5-9.0 pct. bitu. for slag	37	Pa.
	15-35									4.0 - 6 0		38	R.I
	15-30									4.5 - 7 0		39	S.C
	35-55				20-30				6-10	5.0 - 7 0		40	S.Dak.
			22-30					2-8		4.5 - 5.5	Heavy traffic	41	Tenn.
								5-15		3.5 - 6.0	Medium traffic		
	*		0-15		*	3-15	*	3-15	*1-10	3.0 - 6.0		42	Tex.
	20-40				10-30		5-20		3-8	4.5 - 6.0		43	Utah.
	17-55				13-48		8-23		4-7	5.0 - 7.0		44	Vt.
	20-40						3-10			4.5 - 8.0		45	Va
	*			20-55	*	15-45	*	10-35	*4-15	4 0 - 7 0		46	Wash
		10-25				3-10			0-4	3 0 - 6.0		47	W.Va.
	25-50				10-30				3-12	3 5 - 6.0		48	Wisc
	25-45								3-10	4.5 - 6.5		49	Wyo.
0	9/ 12-45			6-35		3-20		1-8	0-5	4.5 - 6.0 2/		50	Ontario

rcent permitted to pass no. 10 sieve.

TABLE 6

MINERAL AGGREGATE GRADATION REQUIREMENTS AND BITUMEN CONTENT OF BITUMINOUS CONCRETE SURFACE-COURSE MIXTURES

	Agency	Method of Specifying Sieve-Size Limits	Basis of Percentage Limits	Gradation Specifications - Mineral Aggregate: Standard Sieve Size or Number - Square Op[enings] (figures are percents by weigh[t])											
				1-1/4"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	No.4	No.8	No.10	No.16	No.
1	Ala.	Percent passing	Total aggregate		100	95-100			60-80		40-60		20-40		
2	Ariz	ditto	ditto		100				45-65				25-45		
3	Ark	Percent retained	"			0					25-45		45-60		
4	Calif.	Percent passing	"		100	95-100			60-75		40-55	30-40			
		ditto	"		100	95-100			65-80		45-60	30-45			
5	Colo	"	"		100	90-100		70-85			40-52	30-40			
6	Conn.	"	"	100	95-100			60-100			28-55		22-44		17
7	Del.	"	"					100	80-100		50-65		30-45		20
8	D.of C.	"	"					100	80-100		55-80		40-75		
9	Fla.	Pct. pass. & ret. 1/							8-39-	8-45	-	9-27	—		5-
10	Ga	Percent passing	"					100	95-100		60-80			35-50	
11	Idaho	ditto	"				100			50-70			30-50		
12	Ill	Pct pass. and ret.	Total mixture		95-100 passing			→	25-50		—	10-30	←	.	
13	Ind.	ditto	ditto					– 2-14	–	20-50→	4/0-22	–	5-20	+	
14	Iowa	Percent passing	Total aggregate		100	98-100		98-100	67-87		47-61	37-55			
15	Kans.	Percent retained	ditto		0	0-5			12-35			35-60			
16	Ky.	Percent passing	"					100	85-100		50-70	35-50		20-40	
17	La	ditto	"			100		85-100			60-80		40-60		
18	Me	"	"					100			35-75		30-55		24
19	Md	"	"		100	88-100			66-80		48 62		32-44		18
20	Mass	Pct pass and ret.	Total mixture	100 passing				→	25-40+		– 6/→.	15-25		4-12	
21	Mich.	ditto	ditto	100 passing			—			50-65			—		
22	Minn.	Percent passing	Total aggregate			100	98-100		70-85		50-65		35-50		
23	Miss	ditto	ditto					100	95-100		80-95		55-75		
24	Mo.	Pct pass. and ret.	Total mixture	100 passing		+	0-3		0-25 -	20-45	-	7-20			7-
25	Mont.	ditto	ditto	100 passing		—	15-40			10-35	-	8-20			10-
26	Nebr.	Percent retained	Total aggregate		0	0-4			5-30		35-55		55-75		
		ditto	ditto			0							55-75		
27	Nev.	Percent passing	"		95-100			60-80		40-55			28-38		
28	N H.	ditto	"					100	80-95		45-75		30-50		17-
29	N J.	Pct pass and ret.	Total mixture		3/	– 0-25		→	20-45	---	5-25		7/—		2-14
		ditto	ditto		3/	– 0-10		--	12-40	–	8-30		7/		2-17
30	N.M	Percent passing	Total aggregate			100		90-100	55-85		40-65		30-50		
31	N Y.	Pct. pass. and ret	Total mixture			– 0-5		–	15-28		20-40	8/	12-30		
32	N C	ditto	ditto	100 passing		–	0-5	—	30-50		–	10-20	-		8-25
33	N.Dak.	Percent passing	Total aggregate			100				50-83			25-60		
34	Ohio	Pct. pass. and ret.	Total mixture	100 pass	-0-5	-	5-20	→7-30 ~		10-35	~0-10			20-45	
35	Okla	Percent passing	Total aggregate			100		90-100			55-80		40-55		
36	Oreg.	Pct. pass and ret	Total mixture	100 passing		.			40-52		-.	11-21	-		12
37	Pa.	Percent passing	Total aggregate					100	80-100		45-75	30-55 2/		20-40	
38	R.I	Pct. pass and ret	Total mixture					100-	0-15-	25-55	- 0-18	-	5-20	-	10-
39	S C.	Percent passing	Total aggregate					100	75-97		58-75		42-60		
40	S.Dak.	ditto	ditto		100	90-100		75-90		50-75			35-55		
41	Tenn	"						100			64-76		46-56		
		"	'					100	95-100		65-85		45-65		
		"	'						100		85-100				
42	Texas	Pct. pass. and ret	Total mixture				3/ 100-	97-100-	25-50	1		15-35	–		0-2
43	Utah	Percent passing	Total aggregate					100	90-100		70-100		60-90		
44	Vt.	ditto	ditto					100	61-92		46-84		24-[illegible]		
45	Va.	"	'					100	80-100		50-70		35-50		
46	Wash.	Pct. pass and ret.	" 10/					-0-10 -	30-50	-	20-40		-		30-
47	W. Va	Percent passing	'					100	85-100		60-80	40-60		25-45	
48	Wisc	ditto	'					95-100	75-100		45-85		30-55		
49	Wyo.	"	'					100			50-70		30-50		
50	Ontario	"						100	75-88	60-74	50-60	41-60		11/ 29-55	
		"	"				100	92-100	77-90	64-77	55-65	45-65		11/ 33-59	

1/ Percent of material passing one sieve and retained on the next finer sieve
2/ Percent of total aggregate
3/ Round sieve-openings, 1/4-in size and larger.
4/ Passing No. 4, retained No. 6 sieve, 0-11 percent, passing No. 6 sieve, retained No 8, 0-11 percent
5/ Maximum. Also, the No. 80 to No 200 material shall be at least 5 percent of total aggregate
6/ Not more than 1/4 of the 1/2-in. to No. 4 fraction in the surface course shall be retained on a 3/8-in sieve
7/ Retained on No. 10, 30-60 percent.

TABLE 6 (continued)

1954 Practice

gs No.30	No.40	No 50	No.80	No.100	No.200	Specified Bitumen Content of Mixture	Remarks	Agency
	10-25		5-15		2-8	5.0-8.0 2/	At least 4 pct. to be retained between consecutive sieves	1 Ala.
	15-25				2-10	4 0		2 Ariz.
	70-85				90-96	5.0-8.0		3 Ark
12-22					3-6	3-7 2/	Heavy traffic	4 Calif.
15-25					3-7	3-7 2/	Medium traffic	
22-30				11-19	4-8	5 0-6 5		5 Colo
	12-37		8-18		4-8	5.5-8.0	At least 4 pct. to be retained between consecutive sieves	6 Conn.
	15-25		10-20		5-10	5.5-8.0		7 Del.
	10-30		3-15		2-8	4.0-8 0		8 D.of C.
	—	9-27	—	5-18	5-8	5.0-9.0		9 Fla.
		15-35		10-20	5-10	6 0-10		10 Ga
					5-12	Not specified		11 Idaho
	—	7-22	—	5-13	- 4-8	5.0-7.0		12 Ill.
10-25		—	2-17	- 1-5	- 3-5	6.5-8.5	45-55 pct. retained No. 6	13 Ind.
19-34		13-26		6+	3-10	6.25		14 Iowa
65-80			89 5/		89-94	5.0-8.0 2/		15 Kans.
		2-20		0-10	0-5	4 0-8 0		16 Ky.
	20-35		12-25		4-10	4.5-6.5		17 La.
	12-40		7-19		3-8	6.0-8 0		18 Me.
	10-20		6-14		2-8	5.0-7.0	At least 4 pct. to be retained between consecutive sieves	19 Md.
6-16	—	6-16	—	4-10	-- 4-6	6.0-7.0	35-45 percent passing No 10	20 Mass.
25-40					-4 5-8	4 5-6.5		21 Mich.
	15-30		8-16		4-8	5.5-6.2	At least 4 pct.to be retained between consecutive sieves except two largest	22 Minn.
	28-42		12-24		6-10	7.2-8.7		23 Miss.
	-	5-20		5-18	—4-10	4.0-7.0		24 Mo
		5-20	·	5-15	— 4-8	5.0-8 5		25 Mont.
		78-88		85-93	90-95	4 5-6.0 2/	Heavy traffic	26 Nebr
		77-87			89-95	4.5-6 0 2/	Medium traffic	
	20-27		13-20		5-11	3.0-7.0		27 Nev.
	10-30		5-20		3-8	5 5-7.5		28 N.H.
—	5-18	— 4-18	-	3-16	- 4-8	5-8	Heavy traffic	29 N.J
—	4-24	6-22		3-20	- 4-8	5.5-9.0	Medium traffic	
	15-30		8-20		4-10	-		30 N M.
5-20			-	1-6	- 2-6	5.8-7.0		31 N.Y.
		7-21	-	4-12	— 2-8	5.0-7.5		32 N.C.
15-42		10-28		5-17	2-8	4.5-9.5		33 N.Dak.
		---	3-15		— 0-5	4.0-9.5		34 Ohio
	20-37		10-25		4-8	5.0-7.5		35 Okla.
	+	3-9	·	3-7	— 3-7	5 0-7 0	At least 10 pct ret. 1/2 inch	36 Oreg.
10-30		5-20		2-12	2-8	5.3-8 5	6.5 to 9.5 pct. bitu for slag	37 Pa.
	-	3-18		-3-5	- 5-8	6 5-8.5		38 R.I.
	25-35		15-25		5-12	6.0-7 5	At least 5 pct. to be retained between consecutive sieves smaller than 3/8 inch.	39 S.C.
	20-30				6-10	5.0-7 0		40 S.Dak.
	19-27			5-11		4 5-7.5	Heavy traffic	41 Tenn.
	15-30		8-20		4-9	4.5-7.5	Medium traffic	
					0-10	5-9	Medium traffic	
	-	5-25	+	5-25	+2-10	4.0-7.5		42 Texas
	30-70		10-40		5-12	5.0-6.5		43 Utah
	19-53		10-26		5-8	6.0-8.0		44 Vt.
	10-25		3-15		2-10	5.5-8.5		45 Va.
	-	20-50	—	10-30	+ 5-16	4.5-7 0		46 Wash.
		7-20			1-5	6.0-10		47 W Va.
	15-35		10-25		5-12	4 0-8.0	At least 5 pct. to be retained between consecutive sieves smaller than 3/8 inch.	48 Wisc.
					5-10	5.0-7.0		49 Wyo.
20-43		11-26		6-12	3-8	5-7 2/	Heavy traffic	50 Ontario
22-47		12-29		6-13	3-8	5-7 2/	Medium traffic	

8/ No 6 sieve.
9/ Passing No. 4, retained No. 6 sieve, 0-8 percent, passing No 6 sieve, retained No. 8, 0-10 percent.
10/ Percent limitations for material finer than No. 10 based on total fraction passing No. 10 Of total aggregate, 20-40 percent permitted to pass No. 10 sieve
11/ No. 14 sieve.

TABLE 7

SPECIFIED TOLERANCES FROM JOB-MIX FORMULAS AND TYPICAL FORMULAS FOR BINDER-COURSE MIXTURES

Agency	Method of Specifying Sieve-Size Limits	Basis of Percentage Limits	Specified Tolerances from Job-Mix Formula																			
			Standard Sieve Size or Number - Square Openings (figures are percentages plus or minus from formula percentage)																			
			2"	1-1/2"	1-1/4"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	No 4	No 8	No 10	No 16	No 20	No 30	No 40	No 50	No 80	No 100	No 200
1 Ala	Percent passing	Total aggregate				4	4		4	1		1		5				5		3		[illegible]
2 Ariz										Not specified												
3 Ark	Percent retained	Ditto					+5,-7		5			+2,-5		5				3				2
4 Calif	Percent passing	'										6					5					[illegible]
5 Colo	Ditto	"							Within design limits													
6 Conn.	"	"							5					4								
7 Del	"	"			7	7	7		7	4		4		4		4		4		4		4
8 D.of C.	"	"							7						5							
9 Fla	Pct pass and ret	"		⊢				5										5				
10 Ga	Percent passing	"				7			7			5			4						4	2
							7			5			4						4		4	2
11 Idaho	Ditto	"								Not reported												
12 Ill	Pct pass and ret	Total mixture				–		5				5		•		3						
13 Ind	Ditto	Ditto																				
14 Iowa	Percent passing	Total aggregate		8		8	8		8	8		8	5									2
15 Kans	Percent retained	Ditto								7			5				+3,-5				+1,-5	1
16 Ky.	Percent passing	"				4	4			4		4	2						2			2
17 La	Ditto	"					7		7			7		5				5		3		2
18 Me	"	"					6		6			6		5		4		4		3		
19 Md	"	"				7	7		7			4		4		4		4		4		2
20 Mass	Pct pass and ret	Total mixture								Not reported												
21 Mich.	Ditto	Ditto											¬	3								
22 Minn.	Percent passing	Total aggregate										4		4								0.
23 Miss.	Percent passing	Total aggregate				7	7		7	7		7		7				6		5		2.
24 Mo.	Pct pass and ret	Total mixture		–			5		--		5			⊦				3				1.
25 Mont	Percent passing	Total aggregate							5			3		2								0.
26 Nebr	Percent retained	Ditto								7		5		5					5		3	2
	Ditto	"								Not reported												
27 Nev	Percent passing	"								Not reported												
28 N H	Ditto	"					10			10		10		4				4				2
29 N J	Pct pass and ret.	Total mixture										¬		5								[illegible]
30 N M	Percent passing	Total aggregate					5					5		4								
31 N Y.	Pct pass and ret	Total mixture																				
32 N C.	Ditto	Ditto				←				7								5				[illegible]
33 N Dak	Percent passing	Total aggregate								Not reported												
34 Ohio																						
35 Okla	Ditto	Ditto							5			5		4				3				[illegible]
36 Oreg	Pct pass and ret	Total mixture						⊢		4		←	4	|		3			2	⌞	2	
	Ditto	Ditto							⊢		4	–	4	·		3		↓	2	-	2	-
37 Pa.	Percent passing	Total aggregate		5		5			5			4	4		4		4		4		4	[illegible]
38 R.I	Pct pass and ret	Total mixture			–		10	–	10	--		10		- 4								
39 S C	Percent passing	Total aggregate							3	7		7		4								[illegible]
40 S Dak	Ditto	Ditto									3							2				
41 Tenn	"	"					7					4									2	
42 Tex.	Pct pass and ret	Total mixture	⊢						5					+		3		-	3	·	3	-
43 Utah	Percent passing	Total aggregate					7			7		5			5			5		3		[illegible]
44 Vt	Ditto	Ditto							8			8		4 5				4 5		4 5		4
45 Va.	"	"					+4,-1			8		8		4						4		
46 Wash	"	"							5		15			+7,-8				+11,-10				+2,
47 W Va	"	"				7	7			4		4			4				4			
48 Wisc	"	"					5			5		5		3				3				
49 Wyo	"	"								-12+15		6		6								
50 Ontario	"	"				3/ 5		5		5		5			4/ 4				4			

1/ Percent of total aggregate
2/ Round sieve openings, 1/4 inch size and larger
3/ 7/8 inch sieve
4/ No 14 sieve
5/ Indicated tolerances are usual working limits and are not specified

TABLE 7 (continued)

1954 Practice

Bitumen Content of Mixture	2"	1-1/2"	1-1/4"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	No 4	No.8	No 10	No 16	No 20	No 30	No 40	No 50	No 80	No 100	No 200	Bitumen Content of Mixture	Remarks	Agency
	Typical Job-Mix Formula — Standard Sieve Size or Number - Square Openings (figures are percent by weight)																						
0 ~										Not reported													1 Ala
										Not reported													2 Ariz.
0 5				0	15		35			58		70				83				97	5 0		3 Ark
										Not reported													4 Calif
0 2			100	95			75			35									12	6	5 7		5 Colo
0 5				100			55					23									5 25		6 Conn.
0 4			100	96	80		60	50		38		26		20		15		10		7	4.9		7 Del
0 3		100		94			79						34								4.9		8 D of C
0 5							80					–				20				>	4 8		9 Fla
0.5		100		97			60			35			20						6	3	4 75	Heavy traffic	10 Ga
0 5				100	97			55			30						12		6	3	4 75	Medium traffic	
										Not reported													11 Idaho
0 5						34	-			34					27						5 0		12 Ill
										Not reported													13 Ind
0 3										Not reported													14 Iowa
1/ 0 5								35			70				85				91	94	1/ 6.0		15 Kans
0 3				100	95			67 5		42 5	27 5						7 5			2 5	5 3		16 Ky
0 5				100	90		65			50		35				25		12		4	5 0		17 La
0 5					100		77			35		26		22		9		2		0 6	5 6		18 Me
-			100	96	87		78			48		30		20		12		9		4	5 0		19 Md
					100	38 8			21 7	|	9 8	'	7 7		5 1		4 7		4 8	–1 2 6	4 8		20 Mass.
0.3										65				35							4.5		21 Mich
0 25					100					46		36								2 2	4 5		22 Minn.
0 3				100	92		79	72		60		50				30		16		8 0	5 5		23 Miss
0 5		·	0 4	9 4		22 6	11 3		16 6	-	9 1			9.4			8 0		6 1	-2 8	4 3		24 Mo
0 3										Not reported													25 Mont.
					0			20		46		69					84		90	93	4.8	Heavy traffic	26 Nebr
					0			3		18		58					83		89	93	5 0	Medium traffic	
										Not reported													27 Nev
0 5					100			63		47		34				15				3	5 4		28 N.H.
0 3										77	–		–	18							5 0		29 N.J
0 3				100	90					55		40								8	6 0		30 N M
										Not reported													31 N Y
0 5				-2		20	-			42		,				29				-2	5 0		32 N C.
										Not reported													33 N Dak
										Binder Course not used													34 Ohio
0 3		100		95			75			50		40				25				5	5 0		35 Okla
0.3					-	14			32		17	-		15		-	6		5 3	5 0	5 7	Heavy traffic	36 Oreg.
0 3							8		33	-	18			16		–	8	-	5 5	— 5 2	6.3	Medium traffic	
0 4		100		95			58			33	25		17		13		9		6	3	4.8		37 Pa
0.5					18 2		40 2			14 6		22									5.0		38 R I
0 5					100		100	80		50		24									5 0		39 S C.
0.2				100					67							22				9	6 0		40 S Dak
0 3										Not reported													41 Tenn
0 4	2/ –		19 6	-		23 7	'	13 9	-	12 2		-		8 9		–	12.6	-	4 1	–|1 0	4 0		42 Tex.
										Not reported													43 Utah
										Not reported													44 Vt.
0.5				100	96			72		50		30						6			5 0		45 Va
1 0						100	95		60			33				21				4	5 5		46 Wash
0 4				100	96			62		36			19				5			2	4 3		47 W Va
0 5					96			72		59		48				26				6	5 0		48 Wisc
																					5 5		
0 5					100			72		55		35								7	5.5		49 Wyo.
0 3				3/ 100		84		49		35			25 4/				12 5			2	5 0	5/	50 Ontario

TABLE 8

SPECIFIED TOLERANCES FROM JOB-MIX FORMULAS AND TYPICAL FORMULAS FOR SURFACE-COURSE MIXTURES

Agency	Method of Specifying Sieve-Size Limits	Basis of Percentage Limits	Specified Tolerances from Job-Mix Formula — Standard Sieve Size or Number - Square Openings (figures are percentages plus or minus from formula percentage)																		
			1-1/2"	1-1/4"	1"	3/4"	5/8"	1/2"	3/8"	1/4"	No 4	No 8	No 10	No 16	No 20	No 30	No 40	No 50	No 80	No 100	No 200
1 Ala	Percent passing	Total aggregate							—		4				5		-			3	
2 Ariz	Ditto	Ditto										Not reported									
3 Ark	Percent retained	"									5		+5 -7				3				2
4 Calif	Percent passing	"									6					5					3
5 Colo	Ditto	"				5		5			+5,-7									+5,-3	+3 -1
6 Conn	"	"									5		4		4		4		4		2
7 Del	"	"						7	7		5		5		5		5		5		5
8 D of C	"	"						7	7		5		5				5		3		2
9 Fla	Pct pass and ret	"						5	-	5	-	5	-		4			3			2
10 Ga	Percent passing	"				7			5			4						4		4	2
									5		5			4				4		4	2
11 Idaho	Ditto	"										Not reported									
12 Ill	Pct pass and ret	Total mixture						-		3			-				3				-1 5
								-		3			-				3				1 5
13 Ind	Ditto	Ditto										2/ 3									
14 Iowa	Percent passing	Total aggregate			8	8		8			8	5									2
15 Kans	Percent retained	Ditto							5			5				+5,-2			+4,-3		1 5
16 Ky	Percent passing	"						4	4		4	2		2				2		2	2
17 La	Ditto	"						/			7		5				5		3		2
18 Me	"	"						6			6		5		4		4		3		2
19 Md	"	"				7			7		4		4		4		4		4		2
20 Mass	Pct pass and ret.	Total mixture																			
21 Mich	Ditto	Ditto								2			-				2				—0 5
22 Minn	Percent passing	Total aggregate					4		4		4		4				4		4		0 5
23 Miss	Ditto	Ditto						7	7		/		7				6		5		2
24 Mo	Pct pass and ret	Total mixture						–		5							3				·1 0
25 Mont	Ditto	Ditto										Not reported									
26 Nebr	Percent retained	Total aggregate							7		5		5					5		3	2
	Ditto	Ditto																			
27 Nev	Percent passing	"										Not reported									
28 N H	Ditto	"						10			10		4				4				2
29 N J	Pct pass and ret	Total mixture			—				4				—								+3,-1
	Ditto	Ditto			—				4				-—								+3,-1
30 N M	Percent passing	Total aggregate						5	5		5		4				4		3	3	3
31 N Y	Pct pass and ret	Total mixture										Not reported									
32 N C	Ditto	Ditto							7		-	5	-		5		-	5		5	- 2
33 N Dak	Percent passing	Total aggregate										Not reported									
34 Ohio	Pct pass and ret	Total mixture										Not reported									
35 Okla	Percent passing	Total aggregate						5	5		5		4				3				2
36 Oreg	Pct pass and ret	Total mixture							4		–	4	+		3		+	2	-	2	- 2
										4		4	·		3		–	2	-	2	2
37 Pa	Percent passing	Total aggregate						5	5		4	4		4		4		4		4	4
								5	5		4	4		4		4		4		4	4
38 R I	Pct pass and ret	Total mixture							10	10	10	2/ 10	4			4		-	4	-	4
39 S C	Percent passing	Total aggregate							7		4		4				4		4		2
40 S Dak	Ditto	Ditto								3							2				2
41 Tenn	"	"							7		4		4				3		3		2
42 Tex	Pct pass and ret.	Total mixture						—			5		--		3			3	-	3	-- 2
43 Utah	Percent passing	Total aggregate							7	→				5			-			3 -	2
44 Vt.	Ditto	Ditto						8	8		8		4 5				4 5		4 5		4
45 Va	"	"									+4,-8		4				4		4		4
46 Wash	"	"						5		15			10				+8,-9				+2 4,-
47 W.Va	"	"						7	5		4	4		4				2			2
48 Wisc	"	"							5		5		3				3		3		2
49 Wyo.	"	"									10		10								3
50 Ontario	"	"						5	5		4			5/ 5				4			2

