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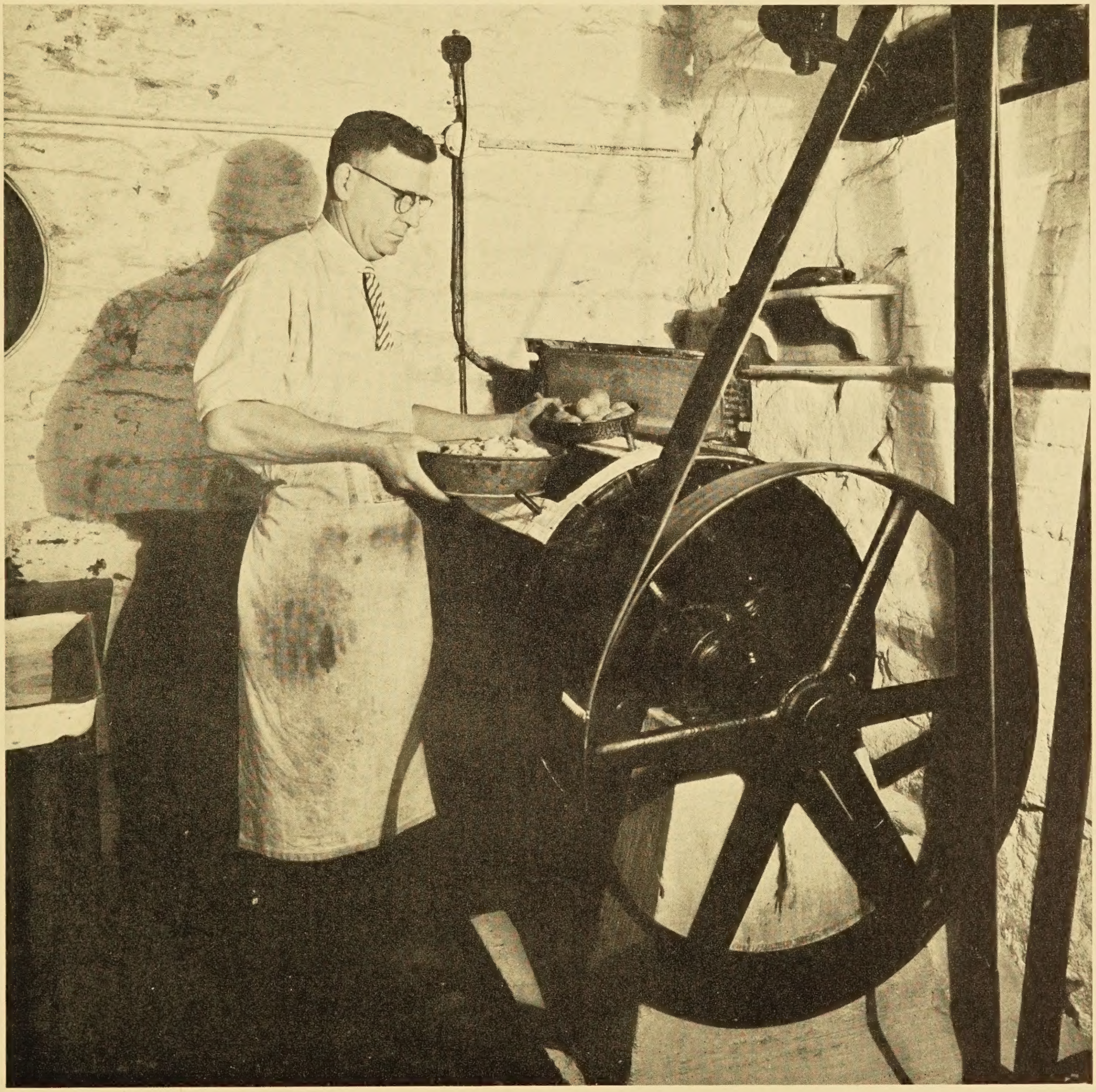

THE LOS ANGELES ABRASION MACHINE

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THE LOS ANGELES ABRASION MACHINE FOR DETERMINING THE QUALITY OF COARSE AGGREGATE

Reported by D. O. WOOLF, Associate Materials Engineer and, D. G. RUNNER, Assistant Materials Engineer, Division of Tests, U. S. Bureau of Public Roads

DURING the past few years there has been a tendency on the part of highway engineers to examine rather critically a number of the time-honored tests for road materials with a view to ascertaining the accuracy with which they measure the ability of materials to meet present-day service requirements.

Two such tests, the standard Deval abrasion test,[1] and the standard toughness test,[2] have been used for many years to determine the quality of ledge rock. The Deval test has been modified by the American Society for Testing Materials to serve as a test for gravel as well as for ledge rock. This modified Deval test for use in testing graded samples of rounded gravel was adopted tentatively in 1928.[3] The American Association of State Highway Officials has also modified the original Deval test for the purpose of testing light-weight materials such as slag.[4]

DEVAL TEST UNSATISFACTORY IN SEVERAL RESPECTS

These modifications, while necessary in order to adapt the Deval test to such materials as gravel and slag, also made necessary the use of entirely different test limits for the various materials even when they were intended for the same service. An illustration of this trend is found in the current specification of one of the State highway departments. For grade A coarse aggregate for concrete that department allows a maximum wear of 6 percent for limestone, 15 percent for blast-furnace slag, and 12 percent for rounded gravel. These requirements are intended to result in the use of aggregates of comparable quality. The differences are necessary because the modified tests give results differing from those given by the standard Deval test on ledge rock of comparable quality. This situation is unfortunate because of the apparent inconsistency which results from the use of different test limits for materials that are to meet the same service requirements.

Criticism is frequently made of the comparatively small range in values given by the Deval test for rock of the quality ordinarily used in road construction. The Deval test is essentially an abrasion test rather than an impact test; for this reason certain types of materials that are very low in toughness, even though they are quite hard, will show relatively low abrasion losses in this test. Certain granitic materials fall in this class. Such materials are frequently reported as giving unsatisfactory results in service, even though their percentages of wear by the Deval test may be quite low.

[1] Method D 2-33, American Society for Testing Materials Book of Standards, Part II, 1933.

[2] Method D 3-18, American Society for Testing Materials Book of Standards, Part II, 1933.

[3] Tentative Method D 289-28T, American Society for Testing Materials Book of Tentative Standards, 1934.

[4] Method T-3, Standard Specifications for Highway Materials and Methods of Sampling and Testing, American Association of State Highway Officials, 1935.

The standard toughness test has also been subjected to considerable criticism recently, much of which has been directed at the accuracy of the test method itself. Attention has been called to variations in results reported by different laboratories on apparently identical materials. A study of the problem indicates that the trouble is caused by the flattening of the spherical end of the plunger of the testing machine through use, with the resultant tendency to give higher values. Most of the test data upon which many of the State specifications for toughness are based were obtained before the necessity for rigidly controlling this variable was appreciated; hence the condition of the testing machine has assumed considerable importance in the acceptance or rejection of materials. The condition of the testing machine is rendered all the more important by the fact that many rocks are borderline materials from the standpoint of toughness, and even a small variation in test results may mean the difference between acceptance and rejection.

The realization of these and other weaknesses in the present standard tests caused the bureau to investigate the possibilities of the so-called "Los Angeles rattler" test used by the State of California as an acceptance test for coarse aggregates.

THE LOS ANGELES ABRASION TEST DESCRIBED

A number of years ago a machine for determining the abrasive resistance of aggregates was developed by the engineers of the city of Los Angeles, Calif.[5] The method developed is radically different from the standard Deval abrasion test in that the test charge is caused to drop instead of to slide or roll, and also in that an abrasive charge and a sample composed of graded sizes of particles are used. A test run of 500 revolutions is used instead of the 10,000 revolutions required in the Deval test, thus greatly reducing the time required for making the test. In 1927 the California State highway laboratory began a study of the Los Angeles abrasion machine to determine its suitability for use as a substitute for the Deval machine. The machine and test method were apparently found to be satisfactory for in that year the Los Angeles test method was adopted by the State as a standard method. Some changes in the method as originally proposed were made, the latest (1930) test method being as follows:[6]

> The machine used in the test consists of a cylindrical drum 28 inches in diameter and 20 inches in length, mounted longitudinally on a horizontal shaft, and having a shelf 4 inches wide extending from end to end on the inside.
>
> The drum is charged with 14 cubical blocks of cast iron having rounded corners and edges and weighing a total of 5,000 grams, along with 5,000 grams of rock, which is graded as follows:

[5] Selection of Rock and Gravel for Highway Construction, by C. L. McKesson, California Highways, vol. 3, no. 4, April 1926.

[6] From an unpublished report of California Division of Highways, Sacramento, Calif., dated June 13, 1930.

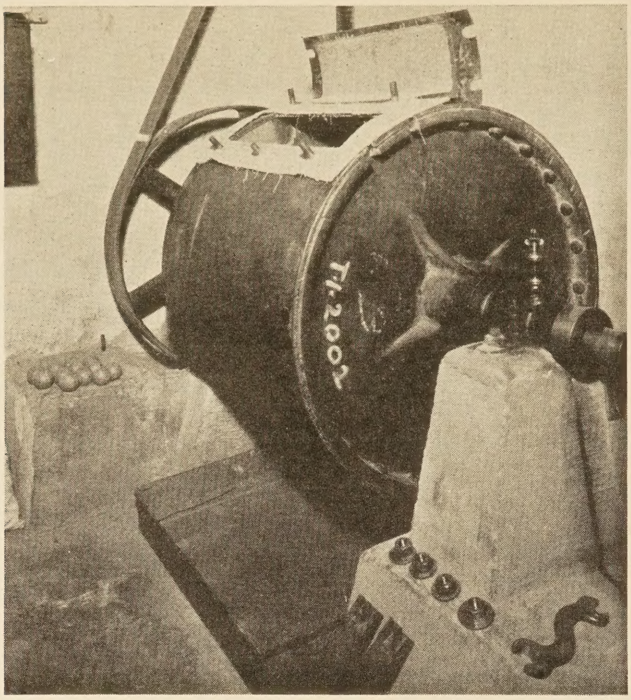

FIGURE 1.—THE LOS ANGELES ABRASION MACHINE SHOWING COVER AND ABRASIVE CHARGE.