1/ Percent of total aggregate
2/ No 6 sieve
3/ Round sieve openings, 1/4 inch size and larger
4/ Five percent pass No 200 sieve for heavy traffic
5/ No 14 sieve
6/ Indicated tolerances are usual working limits and are not specified

TABLE 8 (continued)

1954 Practice

Bitumen Content of Mixture	1-1/2"	1-1/4"	1"	3/4"	5/8'	1/2"	3/8"	1/4"	No 4	No 8	No 10	No 16	No.20	No 30	No.40	No 50	No 80	No 100	No 200	Bitumen Content of Mixture	Remarks	Agency
	Typical Job-Mix Formula — Standard Sieve Size or Number - Square Openings (figures are percent by weight)																					
1/ 0 4									Not reported													1 Ala
									Not reported													2 Ariz
0 5				0					34		52				73				92	6 0		3 Ark
									Not reported													4 Calif
0 2			100	95		80			47									14	5	6 0		5 Colo
0 5						100			47		36		32		24		11		4	6 0		6 Conn
0 4						100	92		58		38		26		20		15		7	5 9		7 Del
0 3						100	90		58		46				26		11		2	5 6		8 D of C
0 4				—	2		13-	28	-	17	-		10		—	12		12	6	5 7		9 Fla
0 5			100	98			68			45						18		10	6	6 5	Heavy traffic	10 Ga
0 5						100	98		70			44				23		14	7	7 25	Medium traffic	
									Not reported													11 Idaho
0 5							39		-	18	-		11		—	13	-	7 5	-6 0	5 5	Heavy traffic	12 Ill
0 5						-	38		—	17			12		—	14	—	7	—6 0	6 0	Medium traffic	
0 3									Not reported													13 Ind
0 3									Not reported													14 Iowa
1/ 0 5							20			55				72			85		92	1/ 7 15		15 Kans
0 3						100	92 5		60	42 5		30				11		5	2 5	5 7		16 Ky.
0 5				100		95			70		50				25		18		8	5 75		17 La
0 5						100			62		43		31		21		11		3 5	6 8		18 Me
			100	95			73		55		38		25		16		11		4			19 Md
0 5								32 2		21 4		11 6		7 8		7 0	—	7 8	—5 9	6 3		20 Mass.
0 2					—			55			—				34					5 5		21 Mich
0 25				100	100		77		55		45				24		12		5 8	5 8		22 Minn
0 3						100	100		88		66				34		18		8	8 0		23 Miss
0 5				—	0 6	-8 6 -		31 5		14 9	-		12 9		—	11 5		9 0	>5 6	5 4		24 Mo
									Not reported													25 Mont.
				0			20		46		69					84		90	93	1/ 4 8	Heavy traffic	26 Nebr
				0			3		18		58					83		89	93	1/ 5 0	Medium traffic	
									Not reported													27 Nev
0 5						100			65		50				20				5	6 5		28 N H
0 3										50					39 25				—5 0	5 75	Heavy traffic 3/	29 N J
0 3										47					42 0				—5 0	6 0	Medium traffic 3/	
0 3				100		85	70		55		40				22		14		7	6 0		30 N M
									Not reported													31 N Y
0 5				--	1	-		36	-	17			19			12		7	4/ 2	6 0		32 N.C
									Not reported													33 N Dak
									Not reported													34 Ohio
0 3						95	85		68		47				27				6	6 0		35 Okla
				—	14		32		—	17	—		15		-	6	—	5 3	—5 0	5 7	Heavy traffic	36 Oreg
0 3						8 —	33		-	18	—		16		-	8	-	5 5	—5 2	6.3	Medium traffic	
0						100	88		55	40		28		20		10		5	4	6 0	Heavy traffic	37 Pa
0 4						100	95		60	46		35		25		15		9	6	6 4	Medium traffic	
0 5						100	5	29	5	2/ 5	5	-		19			13	5	6	7 0		38 R I
0 4						100	90		70		56				30		19		7	6 5		39 S C
0 2			100					67							22				9	6.0		40 S Dak
0 3									Not reported													41 Tenn.
0 4						2 5 -	31 8	-	23 3		-		10 9		—	13 8		10	>2 7	5 0	3/	42 Tex
0 25									Not reported													43 Utah
									Not reported													44 Vt
0 5							100		96		80				33		16		6	7 0		45 Va
1 0					100	95		55			30				18				4	5 5		46 Wash
0 4						100	95		68	45		32				9			2 5	6.5		47 W Va
																				6 0		48 Wisc
0 5						98	86		64		51				25		14		6	6 5		
0 5						100			60		40								7	6 0		49 Wyo
0 3						100	83		55			5/ 36				17			4	6.0	6/	50 Ontario

TABLE 9

USE OF STABILITY TESTS IN DESIGNING AND CONTROLLING BITUMINOUS CONCRETE MIXTURES

Agency	Stability Test	Limits for Test Values Included in Specifications	Limits for Test Values Used in Design Only	Measured Characteristics							
				Stability Value			Flow			Relative De	
				Medium Traffic	Heavy Traffic	Traffic Undiffer.	Medium Traffic	Heavy Traffic	Traffic Undiffer.	Medium Traffic	Heavy Traffic
								(0.01")		(percent of the	
1 Ala.	Marshall		x	1000	1500				m		
2 Ariz.	Hveem		x			30+					
3 Ark	Marshall		x	500					12		
4 Calif.	Hveem	x				35					
5 Colo.	Marshall		x						16-		
	Hveem		x			35					
6 Conn	Marshall		x			1500+			16-		
7 Del.	Marshall		x			500+			20-		
8 D of C.	Hubbard-Field		x			1500					
9 Fla.	Hubbard-Field	x		1200	3000						
	Asphalt Institute	x									95-98
10 Ga.	Hubbard-Field					m					
11 Idaho	Hveem		x			40+					
12 Ill.	Marshall		x	1200+	1500+		12-20	8-16			
13 Ind	Trial and Error										
14 Iowa	Hveem		x								
15 Kans.	Triaxial Compression		x								
16 Ky.	Trial and Error										
17 La.	Marshall	x				1000+			8-18		
18 Me.	Hveem	x				35-50			m		
19 Md.	Marshall		x	1000	1500						
20 Mass.	Hveem		x			35-50					
21 Mich.	Hubbard-Field										
22 Minn.	Marshall		x			500+			20-		
23 Miss	Marshall (modified)	x		200-400	400+					90+	92+
24 Mo.	Hubbard-Field	x				3000+					
25 Mont	Hubbard-Field	x				m					
26 Nebr.	Hubbard-Field					m					
	Immersion-Compression										
27 Nev.	Hveem					m					
28 N.H.	Unconfined Compression					300-400psi					
29 N.J.											
30 N.M.	Marshall		x			1500+			12-20		
31 N.Y.	Trial and Error		x								
32 N.C.	Unconfined Compression		x	200+	300+						
	Immersion-Compression										
	Vibrating Table										
33 N.Dak.	Marshall		x			1000-1500			10-15		
	Hubbard-Field		x	3000-4500							
34 Ohio	Vibrating Table		x								
35 Okla.	Hveem	x				35+					
36 Oreg.	Hveem					m					
37 Pa.	Trial and Error										
38 R.I.	Hubbard-Field		x		2500						
39 S.C.	Marshall	x		600+	2000+						
40 S.Dak.	Marshall		x			500+			20-		
41 Tenn.	Marshall		x			m			m		
	Hubbard-Field					m					
42 Tex.	Hveem (modified)	x				35+					
43 Utah	Marshall		x			1000+			12-18		
44 Vt.	Marshall					m			m		
45 Va.	Marshall			500	1500				20-		
	Hubbard-Field	x		1500	2000						
46 Wash.	Hveem		x			35+					
47 W.Va.	Trial and Error										
48 Wisc.	Marshall		x	1000+	1500+				16-		
49 Wyo.	Direct Compression		x			200 psi					
50 Ontario	Marshall		x			1500+			15-		
	Triaxial Compression		x								

1/ An "m" indicates that the characteristic was reported as measured, but no limiting values were reported.

TABLE 9 (continued)

1954 Practice

...and Limiting Values 1/ ...sity Traffic Undiffer. ...retical)	Voids Medium Traffic	Voids Heavy Traffic	Voids Traffic Undiffer	Voids Filled with Asphalt Medium Traffic	Voids Filled with Asphalt Heavy Traffic	Voids Filled with Asphalt Traffic Undiffer.	Specific Gravity Used in Theoretical Calculations	Miscellaneous	Agency
							Apparent		1 Ala.
							Bulk		2 Ariz.
			3-5				Bulk		3 Ark.
							Apparent, Bulk	Cohesiometer Value 50+ Swell 0.030"+.	4 Calif.
			4-6				Bulk		5 Colo.
94-97							Vacuum Saturated		6 Conn.
Max.			3-5			75-85	Bulk		7 Del.
							Bulk		8 D.of C
									9 Fla.
							Bulk		
m			m				Bulk		10 Ga.
							Apparent		11 Idaho
							Apparent		12 Ill
									13 Ind.
			2-6						14 Iowa
							Bulk	Cohesion 8 psi. Angle of internal friction 25° Modulus of deformation 25000 psi.	15 Kans.
							Surface Dry		16 Ky.
92-96							Bulk		17 La.
							Apparent		18 Me.
							Apparent, Bulk		19 Md.
92+			8-				Bulk		20 Mass.
							Apparent		21 Mich
			4+				Bulk		22 Minn.
							Apparent		23 Miss.
			3-6				Apparent, Bulk		24 Mo.
95-98							Bulk-Surface Dry		25 Mont.
							Bulk		26 Nebr.
									27 Nev.
			3-8				Apparent		28 N.H.
									29 N.J.
94-98						75-85	Bulk		30 N.M.
			3-5				Bulk		31 N.Y.
			4-8				Bulk		32 N.C.
Max.							Bulk		33 N.Dak.
	3	5					Bulk		34 Ohio
94-98							Apparent, Bulk		35 Okla.
m							Apparent, Bulk		36 Oreg.
									37 Pa.
							Apparent		38 R.I.
							Apparent		39 S.C.
94-98						75-85	Effective		40 S.Dak.
							Apparent		41 Tenn.
94-98							Bulk		42 Tex.
			3-7			93-97	Apparent		43 Utah
			m			m	Surface Dry		44 Vt.
90							Bulk		45 Va.
90							Bulk		
							Apparent		46 Wash.
									47 W.Va.
94-98							Apparent		48 Wisc.
92							Apparent		49 Wyo.
94-97			3-6			65-85	Effective		50 Ontario
								Cohesion 15 psi. Angle of internal friction by cell test, 27 + for heavy traffic.	

TABLE 10

BITUMINOUS CONCRETE CONSTRUCTION REQUIREMENTS - PART I

Agency		Plant									
		Aggregate Storage		Temperature Requirements			Maximum	Mixing-Time Requireme			
		Stock Piled Separately	Stock Pile Construction	Aggregate Temperature	Asphalt Cement	Mixture at Discharge	Moisture in Aggregates	Batch-Type Plant			C
								Dry	Wet	Total	Total
				°F	°F	°F	percent	sec.	sec.	sec.	sec.
1	Ala.	Yes	-	225-350	Varies	225-300	0.5	Thorough	45	45	-
2	Ariz.	No	1/ N.S.	375 max.	3/ N.S.	375 max.	1.25	Thorough	30	-	Thorough
3	Ark.	Yes	In layers No segregation	350 max.	300 max.	250-325	N.S.	Thorough	30	-	30
4	Calif.	Yes	No segregation or degradation	275-350	275-350	N.S.	1.0	N.S.	30	30	N.S.
5	Colo.	Yes	N.S.	225-325	200-325	225-325	2.0	Thorough	45	N.S.	45
6	Conn.	Yes	N.S.	300-350	N.S.	265-325	N.S.	15	30	45	45
7	Del.	Yes	No segregation	325 max.	250-350	275-325	N.S.	15	45	90	-
8	D.of C.	Yes	3-ft. layers	250-400	250-350	250-350	N S.	15	45	60	-
9	Fla.	Yes	3-ft. layers Min. 6' height	250-340	250-340	250-340	Dry	15	45	60	60
10	Ga.	Yes	Layers	350 max.	250-350	300 max.	-	15	45	60	45
11	Idaho	No	3-ft. layers	325 max.	200-400	325 max.	1.0	-	30	30	30
12	Ill.	Yes	-	1/250-350-B 275-375-S	250-350	325 max.-B 350 max.-S	Dry	5-B 15-S	30	35-B 45-S	35-B 45-S
13	Ind.	Yes	No coning or segregation	300-375	200-300	225 min.	1 0	15	30-45	45-60	Thorough
14	Iowa	Yes	4-ft. layers	275-335	225-300	310 max.	No foaming	20	30	50	50
15	Kans	Yes	No segregation or degradation	325 max.	275-325	225-325	No foaming	Thorough	35-B 45-S	60	N.S.
16	Ky.	Yes	-	250-325	225-325	250-300	Trace	15	30-45	40-60	
17	La.	Yes	-	250-350	250-325	250-325	1 0	N S.	45	45	
18	Me.	Yes	N.S.	250-300	275 min.	300-350	N S	15	55	70	-
19	Md.	Yes	4-ft. lifts	250-325	250-350	225-350	N S.	15	45	60	-
20	Mass.	Yes	N.S.	-	275-350	250-300	N.S	N S.	45	N.S	-
21	Mich.	Yes	No segregation	400 max.-B 425 max.-S	275-350	280-375	0 0	10	35-B 50-S	45-B 60-S	
22	Minn.	Yes	No intermixing	325 max.	225-300	325 max.	Surface dry	15	25	40	40
23	Miss.	Yes	Layers	250-400	250-350	250-350	Dry	-	-	60	-
24	Mo.	Yes	No segregation	225-350	250-325	N.S.	N.S.	15	30	45	35
25	Mont.	Yes	-	225-275	225-300	225-300	N.S.	Thorough	45	-	-
26	Nebr.	Yes	3-ft. layers	250-325	250-350	275 ±20	N.S.	15	30	45	45
27	Nev.	Yes	N.S.	275-325	250-400	275-325	1.0	10	30	40	-
28	N.H.	Yes	N S.	250-325	250-350	250-350	No foaming	-	45	45	35
29	N.J.	Yes	No segregation	225-350	250-325	325 max.	N.S.	Thorough	45	45	
30	N.M.	No	N.S.	250-325	275 ±20	250-280	Dry	10	30	40	30
31	N.Y.	Yes	N.S.	325 max.	-	225-275	N.S.	15	30	45	-
32	N.C.	Yes	No segregation	250-375	250-325	250-350	N S.	N.S.	45	45	-
33	N.Dak.	N.S.	No segregation	325 max.	300 max.	N S.	Dry	15	20	35	-
34	Ohio	Yes	-	N.S.	300 max.	325 max.	Dry	15	30	45	45
35	Okla.	Yes	No intermixing	325 max.	250-300	325 max	0.5	5	30	35	35
36	Oreg.	Yes	-	325 max.	300 max.	250-325	N.S	Thorough	30	N S.	-
37	Pa.	Yes	4-ft. layers	N.S.	250-325	225-325	Dry	Thorough	40	42-45	-
38	R.I.	Yes	-	300-375	250-350	275-350	N S.	15	45	60-75	
39	S C.	Yes	No segregation	250-350	-	250-350	N.S	Thorough	45	45	-
40	S.Dak.	Yes	-	-	-	235-325	1.0	-	-	35	35
41	Tenn	Yes	No segregation	300-400	250-325	4/ 250-325 5/ 200-300	N S	-	-	30	40
42	Tex.	Yes	-	Varies	180-350	200-350	N.S.	5-20	30	35-50	35-50
43	Utah	No	-	250-320	250-325	250-300	-	-	30	-	-
44	Vt.	Yes	-	275-350	-	275-350	-	Thorough	45	45	-
45	Va.	Yes	5-ft. layers	225-300	225-275	225-275	0.2	15	45	60	45
46	Wash.	Yes	4-ft layers	300-385	250-325	260-375	N S	-	30	-	N.S
47	W Va.	Yes	Preserve quality	300 max.	250-300	200-300	0.5 to 1 0	15	45	60	60
48	Wisc	Yes	N.S	225-350-B 275-375-S	250-350	250-350	1.0	Thorough	45	60 ±	-
49	Wyo.	No	N S	250-325	275-350	250-350	1 0	-	30	Thorough	30
50	Ontario	Yes	Layers	325 max	275 max	N S.	N S	15	25	40	35

1/ B = binder-course material; S = surface-course material 2/ Formula $Sec = \frac{\text{Pugmill Dead Capacity (lbs)}}{\text{Pugmill Output (lbs./sec)}}$ 3/ N

TABLE 10, PART I (continued)

... - Minimum ...inuous-Type Plant How Determined	Temperature Requirements: Air Minimum °F	Temperature Requirements: Mixture at Placing, Range °F	Temperature Requirements: Mixture at Placing, Daily Tolerance °F	Placement: Spreading and Finishing Machine Operating Speed ft. per min.	Lift Thicknesses: Maximum Permitted, Binder inches	Lift Thicknesses: Maximum Permitted, Surface inches	Lift Thicknesses: Normally Placed, Binder inches	Lift Thicknesses: Normally Placed, Surface inches	Agency
rmula 2/	40	-	N.S.	N.S.	-	-	-	-	1 Ala.
Not reported	N.S.	N.S.	N.S.	-	Not used	3½	Not used	2	2 Ariz
Not reported	35	250-325	± 25	-	3	2	2-3	1½ - 2	3 Ark.
-	40	N.S.	N.S.	N.S.	2	2	1½	1½	4 Calif.
rmula	N.S.	225-325	N.S.	-	3	2	1½	1½	5 Colo.
-	60	265-325	± 25	N.S.	2	2	1¼	1¼	6 Conn.
rmula	40	255-305	N.S.	N.S.	2	1¼	-	-	7 Del.
rmula	50	225-350	± 20	-	2	2	1½	1½	8 D.of C.
gmill dead capacity - lbs.	40	250-340	± 30	7-28	2	2	1½	1	9 Fla.
rmula	40	-	-	10-20	-	-	1-2	1 - 1½	10 Ga.
-	35	200-300	N.S.	N.S.	-	2½	-	2½	11 Idaho
rmula	40	250-325-B 250-350-S	± 20	20-25	2	1½	1½	1½	12 Ill.
Not reported	40	225-325	± 20	N.S.	-	-	-	-	13 Ind.
rmula	40	250-275	± 20	35 max.	-	-	-	-	14 Iowa
-	40	225-325	N.S.	10-20	-	-	1½	1½	15 Kans.
rated capacity of plant	40	225-300	N.S.	25 max.	1½	1½	1½	1½	16 Ky.
tinuous plant not used	36	250-325	± 25	N.S.	2	2	2	2	17 La.
rmula	40	275-325	± 25	N.S.	1	1	1	1	18 Me.
rmula	32 rising 38 falling	225-350	± 20	5-30	3	2	2	1½	19 Md.
mula	40	250-300	± 20	N.S.	-	-	-	-	20 Mass.
tinuous plant not used	40	280-375	± 20	5-20	170 p.s.y.	130 p.s.y.	-	100 p.s.y.	21 Mich.
mula	40	N.S.	± 20	30 max.	2½	2½	1½-2	1½-2	22 Minn.
mula	40	225-325-B 250-350-S	± 25	-	-	-	1½-2½	1 -2	23 Miss.
mula	40	200-350	± 25	N.S.	2	2	1 3/4	1¼	24 Mo.
mula	40	300 max.	± 10	10-20	2	2½	1½	1½-2-2½	25 Mont.
mula	40	275 max.	± 20	10-30	-	2	-	1½	26 Nebr.
-	50	275-325	± 20	-	2	2½	-	-	27 Nev.
mula	50	225-350	N.S.	-	3	1	2	1	28 N.H.
tinuous plant not used	40	325 max.	± 15	5-50	-	-	-	-	29 N.J.
mill output	35 rising 40 falling	225-255	± 15	20 max.	-	2	1½	2	30 N.M.
-	50	225-275	N.S.	N.S.	1½	1	1½	1	31 N.Y.
mula	35	225-325	± 30	30 max.-B 20 max.-S	3	2	1½	1½	32 N.C.
mula	35	225 min.	-	30 max.	Var.	Var.	-	2½	33 N.Dak.
-	-	240 min.	± 25	As required	-	1½	-	1-1½	34 Ohio
mula	40	225-300	± 20	-	-	-	2-3	1-2	35 Okla.
mula	40	250-300	N.S.	10-50	3	3	2	1½	36 Oreg.
mula	40	225-300	± 15	-	3	1	2-3	1	37 Pa.
tinuous plant not used	40	250-375	± 20	Avoid tearing	1½	1½	1½	1½	38 R.I.
mula	35	250-350	± 20	-	-	-	-	-	39 S.C.
acity of mixer, drier and halt pump	40	250-325	± 10	30 max.	1-1½	2	1-1½	1½	40 S.Dak.
mula	40	4/225-300 5/175-275	± 20	-	-	-	2½	1½	41 Tenn.
reported	N.S.	N.S.	± 30	-	-	3	-	1	42 Tex.
mula	50	250-300	-	-	1½-2	1-1½	1½	1½	43 Utah
mula	40	275-325	± 25	-	1½	1-1½	1½	1	44 Vt.
mula	40	225-275	± 20	10-30	2	1½	2	1	45 Va.
-	35	250 min.	-	-	3	-	1-3	-	46 Wash.
bservation	45	200-300	± 20	-	-	-	-	-	47 W.Va.
mula	50	225-325-B 250-350-S	± 20	20 max.	1½	1½	1½	1½	48 Wisc.
mula	40	250-350	N S.	Avoid tearing	1¼	2	1¼	1¼	49 Wyo.
mula	45	N.S	N.S.	10-20	2½	1½	2	1¼	50 Ontario

...ecified in specifications. 4/ Stone. 5/ Gravel.

TABLE 10

BITUMINOUS CONCRETE CONSTRUCTION REQUIREMENTS - PART II

Agency	Compaction				
	Rolling Requirements				
	Max Tons Per Roller-Hour	Minimum Number of Rollers	Roller Types 5/	Other Requirements	Maximum Roller Speed mph
1 Ala.	30	2	T or W		2
2 Ariz	2/ N.S.	N.S.	T or P		N.S.
3 Ark.	50	N.S.	T or W		-
4 Calif	100	N.S.	T, P, or W		N.S.
5 Colo.	-	2	T and W		N.S.
6 Conn.	25	1	T and W	First roller tandem, additional rollers 3-wheel	3
7 Del.	40	2	T and W		N.S.
8 D.of C.	-	2	T		1.5
9 Fla.	-	2	T	One roller per 450 s.y. per hr.	N.S.
10 Ga.	N.S.	N.S.	T or W		3
11 Idaho	75	1	T		N.S.
12 Ill.		2	T and W	One tandem and one 3-wheel for 75 ton/hr. or less; additional rollers tandem	1.8
13 Ind.	-	2	T and W	One 3-wheel to two tandem max. ratio	N.S.
14 Iowa	40	2	T and W	Only one 3-wheel roller per job	N.S.
15 Kans.	N.S.	N.S	T or W		1.5
16 Ky.	25	2	T or W	Only one 3-wheel roller per job	N.S.
17 La.	50	N.S.	T or W		N.S.
18 Me.	N.S.	N.S.	T	Initial rolling with 2-axle tandem, final with 3-axle tandem; not over 200 s.y. per rollerper hr.	N.S.
19 Md.	-	N.S.	T	One roller per 300 s.y. per hr; 2-axle or 3-axle tandem only.	3
20 Mass.	37½	N.S.	N.S.		N.S.
21 Mich.	-	2	T	Two rollers for each spreader	N.S.
22 Minn.	50	2	T and W		3
23 Miss.	35	N.S.	T or W		3
24 Mo.	To obtain finish	2	T or W	Tandem roller preferred	3
25 Mont.	80	2	T and W		3
26 Nebr.	40	N.S.	T and W		3
27 Nev.	-	N.S.	T	Require 3-axle tandem	-
28 N.H.	-	N.S.	T	Final rolling by 3-axle tandem	N.S.
29 N.J.	-	2	T and W	One roller per 1000 s.y. per hr.	3
30 N.M.	50	3	T,W and P	Two of three to be steel-tired	Avoid displacement
31 N.Y.	25	N.S.	T or W		3
32 N.C.	-	N.S.	T	One roller per 1000 s.y. per hr.	3
33 N.D.	-	2	T or W	Must obtain required finish	3
34 Ohio	30	2	T and W		2.5
35 Okla	-	2	T,W and P	Pneumatic rollers permitted in excess of two	N.S.
36 Oreg.	75	N.S.	T or W		Avoid displacement
37 Pa.	30	2	T and W	Additional rollers shall be 3-wheel	Avoid displacement
38 R.I.	100	2	T and W		N.S.
39 S.C.	N.S.	N.S.	T		Avoid displacement
40 S.D.		2	T or W	One tandem and one 3-wheel required per spreader	3
41 Tenn.	-	2	T and W	One roller per 500 s.y. per hr.	N.S.
42 Tex.	-	2	T and W	One tandem and one 3-wheel, or one 2-axle and one 3-axle tandem	N.S.
43 Utah	40	N.S.	T,W and P		N.S.
44 Vt.	150	1	T	Additional roller per 200 tons per hr.	3
45 Va.	35	2	T and W		Avoid displacement
46 Wash.	-	2	T or W	Two rollers for each spreader	Avoid displacement
47 W.Va.	30	N.S.	T or W		-
48 Wisc.	30	N.S.	T or W		1.7
49 Wyo.	40	3	T,W or P	Must include one 3-axle tandem. Add roller for each 40 tons/hr. over 160.	Avoid displacement
50 Ontario	40	2	T or W		3

1/ Type of specific gravity of aggregates used in theoretical calculation of density of voidless mass.
- A - Apparent specific gravity.
- B - Bulk specific gravity
- S - Bulk, surface dry specific gravity
- V - Vacuum saturated

2/ Not specified in specifications.
3/ Not specified, but considered desirable.
4/ Percentage values selected for each project individually. Relative densities (voidless, apparent specif
5/ T = Tandem, W = 3 wheel, P = Pneumatic.

TABLE 10, PART II (continued)

1954 Practice

Density Requirements: Relative Density, Binder (percent)	Density Requirements: Relative Density, Surface (percent)	Density upon Which Percentage Requirements are Based	Other Required Surface Smoothness: Binder	Other Required Surface Smoothness: Surface	Agency
85	90	Voidless - A 1/	1/4"-10'	1/4"-10'	1 Ala.
2/ N.S.	N.S.		-	1/4"-10'	2 Ariz.
-	-		3/8'-10'	1/4"-10'	3 Ark.
3/ 97+	3/ 97+	Voidless - A	N.S.	1/8 -10'	4 Calif.
95+	95+	Voidless - B 1/	1/8'-10'	1/4"-10'	5 Colo.
3/93-96	3/93-96	Voidless - V 1/	N.S.	1/4"-10	6 Conn.
-	-		1/4"-16'	1/4"-16'	7 Del.
N.S.	90+	Voidless - A	N.S.	3/16"-10'	8 D.of C.
95+	95+	Voidless - B	1/4"-10'	1/4"-10'	9 Fla.
95+	95+	Hubbard-Field compacted specimen	3/8"-10'	1/4"-10'	10 Ga.
N.S.	N.S.		N.S.	1/4"-10	11 Idaho
95+	95+	Voidless - A	1/4"-10'	1/8"-10'	12 Ill.
-	-		1/4"-10'	1/8"-10'	13 Ind.
98	98	Not stated	1/4'-10'	1/8"-10'	14 Iowa
88+	90+	Voidless - B	1/4"-10'	3/16"-10'	15 Kans.
N.S.	N.S.		1/16"-1'	1/8"-10'	16 Ky.
98	98	Marshall compacted specimen	3/16"-10'	3/16"-10'	17 La.
94-98	94-98	Voidless - A	1/2"-20'	1/4"-20'	18 Me.
92+	92+	Voidless - A	1/8"-10'	1/8"-10'	19 Md.
92+	92+	Voidless - B	-	1/4"-16'	20 Mass.
N.S.	N.S.		1/4"-10'	1/4"-10'	21 Mich.
N.S.	N.S.		N.S.	3/16"-10'	22 Minn.
4/	4/	Marshall compacted specimen	1/8"-10'	1/8"-10'	23 Miss.
94-97	94-97	Voidless - A, B	1/4"-10'	1/8"-10'	24 Mo.
95-98	95-98	Voidless - S	1/2"-10'	3/16"-10'	25 Mont.
3/91-92	3/91-92	Voidless - B	-	3/16"-10'	26 Nebr.
90	90	Not stated	-	-	27 Nev.
3/ 95+	3/ 95+	Voidless - A	1/4"-10'	1/4"-10'	28 N.H.
N.S.	N.S.		-	3/16"to 1/8"-10'	29 N.J.
-	92-96	Voidless - A	3/16"-10'	3/16"-10'	30 N.M.
N.S.	N.S.		1/4"-16'	1/4"-16'	31 N.Y.
95+	95+	Voidless - B	1/4"-10'	1/4"-10'	32 N.C.
N.S.	N.S.		1/4"-10'	1/4"-10'	33 N.D.
-	90-95	Voidless - B	1/4"-10'	-	34 Ohio
92+	92+	Voidless - A, B	3/16"-10'	3/16"-10'	35 Okla.
92+	92+	Voidless - A	1/10"-10'	1/10"-10'	36 Oreg.
3/ 95+	3/ 95+	Voidless	Flex. base 1/4"-16' Rigid base 1/8"-16'	Flex.base 1/4"-16' Rigid base 1/8"-16'	37 Pa.
-	94	Hubbard-Field compacted specimen	-	-	38 R.I.
N.S.	N.S.		N.S.	1/8"-10'	39 S.C.
N.S.	N.S.		N.S.	1/4"-12'	40 S.D.
3/85-90	3/85-90	Voidless-A (flexible, 85 percent; rigid, 90 percent)	1/4"-12'	1/4"-12'	41 Tenn.
3/91-96	3/91-96	Voidless - A	1/4"-16'	1/4"-16'	42 Tex.
92+	92+	Voidless - A	N.S.	1/8"-10'	43 Utah
95-99	95-99	Marshall compacted specimen	N.S.	1/4"-16'	44 Vt.
90+	90+	Voidless - A	1/4"-16'	1/8"-16'	45 Va.
N.S.	N.S.		N.S.	1/8"-10'	46 Wash.
-	-		-	1/8"-10'	47 W.Va.
N.S.	N.S.		N.S.	1/4"-10'	48 Wisc.
3/ 95	3/ 95	Voidless	1/4"-10'	1/4"-10'	49 Wyo.
N.S.	N.S.		1/8"-10'	1/8"-10'	50 Ontario

gravity) of 92+ percent for heavy traffic and 90+ percent for medium traffic.

TABLE 11

BITUMINOUS CONCRETE EQUIPMENT REQUIREMENTS - PART I

Agency	Equipment Used in Storing and Feeding Cold Aggregates: Equipment Used in Conveying Aggregate to Cold Bins	Requirements for Cold-Aggregate Bins: Minimum Number of Compartments	Requirements for Cold-Aggregate Bins: Minimum Capacity	Requirements for Feeders: Mechanical Feeder Required	Requirements for Feeders: Type of Feeder Normally Used	Requirements for Feeders: Adjustable for Proportional Feed	Requirements for Feeders: Adjustable for Total Feed	Require for Contr
1 Ala	Clamshell	3	Supply full mixer capacity	Yes	Combination	Yes	Yes	Produce prop
2 Ariz	N S 1/	N S	-	No	-	-	-	N S
3 Ark	Clamshell	N S	N S	Yes	Combination	No	Yes	Produce prop
4 Calif	Gravity belt and tunnel	2	N S	Yes	Individual	Yes	Yes	-
5 Colo	N S.	N S	N S.	Yes	Combination	Yes	Yes	N S
6 Conn	N S	N S	-	Not required, but used	Compartment	Yes	Yes	N S
7 Del	Clamshell	N S.	Supply plant-rate	No	Compartment	-	-	-
8 D.of C.	-	-	-	Yes	Compartment	Yes	Yes	-
9 Fla.	Clamshell	N S	-	Yes	Combination	Yes	Yes	Produce proj
10 Ga	Dragline	2	Not less than 3x dead-load capacity of mixer	Yes	Compartment	Yes	Yes	Produce proj
11 Idaho	Bulldozer	-	-	No	-	No	No	N S
12 Ill	Crane and elevator	3	-	Yes	Compartment	Yes	Yes	Feed a mini to proper p
13 Ind.	Elevator	3+	-	Yes	-	Yes	Yes	Produce pro
14 Iowa	-		Suppl, plant-rate	Yes	-	Yes	-	Adjustable (
15 Kans	Clamshell	N S	-	Yes	Combination	Yes	Yes	Produce pro
16 Ky.	Clamshell	2	Supply plant-rate	Yes	Combination	Yes	-	Feed a mini to proper p
17 La	Dragline and conveyor belt	One for each aggregate size	N.S	Yes	Compartment	Yes	Yes	N.S
18 Me.	Clamshell	2	Supply plant-rate	Yes	Compartment	Yes	Yes	Adjustable
19 Md.	N.S.	One for each aggregate size	Supply full mixer capacity	Yes	Compartment	Yes	Yes	Feed throug
20 Mass	N S.	-	-	Yes	Compartment	Yes	Yes	Adjustable
21 Mich.	Power shovel and conveyor	-	-	Yes	Compartment	Yes	Yes	Adjustable
22 Minn.	Conveyor belt	-	N S.	Yes	Reciprocating gate feeder	Yes	Yes	Positive co
23 Miss.	Crane or belt conveyor	Varies as to type of mixture	Supply full mixer capacity	Yes	Compartment	Yes	Yes	Accurate me
24 Mo	N.S	One for each aggregate size	N S.	Yes	Individual	Yes	Yes	Produce pro
25 Mont.	Conveyor belt	-	Supply full mixer capacity	Yes	Combination	Yes	Yes	Uniform fee
26 Nebr.	Clamshell	One for each aggregate size	N.S.	Yes	Compartment	Yes	Yes	No locking specified l
27 Nev.	Belts	-	-	Yes	Individual	Yes	-	-
28 N.H.	Trucks		-	Yes	Compartment	Yes	Yes	N.S
29 N.J.	N.S.	One for each aggregate size	-	Yes	Compartment	Yes	Yes	Accurate M
30 N.M.	-	-	-	Yes	Combination (apron type)	-	-	Positive c calibrated
31 N.Y	N.S.	N.S	-	Yes	Compartment	Yes	Yes	Produce pr
32 N.C.	N.S	One for each aggregate size	Supply full mixer capacity	Yes	Reciprocating or vibrating	Yes	Yes	Accurate a total & pr
33 N.Dak.	Mechanical means	One for each aggregate size	No less than 3x dead-load capacity of mixer	Yes	Combination	Yes	Yes	Accurate m
34 Ohio	Clamshell or truck	2	-	Yes	Compartment	Yes	Yes	Produce pr
35 Okla.	Bulldozers or clamshell	One for each aggregate size	In excess of mixer capacity	Yes	Compartment	Yes	-	Accurate m
36 Oreg	Separate tunnels	3	-	Yes	Individual	Yes	Yes	Positive v
37 Pa	Clamshell	2+	-	Yes	Individual	Yes	Yes	Accurate m
38 R.I	Belt and bucket conveyor	-	-	Yes	Compartment	Yes	Yes	Controlled
39 S.C.	-	-	-	Yes	Compartment	Yes	Yes	-
40 S.Dak	Conveyor	-	-	Yes	Individual	-	-	Produce pr
41 Tenn.	Clamshell and conveyor belt	-	-	Optional	Combination	-	-	Accurate m
42 Tex.	Clamshell	3+	-	Yes	Compartment	Yes	-	Feed from compartmen
43 Utah	-	N.S.	Supply plant-rate	Yes	Compartment	-	-	Satisfacto feeder
44 Vt	Crane	2	Supply plant-rate	Yes	Compartment	Yes	Yes	-
45 Va	Clamshell	2	Supply plant-rate	Yes	Compartment	Yes	Yes	Uniform fe
46 Wash.	Belt and elevator	-	-	Yes	Individual	Yes	Yes	N.
47 W. Va.	Mechanical	2	-	No	Compartment	-	-	Uniform fe
48 Wisc.	Clamshell and bulldozer	N S.	-	Yes	Compartment	Yes	Yes	Uniform fe
49 Wyo.	Bucket elevators	-	-	No	Compartment	-	-	Produce pr
50 Ontario	N.S	3	3x mixer capacity	Yes	Compartment	Yes	Yes	-

1/ Not specified in specifications.

TABLE 11, PART I (continued)

1954 Practice

	Requirements for Aggregate Screens			
nts	Scalping Screen Opening Related to Maximum Aggregate Size	Required Capacity of Screens	Screening Efficiency (Tolerances in Specified Bin Sizes)	Agency
proportions	1/4 in larger	In excess of mixer capacity	Not specified	1 Ala
	1/8 in larger	N S	Not specified	2 Ariz
proportions	1/8 in larger	N S	Not specified	3 Ark
	1/4 in larger	Prevent overflow	Not more than 10 pct undersize material in any one bin Maximum variation per day 6 pct on No 4 sieve, 5 pct on No 30 sieve, 3 pct on No 200 sieve	4 Calif
	N S	N S	Not specified	5 Colo
	No scalping screen	In excess of mixer capacity	Not specified	6 Conn
	1/8 in larger	In excess of mixer capacity	Not specified	7 Del.
	1/4 in larger	Synchronized with speed of plant	Not more than 5 pct in any bin larger than top-size screen for bin, not more than 20 pct in intermediate-size-aggregate bin smaller than bottom-size screen for bin, not more than 10 pct in large-size-aggregate bin smaller than bottom-size screen for bin	8 D of C
proportions	1/8 in larger	In excess of mixer capacity	Not specified	9 Fla
proportion	1/4 in larger	In excess of mixer capacity	No carryover	10 Ga
	N S	N S	Maximum carryover of 8 percent	11 Idaho
of 3 sizes ortions	1/2 in larger	-	Size No 1 90+ pct pass No 10 sieve Size No 2 95+ pct pass 1/2-in sieve, 15- pct pass No 10 sieve Size No 3 95+ pct pass 1-in sieve, 15- pct pass 1/2-in sieve	12 Ill
proportions	-	In excess of mixer capacity	Not more than 5 pct in any bin larger than designated top size, not more than 10 pct in No 2 bin to pass No 6 sieve, not more than 20 pct in No 3 bin to pass 1/2 in sieve	13 Ind
es	No larger	In excess of mixer capacity	Not specified	14 Iowa
proportions	N S	In excess of mixer capacity	Not specified	15 Kans
of 3 sizes ortions	1/16-1/4 in larger	-	Not more than 5 pct in any bin larger than top-size screen for bin, not more than 5 pct in No 2 bin passing top-size screen for No 1 bin, not more than 10 pct in No 3 bin passing top-size screen for No 2 bin, not more than 15 pct in No 4 bin passing top-size screen for No 3 bin	16 Ky
	1/4 in larger	N S	Not specified	17 La
es	1/4 in larger	125 pct of plant rated capacity	Not specified	18 Me
eparate bins	1/8 in larger	In excess of mixer capacity	Efficiency of 85 percent, based on laboratory sieves	19 Md
es	-	Min of 50 ton/hr	Not specified	20 Mass
es	1/8 in larger	In excess of mixer capacity	Tolerance of 10 percent, maximum of 5 pct ret No 10 sieve for sand	21 Mich
ol	1/8 in larger	N S	Not specified	22 Minn
nical feeder	1/8 in larger	In excess of production requirement	Not specified	23 Miss
proportions	-	In excess of mixer capacity	Efficiency of 85 percent, based on laboratory sieves	24 Mo.
	-	In excess of mixer capacity	Not specified	25 Mont
ices As ngineer	1/8 in larger	Prevent inter'ption of plant production	Not specified	26 Nebr
	-	In excess of mixer capacity	Not specified	27 Nev
	N S	Min of equivalent to mixer capacity	Not specified	28 N H
nical feeder	No larger	In excess of mixer capacity	Not specified	29 N J
ol	1/4 in larger	In excess of mixer capacity	Maximum carryover of 10 percent	30 N M
proportions	1/16-1/8 in larger	In excess of mixer capacity	Not specified	31 N Y
tments for tional feed	1/8 in larger	In excess of mixer capacity	Not specified	32 N C
nical feeder	No scalping screen	N S	Not specified	33 N Dak
proportions	-	-	Bin No 1 5 pct max retained No 6 sieve Bin No 2 10 pct max retained 1/2-in sieve, 15 pct max pass No 6 sieve Bin No 3 5 pct max retained 1-in sieve, 25 pct max pass 1/2-in sieve Bin No 4 0 pct retained 2-in sieve, 25 pct max pass 1-in sieve	34 Ohio
nical feeder	1/16-1/4 in larger	In excess of mixer capacity	Bin No 1 mineral filler Bin No 2 90-100 pct pass No 10 sieve Bin No 3 85-100 pct retained No 10 sieve, 85-100 pct pass 1/2-in sieve Bin No 4 85-100 pct retained 1/2-in. sieve, 100 pct pass topsize sieve	35 Okla
e control	1/8 in. larger	In excess of plant production	Not specified	36 Oreg.
nical feeder	N S	Meet ASTM-D-995-51	Efficiency of 85 percent, based on laboratory sieves	37 Pa.
ed	N S	-	Not specified	38 R I
	1/8-1/4 in larger	-	Not specified	39 S C
proportions	No scalping screen	Equal to output of drier	Not specified	40 S Dak
nical feeder	-	In excess of mixer capacity	Not specified	41 Tenn
rate	N S	In excess of mixer capacity	Efficiency of 85 pct based on laboratory sieves, except that at least 90 pct of material in fine-size bin must pass No 10 sieve	42 Tex.
echanical	N S	In excess of mixer capacity	Not specified	43 Utah
	1/8 in. larger	In excess of plant capacity	Not specified	44 Vt.
	1/16 in larger	Prevent interuption of plant production	No 2 Bin not more than 10 pct. undersize No 3 bin not more than 15 pct undersize No 4 bin not more than 20 pct undersize	45 Va.
	1/16-1/8 in larger	300 tons per day	Plus or minus 10 pct. undersize or oversize for screen used	46 Wash
	1/2 in larger	N S	Not specified	47 W Va
	N S	In excess of mixer capacity	Not specified	48 Wisc.
proportions	N.S	In excess of mixer capacity	Not specified	49 Wyo.
	N S	N S	Not specified	50 Ontario