Screen size	Total percent passing
1½ inch	100
1¼ inch	80
1 inch	60
¾ inch	40
½ inch	0

After charging, the drum is revolved 100 revolutions and 500 revolutions at a rate of between 30 and 33 revolutions per minute. The result is reported as the percent of wear at 100 and 500 revolutions. At the present time the wear is considered that portion of the sample which, after test, will pass a 10-mesh sieve having a clear opening of 0.065 inch (no. 12 U. S. Standard).

In its report the California Division of Highways cites certain advantages possessed by this method of testing as follows:

The Los Angeles rattler test is decidedly more suitable for determining the hardness and toughness of rock and the amount of soft material than any test or group of tests studied. Its advantages are pointed out as follows:

(*a*) The nature of the treatment is severe, bringing out weaknesses not shown by any one of the other tests studied.

(*b*) It is adapted for testing both crushed and gravel aggregates.

(*c*) It requires very little time for performance.

(*d*) It is not affected materially by changes in volume of aggregate due to specific gravity because of the size of cylinders in which the test is made.

(*e*) It eliminates a large amount of the personal equation which enters into some of the other tests.

A study of the test method was undertaken by the bureau to determine whether the conclusions reached by California can be applied to tests covering a wider range of materials. A Los Angeles abrasion machine was constructed according to plans furnished by the California Division of Highways. This machine is shown in figure 1. The shelf which picks up the charge is mounted on the removable cover. This cover was originally fastened on by two bolts at each end. A few tests showed that the cover sprang at the center, allowing dust to escape, and to prevent this the cover is now fastened by two heavy bars, curved to fit the drum and fitting over stud bolts projecting from the drum. The gasket consists of four thicknesses of heavy canvas firmly sewed together.

Test samples of rock, gravel, and slag were obtained from various parts of the country, largely from commercial producers. Where possible samples of both ledge rock and crushed material were obtained. The producers were requested to furnish crushed and ledge rock of the same quality, and as far as could be observed this was done. These samples represented practically all types of rock and gravel that are used for road building. Although only three samples of slag were tested they represent the type of blast-furance slag (70 to 85 pounds per cubic foot) most widely used in highway construction.

BALLS FOUND TO BE MOST SUITABLE AS AN ABRASIVE CHARGE

Prior to the principal series of tests, a preliminary study was made to determine the possibility of substituting balls for the cubical shot used by California. The procedure followed by California required an abrasive charge of fourteen 1½-inch cast-iron cubes. It was recalled that in the standardization work on the brick rattler, abrasive charges of both cubes and balls were used, and that the balls were finally adopted.[7] The cast-iron balls proposed for use in the Los Angeles machine are the same as the small balls used in the brick-rattler machine, and have a nominal diameter of 1⅞ inches and an initial weight of about 431 grams. Since 12 new balls weigh about 5,170 grams, the stock of used balls from the brick rattler was inspected, and 12 balls were selected whose total weight was $5{,}000 \pm 5$ grams.

To insure representative results in the preliminary series of tests, one sample of each of the three materials—rock, gravel, and slag—was selected for test and at least nine samples of each material were tested with each type of abrasive charge. Determinations of the percentage of wear were made at the end of 100 and 500 revolutions. After 100 revolutions the material was taken from the machine, sieved on a no. 12 sieve, and the particles were brushed free from adhering dust. All of the material retained on this sieve was then weighed.

The entire charge, including the dust, was replaced in the machine. The test was resumed for an additional 400 revolutions and the amount passing the no. 12 sieve was again determined. The results of these tests are shown in table 1. It will be observed that in every instance the balls caused a greater loss in abrasion than the cubes. The greater weight per unit of area of the ball, together with the delivery of impact at a single point, caused greater loss in the test than the edges and corners of the cube.

Besides producing more severe action on the test specimen, the abrasive charge of balls gives slightly more concordant results. Tests with the ball abrasive charge show an average deviation of 3.4 percent in the loss at 500 revolutions, while the corresponding average deviation for the cubes is 5.5 percent. More concordant results were obtained at 500 revolutions than at 100.

The cubes were found to lose weight at a greater rate than the balls. This required constant adjustment of the cube abrasive charge and possibly affected the abrasive loss. The balls lost very little weight after the

[7] A Study of the Rattler Test for Paving Brick, by M. W. Blair and Edward Orton, Jr., Proceedings, American Society for Testing Materials, Vol. 11, 1911.

TABLE 1.—*Comparison of cubes and balls as abrasive charges in Los Angeles machine*

Sample no.	Kind of material	Abrasion loss using— Cubes, 100 revolutions	Cubes, 500 revolutions	Balls, 100 revolutions	Balls, 500 revolutions
		Percent	*Percent*	*Percent*	*Percent*
33265	Slag	8.2	38.3	9.7	46.7
33278	Gravel	13.7	52.0	17.7	59.3
33279	Basalt rock	1.5	6.1	2.0	9.7

first few tests. This feature, combined with the greater abrasion of the test sample and the more concordant results obtained, shows that balls are preferable for use as the abrasive charge. Furthermore, many laboratories are equipped with the brick rattler machine and presumably have a supply of cast-iron balls of suitable size and weight.

RESULTS OBTAINED BY THE TWO METHODS OF TESTING COMPARED

After deciding to use balls as the abrasive charge, the main portion of the investigation was considered. It was desired to compare the results of the Los Angeles abrasion test with those for the Deval abrasion test and, also, to determine the effect of angularity of particle on the Los Angeles test results. To obtain these data, each sample was tested in the Deval and Los Angeles abrasion machines and toughness tests were made on all suitable samples of rock. The Deval abrasion tests on rock and slag were made in accordance with A. S. T. M. standard method D 2–33, and those on gravel in accordance with A. S. T. M. tentative method D 289–28 T. The tests with the Los Angeles machine were made according to the procedure used by California with the exception that the abrasive charge consisted of twelve 1⅞-inch cast-iron balls weighing 5,000 ± 5 grams. To determine the effects of shape and angularity of particles on the test results, tests were made on commercial crushed rock and hand-broken rock of cubical shape with sharp edges and corners, and also on both rounded and angular particles of gravel and rock.

In preparing the test specimens for the Los Angeles test, the samples of gravel, slag, and rock were separated into the various screen sizes and recombined as shown in table 2.

TABLE 2.—*Gradation of Los Angeles abrasion test samples (grading A)*

[Screens with round openings]

Passing	Retained on—	Weight
Inches	*Inches*	*Grams*
1½	1¼	1,000
1¼	1	1,000
1	¾	1,000
¾	½	2,000
Total		5,000

The results of the standard Deval and the Los Angeles abrasion tests using grading A are given in table 3. Most of the test values given are averages of three or more tests. These values have also been plotted in figure 2 together with curves showing the average relation between the standard and modified Deval tests and the results in the Los Angeles machine. The number of points which depart from the average

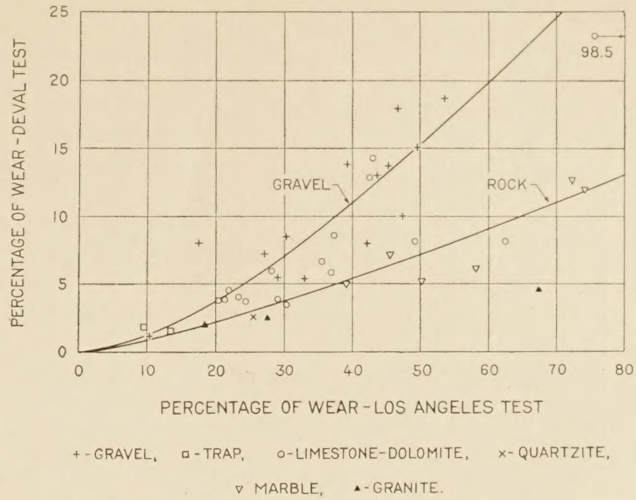

FIGURE 2.—RELATION BETWEEN RESULTS OF TESTS IN DEVAL AND LOS ANGELES MACHINES.

curves demonstrates that the relations are only very general and do not apply to all types of materials nor to all samples of a given type. This is due mainly to the marked difference in the amount of impact produced in the two tests. Although both tests involve both surface wear and impact, the loss in the Deval test is mainly from surface wear, while that for the Los Angeles test is primarily caused by impact. Marble, for example, has about the same wear in the Deval test as limestone or dolomite, but in the Los Angeles test marble shows a much higher loss than the tougher rocks.

Figure 2 is presented with the knowledge that no definite relation between the losses in the Deval and Los Angeles tests that will apply to all materials can be established. However, the figure will serve to show the approximate change in specification requirements if the Deval test is replaced by the Los Angeles test. For instance, it will be observed that, for an average loss of 50 percent in the Los Angeles test, the average Deval abrasion loss is about 7 percent for rock and 15 percent for gravel. This happens to be approximately the same ratio (1:2) that is used in most specifications with the idea of obtaining materials of comparable quality.