TABLE 11

BITUMINOUS CONCRETE EQUIPMENT REQUIREMENTS - PART II

Agency	Equipment Used During Processing of Hot Aggregate: Requirements for Hot-Aggregate-Bins: Number of Compartments: Binder	Surface	Minimum Capacity	Thermometric Equipment for Aggregates: Type of Instrument Permitted: Pyrometer	Thermometer	Recording Instrument Required	Number of Terminals Req'd: Single Drier	Dual Drier	Required Instrument Sensitivity and Efficiency	Required Capacity of Storage Tank	Storage and Heating of Bitu…: Thermom…: Type of Instrument Used: Pyrometer	Thermometer
1 Ala	3	3	Supply full mixer capacity	Yes	Yes	No	4	5	-	One day's run	No	Yes
2 Ariz	-	2	N S 1/	N S	N S	No	N S	N S	-	N S	-	-
3 Ark	3+	3+	N S	Yes	Yes	No	1	-	-	N S	No	Yes
4 Calif	3	3	N S	Yes	Yes	No	N S	N S	10°F in one minute	N S	No	Yes
5 Colo	3	-	N S	Yes	Yes	Yes	N S	N S	N S	N S	N S	N S
6 Conn	3	3	Min of 25 ton per hour-supply full mixer capacity	Yes	No	No	N S	N S	N S	10 hours operation	No	Yes
7 Del	4	3	Supply plant-rate	Yes	Yes	Yes	N S	N S	N S	One day's run	No	Yes
8 D of C	3	3	-	Yes	Yes	No	1	1	-	-	No	Yes
9 Fla	2	3	Supply full mixer capacity	Yes	Yes	Yes	1	2	N S	One day's run	No	Yes
10 Ga.	2+	2+	Not less than 3 times dead-load capacity of mixer	Yes	Yes	No	1	2	-	One day's run	No	Yes
11 Idaho	-	3	N S	Yes	Yes	No	N S	N S	N S	N S	No	Yes
12 Ill	3	3	Min capacity of 6 tons	Yes	Yes	Yes	2	3	N S	One day's run	Yes	Yes
13 Ind	3	3	-	Yes	Yes	Yes	-	-	-	One day's run	No	Yes
14 Iowa	3+	3+	Supply plant-rate	Yes	Yes	Yes	-	-	-	One day's run	No	Yes
15 Kans	3	3	3 times mixer capacity	Yes	Yes	Yes	3	3	10°F in 15 minutes	N S	No	Yes
16 Ky	3	3	Supply plant-rate	Yes	No	Yes	1	1	N S	One day's run	No	Yes
17 La	3+	3+	N S	Yes	Yes	Yes	1	1	N S	N S	No	Yes
18 Me	3	4	Supply plant-rate	Yes	Yes	No	1	2	N S	Min 10,000 gal	No	Yes
19 Md	3+	3+	Supply full mixer capacity	Yes	Yes	No	1	2	N S	N S	-	-
20 Mass	-	-	-	Yes	No	No	-	-	-	Min [illegible],000 gal	Yes	Yes
21 Mich	[illegible]	2	10 times mixer capacity	Yes	No	No	1	1	[illegible]°F in one minute	One day's run	No	Yes
22 Minn	3	3	N S	N S	N S	No	N S	N S	-	N S	No	Yes
23 Miss	Varies as to type of mixture		Supply full mixer capacity	Yes	Yes	No	N S	N S	N S	N S	No	Yes
24 Mo	3+	3+	N S	Yes	Yes	No	-	-	-	Min of 2 tanks if delivered by truck	No	Yes
25 Mont	2	3	Supply full mixer capacity	Yes	Yes	Yes	1	2	N S	One day's run	Yes	Yes
26 Nebr	2+	2+	N S	Yes	Yes	No	1	-	N S	N S	No	Yes
27 Nev	3	3	-	Yes	Yes	No	1	-	-	N S	No	Yes
28 N H	3+	3+	-	Yes	Yes	No	-	-	-	N S	No	Yes
29 N J	3+	3+	Supply plant-rate	Yes	Yes	No	1	2	-	One day's run	No	Yes
30 N M	2	3	-	Yes	Yes	Yes	1	-	-	One day's run	No	Yes
31 N Y	4	4	Not less than 3 times dead-load capacity of mixer	Yes	Yes	No	1	-	N S	N S	-	-
32 N C	3	3	Supply full mixer capacity	Yes	Yes	Yes	1	-	As directed	One day's run	No	Yes
33 N Dak	One for each size aggregate used		Not less than 3 times dead-load capacity of mixer	Yes	Yes	Yes	N S	N S	N S	One day's run	No	Yes
34 Ohio	-	3	-	Yes	Yes	Yes	1	1	-	One day's run	No	Yes
35 Okla	3+	3	Supply plant-rate	Yes	Yes	No	N S	N S	N S	One day's run	No	Yes
36 Oreg	3	3	Supply plant-rate	Yes	Yes	No	-	-	-	Provide continuous operation	No	Yes
37 Pa	3+	2+	-	Yes	Yes	Yes	1	1 to 2	-	N S	No	Yes
38 R I	4	4	-	Yes	Yes	Yes	1	-	-	N S	No	Yes
39 S C	2+	2+	-	Yes	Yes	No	1	2	-	One day's run	No	Yes
40 S Dak	3-	3-	-	Yes	Yes	No	1	-	10°F	Provide continuous operation	No	Yes
41 Tenn	3+	3+	Supply plant-rate	Yes	Yes	Yes	N S	N S	N S	ditto	No	Yes
42 Tex	4+	4+	-	Yes	Yes	Yes	N S	N S	N S	N S	No	Yes
43 Utah	3	3	Supply plant-rate	Yes	Yes	Yes	1	2	N S	Provide continuous operation	No	Yes
44 Vt	3	3	Supply plant-rate	Yes	Yes	Yes	1+	-	-	In excess of plant capacity	No	Yes
45 Va	3	3	Supply plant-rate	Yes	Yes	Yes	1	2	N S	One day's run	No	Yes
46 Wash	3	3	-	Yes	Yes	Yes	1+	1+	-	N S	No	Yes
47 W Va	3	2	-	Yes	Yes	Yes	1	-	N S	Min 500 gal	No	Yes
48 Wisc	3	2+	N S	Yes	Yes	No	1	2	N S	N S	No	Yes
49 Wyo	3	3	Supply plant-rate	Yes	Yes	Yes	N S	N S	-	One day's run	No	Yes
50 Ontario	3	3	3 times mixer capacity	Yes	No	Yes	1	N S	N S	One day's run	No	Yes

1/ Not specified in specifications

TABLE 11, PART II (continued)

1954 Practice

ous Material Equipment		Requirements for Mixing Plants										
		Type of Mixing Plant				Aggregate Weighing Equipment (Batch Plant)		Measuring Bituminous Material (Batch Plant)				
		Permitted		Normally Used				Metered	Measured by Weight			
ording Instru- t Used	Required Instrument Sensitivity	Batch	Contin-uous	Batch	Contin-uous	Type Used	Required Accuracy	by Volume	Weighed	Type of Equipment	Required Minimum Weigh-Bucket Capacity	Agency
No	-	x	x	x		Multiple beam, springless dial	0 5 pct of max load		x	Beam or springless dial	10 pct of mixer capacity	1 Ala.
-	-	x	x	x	x	N S	N S		x	Spring-type scales	N S	2 Ariz.
No	-	x	x	x	x	Multiple beam, springless dial	0 5 pct of max load		x	Springless dial	N S	3 Ark
No	-	x	x	x		ditto	Not greater than 2 pct for any setting nor 1 5 pct for any batch		x	Springless dial	N S	4 Calif
No	-	x	x		x	Scales	0 5 pct of load		x	Recording scales	N S	5 Colo
No	-	x	x	x		Multiple beam or springless dial	0 5 pct of load	x	x	Scales	15 pct of aggregate weight	6 Conn
No	N S	x	x	x		ditto	0 4 pct through load range		x	Beam or springless dial	Not greater than twice wt of matrl to be weighed	7 Del.
No	-	x	x	x	x	ditto	0 5 pct or less of load	x	x	-	-	8 D of C
No	-	x	x	x	x	ditto	0 5 pct of max load		x	Beam or springless dial	-	9 Fla
No	-	x	x	x		ditto	0 5 pct of load	x	x	Scales	20 pct of aggregate weight	10 Ga
No	N S	x	x	x	x	Springless dial	±5 pounds	x	x	Springless dial	Sufficient for one batch	11 Idaho
No	-	x	x	x		ditto	0 4 pct of weigh-hopper load	x	x	Springless dial	10-20 pct of mixer capacity	12 Ill
No	-	x	x	x	x	Multiple beam, springless dial	0 5 pct of true weight of load	x	x	-	15 pct of aggregate weight	13 Ind
-	-	x	x	x	x	ditto	0 5 pct of max load, ±5 lbs	x	x	-	-	14 Iowa
No	-	x	x		x	ditto	1 0 pct of max load		x	Beam or springless dial	20 pct of mixer capacity	15 Kans
No	-	x	x	x	x	ditto	0 4 pct of max load	x	x	-	12 pct of max mixer capacity	16 Ky.
No	-	x		x		ditto	0 5 pct of load	x	x	-	N S	17 La
No	-	x	x	x		ditto	0 5 pct of max load	x	x	-	25 pct of rated capacity	18 Me
-	-	x	x	x	x	ditto	0 5 pct of max load		x	Scales	15 pct of mixer capacity	19 Md
No	-	x	x	x		Springless dial	0 5 pct of max load	x	x	-	10 pct of mixer capacity	20 Mass
No	-	x		x		ditto	5-lb min gradation		x	Springless dial	Sufficient for one batch	21 Mich
N	-	x	x	x		Multiple beam, springless dial	0 5 pct of net load		x	Beam or springless dial	N S	22 Minn
No	-	x	x	x	x	ditto	0 5 pct of load		x	Beam or springless dial	Sufficient to charge mixer at max capacity	23 Miss
No	-	x	x	x	x	ditto	0 4 pct of net load	x	x	-	15 pct of mixer capacity	24 Mo
Yes	N S	x	x	x		ditto	0 5 pct of load		x	Beam or springless dial	Sufficient for one batch	25 Mont
No	-	x	x	x	x	Hopper & scales	N S		x	Scales	N S	26 Nebr
No	-	x	x	x		Multiple beam, springless dial	0 5 pct of load		x	-	N S	27 Nev
No	-	x	x	x		Standard makes	Approved	x	x	Scales	Sufficient for one batch	28 N H
No	-	x		x		Weigh box or hopper suspended on scale	Approved	x	x	Beam or springless dial	Sufficient for one batch	29 N J
No	-	x	x	x	x	Springless dial	0 5 pct of load		x	Scales	-	30 N M
-	-	x	x	x		Multiple beam, springless dial	0 5 pct of max load	x	x	Scales	N S	31 N Y
No	-	x	x	x	x	ditto	0 5 pct of max load	x	x	Scales	N S	32 N C
No	-	x	x	x	x	ditto	± 20 pounds	x	x	-	20 pct of aggregate weight	33 N Dak
No	-	x	x	x		Springless dial	-	x	x	-	-	34 Ohio
No	-	x	x	x	x	Multiple beam, springless dial	0 5 pct of max load	x	x	Beam or springless dial	15 pct of mixer capacity	35 Okla
No	-	x	x	x		ditto	0 5 pct of max load	x	x	-	N S	36 Oreg
No	-	x	x	x		ditto	-	x	x	Beam or springless dial	11 pct of mixer capacity	37 Pa
No	N S	x		x		Springless dial	N S		x	Beam or springless dial	10 pct of mixer capacity	38 R I
No	-	x	x		x	Multiple beam, springless dial	0 5 pct of load		x	-	N S	39 S C
No	-	x	x		x	ditto	±50 lbs per batch		x	-	20 pct of mixer capacity	40 S Dak
No	N S	x	x	x		ditto	0 5 pct of total load	x	x	Scales	20 pct of mixer capacity	41 Tenn
Yes	N S	x	x	x		ditto	0 4 pct of net loads	x	x	Springless dial, cylinder	N S	42 Tex
No	Satisfactory	x	x	x		ditto	0 5 pct of total load		x	Beam or springless dial	N S	43 Utah
No	As required	x	x	x	x	Weigh box or hopper or scales	N S		x	-	-	44 Vt
No	-	x	x	x	x	Multiple beam, springless dial	±2 lbs		x	springless dial	12 pct of mixer capacity	45 Va
No	-	x	x	x	x	ditto	0 5 pct of max load	x	x	Beam or springless dial	Not greater than twice wt of mtrl to be weighed	46 Wash
No	-	x	x	x	x	ditto	0 5 pct of max load	x	x	-	10 pct of mixer capacity	47 W Va
No	-	x	x	x	x	ditto	0 5 pct of max load	x	x	Beam or springless dial	N S	48 Wisc
Yes	N S	x	x	x	x	ditto	1/2 of min gradation		x	Beam or springless dial	Adequate	49 Wyo
No	-	x	x	x	x	ditto	0 5 pct of max load		x	-	20 pct of agg weight	50 Ontario

TABLE 11

BITUMINOUS CONCRETE EQUIPMENT REQUIREMENTS - PART III

Agency	Requirements for M					
	Pugmill Mixer (Batch Plant)				Timing Device	
	Type of mixer Normally Used	Permissible Minimum Capacity of Mixer	Mixer-Blade Rotation Rate	Max. Allowable Mixer-Blade Clearance	Time Lock Used	Specified Minimum Interval
		lbs.	rpm	in		sec.
1 Ala.	Twin shaft	1000	-	-	No	-
2 Ariz.	ditto	N.S. 1/	-	N.S.	No	-
3 Ark.	"	N.S.	-	3/4	No	-
4 Calif.	"	N.S	70-90	N.S	Yes	2
5 Colo.	"	N S.	N.S.	N S	N.S	N.S.
6 Conn	"	750	-	1	No	-
7 Del	"	N.S.	N.S.	2	Yes	-
8 D.of C.	"	1500	40	2	No	-
9 Fla.	"	N.S.	-	N S.	No	-
10 Ga	"	1000	-	3/4	No	-
11 Idaho	"	N.S.	N.S.	N.S.	No	-
12 Ill	"	1000	55-75	3/4	Yes	5
13 Ind	Batch	2000	-	3/4	Yes	-
14 Iowa	Twin shaft	-	-	3/4	Yes	5
15 Kans	ditto	2000	N.S.	3/4	Yes	5
16 Ky.	"	2000	N S	2	Yes	5
17 La	"	N.S.	56	N.S	Yes	N.S.
18 Me.	"	½ rated capacity	As rated by manufacturer	-	Yes	-
19 Md	"	1500	-	2	No	-
20 Mass.	"	52 cubic ft	-	2	No	-
21 Mich.	"	2000	60+	1	Yes	-
22 Minn	"	N.S	-	3/4	No	-
23 Miss.	Rotary drum or twin shaft	N S	N.S.	N.S.	Yes	-
24 Mo.	Twin shaft	2000	N.S	3/4 (1-in.agg.)	Yes	N.S.
25 Mont.	ditto	Rated capacity	Produce uniform mix	3/4	Yes	-
26 Nebr.	"	N.S.	N.S.	N.S,	Yes	5
27 Nev	"	N.S.	-	-	No	-
28 N.H.	"	2000	-	-	No	-
29 N.J.	"	1000	-	-	No	-
30 N.M.	"	-	As rated by manufacturer	1/2	Yes	10
31 N.Y.	"	2000	N.S.	3/4	Yes	5
32 N.C.	"	2000	N.S.	3/4	Yes	5
33 N.D.	Rotary drum or twin shaft	2000	N.S.	3/4(1½-in.agg.)	N.S.	-
34 Ohio	Twin shaft	2000	-	-	Yes	5
35 Okla	ditto	1500	-	3/4(1½-in.agg.)	Yes	5
36 Oreg.	"	Depends on job tonnage	70-90	N.S.	No	-
37 Pa.	"	N.S.	Most effective speed	3/4	Yes	-
38 R.I.	"	Rated capacity	58-60	2	No	-
39 S.C.	"	-	-	2	No	-
40 S.Dak.	"	2000	60	2	No	-
41 Tenn.	"	2000	-	3/4	Yes	5-
42 Tex.	"	1500	N.S.	N.S.	Yes	N.S.
43 Utah	"	2000	N.S.	N.S.	Yes	-
44 Vt.	"	-	N.S.	N.S.	No	-
45 Va.	"	2000	40-60 rpm	1-1½	No	-
46 Wash.	"	300 ton 18-hr. day	As rated by manufacturer	N.S.	No	-
47 W.Va.	"	2000	N.S.	N S.	Yes	15
48 Wisc.	"	N.S.	N.S.	3/4	Yes	N.S.
49 Wyo.	"	N.S	N.S.	3/4	Yes	-
50 Ontario	"	2000	-	3/4	N.S.	N.S

1/ Not specified in specifications.

TABLE 11, PART III (continued)

ixing Plant					Transpor	
Mixer (Continuous Plant)					Truck Insulatic	
Type of Mixer Normally Used	Paddle Requirements: Usual Maximum Rate of Production	Angular Adjustment	Capable of Reverse Motion	Minimum Allowable Capacity of Discharge Hopper	Cover Requirement: Cover Required	Type Specified
	tons per hour			lbs.		
Twin pug	120	Ye-	Yes	N S	Yes	-
ditto	125	Yes	No	N S.	No	-
"	For satisfactory mix	Yes	No	N.S.	When req. by Engineer	-
"	For satisfactory mix	Yes	No	N.S	Yes	Tarpaulins
"	N S.	Yes	No	N S.	Yes	Canvas
"	For satisfactory mix	Yes	Yes	N S	Yes	Waterproof canvas
"	50	-	Yes	N.S.	Yes - below 50°F	Canvas
"	120	Yes	Yes	-	Yes	-
"	N.S.	Yes	Yes	N.S.	Yes	Waterproof canvas
"	Screen capacity controls	Yes	Yes	-	Yes	Tarpaulins
"	50	Yes	-	One batch	No	-
"	40-120	Yes	Yes	2000	Yes	Canvas
"	-	Yes	Yes	-	Yes	Canvas
"	Mfr's. rated capacity	Yes	Yes	2000	Yes	-
"	Mfr's. rated capacity	Yes	Yes	2000	When req by Engineer	-
"	Mfr's rated capacity	Yes	Yes	N.S	Yes.	-
	Type not used				Yes	-
-	-	-	-	-	Yes	Canvas
Twin pug	120	Yes	Yes	N.S.	Yes	-
ditto	N.S	Yes	Yes	N.S.	Yes	-
	Type not used				Yes	-
"	N.S	No	No	N.S.	Yes	Waterproof canvas
"	80-100	Yes	Yes	N S.	Yes	Canvas
"	N.S.	Yes	Yes	N S.	Yes	Canvas
"	Mfr's. rated capacity	Yes	Yes	N.S.	Yes	As by Engineer
"	N.S.	Yes	No	200	Yes	-
-	-	-	-	-	Yes	-
Twin pug	Mfr's. rated capacity; min. of 80 tons per hr.	Yes	Yes	-	Yes	-
	Type not used				Yes	Canvas
Twin pug	Screen capacity controls	Yes	No	N.S.	No	-
-	-	-	-	-	Yes	Canvas
Twin pug	Mfr's. rated capacity	Yes	Yes	N.S.	Yes	Canvas
ditto	Mfr's. rated capacity	Yes	Yes	N.S.	Yes	-
"	-	Yes	No	-	Yes	-
"	N.S.	Yes	Yes	N.S.	Yes	-
"	N.S.	Yes	Yes	N.S.	As needed	-
"	For satisfactory mix	Yes	Yes	-	Yes	Canvas or heavy paper
"	Type not used				Yes	Canvas
"	For satisfactory mix	Yes	No	-	Yes	-
"	160	Yes	Yes	1000	In cool weather	-
"	-	Yes	Yes	-	Yes	Tarpaulin
"	N.S.	Yes	No	N.S.	In cool weather	Canvas
"	-	Yes	No	N.S.	Yes	Canvas
"	Plant size controls	Yes	No	N.S.	Yes	Canvas
"	Mfr's. rated capacity	Yes	No	N.S.	Yes	Tarpaulin
Twin, single	N.S.	No	No	N.S.	Yes	Tarpaulin
Twin pug	40	Yes	No	-	Yes	Waterproof canvas
ditto	120	Yes	Yes	N.S.	Yes	-
"	N.S.	Yes	Yes	N.S.	Yes	Canvas
Twin, single	N.S.	Yes	Yes	2000	Yes	-

TABLE 11, PART III (continued)

...tation ...n Requirements — Body Insulation Requirement: Insulation Required	Body Insulation Requirement: Type Specified	Spreading and Finishing Machine — Side Forms: With	Side Forms: Without	Leveling Device to Compensate for Irregularities: Used	Leveling Device: Not Used	Leveling Device: Description	Placing — Use Screed Heater: Yes	Use Screed Heater: No
							x	
No	-		x	-	-	-		
No	-		x		x	-		x
No	-		x		x	-	x	
No	-		x	x		Adjustable screed	x	
-	-		x	x		Barber Greene - Adnun	x	
No	-		x		x	-	x	
Yes	-		x	x		Barber Greene	x	
Yes	-		x		x	-	x	
No	-		x		x	-	x	
No	-		x	x		Screed riding on compacted surface	x	
No	-	x		x		-	N S.	
Yes	3/4-in.		x	x		Barber Greene	x	
-	-	-	-	x		-	-	-
No	-		x	x		Controlled by tracks on runners	x	
-	-		x	x		Self-leveling screed	x	
No	-		x		x	-	x	
No	-		x		x	-	x	
No	-		x	x	x	-	x	
No	-		x	x		-	x	
No	-		x	x		-	-	-
Below 50 F. or long haul	3/4-in.		x	-	-	Barber Greene - Adnun	x Bar.Gr	x Adnun
Yes - after Sept. 15th	1/2-in.		x	x		Equalizing runners, straight-edge runners, evener arms	x	
-	-		x	-	-	Barber Greene - Adnun	x	
No	-	x	x		x	-	x	
No	-		x	x		Barber Greene	x	
No	-		x		x	Barber Greene	x	
Yes	-		x	x		Screeds	x	
No	-		x		x	-	x	
Yes	-		x	x		Equalizing runners straight-edge runners, evener arms	-	-
No	-	x	x		x	Activated strike-off	x	
-	-		x	x		Adjustable strike-off	x	
No	-		x	x		Equalizing runners, straight-edge runners, or evener arms	x	
No	-		x	x		Mechanical straight-edge runners, evener arms	x	
Yes	-		x	x		Leveling arms	x	
-	-		x	x		Delayed screed reaction	x	
No	-		x	x		Adjustable activated screed	x	
In cool weather	-		x	x		10-ft runner	x	
When req by Engineer	Wood		x	x		Hand-screw mechanism	x	
-	-		x		x	-	x	
No	-		x	x		Barber Greene with crawler treads	x	
No	-		x		x	Screed	x	
In cool weather	-		x		x	-	x	
When req by Engineer	-		x	x		Barber Greene	x	
-	-	x		x		Barber Greene	x	
No	-		x	x		Equalizing runners, straight-edge runners, evener arms	x	
-	-		x	x		Adjustable screed	x	
Yes	Celotex		x	x		Evener arms	x	
When req. by Engineer	-		x		x	-	x	
No	-		x		x	-	x	
No	-		x	x		Hinged floating screed	x	