More concordant results are obtained in tests of gravel and crushed rock or slag in the Los Angeles machine than in tests by standard methods using the Deval abrasion machine. Test results in the Los Angeles abrasion machine show a mean variation from the average of 2.7 percent, while those in the Deval machine show a mean variation of 3.9 percent. The difference is not great but it is worthy of notice. It was observed that the speed of operation of the Los Angeles abrasion machine had a great effect on the loss during the test and it was found advisable to equip the motor with a speed control. Each test run was timed to insure that a constant speed of rotation had been used.

EFFECT OF SHAPE AND ANGULARITY OF PARTICLE STUDIED

In its report on the Los Angeles abrasion machine the California Division of Highways stated that the test results are not appreciably affected by the shape or angularity of the particles. The results obtained in the tests reported here are not entirely in agreement with the above statement. To investigate this feature samples of Cheat River, Potomac River, and Delaware

TABLE 3.—*Percentage of wear and toughness as determined by abrasion and toughness tests*

Sample no.	Location	Kind of material	Wear by— Deval test	Wear by— Los Angeles test (500 revolutions): Gravel, crushed rock, slag	Wear by— Los Angeles test (500 revolutions): Hand-broken rock	Toughness
			Percent	*Percent*	*Percent*	
33262	Pennsylvania	Slag [1]	7.8	34.8	------	------
33263	Maryland	Aplite	2.0	18.4	15.9	16
33264	West Virginia	Limestone	3.8	29.2	24.2	6
33265	Ohio	Slag [2]	14.8	46.7	------	------
33266	New Jersey	Gravel	[3] 15.1	49.8	------	------
33269	Ohio	Dolomite	5.8	37.0	30.7	5
33270	South Carolina	Biotite granite	2.5	27.7	21.9	12
33271	Wisconsin	Quartzite	2.6	25.6	19.6	12
33272	Kansas	Argillaceous limestone	3.5	30.5	26.4	6
33273	New Jersey	Diabase	1.5	13.5	8.3	20
33274	Illinois	Dolomite	5.9	28.4	26.1	6
33275	Washington	Gravel	[4] 1.1	10.4	------	------
33276	Ohio	Slag [5]	11.8	36.9	------	------
33278	West Virginia	Gravel	[4] 10.0	[6] 47.5	------	------
33278	do	do	------	[7] 59.3	------	------
33279	Minnesota	Basalt	1.8	9.7	7.0	32
33992	District of Columbia.	Gravel	[4] 8.4	[6] 30.3	------	------
33992	do	do	[8] 17.5	[7] 35.3	------	------
34165	Kansas	Limestone	14.4	43.0	------	3
34542	do	Gravel	[4] 7.5	17.6	------	------
34543	do	Argillaceous limestone	12.8	42.9	------	4
34544	Ohio	Dolomite	23.6	98.5	------	2
34545	do	Gravel	[4] 13.8	39.3	------	------
34571	do	Dolomite	8.2	49.2	------	4
34572	do	Gravel	[4] 7.2	27.3	------	------
34671	Georgia	Marble	6.2	58.3	------	3
34672	do	do	5.4	50.4	------	4
34673	do	do	12.8	72.2	------	3
34674	do	do	12.0	74.4	------	3
34675	do	Dolomitic marble	7.2	45.5	------	3
34676	do	do	5.0	39.2	------	------
34685	Florida	Limestone	6.7	35.6	------	------
34700	Virginia	Gravel	[4] 13.7	45.1	------	------
34701	Maryland	do	[4] 18.6	53.7	------	------
34704	Georgia	Micaceous granite	4.8	67.4	------	------
34713	Virginia	Gravel	[4] 13.0	43.8	------	------
34714	New York	do	[4] 7.6	42.1	------	------
34715	West Virginia	Argillaceous limestone	4.0	23.4	------	------
34717	Ohio	Limestone	4.5	22.0	------	------
34722	do	Dolomite	8.6	37.3	------	------
34723	do	Argillaceous dolomite	3.7	24.4	------	------
34724	Illinois	Gravel	[4] 5.3	33.2	------	------
34732	Virginia	Dolomite	3.9	21.5	------	------
34733	Ohio	Limestone	8.2	62.8	------	------
34734	do	Argillaceous dolomite	3.9	20.8	------	------
34749	Pennsylvania	Gravel	[4] 5.5	[6] 29.3	------	------
34750	do	do	[8] 15.2	[7] 34.6	------	------
34756	Massachusetts	do	[4] 17.9	46.8	------	------

[1] Weight per cubic foot, 80.7 pounds.
[2] Weight per cubic foot, 72.2 pounds.
[3] Grading B, rounded particles only. (See A. S. T. M. Tentative Method D289-28T.)
[4] Grading A, rounded particles only.
[5] Weight per cubic foot, 77.0 pounds.
[6] Rounded particles only.
[7] Angular particles only.
[8] Grading A, angular particles only.

River gravels were carefully hand-picked, and the rounded and angular particles were separated. Tests were made in the Los Angeles abrasion machine with both kinds of particles, and the results obtained are given in table 4.

In the preparation of the Cheat River and Delaware River gravels for use as concrete aggregate the oversize material was crushed. It is quite possible that the majority of the angular particles used in the tests came from this oversize material. Visual inspection, however, failed to show any marked difference in quality between the rounded and angular fragments. The Potomac River gravel sample did not contain crushed material. The angular particles obtained from this material were distributed throughout the entire range of sizes, and had the same petrographic analysis as the rounded particles. The test results for these three gravels indicate that angular particles will give a somewhat higher loss than rounded particles of the same quality.

TABLE 4.—*Percentages of wear on rounded and angular gravel tested in the Los Angeles machine* [1]

Sample no.	Material	Wear on— Rounded particles	Wear on— Angular particles	Loss of angular particles expressed as a percentage of loss of rounded particles
		Percent	*Percent*	
33278	Cheat River gravel	47.5	59.3	125
33992	Potomac River gravel	30.3	35.3	117
34749, 34750	Delaware River gravel	29.3	34.6	118

[1] Each value is the average of at least 3 tests.

Results of tests on hand-broken and crushed rock shown in figure 3 also demonstrate that the shape of the particle exerts a considerable influence on the test result, and show that the partially wedge-shaped fragment of crushed rock has a loss of approximately 120 percent of that for the hand-broken fragments of cubical shape. In the tests of the three gravels, the rounded samples contained a greater proportion of particles that tended toward being spherical and offered more resistance to impact than the samples containing angular particles. It is reasonable to apply the findings from the crushed-rock and hand-broken-rock tests to these tests of gravel due to the difference between the shape of the particles of rounded and angular gravel. On this basis, a sample of angular gravel would be expected to give a loss of approximately 120 percent of that found for a sample of rounded gravel of the same quality. It will be observed that approximately this same ratio was obtained in the tests of the three samples of gravel (see table 4).

Further tests to determine the effect of shape and angularity were made on samples of angular and artifically rounded rock. One large sample of crushed rock and two samples of hand-broken rock were obtained, and a portion of each was run in the Deval abrasion machine until the sharp edges and corners had been worn off. Two test samples were then prepared from each material; one sample contained fragments with sharp edges and corners; and the other was composed of rounded fragments. Each sample was tested in the Los Angeles machine and the results obtained are shown in table 5.

The angular rock shows a slightly higher loss than the rounded rock, but in no instance is the increase in wear similar to that found in the tests of gravel or crushed and hand-broken rock. It is apparent that while the sharpness of edge and corner may have some influence on the loss in the Los Angeles test, the shape of the particle exerts a much greater effect and for most purposes the sharpness of edge and corner may be ignored.

Samples of aggregates that contain large percentages of flat or elongated fragments will show a much higher percentage of wear than materials of equal hardness in which the fragments tend more toward cubical shape. This difference between fragments of different shape indicates that the desire of highway engineers to limit the percentage of flat and elongated particles in aggregates is justified. The relatively small effect of sharpness of edge and corner will permit the use of a single specification limit for crushed stone and for either rounded or angular gravel.

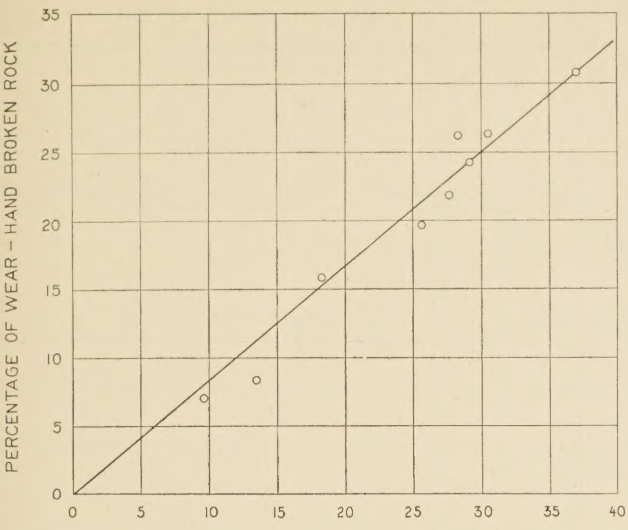

FIGURE 3.—RELATION BETWEEN TEST RESULTS ON HAND-BROKEN ROCK (CUBICAL SHAPE) AND CRUSHED ROCK (PARTIALLY WEDGE SHAPED) IN THE LOS ANGELES MACHINE.

TABLE 5.—*Percentages of wear on rounded and angular rock tested in the Los Angeles machine*

Sample number	Material	Wear on—[1] Rounded particles	Wear on—[1] Angular particles	Loss of angular particles expressed as a percentage of loss of rounded particles
		Percent	*Percent*	
34549	Crushed limestone	31.4	33.4	106
34631	Hand-broken sandstone	62.8	64.4	103
---------	Hand-broken limestone	22.4	23.9	107

[1] Each value is the average of 3 tests.

COMPARISON OF LOSSES AT 100 AND 500 REVOLUTIONS WILL INDICATE PRESENCE OF SOFT ROCK

The method of test used by California requires the determination of the percentage of wear after both 100 and 500 revolutions of the Los Angeles abrasion machine. The determination after 100 revolutions is expected to be useful in determining if soft particles are present in the material. In this connection it was desired to determine if a sample of uniform composition shows a straight-line relation between loss and number of revolutions. Table 1 shows the results of preliminary tests made with cast-iron balls. Figure 4 presents the relation between the length of test and the percentage of loss. It will be seen that for materials 1 and 2 the percentage of loss varies directly with the number of revolutions. Material 3, however, is of nonuniform hardness since the percentage of loss at 100 revolutions is proportionately greater than that at 500 revolutions.

Results of tests to determine the effect of known amounts of soft rock in the sample are shown in table 6 and figures 5 and 6. A hard limestone of uniform composition was used as the base material, and soft rock of varying amounts and sizes was added to it to determine the effect on percentage of wear.

In the first series of tests the amount of soft rock in each sample was held constant at 10 percent of the total weight of the sample while the size of the fragments of soft rock was varied. Tests were made with the soft rock contained entirely in each separate size and also

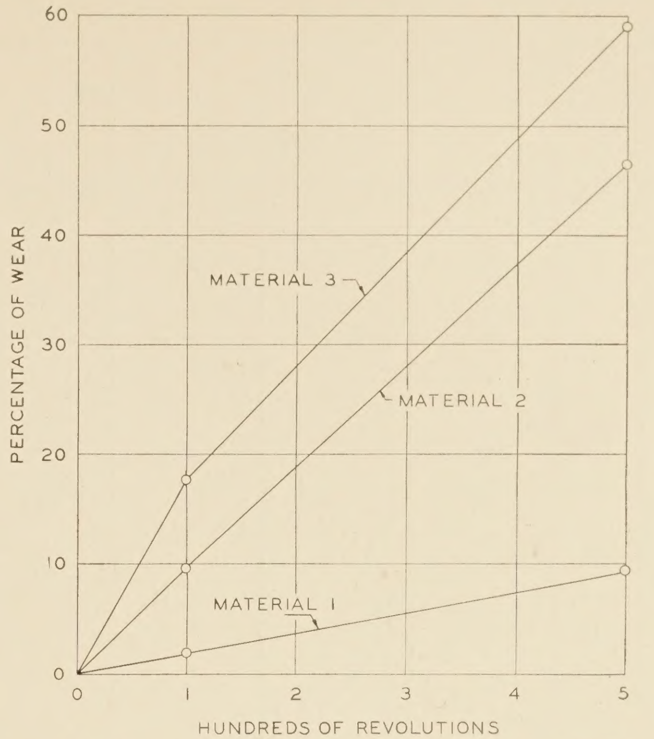

FIGURE 4.—RELATION BETWEEN LENGTH OF TEST AND PERCENTAGE OF WEAR, SHOWING EFFECT OF SOFT PARTICLES IN MATERIAL.

with the soft rock distributed in size from 1½ to ½ inch in the same proportions as is specified for the total sample. Determinations of the percentage of wear were made at 100 and 500 revolutions. As shown in figure 5, the loss at 100 revolutions is affected slightly by the size of the soft rock fragments, the loss increasing

TABLE 6.—*Percentages of wear for different sizes and amounts of hard and soft rock*

FIRST SERIES

Composition of sample: Hard rock	Composition of sample: Soft rock	Classification of soft rock: Type	Classification of soft rock: Size	Wear at—100 revolutions	Wear at—500 revolutions
Percent	*Percent*		*Inches*	*Percent*	*Percent*
90	10	Dolomite	1½-1¼	11.2	40.3
90	10	do	1¼-1	12.1	40.2
90	10	do	1 - ¾	13.3	40.2
90	10	do	¾- ½	13.9	40.1
90	10	do	1½- ½	13.0	39.9
90	10	Sandstone	1½-1¼	10.1	39.1
90	10	do	1¼-1	10.9	38.9
90	10	do	1 - ¾	11.3	39.0
90	10	do	¾- ½	13.1	38.8
90	10	do	1½- ½	11.4	39.4

SECOND SERIES

Composition of sample: Hard rock	Composition of sample: Soft rock	Classification of soft rock: Type	Classification of soft rock: Size	Wear at—100 revolutions	Wear at—500 revolutions
100	0	None	--------	8.0	35.7
95	5	Dolomite	1½- ½	10.7	37.2
90	10	do	1½- ½	13.0	39.9
80	20	do	1½- ½	18.0	45.0
0	100	do	1½- ½	44.0	98.5
95	5	Sandstone	1½- ½	9.5	36.9
90	10	do	1½- ½	11.4	39.4
80	20	do	1½- ½	14.6	45.0
0	100	do	1½- ½	33.6	94.7
95	5	Limestone	1½- ½	8.0	35.4
90	10	do	1½- ½	8.6	37.0
80	20	do	1½- ½	9.0	38.9
0	100	do	1½- ½	12.3	55.4

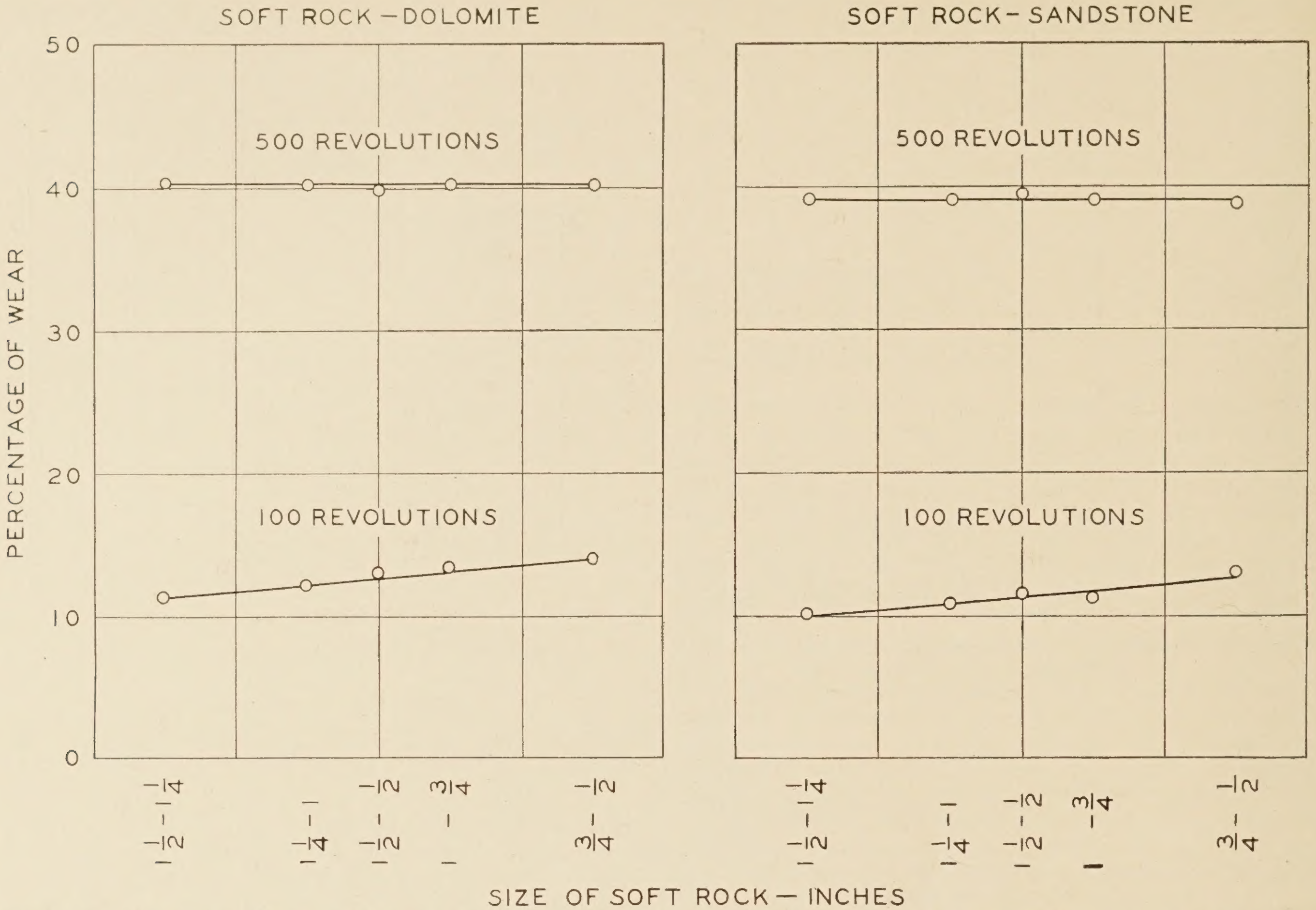

FIGURE 5.—EFFECT OF SIZE OF SOFT ROCK FRAGMENTS; EACH SAMPLE CONTAINED 10 PERCENT (BY WEIGHT) OF SOFT ROCK.

with reduction in size. At 500 revolutions, however, the size of the soft fragments has no apparent effect on the percentage of wear.