TABLE 11, PART III (continued)

1954 Practice

Compacting Rollers: Types Required or Permitted: T=Tandem W=3 Wheel, P=Pneumatic	Specified Total Weight Limit tons	Specified Compression Weight lbs./in. roller width	Agency
T or W	5-10	330	1 Ala.
T or P	10-14	N.S.	2 Ariz.
T or W	7-10	200	3 Ark.
T, W or P	T 8, W 10	325	4 Calif.
T and W	T 5-8; W 10	N.S.	5 Colo.
T and W	10	N.S.	6 Conn.
T and W	T 8-10; W 10-12	250	7 Del.
T	8-12	200	8 D.of C.
T	8-10	200+	9 Fla.
T or W	T 7-10; W 10	200	10 Ga.
T	8+	N.S.	11 Idaho
T and W	8-12	250-400	12 Ill.
T and W	10+	300+	13 Ind.
T and W	8+	250+	14 Iowa
T or W	8-12	N.S.	15 Kans.
T or W	T 7; W 10	350 (W)	16 Ky.
T or W	N.S.	N.S.	17 La.
T	T 8-10 3-axle T 16-21	250	18 Me.
T	8+	200	19 Md.
N.S.	-	240-285	20 Mass.
T	8+	-	21 Mich
T and W	10+	250+	22 Minn.
T or W	T 7-10; W 10	200+	23 Miss.
T or W	8-12	200+	24 Mo.
T and W	10+	200+	25 Mont.
T and W	8-12	T 200; W 300	26 Nebr.
T	8-12	-	27 Nev.
T	8+	260+	28 N.H.
T and W	-	200	29 N.J.
T, W and P	8-10	325	30 N.M.
T or W	T 8-12; W 10-12	250	31 N.Y
T	N.S.	250+	32 N.C.
T or W	5-10	200+	33 N.D
T and W	T 8-12; W 10-12	-	34 Ohio
T, W, and P	N.S.	N.S.	35 Okla.
T or W	T 6; W 10	200	36 Oreg.
T and W	8-10	T 250; W 330	37 Pa.
T and W	10-12	N.S.	38 R.I.
T	8-10	250+	39 S.C.
T or W	10+	250+	40 S.Dak.
T and W	T 6-10; W 10	N.S.	41 Tenn.
T and W	T 8; W 10	N.S.	42 Tex.
T, W and P	10-14	N.S.	43 Utah
T	8+	-	44 Vt.
T and W	T 7-10; W 10-12	250	45 Va.
T or P	10	N.S.	46 Wash.
T or W	T 8-10; W 10	-	47 W. Va.
T or W	8-12	250	48 Wisc.
T, W or P	3-axle T 12-19	250 (P)	49 Wyo.
T or W	8+	T 200-250 W 310-350	50 Ontario

TABLE 12

TESTS PERFORMED ON SAMPLES OF PLANT-PREPARED BITUMINOUS-CONCRETE MIXTURES

Agency	Tests Performed in Field Laboratory					Tests Per			
	Gradation	Extraction	1/ Density	Marshall	Others	Gradation	Extraction	1/ Density	Marshall
1 Ala.	L 2/	L, C 2/	C			L	L, C	C	
2 Ariz.	L					L	L		
3 Ark.	L	L					L	C	
4 Calif.	N 2/	N	C			L, C	L, C	L, C	
5 Colo.	L	L	C	N		L	L		
6 Conn.	L, C	L, C		L		L, C	L, C	C	L
7 Del.	L	L		C			L	C	
8 D.of C.	L					L	L	C	
9 Fla.	L	L	C		Compaction (L)		L	C	
10 Ga.	L	L	C		Hubbard-Field (L)	L	L	C	
11 Idaho	L	L			Moisture content (L)	L	L		
12 Ill.			C			L	L	C	L
13 Ind.		N	C			C	C		
14 Iowa	C		C			L, C	L, C	C	
15 Kans.	L, C	L, C	C			L			
16 Ky.	L	L	C				L		
17 La.	L, C	L	L, C	L		L, C	L	L, C	L
18 Me.	C	C	C			C	C	C	C
19 Md.	L					L	L	C	
20 Mass.	L						C	C	
21 Mich.	L	L				L	L		
22 Minn.	L, C					L, C	L, C	C	
23 Miss.	L, C	L, C	L, C	L				L, C	L
24 Mo.	L		C			L, C	L, C	C	
25 Mont.	L, C		C			L, C	C	L, C	
26 Nebr.		C	C			L	L	L	
27 Nev.							L, C		
28 N.H.	L	L				L	L	C	
29 N.J.	L, C	L, C	L, C			L, C	L, C	L, C	
30 N.M.	C	C	C	L		C	C	C	L
31 N.Y.	L	L				L	L		
32 N.C.	C	C	C			L	L	C	
33 N.Dak.	L		C		Thickness (C)		L	C	L
34 Ohio	L	L	C				L		
35 Okla	L	L	L, C						
36 Oreg.	C	C					L, C	C	
37 Pa.	L	L					L		
38 R.I.	L					L	L	C	
39 S.C.	L, C	L, C				L, C	L, C	L, C	L
40 S.Dak.	L			L		L	L		L
41 Tenn.	L	L	C			L	L		
42 Tex.	L	L	L						
43 Utah	L	L	C			L	L		C
44 Vt.	L, C	L, C		C		L, C	L, C		L, C
45 Va.	L	L	C			L	L		C
46 Wash.	L					L	L	C	
47 W. Va.	C	C				C	C		
48 Wisc.	L		C			C	C	C	
49 Wyo.	L	L	C		Thickness (C)				
50 Ontario	C	C				C	C		

1/ Many agencies calculate the theoretical void content following the determination of density of sa

2/ L - Sample of loose mixture.
C - Sample of compacted pavement.
N - Not known whether sample is of loose mixture or of compacted pavement.

TABLE 12 (continued)

1954 Practice

...rmed in Central Laboratory					Minimum Frequency of Sampling Compacted Pavement for Density Test	Method of Removal of Density-Test Specimens From Pavement	Agency
Hveem ...abilometer	Hubbard-Field	Abson Recovery	Thickness	Others			
					One per day	Hand tools	1 Ala
					Rarely	Not reported	2 Ariz.
					One per 2000 tons	Hand tools	3 Ark.
				Hveem (L) cohesiometer	One per mile	Hand tools	4 Calif.
					One each 4 hours	Core	5 Colo.
		L, C			One per day	Air hammer	6 Conn.
					-	Core	7 Del.
					Occasionally	Asphalt cutters	8 D.of C.
				Compaction (L)	One per day	Core	9 Fla.
	L		C		One per day	Core	10 Ga.
				Moisture content (L)	Seldom	-	11 Idaho
					One per day	Hand tools	12 Ill.
					-	-	13 Ind.
					One or two per day	Saw	14 Iowa
				Triaxial (L) compression	One per day	Hand tools	15 Kans.
					One per day	Hand tools	16 Ky.
			C		One per day	Hand tools	17 La.
					One per 100 tons	Core	18 Me.
	C				Each contract	Saw	19 Md.
		C			One per 1000 tons	Air hammer	20 Mass.
					None	-	21 Mich.
					-	Air hammer	22 Minn.
					Engr's. discretion	Hand tools	23 Miss.
	L	C			One per day	Saw	24 Mo.
					One per day	Hand tools	25 Mont.
	L				One per 200 tons	Hand tools	26 Nebr.
					One per day	Varied	27 Nev.
				Unconfined (N) compression	one per day	Saw, hand tools	28 N.H.
					One per 15,000 s.y. or less laid each day	Air hammer	29 N.J.
					Four per day	Split ring	30 N.M.
					None	-	31 N.Y.
			C	Unconfined (N) compression	One per day	Cutting tool	32 N.C.
					-	Hand tools	33 N.Dak.
					Engr's. discretion	Core	34 Ohio
					One per day	Saw	35 Okla.
					Start of job - occasional check	Core, hand tools	36 Oreg.
					-	Core, saw	37 Pa.
					-	Core	38 R.I.
			C		One per day	Saw, hand tools	39 S. C.
					None	-	40 S.Dak.
					Two per day	Cutting tool	41 Tenn.
					None	-	42 Tex.
					One per 5000 s.y.±	Rings	43 Utah
					-	Core	44 Vt.
	C	C			One per day	Core	45 Va.
, C				Swell (C) Hveem cohesiometer (L, C)	-	Core, hand tools	46 Wash.
					-	Not reported	47 W. Va.
					Average one every other day	Not reported	48 Wisc.
					Each shift	Hand tools	49 Wyo.
				Triaxial compression (C)	-	Saw	50 Ontario

... from the compacted pavement.

TABLE 13

BASE PRIMING IN CONNECTION WITH BITUMINOUS CONCRETE CONSTRUCTION

Agency	Bituminous Grades Used for Prime Coat		Bituminous Grades Normally Used for Prime Coat		
	Asphalt	Tar	On Flexible Base	On Rigid Base	Grade Reported
1 Ala.	RC-1,2, MC-1,2	RT-1,2	RC-1,2; MC-1,2	RC-0,1, MC-0,1	--
2 Ariz.	MC-2	Not permitted	MC-2	No rigid base	MC-2
3 Ark.	RC-1;MC-0,1,Emulsion	Not permitted	MC-0,1	RC-1,Emulsion	MC-1
4 Calif.	SC-2,Pen.Emulsion	Not permitted	SC-2	Pen. Emulsion	SC-2
5 Colo.	MC-0	Not reported	Not reported	Not reported	MC-0
6 Conn.	No prime coat required				
7 Del.	RC-1, 3	Not permitted	RC-1	RC-3	
8 D.of C.	RC-2	Not reported	Not reported	RC-2	RC-2
9 Fla.	RC-1	RT-3, 4	RT-3,4, RC-1	None	RC-1
10 Ga.	MC-1	Tar	Tar	Tar	MC-1
11 Idaho	RC-0,1, MC-0,1	Not permitted	Not reported	Not reported	RC-0, 1 MC-0, 1
12 Ill.	RC-0	RT-6	Not reported	RC-0	RC-0
13 Ind.	RC-1,2,3,4,Emulsion	Not permitted	RC-1,2,3,4 Emulsion	RC-3,4 Emulsion	
14 Iowa	RC-0	Not reported	Not reported	RC-0	RC-0
15 Kans.	RC-1; MC-2	Not permitted	MC-2	RC-1	MC-2
16 Ky.	RC-2, Emulsion	Tar	Tar	Emulsion	RC-2
17 La.	RC-1	Not permitted	RC-1	RC-1	RC-1
18 Me.	MC-0	Not reported	Not reported	Not reported	MC-0
19 Md.	MC-1	Tar	Asphalt	Asphalt	MC-1
20 Mass.	RS-1	Not reported	Not reported	RS-1	RS-1
21 Mich.	MC-0, AE-2	T-3,4	MC-0	AE-2	MC-0
22 Minn.	RS, RC, MC-0,1,2	RT-1,2,3,4	Med. Curing Cut-Back	Emulsion Rapid Curing Cut-Back	MC-0,1,2
23 Miss.	MC-1	RT-2,3,4	MC-1	Not reported	MC-1
24 Mo.	MC-0 RC-0	Not permitted	MC-0	RC-0	RC-0
25 Mont	MC-0,1	Not permitted	MC-1	MC-0	MC-1
26 Nebr.	RC-1, MC-1	Not permitted	MC-1	RC-1	MC-1
27 Nev.	MC-1	Not permitted	Not reported	Not reported	MC-1
28 N.H.	RS-1 MC-2	RT-3,4,5	Asphalt	RS-1	MC-2
29 N.J.	MC-0,1 RC-0 RS-1	RT-1,2	MC-0,1, RT-1,2	RC-0, RS-1	All
30 N.M.	MC-1	Not permitted	MC-1	None	MC-1
31 N.Y.	No prime coat required				
32 N.C.	MC-0 AE-7 RC-0	Not permitted	MC-0, RC-0,AE-7	MC-0, RC-0, AE-7	RC-0 MC-0
33 N.Dak.	MC-0,1,2	Not permitted	MC-1	No rigid base	MC-1
34 Ohio	RC-1,2, MS-2	RT-1,2	RT-1,2	MS-2, RC-1,2	
35 Okla.	RC-1,2, MC-1, AE-5	Not permitted	MC-1	RC-1,2,AE-5	RC-1 MC-1
36 Oreg.	RC-3; MC-2; RS-1	Not reported	MC-2, RC-3	RS-1	RS-1 RC-3 MC-2
37 Pa.	Asphalt, Emulsion	Tar	Tar	Asphalt	
38 R.I.	MC-2	T-2,3	RT-2,3	None	MC-2
39 S.C.	Asphalt	Tar	MC-0	Emulsion	
40 S.Dak.	RC-1, MC-1	Tar	MC-1	RC-1	MC-1
41 Tenn.	MC-1,2	Tar	Tar	MC-1,2	MC-1,2
42 Tex.	Emulsion RC-2, MC-2	Not permitted	MC-2	RC-2	MC-2
43 Utah	RC-1,2; MC-1,2	Not permitted	MC-1	RC-2	RC-1,2 MC-1,2
44 Vt.	MC-2, RS-1	RT-5	Not reported	Not reported	RT-5 MC-2 RS-1
45 Va.	RC-2	Not reported	Cut-back	Cut-back	RC-2
46 Wash.	MC-3, Emulsion	Not reported	Not reported	Not reported	MC-3
47 W. Va.	AE M-1	RT-3,203	RT-3	AE M-1	
48 Wisc.	RS-1, RC-0,1, MC-0,1	Tar	MC-0, 1	RC-0,1, RS-1	MC-0
49 Wyo.	MC-0	Not reported	MC-0	Not reported	MC-0
50 Ontario	DHO Primer	Not permitted	DHO Primer	DHO Primer	DHO Primer

TABLE 13 (continued)

Reported Specifications for Prime-Coat Materials
Required Physical Characteristics of Bituminous Material
--
AASHO M82-42
AASHO M82-42
AASHO M141-49
AASHO M82-42
No prime coat required
Not reported
AASHO M81-42
AASHO M81-42 except viscosity at 122°F. is 75-150 sec, and penetration at 77°F., 100 g., 5 sec. is 80-120.
AASHO M82-42
AASHO M81-42
AASHO M82-42
AASHO M81-42 except flash point is 80°F.+
Not reported
AASHO M81-42
AASHO M82-42 except distillation test to 500°F. is 25 to 55, residue from dist. to 680°F. is 70+, and penetration @ 77°F., 100 g., 5 sec. is 150 to 225.
AASHO M81-42
AASHO M81-42
AASHO M82-42 except penetration at 77°F. 100 g., 5 sec. is 80 to 120.
AASHO M82-42
AASHO M140-49
AASHO M82-42
AASHO M82-42
AASHO M82-42
AASHO M81-42
AASHO M82-42
AASHO M82-42 except no requirements are specified for the flash point.
Not reported
AASHO M82-42
AASHO Specifications
AASHO M82-42 except residue from dist. to 680°F. is 63 to 73; & penetration @ 77°F.. 100 g., 5 sec. is 120 to 220.
No prime coat required
AASHO M81-42
AASHO M82-42
AASHO M82-42 except viscosity @ 122°F is 75 to 100
Not reported
AASHO M81-42 except flash point is 80+
AASHO M82-42
AASHO M140-49
AASHO M81-42
AASHO M82-42
Not reported
AASHO M82-42
Not reported
AASHO M82-42
AASHO M82-42
Flash point 150°F. +, viscosity @ 140°F. 100 to 200; distillation test 437°F. 0 to 2, 600°F. 10 to 20; residue from dist. to 680°F. 63+, penetration @ 77°F., 100 g. 5 sec. 100 to 200, ductility @ 77°F. 100+.
AASHO M81-42
AASHO M82-42
AASHO M52-42
AASHO M82-42
AASHO M140-49
AASHO M81-42 except distillation test to 374°F. is 35+, to 437°F. is 65+, to 500°F. is 75+, & residue from dist. to 680°F. is 70+.
AASHO M81-42 except the penetration @ 77°F., 100 g., 5 sec. is 120 to 220
Not reported
AASHO M82-42 except distillate to 600°F. is 75 to 93
AASHO M82-42
Flash Point 80+, viscosity @ 122°F. 15 to 25, distillate to 374°F. 10+, 437°F. 16+, to 500°F. 20+, residue from dist. 680°F. 50+, penetration @ 77°F., 100 g., 5 sec., 100 to 200; ductility @ 77°F. 100, & bitumen soluble in C_2S 99.5.

TABLE 13 (continued)

Spot Test on Residue from Distillation: Standard Naphtha Solvent	Neg. with Naphtha Xylene Solvent (% Xylene)	Neg. with Heptane Xylene Solvent (% Xylene)	Application Rate (gallons: Flexible Base	Rigid Base
Yes	No	No	0.25-0.28	Not reported
--	--	35	0.5	No rigid base
Yes	--	--	0.3 -0.4	0.03-0 10
--	--	35	0.15-0 25	Not a practice
	Not required		0.25 ±	0.10 approx.
No prime coat required				
	Not required		0.2	0.1
Neg.	--	--	0.25-0.5	0.10
	Not required		0 2	0.06
Neg.	--	--	0.15-0.50	0.15-0 50
--	--	35	0.20-0.50	Not reported
Neg.	--	--	Not reported	0.05-0.10
Neg.				
	Not reported		0.2-0.3	0.05-0 10
Neg. or positive	Pos. -60% if pos. with Std. test		Not specified	0.12- 0.15
	Not reported		0.25	0.25
Neg.	--	--	0.25 -	0.15 -
	Not reported		Not reported	0.17
	Not required		0.33-0 50	0.07
	Not reported		Not reported	0.07
Neg.	--	--	0.25(T-3 or MC-0)	0.10-0.15 (Emulsion)
Not required	10-(MC-2)	Not required	0 1-0.3	0.03-0 10
Neg.	--	--	0.15-0.50	Not specified
Neg.	--	--	0.2 - 0.5	0.02- 0.1
	Not required		0.15-0.25	0.1 -
--	10	--	0.25-0.30	0 04-0 10
	Not reported		0 375	Not reported
	Not reported		0.5	0.15 ±
	Not required		0.1-0.25	0.10-(RC-0)
--	15	--	0.25-0.5	None
No prime coat required				
	Not reported		0 3	0.06-0.12
	Not required		0.35	No rigid base
	Not reported		0.25-0.35	0.10 -
Neg.	--	--	0.25	0 1
	Not required		0.25-0.50	0.1-0.2
	Not reported		0.15-0.25	0.05-0.07
	Not required		0.33	None
	Not required		0 1 approx	0.1 approx
--	15	--	0.4	0.08
Neg.	--	--	0.15-0 45	0.05-0 15
Yes	--	--	0.25	0 03
--	--	35	0.25-0.50	0.08-0 15
	Not reported		0.3-0 4	0.1
Neg.	--	--	0 1	0.05
--	--	35	0 25	0 02-0 05
	Not reported		0 30-0 60	0 15-0 25
Neg.	--	--	0 1-0.35	0.03-0 1
--	15	--	0 4	Not reported
	Not required		0.17-0.25	Not specified

TABLE 13 (continued)

1954 Practice

Application of Prime Coat per sq. yd.) Method of Control	Application Temperature (°F.)	Required Curing Period	Agency
Tachometer	120-140	3 days	1 Ala.
Tachometer	150-200	Until penetrated or blotted	2 Ariz.
Tachometer	50 -125	Not specified	3 Ark.
Tachometer	150-225	Not specified	4 Calif.
Synchronizer			
Tachometer	120 -	24 hours	5 Colo.
No prime coat required			6 Conn.
Tachometer	Not specified	Several hours	7 Del.
Tachometer	125-175	Not reported	8 D.of C.
Tachometer	100-150	Not specified	9 Fla.
Tachometer	100-160	Not specified	10 Ga.
Tachometer	150	Not specified	11 Idaho
meter-vol			
Tachometer	Not specified	Until no pick-up under traffic	12 Ill.
Not reported			13 Ind.
Tachometer	80- 90	24 hours	14 Iowa
Tachometer	125-200	Not specified	15 Kans.
Visual inspection measure & calculate	Not reported	Not reported	16 Ky.
Tachometer	Not specified	Not specified	17 La.
Tachometer	Air temperature	1 hour +	18 Me.
Tachometer	120 -	24 hours +	19 Md.
Not reported	60 - 120	Not reported	20 Mass.
Tachometer	50-120 (MC-0) 60-175 (Emulsion)	48 hours (MC-0 1000-1500 ft. ahead (Emulsion)	21 Mich.
Tachometer	80-125(MC-0) 60-125 RT-1,2) 100-175(MC-1) 80-150 RT-3,4) 150-200 (MC-2)	Until no pick-up under traffic	22 Minn.
Tachometer	175 -	Not specified	23 Miss.
Tachometer	80-120	Until properly cured	24 Mo.
Tachometer	100-175	24 hours +	25 Mont.
Tachometer	Not specified	Not specified	26 Nebr.
Tachometer	Not reported	Not reported	27 Nev.
Tachometer	Not specified	24 hours +	28 N. H.
Tachometer	50-120	Until properly cured	29 N. J.
Tachometer	125-200	24 hours	30 N M.
No prime coat required			31 N. Y.
Tachometer	90-130	Until properly cured	32 N. C.
Tachometer	75-200	2 - 3 days	33 N.Dak.
Tachometer	Not reported	Not reported	34 Ohio
Tachometer	75-120	Until properly cured	35 Okla.
Tachometer, pressure & volume gage	150-175	72 hours	36 Oreg.
Tachometer	175 -	Until tacky	37 Pa.
Tachometer	120	Not reported	38 R. I.
Tachometer	Not specified	Until tacky	39 S. C.
Tachometer	150 -	24 hours	40 S.Dak.
Tachometer	100-150	Until properly cured	41 Tenn.
Tachometer	140	12 hours	42 Tex.
Tachometer	150-200	Not specified	43 Utah
Tachometer	140-150 (tar) 150-160 (MC-2)	7 days except emulsion on conc.	44 Vt.
Tachometer	140-160	Until tacky	45 Va.
Tachometer	50 +	Not specified	46 Wash.
Tachometer	80-150	Not reported	47 W. Va
Tachometer	100-120	24-48 hours	48 Wisc.
Tachometer	100-200	24 hours	49 Wyo
Synchronizer			
Tachometer	70-100	Not specified	50 Ontario