In the second series of tests the soft rock was distributed in all sizes of each sample in proportion to the amount of each size in the total sample. Soft rock amounting to 5, 10, and 20 percent of the total weight of the sample was used. The results are shown in figure 6. Tests were also made on samples composed entirely of hard or soft rock. The hard-rock sample gave a practically straight-line relation between percentage of wear and number of revolutions. With the addition of soft rock, the loss at 100 revolutions was more than one-fifth of the loss at 500 revolutions, and the curve assumed a characteristic hump denoting a material of nonuniform hardness. It is of interest to note that the actual loss under test of a mixture of hard and soft rock agrees fairly well with a weighted loss computed from the percentages of wear for the separate materials.

It does not appear possible to determine the percentage of soft rock in a test sample entirely by inspection of the results of the 100- and 500-revolution tests. Figure 6 shows that the difference in slope of the lines from zero to the 100-revolution point, and between the 100- and 500-revolution points, may be used to indicate the relative effect of soft rock in the test sample. This difference in slope increases with increase in the amount of soft rock present. It is possible to determine if the sample under test contains soft rock, but whether the adulterating material consists of a small amount of very soft rock or a large amount of moderately soft rock cannot be determined by the present method of test. The test results give a general indication of the uniformity of the sample and in certain cases this may be of considerable interest. It is possible that some difference may be found by determinations of the loss at some point of the test other than at 100 and 500 revolutions, or that a complete mechanical analysis of the sample after testing will show the character of the adulterating material more clearly.

COMPARISON OF TEST RESULTS WITH SERVICE RECORDS SHOWS ADVANTAGES OF LOS ANGELES TEST METHOD

During the winter of 1933 a number of research organizations studied the problem of devising a satisfactory method of determining the quality of crushed material proposed for use in road surfacing. Reports from a number of different sources stated that the results of the Deval abrasion test bore no relation to the service record of materials used in surface treatment or other types of low-cost road construction. The extensive use of these types of construction necessitated the development of a test that would indicate the suitability of materials for use in this work. One proposed test was to determine the resistance of crushed and graded material to the crushing action of

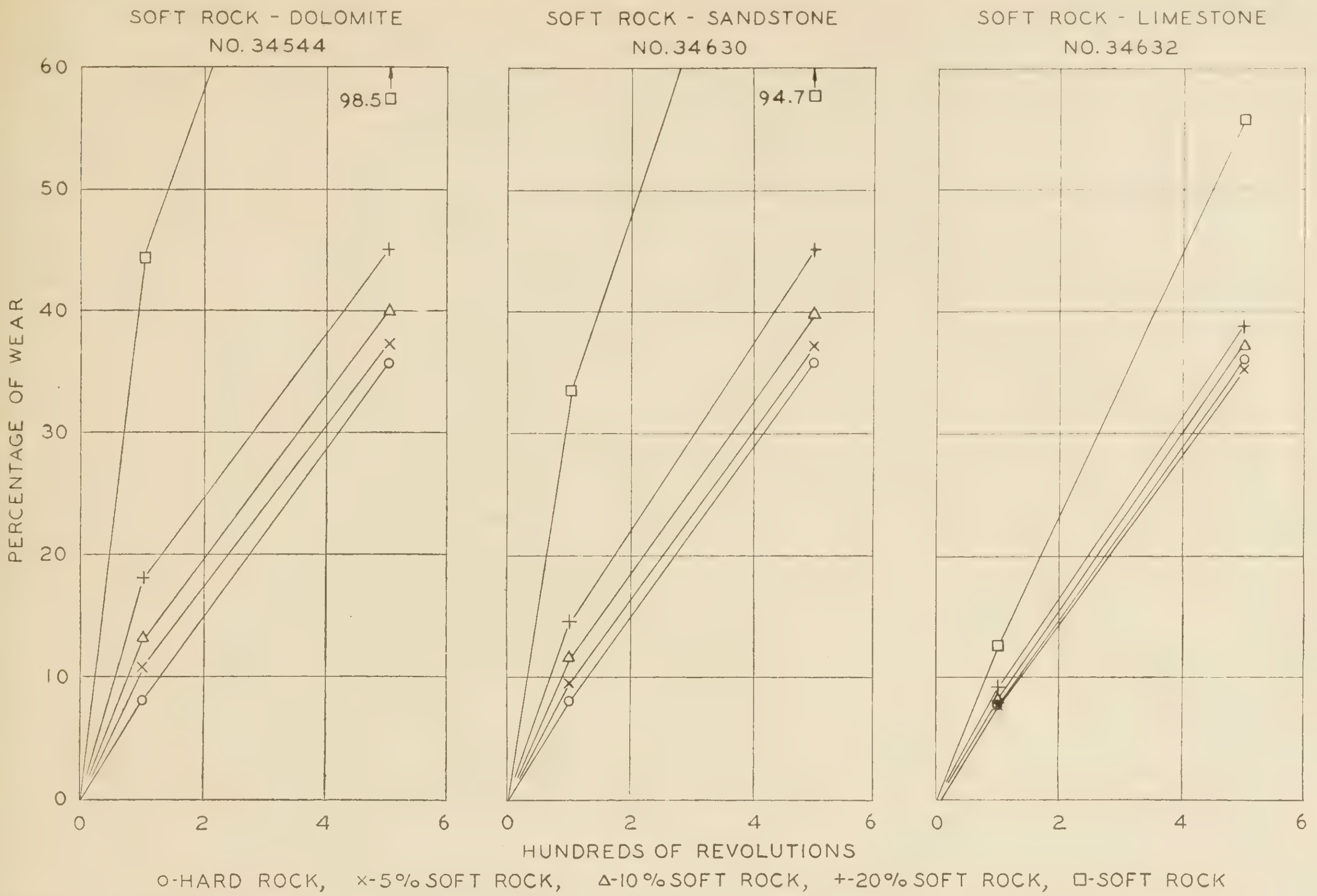

FIGURE 6.—RELATION BETWEEN LENGTH OF TEST AND PERCENTAGE OF WEAR, SHOWING EFFECT OF VARYING AMOUNTS OF SOFT ROCK.

a heavy roller in passing over a thin layer of the material.[8] Although excellent results were obtained by the roller test, the labor and time required rendered it unsuitable as an acceptance test and it was suggested that possibly the less-involved Los Angeles abrasion test could be used to derive information of equal value.

It was realized that in order to cover the range in size of materials used in surface-treatment work provision should be made for testing aggregate having a maximum size of about ¾ inch. In other types of low-cost road improvement the aggregate has a maximum size of about 1½ inches, and it was decided to test samples having gradings suitable for each of these classes of work. In preparing these samples, sieves were used rather than screens since it is the general practice to use square openings in the analysis of this class of materials.

After considerable experimenting, two gradings for the Los Angeles abrasion test were adopted that were believed to be suitable for testing practically any size of material used in bituminous or concrete pavements. It was found that if the amount of abrasive charge for the smaller grading was made slightly less than that for the larger grading, the loss for both gradings would be approximately the same. This permits the establishment of a single specification limit for a material irrespective of the grading used in the test. The gradings and abrasive charges finally adopted are given in table 7.

TABLE 7.—*Composition of sample for Los Angeles abrasion test*

GRADING OF MATERIAL

Size of square opening	Grading B	Grading D
	Grams	*Grams*
1½ to 1 inch	1, 250	
1 to ¾ inch	1, 250	0
¾ to ½ inch	1, 250	2, 500
½ to ⅜ inch	1, 250	2, 500
Total	5, 000	5, 000

ABRASIVE CHARGE

Number of 1⅞-inch balls	12	11
Total weight, grams	5, 000±5	4, 583±5

Some concern was expressed as to the possibility that with the change from the previously used grading A (round openings) to gradings B and D, the relations established for grading A could not be applied to the other gradings. However, it was found that the losses for grading B were so nearly the same as those for grading A that for all practical purposes the established data could be applied to test results for grading B.

In order to obtain definite information regarding the significance of the Los Angeles abrasion test in terms of service behavior, samples of crushed rock, gravel, and slag that had been used in surface-treatment of roads were obtained from a number of State highway depart-

[8] A simple and inexpensive machine for this test is described in a summary of research activities by State highway departments in Rock Products, vol. 34, no. 2, pp. 51-57, Jan. 17, 1931. A more elaborate apparatus is described in A Laboratory Service Test for Pavement Materials, by A. T. Goldbeck, J. E. Gray, and L. L. Ludow, Proceedings of American Society for Testing Materials, vol. 34, Part II, 1934.

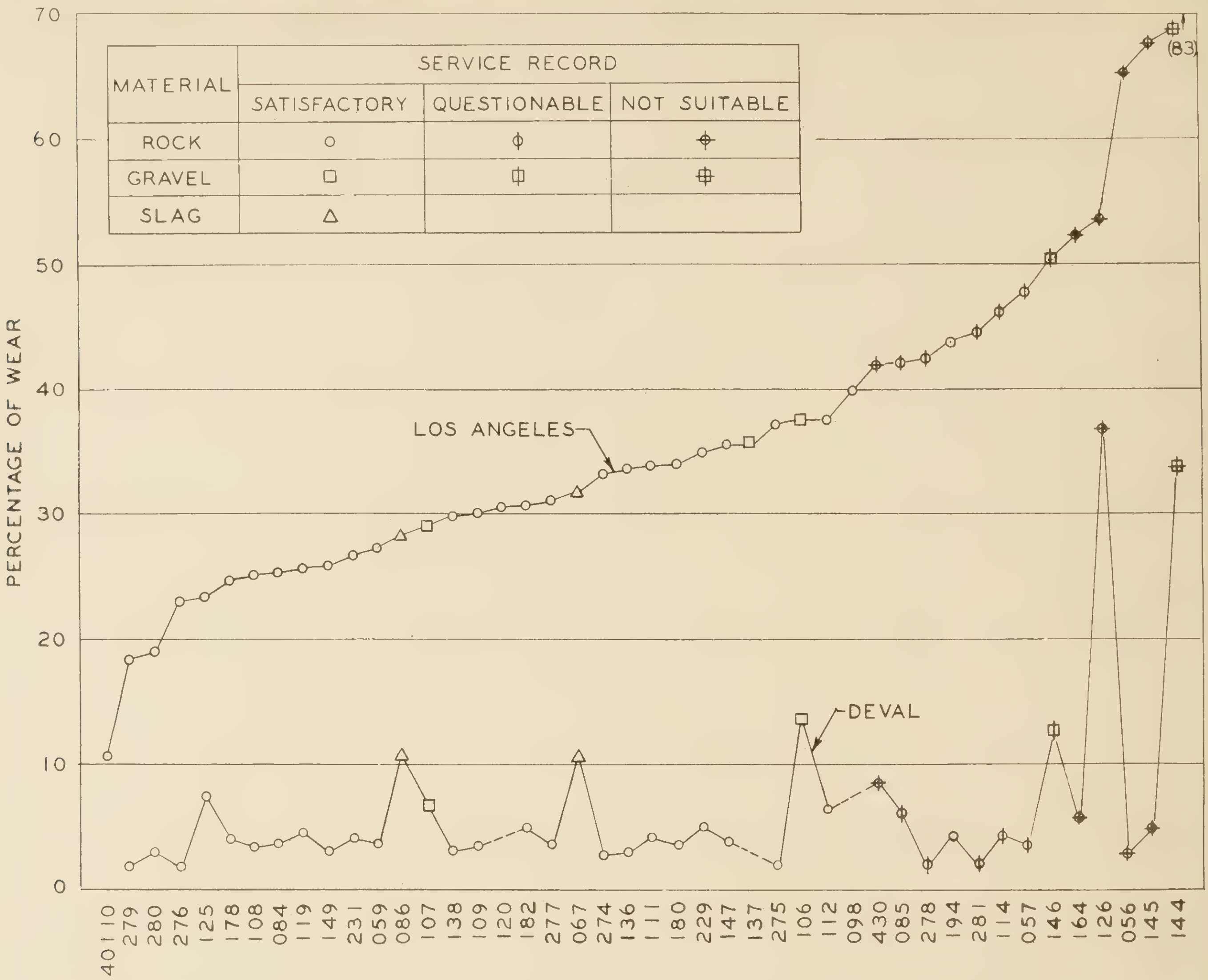

FIGURE 7.—COMPARISON OF LOS ANGELES AND DEVAL ABRASION TEST RESULTS WITH SERVICE RECORD.

ments. Tests of these materials were made in the Los Angeles abrasion machine using gradings A, or when possible using gradings B and D. In the majority of instances, at least three tests were made with each grading. The results of these tests are shown in table 8. In figure 7 a very close agreement is shown between the average results of the Los Angeles abrasion test and the service records of the materials. With the exception of one sample, all materials that were found to be of satisfactory quality in service show losses in the Los Angeles abrasion test of 40 percent or less. Materials of questionable suitability show losses between 40 and 50 percent, and, with one exception, materials that had been found to be unsuitable for use had losses of over 50 percent.

No relation was found between the service record and the loss in the Deval abrasion test. Of 10 samples of rock reported as questionable or unsatisfactory, 8 had percentages of wear of 6 or less and would be considered suitable for use under many present specifications. The one sample of gravel that was reported as questionable had a Deval loss of 12.4 percent and would also probably be accepted for use on the basis of present standard methods of testing coarse aggregates. The great difference in the suitability of the Los Angeles and Deval tests in showing clearly the quality of coarse aggregate is well illustrated in figure 7. As an example, samples 40279 and 40281 had almost the same percentage of wear in the Deval test but in the Los Angeles test the latter material had over twice the loss of the former.

These comparisons between losses in the Los Angeles abrasion test and service records were made on materials from 44 different sources. It is believed that the remarkable concordance of the results justifies the tentative establishment of a loss in the Los Angeles abrasion test of 40 percent as an acceptable limit for material that will prove satisfactory for use in surface-treatment work.

The tested samples of both gradings B and D had nearly equal percentages of wear. As shown in figure 8, in only five samples does the loss for one grading differ by more than 3 percent from that for the other. For 3 of these 5 samples, the loss for grading D is the greater, and it is believed that in the crushing operations the softer rock was reduced in size to a greater extent than

Table 8.—*Comparison of Los Angeles and Deval abrasion test results with service behavior of materials*

Sample no.	Location	Kind of material	Percentage of wear using— Deval test	Los Angeles test Grading A	Los Angeles test Grading B	Los Angeles test Grading D	Reported service record
			Percent	*Percent*	*Percent*	*Percent*	
40110	Wisconsin	Altered basalt	-----	-----	-----	10.5	Satisfactory.
40280	Virginia	Argillaceous dolomite.	2.9	-----	17.2	20.9	Do.
40279	do	Aplitic granite	1.7	-----	17.4	19.2	Do.
40125	Ohio	Argillaceous limestone.	7.3	-----	20.2	26.0	Do.
40276	Virginia	Amphibolite	1.7	-----	23.0	22.8	Do.
40178	New York	Argillaceous limestone.	3.9	-----	24.8	24.3	Do.
40084	Georgia	Dolomite	3.6	-----	25.2	-----	Do.
40108	Wisconsin	do	3.2	-----	25.3	24.6	Do.
40119	Pennsylvania	Quartzite	4.4	-----	26.5	24.6	Do.
40149	Tennessee	Argillaceous limestone.	3.0	-----	26.6	25.0	Do.
40059	Georgia	Limestone	3.6	27.2	-----	-----	Do.
40231	New York	Argillaceous limestone.	4.0	-----	28.0	25.4	Do.
40086	Alabama	Slag	10.5	-----	28.2	-----	Do.
40107	Wisconsin	Gravel	6.6	-----	29.1	28.9	Do.
40109	do	Dolomite	3.3	-----	30.1	30.0	Do
40138	Tennessee	Limestone	3.0	-----	30.2	29.4	Do.
40182	New York	Crystalline argillaceous limestone.	4.9	-----	-----	30.6	Do.
40277	Virginia	Argillaceous limestone.	3.5	-----	31.1	30.7	Do.
40120	Illinois	Dolomite	-----	-----	31.3	29.6	Do.
40067	Georgia	Slag	10.5	31.6	-----	-----	Do.
40274	Virginia	Granite	2.6	-----	32.7	33.4	Do.
40180	Michigan	Limestone	3.4	-----	33.7	33.8	Do.
40111	Wisconsin	Dolomite	4.1	-----	34.4	33.0	Do.
40136	Tennessee	Limestone	2.8	-----	34.6	32.4	Do.
40229	New York	Argillaceous limestone.	4.9	-----	34.8	-----	Do.
40137	Tennesee	Gravel	-----	-----	34.1	37.7	Do.
40147	South Carolina	Granite	3.8	-----	35.0	36.0	Do.
40275	Virginia	do	1.8	-----	36.6	37.6	Do.
40106	Wisconsin	Gravel	13.4	-----	-----	37.5	Do.
40112	do	Argillaceous limestone.	6.3	-----	39.4	35.6	Do.
40098	Oklahoma	Limestone	-----	-----	40.4	39.4	Do.
40194	New York	Biotite gneiss	4.2	-----	47.9	39.5	Do.
40085	Georgia	Dolomitic marble	6.0	-----	41.9	-----	Questionable.
40278	North Carolina	Granite	1.9	-----	41.0	43.6	Do.
40281	Virginia	do	1.9	-----	41.8	46.9	Do.
40114	Maryland	Dolomitic marble	4.1	-----	47.0	45.4	Do.
40057	Georgia	Granite	3.5	47.7	-----	-----	Do.
40146	South Carolina	Gravel	12.4	-----	50.0	51.0	Do.
40430	Tennessee	Limestone	8.5	-----	41.4	42.0	Not suitable.
40164	Michigan	do	5.7	-----	53.0	51.0	Do.
40126	Ohio	do	36.8	-----	54.8	52.2	Do.
40056	Georgia	Granite	2.8	65.2	-----	-----	Do.
40145	South Carolina	Gneissoid granite	4.8	-----	67.6	-----	Do.
40144	do	Gravel	33.6	-----	83.0	-----	Do.

the harder rock. This would account for the greater loss of the finer grading. The other two samples, a biotite gneiss and an argillaceous limestone, contained an appreciable percentage of flat fragments. The excessive loss for grading B is attributed to these flat fragments that are found to a greater extent in the larger sizes of the sample. For all samples tested, the average difference between the losses for gradings B and D is only 1.9 percent. It is believed that either grading may be used in acceptance or control tests of coarse aggregates.

CONCLUSIONS

The results of this investigation demonstrate that the Los Angeles abrasion machine is superior to the present standard Deval machine in the following respects:

1. Los Angeles abrasion tests can be made much more rapidly and are more accurate than Deval abrasion tests.

2. Both round and angular particles may be tested with very little difference in percentage of wear due to the degree of angularity.