TABLE 14

THICKNESS OF PAVEMENTS INVOLVING A BITUMINOUS CONCRETE SURFACE

Agency	Design Method Used to Determine Thickness of Flexible Pavements	Use of Subgrade Soil Characteristics to Determine Thickness of Flexible Pavement
1 Ala	Not reported	Not reported
2 Ariz	Consider PI and amount of minus No 200 sieve material in subgrade soil	Total thickness based on PI and amt of minus No 200 sieve material in subgrade soil Same characteristics of subbase material determine subbase and base thickness
3 Ark	Consider HRB soil classification of subgrade soil	HRB soil classification of subgrade soil determines subbase thickness
4 Calif	California Method - consider stabilometer "Resistance Value" of base and volume and magnitude of traffic	Shearing resistance and expansive characteristics of soil evaluated
5 Colo	Colorado Method - consider soil CBR and moisture condition, traffic, and climate	Consider CBR
6 Conn	Past experience - consider soil type frost penetration, ground water, and traffic	Subgrade soil type considered in determining subbase thickness
7 Del	Consider CBR and frost penetration	Consider CBR of subgrade soil in determining subbase thickness
8 D of C	Past experience	Not reported
9 Fla	Past experience - consider traffic	Subgrade soil characteristics not considered
10 Ga	Not reported	Not reported
11 Idaho	Hveem Method	Hveem Method
12 Ill	Consider HRB soil classification, traffic, drainage, and frost penetration	Consider HRB soil classification
13 Ind	Not reported	Not reported
14 Iowa	Not reported	Not reported
15 Kans	Kansas Triaxial Method	Consider modulus of deformation from triaxial compression test
16 Ky	Consider CBR	Consider CBR
17 La	Not reported	Not reported
18 Me	Consider volume and type of traffic	Subgrade soil characteristics not considered
19 Md	Consider HRB soil classification and CBR	Consider HRB soil classification and CBR in determining total thickness
20 Mass	Consider volume and type of traffic	Subgrade soil characteristics may influence choice of subbase thickness
21 Mich	Consider traffic in surfacing design Consider soil profile classification and estimated stability in foundation design	Consider estimated spring CBR
22 Minn	Consider CBR (modified test), and rely on past experience	Thicknesses modified on basis of HRB soil classification
23 Miss.	Consider CBR (modified test), of pavements designed to carry wheel loads of over 9000 lbs	Consider CBR
24 Mo	Consider HRB soil classification and traffic volume	Consider HRB group index
25 Mont	Consider HRB soil classification	Consider HRB soil classification
26 Nebr	Consider traffic, rainfall, drainage and HRB group index of subgrade soil	Consider HRB group index
27 Nev	Consider HRB soil classification	Consider HRB soil classification
28 N H	Past experience	Subgrade soil type influences choice of subbase thickness
29 N J	Past experience	Thickness increased for A-6 to A-8 subgrades
30 N M	Consider traffic and rainfall, and gradation and Atterberg limits of base and subbase material	Consider soil type
31 N Y	Rational determination	Knowledge of previous behavior
32 N C	Consider traffic and bearing value of subgrade	Consider bearing value of subgrade in determining total thickness
33 N Dak	North D kota Method - consider North Dakota cone test values and subgrade soil type	Subgrade soil type and North Dakota cone value of subgrade soil considered in determining subbase thickness
34 Ohio	Not reported	Not reported
35 Okla	Consider CBR	Consider CBR of subgrade soil in determining subbase thickness
36 Oreg	Triaxial - modified Hveem Method	Consider "R" value (from vertical and horizontal pressure ratio) and silt content
37 Pa	Not reported	Not reported
38 R I	Past experience	Non-drainable material usually removed
39 S C	Past experience	Not reported
40 S Dak	Past experience	Evaluate bearing ability
41 Tenn	Past experience	Evaluate bearing ability
42 Texas	Triaxial tests of pavement and subgrade material	Consider shear strength as determined by triaxial method
43 Utah	Experience and "R" value from Hveem stability test	Consider subgrade characteristics in determining base and subbase thickness
44 Vt	Bituminous concrete used mostly to resurface existing PCC pavements	Not reported
45 Va	Consider CBR (modified)	Total thickness related to strength of subgrade as indicated by modified CBR
46 Wash	Consider test values from Hveem Stabilometer and swell-pressure tests	Total thickness related to Hveem Stabilometer and swell-pressure test values
47 W Va	Ky design curves (CBR) and Ohio design curves (HRB class)	Total thickness determined from design curves
48 Wisc	Consider traffic volume and soil type	Consider load-carrying capacity as affected by drainability
49 Wyo	Consider CBR (modified) and test values from Hveem Stabilometer	Consider CBR (modified) and test values from Hveem Stabilometer - add extra cover on frost-reactive materials
50 Ontario	Past experience - consider results of mechanical analysis and plate-bearing tests	Consider results of mechanical analysis and plate-bearing tests

1/ The given conditions do not occur, or occur infrequently, in some areas of the country However, some of the agencies in these areas have listed the thicknessess that their design methods would indicate to be satisfactory

2/ Thickened edges

TABLE 14 (continued)

Average Thicknesses (in inches) Likely to be Us										
No Differentiation as to Traffic										
Rigid Base					Flexible Base					
Subbase	Base	Binder	Surface	Total	Subbase	Base	Binder	Surface	Total	Subbase
										10 6½
8+	8	1 1/8	1 1/8	18¼+	12	8	1½	1	22½	-
										6
12	-	-	-	-	4-6 12	2-10 4½	2 1¼	1½ 1¼	- 19	3
-	-	1½	1½	-	6 11	8 2	2½ 1½	1½ 1½	18 16	12 6
 -	7 -	- 2	3 2	10 -	- 0-13	- 3	2 2	2 2	- 5-18	12
4	-	-	-	-	5 6	2 8	- -	2½ -	9½ -	
6-12	6-8	1½	1½	15-23	6-18 4-12 -	5-6 4-8 6	1½ 1-1½ 4	1½ 1½-2 1½	14-27 10½-23½ 11½	6
					8	6	2½	1½	18	12½

TABLE 14 (continued)

...ed Under These Conditions: 1/ Subgrade Soil A-6, Average Annual Rainfall 32 Inches, Average Ann...

Heavy-Traffic Pavement									
Rigid Base				Flexible Base					
Base	Binder	Surface	Total	Subbase	Base	Binder	Surface	Total	Subbase
-	-	-	-	10	10	-	-	-	6
				12-18	3	-	2½	17½-23½	
				12	12	3	1½	28½	
8	1½	1'	17½	13	8	1½	1½	24	4
8	1½	1½	11	20	4	1½	1½	27	-
				20(cut)	6	1¼	1¼	28$_2$(cut)	
				12 (fill)				20½(fill)	
				9	8	2	1¼	20¼	
				0-18	5-18	-	3	-	
				7	10	1½	1½	20	
6	1½	1½	15	8	6	1½	1$_2$	17	0
7	1½	1½	13	-	12	1½	1½	15	
				24-36	6	1	1	32-38	
				-	4½	-	-	-	
8	1 7	1 3	23	24	10	1 7	1 3	37	12
-	1½	1½	-	15	9+	2	2	28	-
				-	8	1 3/4	1¼	11	
				4	3	-	3	10	
				0-12	24	2	1	27-39	
				3-13	3	0	2	8-18	
8-9	1½	1	22½	12	7	1½	1	21½	
				0-6	5-14	1½	1½	17	4
				5+	2	-	2½	9½+	
					12-21	2	1½	15½-24½	
									-
10	0	1	17	9	8	0	1	18	6
				8-12	3-6	2	1	14-21	
				6-10	6-10	1½	1-1½	14½-23	
4	2	1	19½	17	4	2	1	24	10
				6-9	10-14	1½	1½	19-26	
				10½	2/6½-5-6½	1¼	1¼	2/19½-18-19½	
				18-20	4	3½	1½	29	

TABLE 14 (continued)

1954 Practice

al Frost Penetration 28 Inches									Agency
Medium-Traffic Pavement									
Rigid Base				Flexible Base					
Base	Binder	Surface	Total	Subbase	Base	Binder	Surface	Total	
-	-	-	-	6	8	-	-	-	1 Ala
				6-15	3	-	2½	11½-20½	2 Ariz
				8-12	8-10	2	1½	19½-25½	3 Ark
6	1½	1½	13	10	6	1½	1½	19	4 Calif
6	1½	1½	9	15	4	1½	1½	22	5 Colo
				15(cut) 12(fill)	6	1¼	1¼	23½(cut) 18½(fill)	6 Conn
				7	6	2	1¼	16¼	7 Del
									8 D of C
									9 Fla
									10 Ga
				0-18	5-18	-	2½	7½-38½	11 Idaho
				7	9	1½	1½	19	12 Ill
									13 Ind
									14 Iowa
6	1½	1½	8½	0	7	1¼	1¼	9½	15 Kans
				-	8	1½	1½	11	16 Ky
									17 La
				18-24	-	2	1	21-27	18 Me
									19 Md
				12	3	1¼	1¼	-	20 Mass
8	-	2	22	18	8	-	2	28	21 Mich
-	1½	1½	-	12	6+	1½	1½	21	22 Minn
									23 Miss
				-	6	1 3/4	1¼	9	24 Mo
									25 Mont
				3	2	-	2	7	26 Nebr
									27 Nev
				0-12	18	2	1	21-33	28 N H
									29 N J
				0-13	3	0	2	5-18	30 N M
				12	4	1½	1	18½	31 N Y
-	-	-	12	0-10	7-10	0-2	1	11	32 N C
				5	2	-	2½	9½	33 N Dak
									34 Ohio
									35 Okla
				-	7-12	2	1½	10½-15½	36 Oreg
									37 Pa
6-8	1½	1½	9-11	6-12	5½-6	1½	1½	8½-9	38 R I
									39 S C
									40 S Dak
									41 Tenn
9	0	1	16	8	7	0	1	16	42 Texas
									43 Utah
									44 Vt
				4-6	4-6	1	1	10-14	45 Va
4	1½	1	16½	14½	4	1½	1	21	46 Wash
									47 W Va
				6-9	6-10	1½	1	14½-21½	48 Wisc
				9	4-5½	1	1	15 -16½	49 Wyo
				12-14	4-6	2-4	1½	19½-25½	50 Ontario

Foamed Asphalt in Bituminous Paving Mixtures

LADIS H. CSANYI, Professor in Charge, Bituminous Research Laboratory
Engineering Experiment Station, Iowa State College

●THE physical properties and characteristics of the various bituminous binders used in bituminous paving mixtures greatly influence the manner in which such mixtures are made and the methods used in laying the mixes. Among the physical properties and characteristics, viscosity and surface tension of the binder are of particular importance. The viscosity of the binder is significant both in the manufacture and laying of the mixture. In making the mixture the binder must be liquid enough to flow readily through the entire aggregate mass and develop films of binder around the aggregate particles. In laying the mixture the binder must remain sufficiently plastic for easy and smooth spreading, and as soon as the mixture is spread it must harden rapidly so that the pavement may be compacted and opened to traffic as quickly as possible. The surface tension of the binder is especially significant in mixing. Adhesion between the film of binder and an aggregate particle depends largely upon the surface tensions of the two materials and the interfacial tension developed. The surface tension of the binder must therefore be such, in relation to that of the aggregate, that surface moisture on the aggregate can be displaced and a strong physical bond generated between the binder and aggregate. The importance of these two properties has been recognized; and processing, mixing and laying practices have been adjusted accordingly.

In the preparation of high type plant mix hot bituminous paving mixtures, with asphalt cement used as the binder, the viscosity of the binder is adjusted and controlled by the temperature of the binder and the aggregates. A relatively high temperature must be maintained in this type of mix during transportation and laying to assure a desired plasticity for spreading. Once spread, the binder hardens rapidly, permitting compaction and the opening of the pavement to traffic without undue delay. The heating of the binder to adjust its viscosity and heating of the aggregates to dry them and maintain the temperature of the mix are costly. Such mixes are therefore used generally for high type heavily travelled pavements.

On roads which do not need or cannot afford such high type mixes, other binders, such as cut-back asphalts or emulsified asphalts, can be used as the binder. Since the viscosity of a cut-back asphalt is adjusted by the type and quantity of solvent added to the base asphalt cement, the need for further adjustment of viscosity of the binder by heat during mixing is materially reduced. When this binder is used in conjunction with wetting agents, the heating of the aggregates can also be materially reduced. The viscosity of an emulsified asphalt is adjusted by the method used in preparing the emulsion, by the type of emulsifier used, and by the quantity of water added. A wide variety of grades of emulsified asphalts are available to meet various applications. When an emulsified asphalt is used in a bituminous mix as the binder, the need for heating the binder is practically eliminated. Furthermore, by virtue of the emulsifying agent used in this type of binder, good adhesion, even with cold and damp aggregates, can be attained. When emulsified asphalts are used in a mixture, heating of either or both the binder and aggregate can be materially reduced. Satisfactory mixes have been produced with the use of either cut-back asphalts or emulsified asphalts.

Although production of a bituminous mix is simplified when these materials are used as the binder, laying procedures become more complicated. Since the binder should set rapidly after the spreading of the mix to permit proper compaction, the solvent in a cut-back asphalt should be removed rapidly, the emulsified asphalt should break at the proper time, and the water released from the emulsion should be eliminated quickly. For these reasons mixes using these materials as the binder must be aerated to permit the evaporation of either the solvent or the water. This not only requires additional construction equipment and operations, but it also delays the opening of the road to traffic. So, although the use of these materials as binders improves one phase of the procedure, it falls short in another.

An ideal binder for use in low cost paving mixtures then would be one whose physical properties, such as viscosity and surface tension, were such that cold and even damp aggregates could be used in mixing, retaining a desired plasticity of the mix until spread and, after spreading, the mix would set quickly.

Since this discussion deals with asphalt cements, the question arises as to how the physical properties of a bituminous binder may be adjusted in other ways without altering its chemical composition so that it may approach more nearly the properties and characteristics desired in an ideal binder.

One way in which this could be accomplished is by foaming the binder. Anyone who has had the misfortune to encounter a large mass of foamed asphalt has had an unwelcome opportunity to become acquainted with some of its unusual properties at first hand. A relatively hard asphalt cement, when foamed, expands greatly in volume. The foam creeps and flows even at low temperatures, penetrating dirt, clothing, shoe leather, or anything it comes in contact with, and oozes into cracks and crevices. The foam remains soft even at temperatures at which the parent asphalt cement has stiffened materially. The foam has a rubbery nature and is extremely sticky, adhering tenaciously to all types of materials it touches, and once it has stuck it is very difficult to remove or clean up. Uncontrolled foaming of asphalt around a plant is a considerable nuisance and should be guarded against and avoided. Chemicals are now available to prevent foaming or check it, should it get started, and thus avoid the mess it creates.

Although uncontrolled foaming of asphalt is highly undesirable, when the usual properties of the foam are considered, a foam under proper control could be advantageously used in preparing bituminous mixes.

A study of foamed asphalt discloses many interesting features, which when applied to bituminous mixes, could be used to advantage. Asphalt cement and other bituminous binders expand to many times their original volume when foamed. Therefore, if a quantity of asphaltic binder is applied as a foam, a wider and more uniform distribution of the binder can be obtained in mixing with aggregates than if the same quantity of binder is used as a liquid. An asphalt cement having a penetration of 85 to 100, when foamed, will have a penetration of over 300 at the same temperature for some time after it has been foamed. Chemical constituent tests indicate that the asphalt has not changed even though its consistency and viscosity have changed. This change in physical properties is due no doubt to the bubbles of gas or vapor the mass of material contains. Therefore, if foamed asphalt is added in mixing, the distribution of the binder throughout the aggregate can be accomplished at a much lower temperature than if the binder is added as a liquid. Further, since the binder remains soft for some time as a foam, mixes using foamed asphalt as the binder can be laid at lower temperatures. The foamed asphalt cement has a rubbery nature and is extremely sticky, with both high cohesive and high adhesive properties. When a foamed asphalt is used as a binder in a bituminous mix, it would be expected that there is improved adhesion between binder and aggregate, and a more cohesive mix would result. Preliminary tests indicate that this is true. The high adhesive property noted is no doubt due to the high wetting power generally exhibited by foams. The modified surface tension of the asphalt as a foam probably plays an important part in this behavior. Another great advantage is that the asphalt cement is in the form of bubbles. Here we have ready-made thin films of asphalt cement with powerful natural surface tension forces available to coat particles of matter on contact as the bubble breaks. The fact that foamed asphalt will penetrate small voids and crevices can be utilized to advantage because foamed binder will penetrate agglomerations of dusts which liquid asphalts will only coat with a layer of binder. Foamed asphalt thus lends itself more readily to soil stabilization than some other binders.

The various desirable properties of foamed asphalt can be utilized practically and their advantages gained in preparing bituminous mixes only if the foamed binder is under close control. The asphaltic binder must be foamed at the proper time, at the desired place, in the required quantities, and in a prescribed manner. The condition of the foam, the size of the bubbles, and other factors must also be controlled to obtain consistant results.

Foamed asphalt can be created easily by several methods. One involves the addition of small quantities of water to the asphalt and then heating the asphalt. The same result is secured by gradually injecting small quantities of saturated steam into the heated asphaltic binder. The problem that had to be solved in this development was the generation of a foamed asphalt in the quantity and kind desired, at the place, time, and in the manner in which its properties could be most effectively utilized.

This problem was solved by the development of a nozzle for foaming a bituminous material instantaneously into a foam of a desired character and for introducing a desired quantity into a mixer at the proper time and in the proper manner. The nozzle devised consists of a body, nozzle tip, steam tube, and its adjustments and other appurtenances (Figure 1). The asphaltic binder enters the nozzle through the body and passes on to the nozzle tip. The saturated steam enters the nozzle by way of the steam tube which carries it to the tip of the nozzle. The steam leaving the tube combines with the bituminous binder just above and in the throat of the nozzle tip orifice, creating the foamed asphalt. The foamed asphalt is then emitted from the nozzle by the flow of the steam and binder through the nozzle. The type of foam produced can be controlled by the dimensional characteristics of the throat of the nozzle orifice and the position of the end of the steam tube in relation to the entrance to the throat; an adjustment is provided to set this position, and to control the quantity and pressure of both the steam and binder introduced into the nozzle.

Two basic types of foam can be produced by this nozzle. One type of foam created is referred to in this paper as a "discrete foam." This foam is in the form of sepa-

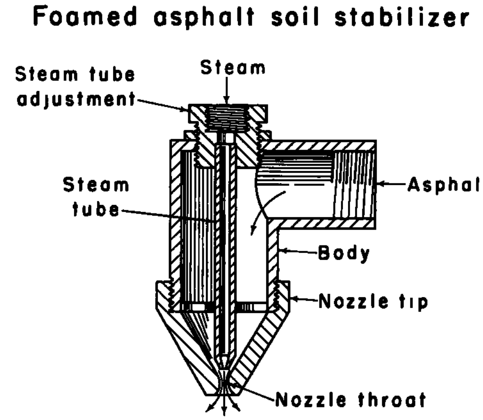


Figure 1. Foamed asphalt nozzle.

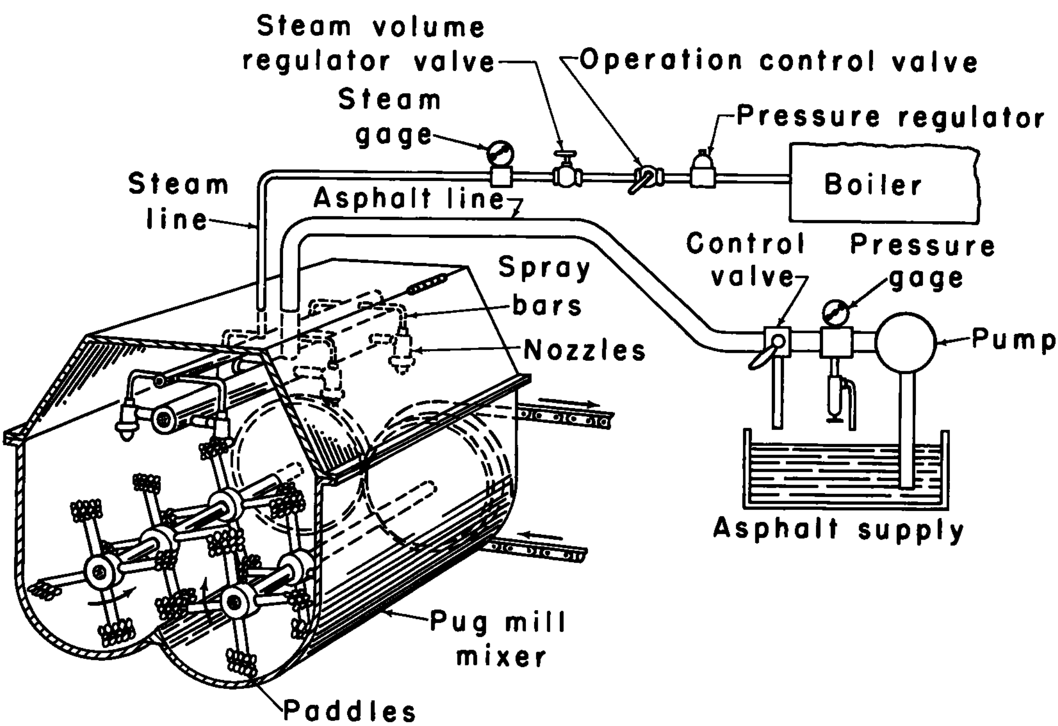


Figure 2. Foamed asphalt system.

rate individual small bubbles as it leaves the nozzle. The size of the bubbles can be controlled by a steam tube adjustment and by the adjustment of the steam and binder pressures when the discrete foam nozzle tip is used. A nozzle equipped with a discrete foam tip, under proper adjustment, will create a discrete foam with a small quantity of steam at 60 to 90 psi and binder pumped at 50 to 80 psi. The binder pressure must always be below that of the steam pressure to prevent binder backing into the steam tube. Bubbles of various sizes can be produced within these ranges of pressures by other nozzle adjustments.