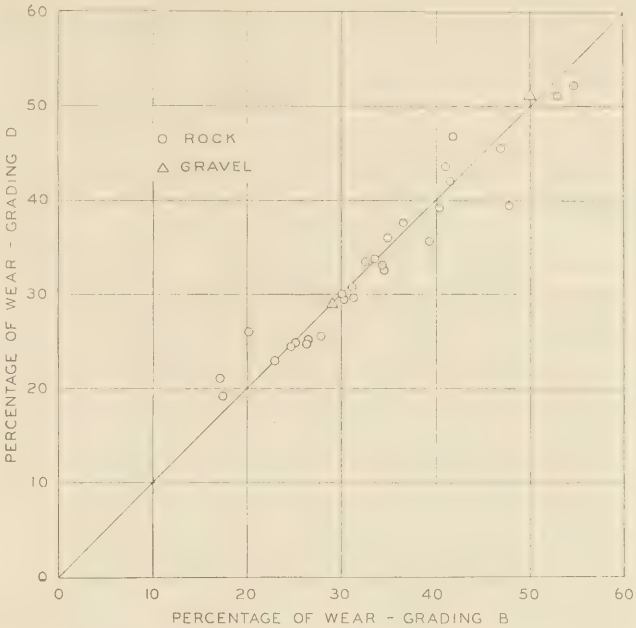

Figure 8.—Relation Between Losses of Gradings B and D by Los Angeles Abrasion Test.

3. The Los Angeles abrasion test result is greatly affected by the shape of the particles. Thus the presence of flat or elongated fragments in a sample increases the loss in the Los Angeles test, while in the Deval test these possibly objectionable particles might have little effect on the percentage of wear.

4. The presence of soft or friable rock can be detected with the Los Angeles test but not with the Deval abrasion test.

5. A definite relation seems to exist between the loss in the Los Angeles abrasion test and the service record of materials used in surface treatment of roads. Based on the results available to date, materials having a loss in the Los Angeles abrasion test of 40 percent or less may be expected to furnish satisfactory results when used in surface treatments.

6. Differences in the volume of different test samples due to differences in specific gravity need not be considered due to the relatively large capacity of the Los Angeles abrasion machine.

7. Dust produced in the test does not affect the result as it does in the Deval test.

8. The Los Angeles test is made on material as prepared for use on the project, while the Deval test for rock requires the use of ledge rock that may not represent the material actually used. The two gradings, B and D, proposed for use in the Los Angeles abrasion test, furnish practically the same result, and specification tests may be made using the grading which can most readily be prepared from the material submitted for test.

9. The effect of personal equation in the preparation of the test sample is largely eliminated in the Los Angeles test method.

A disadvantage of the Los Angeles test is that no provision is made for testing ledge rock taken from undeveloped quarries. However, as shown in figure 3, a fairly definite relation exists between samples of crushed and hand-broken rock, and tests could be made on the ledge rock provided the result is corrected to agree with those for the crushed material.

A ROLLER-TESTING MACHINE FOR MEASURING THE STABILITY OF BITUMINOUS MIXTURES

BY THE DIVISION OF TESTS, U. S. BUREAU OF PUBLIC ROADS

Reported by E. L. TARWATER, Assistant Highway Engineer

DURING recent years numerous laboratory studies have been made of hot asphaltic paving mixtures of both the fine- and coarse-graded types. These studies have been directed primarily towards the development of laboratory tests for predetermining the actual road behavior of various combinations of mineral aggregates and asphaltic materials. The studies have been carried on by various organizations, using different kinds of apparatus and methods of testing. As a result there are now in use several types of tests that appear to be of value in the study and design of bituminous mixtures. All of these tests are designed to measure the probable stability or resistance to displacement under traffic, and a majority of them involve the measurement of resistance to shearing stresses. Two of the better-known tests are the Hubbard-Field and the Skidmore tests.[1]

In the Hubbard-Field test a compressed specimen 2 inches in diameter and 1 inch deep is forced through a 1¾-inch circular opening. The load in pounds required to do this is designated as the stability of the specimen. Specimens are normally tested at a temperature of 60° C. This test is used in the study and design of mixtures of the sheet asphalt type. The Hubbard-Field testing machine is illustrated in figure 1.

The Skidmore test is used for both the fine- and coarse-graded types of mixtures, and the stability is designated as the load in pounds required to shear off the free section of a cylindrical test specimen, part of which is held in a frame or mold. This test is made by applying the load in successive increments. Specimens are tested at a temperature of 60° C. Mixtures containing both fine and coarse aggregate are tested in this manner, the sizes of the test specimens and testing apparatus being increased for the coarse-aggregate mixtures.

Another form of shear test is the extrusion test developed by the Bureau.[2] In this test specimens 2¼ inches by 8 inches by 6 inches deep are formed with a power tamping device and, after being brought to a temperature of 60° C., are placed in a testing mold. A uniformly distributed load is applied to the top of the specimen, causing the mixture to extrude through openings in the bottom and ends of the mold. Stability is designated as the maximum load in pounds supported by the specimen.

The results of this test are influenced by slight variations in the composition of mixtures, and the test was thought to be well adapted to the study of resistance to displacement. However, in testing mixtures containing appreciable amounts of aggregate larger than ½ inch, erratic results were obtained and were attributed to the arching action of the coarser particles. It seemed impossible to eliminate this difficulty without increasing the size of the specimen to unwieldy proportions. It was realized also that the test bore little relation to the action of traffic, and it was thought desirable to develop a method of testing that would more closely simulate actual conditions of use.

ROLLER-STABILITY MACHINE DESCRIBED

With this objective, the bureau designed and constructed a machine in which specimens 8 inches by 4 inches by 2¼ inches deep were subjected to a rolling load causing longitudinal deformation.[3] This roller machine was later rebuilt to eliminate certain objectionable features and as rebuilt was used in the work covered by this report. The machine in its present form is designed to subject the test specimen to the compressive action of smooth metal rollers which pass over it slowly and without impact. The rollers move in one direction under controlled conditions of speed, load, and temperature.

Figure 2 shows a general view of the testing machine. It consists of a rigid base, *A*, carrying the driving motor on one end and a countershaft on the other. In the center of the base there is a pair of vertical guides, *B*. Eleven hollow steel rollers, *C*, 4 inches in diameter and 3 inches long, are arranged between and at equal intervals along the peripheries of two steel disk side plates, *D*. These plates are rigidly fastened to a short horizontal shaft that rotates in bearings mounted on a frame, *E*. These parts constitute the roller assembly and this entire unit is free to move vertically between the guides, *B*. The roller assembly is driven by suitable gearing and may be lifted at will by means of a power-driven elevating mechanism at the top of the guide frame.

The total weight of the roller assembly is 450 pounds, all of which is normally imposed on the test specimen. It is possible, however, to reduce the pressure on the specimen by means of a suspended counterweight attached to the top of the yoke (*E*, fig. 2). This attachment was not on the machine when the photograph was taken. The roller assembly moves at a speed of 2.1 revolutions per minute during tests.

Directly underneath the roller assembly is a rectangular steel tank or water bath, *F*, in which the test specimen is mounted. When the roller assembly is rotated there is a periodic variation of its effective radius (the distance between the surface of the test specimen and the center of the disks, *D*). When one of the rollers is directly below the axis of rotation of the disks this effective radius is a maximum (9.4 inches), and when the midpoint between two of the rollers is directly below this axis the effective radius is a minimum (9.1 inches). In the first position, one roller rests in

[1] Circular no. 34 of the Asphalt Association.

[2] Emmons and Anderton, A Stability Test for Bituminous Paving Mixtures. A. S. T. M. Proc., vol. 25, part 2, p. 346.

[3] Researches on Bituminous Paving Mixtures, by W. J. Emmons. PUBLIC ROADS, vol. 7, no. 10, December 1926.

FIGURE 1.—HUBBARD-FIELD STABILITY TESTING MACHINE.

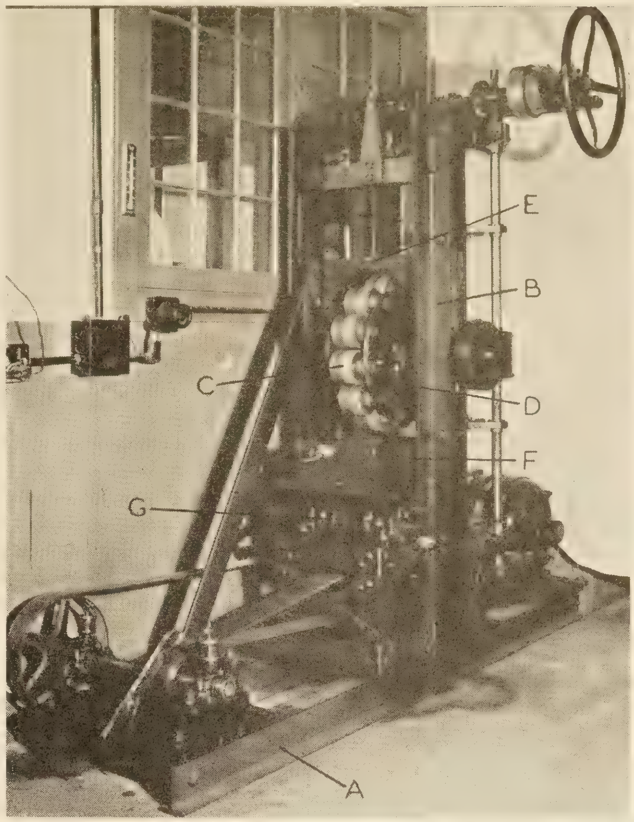

FIGURE 2.—ROLLER STABILITY TESTING MACHINE.

the center of the specimen and carries all of the weight, while in the second position two rollers rest on the specimen and each carries half of the imposed weight. If the tank containing the specimen were fixed in elevation, this variation in the effective radius of the roller assembly would cause the entire mass of the assembly to be raised and lowered through a distance of about 0.3 inch 11 times per revolution. In the first machine built the tank and specimen were in a fixed position, and this motion took place and produced an undesirable impact on the test specimen.