The other type of foamed binder which can be created by this nozzle is referred to as a "concentrated foam" in this paper. In this case the bubbles of the foamed binder are joined together and a mass of foam is emitted from the nozzle. This type of foam can be produced by a concentrated foam nozzle tip and nozzle adjustment with saturated steam pressures as low as 35 psig and binder pump pressures as low as 20 psig. A wide range of foam characteristics can also be attained in this case by adjustment of steam and binder pressures and quantities admitted to the nozzle, and adjustment of the setting of the steam tube. It should be noted that in the operation of the foaming nozzle the steam primarily is used to create the foamed binder, and secondarily, by varying the pressure and quantity of the steam, it is used to control the character of the foam in some measure. The steam also serves to heat the nozzle and blow the nozzle orifice clear of foamed or congealed binder; the nozzle is thus in good working order even under intermittent operations.

After a means of generating a foam of a desired character was devised, a method of applying the foam in a mixer in the required quantity, at the proper time and in a suitable manner was necessary. A spray bar system as shown in Figure 2 was devised. The spray bar is fitted with the number of nozzles needed to distribute the foam in the mixes uniformly. The asphaltic binder may be measured either in a weigh tank or by a meter and then pumped through the asphalt line and the spray bar to the nozzle. The asphalt system is fitted with such appurtenances as a control shut off value pressure gauge, return circulating line, and pressure relief valve. Since the asphaltic binder need never be pumped in excess of 80 psi, standard low pressure piping may be used in this system. The steam needed for the foaming of the binder can be generated in a steam boiler having a pressure range of 45 to 100 pounds. In the steam line from boiler to nozzle, or from a local source of steam to the nozzle, must be a pressure regulating valve, a shut-off valve, a volume control valve and a steam pressure gauge. The pressure regulating valve is used to adjust the pressure of the steam being supplied to the nozzle. A volume control valve, which may be a simple needle valve, controls the quantity of steam furnished to the nozzle. Adjustments can readily be made to produce the foam characteristics desired with these control devices in the system.

The operation of the foamed asphalt system is simple once the proper nozzle adjustments and control settings have been made. The steam is turned on first to clear the nozzle tips, to remove moisture condensed in the steam line and to prevent the binder backing up in the steam tube of the nozzle. The binder is then pumped to the nozzle where the steam foams the binder and foamed binder is emitted from the nozzle into the mixer. When the proper quantity of binder has been introduced into the system, it is shut off. After the binder is shut off the steam flow is continued to clear the nozzle of binder. Then the steam is shut off until the next sequence.

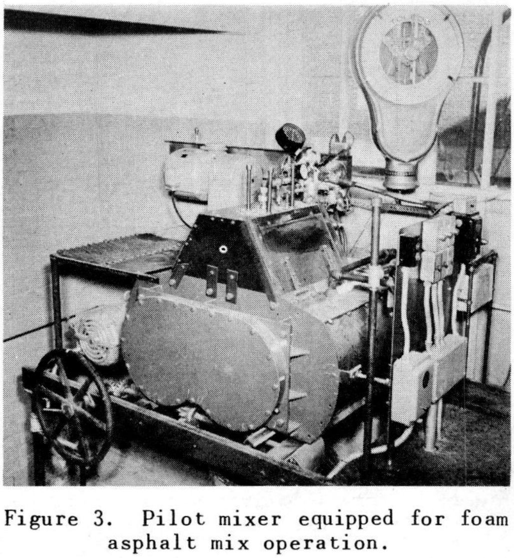


Figure 3. Pilot mixer equipped for foam asphalt mix operation.

The steam and binder controls may be interlocked so that steam is turned on first and shut off last. The steam in the nozzle serves another useful purpose in that it keeps the nozzle warm, thus minimizing the clogging of the nozzle between operations.

The foamed asphalt system can be adapted to any standard twin shaft pug mill type mixer and to other usual applications with a minimum of modifications that will be discussed as various applications are reviewed.

After a means of producing foamed asphalt under controlled conditions suitable and applicable to a wide variety of purposes was developed, the next step was to determine how the foamed asphalt performed in the mixing of bituminous mixes and to ascertain how foamed asphalt affected the properties of such mixes. A small 50-lb laboratory pug mill mixer for laboratory tests and a larger pilot plant 300-lb mixer for small scale mixing and field laying tests were adapted to foam asphalt mixing operations. Both of these mixers were fitted and equipped so that standard, atomized asphalt and bituminous slurry type mixes could be produced for comparative purposes.

The adaptation of these mixers necessitated the purchase of a small steam boiler to produce and supply the saturated steam required to both mixers. This boiler is the steam jenny type, fitted with a 60 gallon boiler, automatic electric fuel oil burner and all necessary safety devices. Steam pressures of this boiler can be regulated and automatically controlled between 5 and 100 psi (Figure 4). The pilot plant mixer, (Figure 3) was equipped with a variable speed motor drive for the asphalt pump to control the quantity of binder delivered to the nozzles. A two nozzle spray bar is used to introduce the binder into the mixer. All asphalt lines are electrically heated. On this unit the binder is measured in a weigh bucket from which it is pumped to the spray bar. The steam line from the boiler to the nozzles is equipped with an adjustable steam pressure regulator, an electric solenoid shut-off valve, a steam volume control needle valve and a steam pressure gauge. The mixer is also equipped with a water spray bar at the rear of the mixer to furnish water for wet slurry and soil stabilization mixes. The mixer also has interchangeable fluffing and kneading paddle tips. The small laboratory mixer is similarly equipped with the addition of a variable speed motor drive on the mixer shafts. The mixing speed of the shafts of the pilot plant can also be varied by changing the size of the drive shaft pinion. Standard, foamed asphalt, atomized asphalt, bituminous slurry and soil stabilization mixes can be produced with two mixers so equipped in the quantities needed both for laboratory and for field tests.

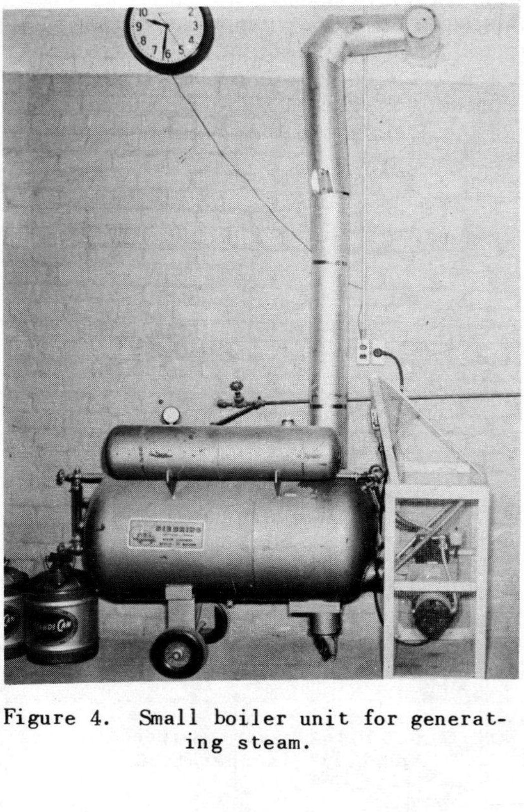


Figure 4. Small boiler unit for generating steam.

The next step in the development involved the production of various types of mixes to test the efficacy of the use of foamed asphalt in mixing procedure and the affect of foamed asphalt on the physical properties of such mixes. Included in the various mixes prepared and tested were: ungraded aggregate mixes, plant mix soil stabilization mixes, in place soil stabilization mixes, and also high type standard specification mixes.

UNGRADED AGGREGATE MIXES

The Bituminous Research Laboratory of the Engineering Experiment Station, Iowa State College, under the sponsorship of the Iowa Highway Research Board, recently completed the development of a mastic theory of design and a method of producing bituminous paving mixtures utilizing local ungraded aggreates 1, 2. Since the present work is under the same sponsorship, the application of foamed asphalt in the production of mixes of this type was investigated first. Bituminous paving mixes using ungraded aggregates, similar to those used in the previous work, were therefore produced using foamed asphalt as the binder. These mixes were studied to determine whether or not the mastic theory of design was applicable to them. The physical properties of these mixes were determined and compared with those made by the earlier method.

The mixes were produced with the use of a discrete foam nozzle which emits the foamed asphalt in the form of separate, individual, small bubbles of binder. The mixer was equipped with an open grid type fluffing paddle tip. (Later it was found that the usual paddle tips can perform this function.) The purpose of this type paddle tip is to fluff and loosen or disperse the aggregate in the mixer during the mixing so that the bubbles of foamed binder may penetrate and contact all the particles of the aggregate. As each bubble of the binder enters the loosened and fluffed mass of aggregate and comes in contact with the aggregate particle the bubble bursts, forming a thin film of binder over the surface of the particle. When the bubble bursts the surface tension spreads the thin film of binder forcefully and rapidly over the surface of the aggregate. The modified surface tension of the binder when in the form of a bubble also provides natural forces which induce a high adhesion between binder and aggregate particle. It should be noted in comparing this method with the earlier method developed, that bubbles of binder are used in place of atomized droplets of binder, that bubble and aggregate are brought into contact only, rather than having a high speed impact between droplet and aggregate, and that the aggregate is fluffed in the body of the mixer rather than casting of aggregate into binder spray.

The materials used in these tests included blow sand, fine sand, pulverized loess, limestone dust as aggregates, and a 150 to 200 penetration asphalt cement as the binder. The gradation of the mineral aggregates was as follows:

TABLE 1

Total % Passing	Fine Sand	Blow Sand	Pulverized Loess 38% Clay	Limestone Dust
No 4 sieve	99	100	-	-
No 10 sieve	94	99	-	-
No 40 sieve	20	98	-	-
No. 60 sieve	-	-	-	98
No. 80 sieve	3	33	-	93
No. 100 sieve	-	-	-	90
No 200 sieve	1	4	100	65

These materials are essentially the same as those used in the previous work (1, 2).

Mixes containing various combinations of these aggregates with various binder contents were prepared for test. The mixes were prepared by placing the proper proportion of hot dry sand at about 400 F and dry dust at room temperature into the laboratory mixer and mixing for a few seconds to fluff materials in the mixer and to permit the dust to absorb some heat from the sand. The foamed asphalt cement was then introduced in the form of a discrete foam by the foam nozzle operating at a binder pressure of 50 psi and a saturated steam pressure of 60 to 70 psi. The mixing of a 25 pound batch required about 7 to 11 seconds. The temperature of the mixture discharged from the mixer was between 300 and 350 F. All mixes prepared were homogeneous, with all particles fully coated by thin films of binder and with a well formed mastic as desired.

Immediately after mixing, Hubbard-field stability test specimens, 2-in. in diameter and about 1 in. in height were prepared. These specimens were tested three days after forming for Hubbard-field stability at 140 F after 1 hour immersion in a hot water bath at 140 F. Void content determinations and freezing and thawing tests were also made on these specimens.

The results of these tests on the various mixes prepared are shown in Tables 2-6.

Mix proprtions are given as percent of total aggregate for aggregates and percent of binder added to total aggregates for the binder.

The results of these tests prove conclusively that bituminous mixes containing ungraded aggregates can be efficiently and successfully produced when foamed asphalt in the form of a discrete foam is used as the binder. The results of the tests also show that the mixes made in this manner also have very much higher stability and a much

TABLE 2

BLOW SAND 70%, PULVERIZED LOESS 30%

	Foamed Binder	Atomized Binder
8% Asphalt Cement		
Hubbard field stability	1650	1250
Voids, %	13 5	14
Resistance to freezing-thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard field stability	1600	1450
Voids, %	12.4	10 7
Resistance to freezing-thawing	Satisfactory	Satisfactory
10% Asphalt Cement		
Hubbard field stability	1650	1350
Voids, %	9.6	10.3
Resistance to freezing-thawing	Satisfactory	Satisfactory
11% Asphalt Cement		
Hubbard field stability	2050	1300
Voids, %	6 0	7 1
Resistance to freezing-thawing	Satisfactory	Satisfactory

TABLE 3

BLOW SAND 75%, PULVERIZED LOESS 25%

	Foamed Binder	Atomized Binder
7% Asphalt Cement		
Hubbard field stability	1450	1050
Voids, %	16 3	15 6
Resistance to freezing-thawing	Satisfactory	Poor
8% Asphalt Cement		
Hubbard Field Stability	1900	1300
Voids, %	14 2	13 6
Resistance to freezing-thawing	Satisfactory	Poor
9% Asphalt Cement		
Hubbard Field Stability	1600	1250
Voids, %	14 1	10.9
Resistance to freezing-thawing	Satisfactory	Satisfactory
10% Asphalt Cement		
Hubbard field stability	1500	1350
Voids, %	9 0	8.4
Resistance to freezing-thawing	Satisfactory	Satisfactory

TABLE 4

FINE SAND 80%, PULVERIZED LOESS 20%

	Foamed Binder	Atomized Binder
5% Asphalt Cement		
Hubbard field stability	1400	1300
Voids, %	11 7	11 6
Resistance to freezing-thawing	Fair	Poor
6% Asphalt Cement		
Hubbard field stability	2000	1650
Voids, %	9 7	9.0
Resistance to freezing-thawing	Fair	Poor
7% Asphalt Cement		
Hubbard field stability	1650	1500
Voids, %	5.9	6.6
Resistance to freezing-thawing	Satisfactory	Satisfactory
8% Asphalt Cement		
Hubbard field stability	1700	1350
Voids, %	3 7	4 7
Resistance to freezing-thawing	Satisfactory	Satisfactory

TABLE 5

FINE SAND 75%, PULVERIZED LOESS 25%

	Foamed Binder	Atomized Binder
6% Asphalt Cement		
Hubbard field stability	2400	1700
Voids, %	9 2	8.9
Resistance to freezing-thawing	Satisfactory	Poor
7% Asphalt Cement		
Hubbard field stability	2200	1200
Voids, %	7 1	8 3
Resistance to freezing-thawing	Satisfactory	Satisfactory
8% Asphalt Cement		
Hubbard field stability	1800	1000
Voids, %	4.6	4.5
Resistance to freezing-thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard field stability	2100	1400
Voids, %	1 7	2.7
Resistance to freezing-thawing	Satisfactory	Satisfactory

TABLE 6

BLOW SAND 70%, LIMESTONE DUST 30%

	Foamed Asphalt	Atomized Asphalt
6% Asphalt Cement		
Hubbard field stability	1950	-
Voids, %	14.5	-
Resistance to freezing-thawing	Satisfactory	-
7% Asphalt Cement		
Hubbard field stability	2600	1800
Voids, %	10 0	12.0
Resistance to freezing-thawing	Satisfactory	Satisfactory
8% Asphalt Cement		
Hubbard field stability	2350	1800
Voids, %	10.5	11 2
Resistance to freezing-thawing	Satisfactory	Satisfactory
9% Asphalt Cement		
Hubbard field stability	3500	2350
Voids, %	8 2	5.7
Resistance to freezing-thawing	Satisfactory	Satisfactory

greater general resistance to the effects of freezing and thawing than the same mixes prepared with the binder in an atomized form. There are other advantages of the use of foamed asphalt as the binder when compared with the use of the binder in an atomized form. The foamed asphalt process requires low pressures of 25 to 50 psi for pumping the binder, instead of the very high pressures of 300 psi and more required by the atomizing process. The need for high pressure piping is eliminated, smaller units of equipment can be used, power consumption for operation is greatly reduced, leaks in the system are minimized and operational safety is greatly enhanced.

Having demonstrated that bituminous mixes containing ungraded aggregates could be successfully produced with a binder in the form of a discrete foam, a study was made to determine if the same mixes could be prepared with the binder in the form of a concentrated foam. This study disclosed that these mixes can be prepared with the binder in such form but that mixing procedure must be altered.

The mixes utilizing the binder in a concentrated form of foam can be made in a standard pug mill mixer having the usual kneading paddle tips and operating at manufacturer's design speed. The binder is introduced as a concentrated foam by a properly adjusted foam nozzle operating at 25 psi binder pressure and 50 psi saturated steam pressure. The mixing is done in a conventional manner. After placing aggregates into the mixer they are given a 5 to 10 second dry mix followed by the addition of the binder and a wet mixing for about 20 to 25 seconds. A total mixing time of about 30 seconds is required. It should be noted that no special paddle tips nor increase of mixer speed is required when a concentrated foam is used.

Bituminous mixes containing ungraded aggregates were prepared with the binder in the form of a concentrated foam. The mixes were uniform in nature with all aggregate particles coated with thin films of binder and the mix contained the desired mastic. Specimens were prepared and tested as before. The results of those tests were very much the same as those obtained from mixes in which the discrete foam was used.

In the process of this study it was also found that the fine aggregates need only be heated to 290 F and the pulverized loess or mineral filler can be used at air temperature when concentrated foam is used. When the discrete foam or atomized binder methods were used it was necessary to heat the fine aggregate to over 350 F to warm up the cold filler sufficiently for proper coating with binder.

This is a method of producing bituminous mixes containing ungraded aggregates in standard batch plants with little or no modification of operations and procedures other than introducing the binder in the form of a concentrated foam. All indications noted during the study are that this method is also readily adaptable to continuous mixer operation.

PLANT MIX SOIL STABILIZATION

Observations made during the mixing indicated that this method of introducing the binder in the form of a concentrated foam might be applied advantageously to soil stabilization. The use of the binder in the form of a concentrated foam in the preparation of plant mix soil stabilization mixes was investigated.

In the preceding work on the preparation of bituminous mixes containing ungraded aggregates the filler used to form the mastic was a dry mineral dust. Therefore the first series of tests conducted in relation to soil stabilization was made to determine whether or not an unpulverized or raw damp loess could be used as the filler.

The pilot plant mixer was used to prepare the mixes tested in this part of the study. This mixer is a 300-lb capacity, batch type, standard twin shaft pug mill mixer, equipped with conventional kneading paddle tips and operating at a shaft speed of about 90 rpm. The mixer is also equipped with a foamed asphalt system having two foam nozzles on the spray bar. The nozzles were adjusted to produce a concentrated foam of the binder when the system operated at 20 psi pressure for the binder and about 50 psi for the saturated steam pressure.

Tests were first made on mixes containing 75 percent fine sand and 25 percent raw loess by weight as aggregates, and 5 percent and 6 percent 150 to 200 penetration asphalt cement introduced into the mix in the form of a concentrated foam as the binder. The fine sand used in these mixes is the same as that used in previous mixes (Table 1). The loess is the same base material containing 38 percent clay, but in these tests it was used directly from stockpile, containing agglomerations and lumps as large as 3 in. in diameter instead of being processed and pulverized. Both materials were used at air temperature and contained some moisture. The materials were proportioned by weight in 150-lb batches containing 75 percent fine sand and 25 percent raw loess.

The proportioned aggregates were placed directly into the mixer. The mixing was started, and water was added to the materials in the mixer until the raw loess softened, agglomerations and lumps broke apart, and the loess was uniformly distributed throughout the mix. The quantity of water needed depended upon the initial moisture in the aggregates. It was found, however, that a total moisture content of about 8 percent in the mixer was sufficient to break down and distribute the loess. It was also found that about 30 seconds of mixing was required to secure a uniform mixture. As soon as a uniform mixture was secured, the binder, a 150 to 200 penetration asphalt cement at 300 F, was added to the mix in the form of a concentrated foam. Mixes containing 5 percent and 6 percent of binder by weight were produced. The time required to add the binder in this manner was about 10 seconds. Mixing was continued after the addition of the binder for about 20 to 30 seconds to provide for the distribution of the binder throughout the mixture. The total mixing time per batch was about 60 to 70 seconds. Excellent mixes were produced of uniform character containing an evenly distributed mastic.

The water added to the aggregates during mixing serves several important purposes. It so softens the clayey materials or heavy soil fractions in the mix that lumps or agglomerations are broken up and the material can be distributed uniformly throughout the mixture. The water also separates the fine particles and suspends them in the water medium during mixing. These channels of moisture in the mix, particularly around the fine particles, provide paths through which the foamed binder can readily travel to coat all the mineral particles during mixing. Without sufficient water in the mixture satisfactory mixes could not be produced, but if the aggregates contain sufficient moisture no water need be added. If they do not contain sufficient water then water must be added, but water should be added carefully because excess water is as detrimental as insufficient water. The proper quantity of water for any mix combination of aggregates can be readily determined by a few trial batches.

Test specimens were prepared from these mixes and tested in the same manner as those of previous mixes. It should be noted that the curing time was three days prior to testing. The curing time is significant as will be noted later. The results of these tests are shown in Table 7.

The Hubbard-field stability test was used to compare the results of these mixes directly with the results of other mixes prepared by this method. Since the specimens were cured for only three days, to make direct comparisons, the specimens were still damp. The tests made after submerging the specimens in water at 140 F for 1 hour yielded only 600 to 650-lb stability. Specimens cured for 11 days prior to testing were much drier and yielded a stability of 1,100 lb. It seems that as the mix dries its stability increases and once dried it retains its higher stability.

About 3 tons of the mix containing 6 percent A. C., as shown in Table 7, was prepared and laid as a small field test area. The test was placed as a section of a roadway, 8 ft wide, 20 ft in length and 6 in. in depth, carrying about 400 cars a day. The mix laid in one lift 6 in. in depth spread easily and smoothly by raking. The mix was compacted readily by medium weight wobble wheel pneumatic rolling to a compacted depth of 5 in. The test pavement was opened to traffic 18 hours after laying. The behavior of the pavement was observed daily for about seven days. No settlement, ravelling, or rutting was observed, even after a heavy rain on the third day during this period. Slight scuffing of the surface was however noted which lead to the decision to seal the surface. The surface was sealed on the eighth day with a single layer sand seal. This seal consisted of a prime coat of 0. 1 gallon Mc-0, followed by 0. 2 gallons, 150-200 pen. A. C. and 20 lb of coarse sand per sq yd. This pavement laid early in September 1956 has been performing excellently for the past four months. Weather conditions during this period have varied from 90 F and 10 F with heavy rains, snow and ice on the surface.

In preparation for in-place soil stabilization studies of this method, the material removed from the roadway in the above test area was tried in plant mix operations. The existing roadway was surfaced with power house cinders laid about 1½ to 2 in. thick upon a heavy clay soil. The upper 4 in. of the material removed from the roadway, consisting of 2 in. of cinders and 2 in. of soil, were used in this test. The gradation of this combined material was as follows:

Sieve	Total Percent Passing
⅜	93
4	82
10	68
40	46
80	34
200	26

In preparing these mixes, the cinder-

TABLE 7

MIX. 75% FINE SAND, 25% RAW LOESS

Moisture content during mixing 8%	6% A C.	5% A C.
Hubbard field stability 77 F dry	3000	3100
140 F dry	1650	2200
Standard 140 F wet	600	650
% voids in compacted mixture, not corrected for moisture	12%	14%
Unit weight, pcf	148	151
Resistance to freezing-thawing	Good	Good
Max volume change	4%	3 6%

clay combination was placed in the mixer and water was added in a quantity sufficient to distribute the clayey soil uniformly throughout the mixture. Then 6 percent of 150-200 pen. A. C. was added in the form of a concentrated foam and mixing continued for 30 seconds. Since this mix contained coarse particles Marshall-stability test specimens were prepared. The results of these tests were as follows:

TABLE 8

Moisture in mixture	8%
Marshall stability 140 F wet	480 lb
Voids in compacted specimen	16.7
Resistance to freezing-thawing	Fair
Unit weight per cu ft	142 lb

Similar mixes were produced in which 20 percent of raw loess was added to the cinder clay soil combination. The mixes were prepared and tested in the same manner as the cinder clayey soil mixes. The test results are shown in Table 9.

Analysis of these test results indicates that some bituminous soil stabilization mixes can be produced by this method which closely approach Marshall stability criteria for asphaltic concrete. These encouraging results lead to a study of adapting this method to in-place soil stabilization.

IN-PLACE BITUMINOUS SOIL STABILIZATION

The applicability and the efficacy of the use of a bituminous binder in the form of a concentrated foam in in-place bituminous soil stabilization was tried and tested on a Seaman-Andwall Pulvi-Mixer, stock model D. S. 47 having an 8 ft wide hood assembly. This machine was secured by the Bituminous Research Laboratory for research purposes through the courtesy of the Seaman-Andwall Company of Milwaukee, Wisconsin.

Since this machine was a standard model and only on loan to the Laboratory, it was necessary that it be adapted to the foamed binder process with as little modification of the base unit as possible. The equipment necessary for this adaption included a small steam boiler to furnish the steam required for foaming the binder, a spray bar equipped with foaming nozzles at the assembly hood, and such piping, fittings, and controls as were necessary to convey the steam and binder to the spray bar.

The steam boiler used was a 60 gallon capacity steam jenny type fired by an automatic pressure controlled electric fuel oil burner. Steam pressure of this boiler could be automatically controlled at any pressure between 5 and 100 lb. This boiler was mounted on temporary steel bracket supports at the front end of the mixer (Figure 5). A small motor generator set was mounted on the running board of the mixer to supply the power needed to operate the electric fuel oil burner. Two main steam lines, each ¾ in. in diameter and insulated, were installed to convey steam from the boiler to the spray bar. One line, fitted with suitable operating controls for controlling the pressure and volume of the steam, was used to furnish steam to the foam nozzles. The other line was used to furnish steam to heat the steam jacketed spray bar.

The spray bar installed just in front of the hood assembly consisted of eight 2-in. ID steam jacketed tee fittings bolted together with one small steam jacketed straight section to form a continuous spray bar spanning the width of the hood assembly (Figure 6). Each tee fitting of the spray bar was equipped with a bituminous foam nozzle (Figure 7). The spray bar was so adjusted and positioned that the eight nozzles sprayed a uniform spread of foamed binder in front of the cutter and mixer

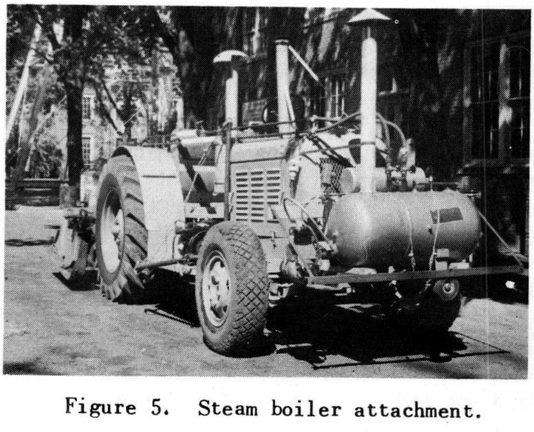


Figure 5. Steam boiler attachment.

TABLE 9

	5% A. C.	6% A. C.
Moisture in mix	8%	8%
Marshall stability 140 F wet	500	460
Flow	16	21
Voids in compacted mixture	15.1	15.5
Resistance to freezing-thawing	Fair	Fair
Unit weight	148	142

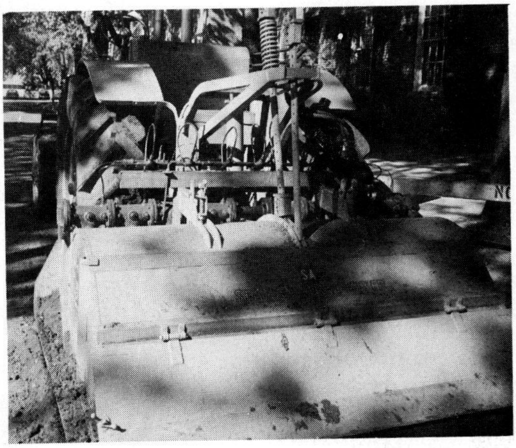


Figure 6. Spray bar attachment.

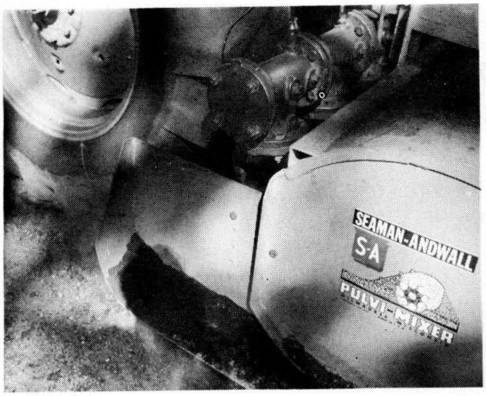


Figure 7. Spray bar showing nozzle for foaming the asphalt.

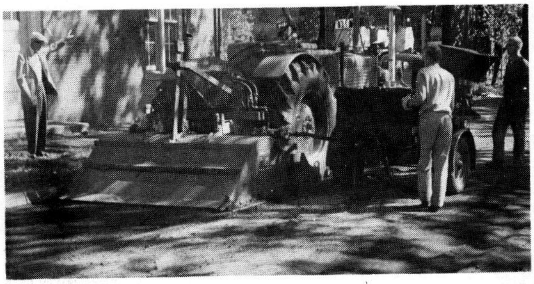


Figure 8. Stabilizer in operation.

blades of the hood assembly. The main steam lines from the boiler were connected to two steam manifolds, one of which distributed saturated steam to the nozzles, and the other steam to the steam jacketed sections of the spray bar. Steam operating pressure and volume controls on the main steam line carrying steam to the nozzles were placed within easy reach of the operator in the driver's seat.

The bituminous binder used in the operation was heated in a 160 gallon asphalt heater kettle. This kettle was towed alongside the mixer by an outrigger tow bar temporarily mounted on one side of the mixer. The binder was pumped from the kettle to the spray bar by a gasoline engine drive asphalt pump mounted on the kettle. A flexible metal hose connected this pump to the spray bar (Figure 8). Operation of binder controls was done manually by signal from the mixer operator. The mixer and asphalt supply kettle moved forward in unison during in-place soil stabilization operations.

The operation of the Pulvi-Mixer, adapted in the manner described to the use of a foamed bituminous binder, was tested on a section of test road 24 ft wide and about 250 ft in length. The surface of the test area consisted of a layer of power plant cinders about $1\frac{1}{2}$ to 2 in. thick laid upon a natural heavy clayey soil. A layer 4 in. deep consisting of approximately 2 in. of cinders and 2 in. of soil was stabilized in these tests. An average gradation of the mixture of these materials is given in the preceding section on plant mix soil stabilization. Moisture content of the road material varied from 6 to 16 percent during the tests, as will be noted, due to weather conditions. Two types of binder were used, an 85 to 100 penetration asphalt cement and a 150 to 200 penetration asphalt cement. Both types were heated to 300 to 330 F during application.

Since the materials in the road were stratified, it was deemed desirable that a mixing and blending pass be made prior to application of the binder. This pass served to loosen the layer of soil to be stabilized, to blend and mix it thoroughly and uniformly, and to break up clay agglomerations prior to stabilization. This was done prior to each run. In this preliminary pass the cutting blades in the hood assembly were set to a depth of 4 in. Each pass yielded about a 6-in. depth of loose mixed and blended material.

The application of the binder during the soil stabilization pass was made in the following manner: The Pulvi-Mixer was moved into position at one end of the mixing and blending pass, and the hood was lowered into position. The cutting blades were set to mix the full depth of loose material. Steam pressure of about 65 psi at the boiler was reduced to about 40 psi by the controls and turned on to check if all foam nozzles were functioning properly. Then bituminous soil stabilization was started. As soon as the mixer began moving forward the asphalt was turned on to the spray bar. During the soil stabilization pass the mixer travelled at a speed of 40 ft a minute. This was the slowest speed at which this machine could be operated. The binder was shut off a few feet ahead of the end of the run to permit the spray bar and nozzles to drain. As soon as this drainage was completed, the steam was shut off. Due to the speed of the mixer and the limited capacity of the asphalt pump on the kettle, it was found that only 1 percent of binder could be applied at each pass. It was also noted that under these conditions no asphalt pressure was developed at the nozzles. The nozzles functioned satisfactorily under this condition. To introduce the desired quantity of binder, about 6 percent, several successive soil stabilization passes had to be made. This, however, served a useful purpose, because the characteristics of the mix with increasing quantities of binder could be observed.

The test road was constructed in three 8-ft wide parallel and adjacent lanes. The first outer lane was started by making a blending and mixing pass with the Pulvi-Mixer. Soon after this pass was made, an unforecast shower arrived and work was stopped. Then it continued to rain for two days for a total rainfall of 4 in. This rainfall thoroughly saturated the loosened material and the subgrade in this lane. When work was again started, it was found that the soil contained 24 percent moisture. Consequantly several aeration passes were made on successive days to dry out the soil. Bituminous soil stabilization was started when the soil moisture was at 16 percent. Four stabilization passes were made, introducing 4 percent of A. C. The binder was uniformly distributed in the mix which was somewhat spongy. Nevertheless it rolled well under a pneumatic roller and compacted tightly. In a few places where subgrade was still saturated the pavement showed subgrade failure under traffic. After the subgrade had dried somewhat, two additional stabilization passes were made, adding 2 percent of binder, raising the total to 6 percent. Moisture content in the paving at this time was about 6 percent. This mixture rolled very well and compacted tightly. It showed no displacement other than a slight scuffing under traffic. The binder used in this lane was 150 to 200 penetration asphalt cement. The other outer lane was treated with 85 to 100 penetration asphalt cement. At the time of treatment soil moisture was about 8 percent. The first mixing and blending pass was followed by successive stabilization passes applying 6 percent binder to the soil. An excellent uniform mix was secured. Initial compaction was made with two passes of a Jackson vibrating compactor. Good compaction was secured. The center lane was processed in the same manner as the second outer lane. Soil moisture in this lane was about 6 percent, and 150 to 200 penetration asphalt cement was used as the binder. Compaction was secured by two passes of the Jackson vibratory compactor, followed by pneumatic tire rolling.

The test area was opened to traffic on each lane as it was completed. Behavior was observed under traffic for about a week. During this period no displacement in any of the lanes was noted. A slight surface scuffing, however, did occur, and to prevent further scuffing of this nature the entire test area was sealed. One half was sealed with a single layer sand seal consisting of a prime coat of 0. 1 gallon per sq yd of MC-0 cutback followed by 0. 2 gallons per sq yd of 150 to 200 penetration asphalt cement covered by 20 lb per sq yd of coarse sand. The other half was sealed with Schlamme (3) applied at the rate of about 8 lb per sq yd, giving a layer about ⅛ in. in thickness. The paving in the test area has given excellent service during the past four months up to the time of this report. Traffic averages about 400 cars per day, and weather during this period has been comparatively severe, fluctuating between 90 F and 10 F in temperature and with heavy rains, sleet, freezing rain and about 4 in. of snow. The pavement is tight, sheds water readily, and shows no distress of any type.

Further tests with this machine in other areas with other types of soil had to be discontinued due to cold and inclement weather. It is expected that tests will be resumed early next spring. The work completed, however, has shown that the use of a foamed binder can sucessfully and effectively stabilize a heavy soil in an in-place soil stabilization operation. It has also shown that it can handle cinders, one of the most difficult materials to stabilize with a bituminous binder.

STANDARD SPECIFICATION MIXES

The knowledge and experience gained in the preceding studies led to a study of the use of foamed binder in conjunction with standard specification mixes. The question here was whether the foamed binder could be used with cold moist aggregates in the preparation of these mixes.

In this phase of the work, aggregates secured from an actual construction job under Iowa State Highway Specification were used. The gradation of these aggregates blended for the mix was as follows:

TABLE 10

BLEND OF ¾-⅜ STONE, 30%; PREBLENDED SAND 35%; CHIPS, 35%

Sieve No.	Total % Passing	Iowa Specifications Type A
1 in.	100	98-100
¾ in.	99	98-100
½ in.	92	-100
⅜ in.	81	67-87
No. 4	60	47-68
No. 8	46	37-55
No. 30	25	19-34
No. 50	18	13-26
No. 100	10	6-
No. 200	6	3-10

A sample of the Type A asphaltic concrete mix was also secured from this construction job and tested, using the Marshall stability test. This test was used for comparative purposes to correlate this study with previous and future studies carried on in the laboratory. The results of this test are shown in Table 11.

The first sequence of tests was made using cold damp aggregates at 70 F and containing about 3 percent moisture. Mixing was done in the laboratory mixer with standard kneading paddle tips in the following manner: Proportioned aggregates were placed into the mixer and mixed for 10 seconds, then 7 percent of an 85-100 penetration asphalt cement in the form of a concentrated foam was added, followed by a 30 second wet mix. The total mixing time was 47 seconds. In this mix an excellent mastic was formed with the fine aggregate and dust particles thoroughly and uniformly coated, but the coarse particles were only partially coated. When 150 to 200 penetration asphalt cement was used as the binder in this mix an improved coating of coarse particles was obtained. When the moisture in the aggregates was raised to 8 percent, improved coating of the coarse particles was also secured.

TABLE 11

TYPE A ASPHALTIC CONCRETE CONSTRUCTION SAMPLE

% asphalt cement	6.5
Marshall stability, lb	1260
Flow	12
Unit weight, pcf	142
Percent voids	7.1

The second sequence of tests made utilized aggregates dried and heated according to specifications. The mix was prepared in the same manner as those in the first sequence. Excellent mixes were secured which produced test results equal to those of the construction mix control. This sequence of tests disclosed that the foamed binder method can be applied successfully to standard mixes, mixed in the conventional manner in regular pug mill mixers, in which no special paddle tips or mixer speed changes are required.

A third sequence of tests was conducted to determine the limiting effects of the temperature of the aggregates. Mixes were made with the temperature of the aggregates reduced step by step. The character of each mix was carefully observed. It was noted that at aggregate temperatures of 180 F and above excellent mixes were secured. When the temperature was lowered to 160 F the coarse aggregate particles were not wholly coated with binder. Mixes made with the temperature of the aggregates at 180 F and 200 F were tested. The results of these tests are shown in Table 12.

TABLE 12

Aggregate temperature	180 F	200 F
% asphalt cement content	6%	7%
Marshall stability	610	700
Flow	8	10
% voids in compacted specimen	8	5
Unit weight, pcf	138	138

Analysis of the results of these tests confirms the effect of aggregate temperature upon some of the physical properties of the mix when asphalt cements are used as the binder. It was however noted from experience in previous work that the effects of aggregate temperature are not nearly as great when the binder is applied in the form of a concentrated foam as it is when the binder is applied in either liquid or atomized droplet form. This characteristic of a foam binder in relation to aggregate temperature can have a material effect upon increasing plant production. Since the output capacity of most asphalt plants is limited by its drier capacity, any increase in drier capacity by reason of lowered aggregate temperature required would materially increase plant production.

CONCLUSIONS

In this research work the feasibility of efficiently and effectively producing a foam of a bituminous binder in several forms has been studied and the applicability and the efficacy of such foamed binders in bituminous paving mixtures and in bituminous soil stabilization has been investigated. Although the work was somewhat exploratory in nature, a mass of significant data and results of tests have been compiled from which many specific and definite conclusions may be drawn.

1. The study disclosed that a bituminous binder can be efficiently and effectively foamed in several forms. Special foaming nozzles were developed and designed, together with necessary adjunct apparatus, that can instantaneously create the character of foam desired at the time and place required. The foam can be introduced into a mixture in the manner and quantity required.

2. The physical properties of a bituminous binder can be temporarily modified without altering the chemical constitution of the binder by foaming the binder. The viscosity can be lowered materially to provide easier and more uniform distribution of the binder during mixing. The lowered viscosity increases the plasticity of the mixture at lower temperatures during placing or laying. The viscosity is restored to normal during compaction of the mixture, permitting it to set rapidly. The surface tension of the binder is so modified that coating of the aggregate is accomplished more readily, and improved adhesion between binder and aggregate is attained. Since the binder is in the form of a bubble rather than a liquid thin films of binder form on the aggregate surface merely upon contact, regardless of the size of the aggregate particle.

3. Bituminous mixes containing local ungraded aggregates can be produced more readily and safely by this method than by any other method studied and investigated in this or any other previous research projects conducted at the Bituminous Research Laboratory. When foamed binder is used, higher strengths, greater resistance to freezing and thawing, and other desirable properties are obtained than by any other method investigated. When a foamed binder is used the aggregates need not be heated to as high a temperature as that required by the atomized binder method to obtain satisfactory mixes.

4. Bituminous mixes containing local ungraded aggregates can be produced by the foamed binder method in standard twin shaft pug mill mixers without any change of mixer paddle tips or modification of mixing procedure.

5. Plant mix soil stabilization mixes can be produced readily and effectively without need of dry pulverization of fine fractions and with asphalt cement as the binder when the foamed binder method is used. Breakdown of agglomerations or lumps of fine or clayey fractions is achieved by the addition of the proper quantity of water prior to the addition of the foamed binder. The water also assists in the uniform distribution of the foamed binder throughout the mix. Mixing of this type of mixture can be accomplished in standard conventional mixers.

6. The use of the foamed binder method is readily and effectively applicable to in-place soil stabilization operations, using commercially available equipment. When reasonable soil moisture control is exercised, excellent mixes having the binder uniformly distributed throughout the soil can be obtained. Soil stabilization mixes containing heavy clayey soils and 6 percent of 150 to 200 penetration asphalt cement can be produced by this method. The mixes possess high stability, good resistance to freezing and thawing, good waterproof character, and other desirable properties.

7. Standard specification high and medium type asphaltic concrete mixes can also be produced by the foamed binder method. Such mixes have physical properties equiva-

lent to the same mixes made by conventional means. Mixing time can, however, be reduced and still secure uniform distribution of the binder throughout the mixture. Aggregate temperatures may also be somewhat lowered in high type, and may be considerably lowered in medium type asphaltic concrete mixes without adversely affecting the physical properties of the mixture when the foamed binder method is used. Plant capacity can be increased by producing mixes using the foamed binder method.

8. The foamed binder method can be used in conjunction with either batch type or continuous type mixers.

FURTHER WORK

The work concerning foamed bituminous binders up to this time has been aimed toward determining their application to and their efficacy in the production of a variety of bituminous paving and soil stabilization mixes. With this phase of the work nearing completion, attention is being directed toward the details of optimums of design and to the control of the wide variety and numerous types of bituminous mixes which can be produced by utilizing the foamed binder method.

PATENTS

The new developments made or discovered in the prosecution of this work have been assigned to the Iowa State College Research Foundation. The Iowa State College Research Foundation has filed patent applications covering the method; the apparatus, including the nozzles; the use of the various forms of foamed binder and its application to the various types of bituminous mixes. Patent applications have been filed in the United States and Germany, and may also be filed elsewhere as deemed desirable.

REFERENCES

1. Csanyi, L.H. and Fung, H.P., "Ungraded Aggregates in Bituminous Mixes." Bulletin 109, Highway Research Board (1956).

2. Csanyi, L.H. and Nady, R.M., "The Design of Bituminous Paving Mixtures by a Mortar Theory Using Local Ungraded Aggregates." Proceedings Association Asphalt Paving Technologists, pp. 282-331 (1955).

3. Csanyi, L.H., "Bituminous Mastic Surfacings." Proceeding Association Asphalt Paving Technolodists (1956).

HRB:OR-91

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

The NATIONAL RESEARCH COUNCIL was established by the ACADEMY in 1916, at the request of President Wilson, to enable scientists generally to associate their efforts with those of the limited membership of the ACADEMY in service to the nation, to society, and to science at home and abroad. Members of the NATIONAL RESEARCH COUNCIL receive their appointments from the president of the ACADEMY. They include representatives nominated by the major scientific and technical societies, representatives of the federal government, and a number of members at large. In addition, several thousand scientists and engineers take part in the activities of the research council through membership on its various boards and committees.

Receiving funds from both public and private sources, by contribution, grant, or contract, the ACADEMY and its RESEARCH COUNCIL thus work to stimulate research and its applications, to survey the broad possibilities of science, to promote effective utilization of the scientific and technical resources of the country, to serve the government, and to further the general interests of science.

The HIGHWAY RESEARCH BOARD was organized November 11, 1920, as an agency of the Division of Engineering and Industrial Research, one of the eight functional divisions of the NATIONAL RESEARCH COUNCIL. The BOARD is a cooperative organization of the highway technologists of America operating under the auspices of the ACADEMY–COUNCIL and with the support of the several highway departments, the Bureau of Public Roads, and many other organizations interested in the development of highway transportation. The purposes of the BOARD are to encourage research and to provide a national clearinghouse and correlation service for research activities and information on highway administration and technology.