In the rebuilt machine the impact has been eliminated by mounting the specimen bath on four hardened-steel cams (*G*, fig. 2), shaped so that the vertical motion imparted to the specimen by the cams exactly compensates for the changes in effective radius of the roller assembly. The cams are synchronized with the motion of the rollers through suitable gears. The effectiveness of the arrangement in preventing impact is evidenced by the absence of vertical motion of the roller assembly.

The specimen is confined in an adjustable testing mold that has one end and the top surface open as illustrated in figure 3. Upward deformation at the sides of the specimen is prevented by a section of angle iron (*K*, fig. 4), that is clamped over the mold's edges and extends ½ inch over the top of the sample at either side, leaving a 3-inch open surface over which the rollers pass. Rotation of the rollers is induced as they pass over the top surface of the specimen, tending to deform it longitudinally through the open end of the mold. Deformation is measured with an Ames dial (*H*, fig. 4), and a counter, *J*, records the number of roller passages over the specimen. Figure 4 shows the specimen and rollers in testing positions.

LONGITUDINAL DEFORMATION A MEASURE OF STABILITY

The resistance of a test specimen to longitudinal deformation is an indication of its stability. In this study stability was defined as the number of roller passages required to produce a deformation of 0.3 inch. This limit of deformation was adopted after a preliminary investigation showed that for movements in excess of 0.3 inch the relation between the number of roller passages and the amount of deformation became erratic. Figure 5 shows the variations in test results for comparable test specimens. The curves represent test results with three different mixtures from each of which two specimens identical in composition and density were molded. This figure shows that test results on the comparable sheet asphalt specimens, *A* and *B*, and *C* and *D*, were identical up to 0.3 inch deformation, and that considerable variation occurred beyond this point. For the bituminous concrete specimens, *E* and *F*, very close agreement in test results was obtained up to 0.3 inch deformation, while beyond this point an even greater variation occurred than for the sheet-asphalt specimens.

The temperature of the test specimen was held at 60° C during the test. The selection of this temperature was based upon a study made by the Bureau [4] some years ago in which 60° C. was the highest temperature found within a road surface under actual field

[4] Temperature as a Factor in the Stability of Asphaltic Pavements, by W. J. Emmons and B. A. Anderton. PUBLIC ROADS, vol. 7, no. 2, April 1926.

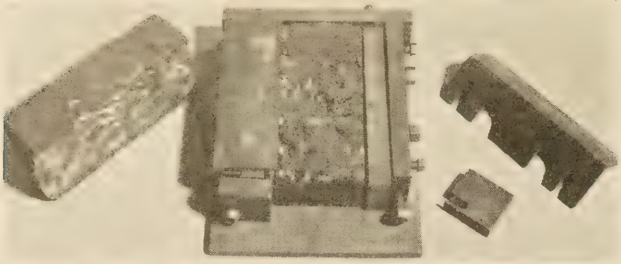

Figure 3.—Mold for Holding Specimens During Test in the Roller Stability Machine.

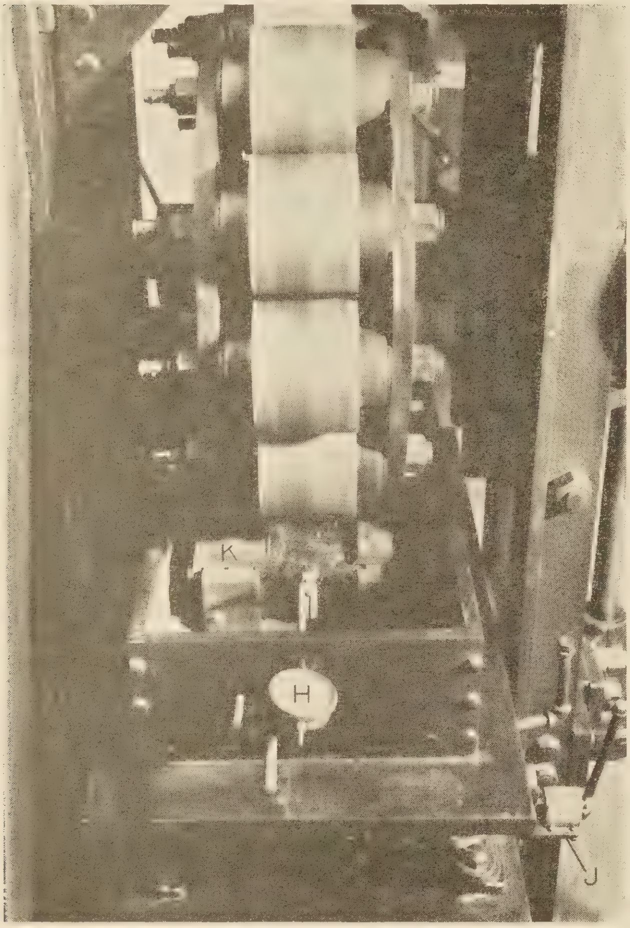

Figure 4.—A Specimen in Place Ready for Testing.

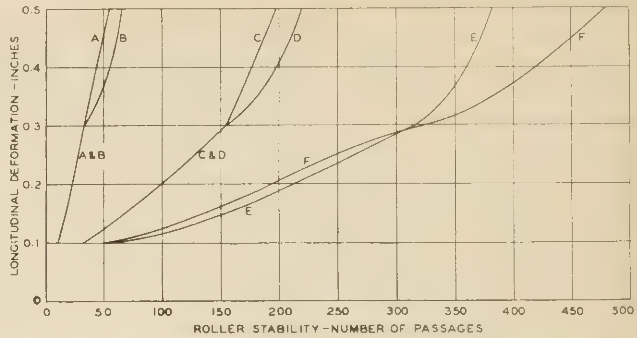

Figure 5.—Relation of Number of Roller Passages to Longitudinal Deformation.

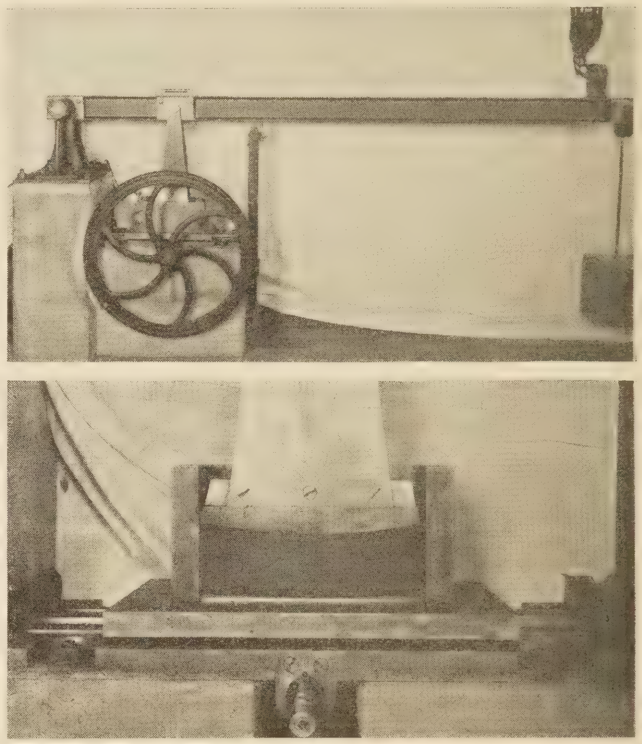

Figure 6.—The Upper Picture Is a General View of the Molding Machine. The Lower Picture Shows a Sheet-Asphalt Specimen in the Molding Machine.

conditions. This temperature was recorded a number of times, indicating that it was not unusual, and it has generally been used in stability test work by other investigators. The stability values given herein consequently represent the minimum that the mixtures may be expected to possess under normal service conditions.

The power tamping device, formerly used in forming specimens for the extrusion test and for the first roller machine, was discarded in favor of a molding machine in which the specimens are compacted by a rolling load. This machine, illustrated in figure 6, and described in Public Roads, vol. 10, no. 2, April 1929, more nearly simulates actual compaction on the road and produces specimens sufficiently uniform in density and of any workable density desired. This machine was used in forming specimens for the roller stability tests, and also in forming specimens from which cores for the Hubbard-Field test were taken.

The adequacy of any laboratory test for determining the relative stability of paving mixtures is dependent upon its ability to distinguish between mixtures of variable compositions, whether laboratory prepared specimens or sections taken from pavements that have shown different service behaviors. Hubbard and Field have demonstrated that their stability test is quite sensitive to variations in consistency and quantity of asphalt cement, kind and quantity of filler, and character and grading of the sand in sheet asphalt pavements. They have also shown,[5] by tests on cores taken from pavements in use, that the stability values obtained in the laboratory are a measure of the resistance of the surfaces to displacement under traffic. The test as designed by them, or as slightly modified to utilize available laboratory equipment, is widely used as a method of measuring stability.

[5] Correlation of the Stability Test with the Behavior of Pavements under Traffic. Proc. Fifth Annual Asphalt Paving Conference.

TESTS MADE ON SHEET ASPHALT AND ASPHALTIC CONCRETE MIXTURES

In order to determine the value of the roller stability machine, sheet asphalt mixtures of variable composition were tested for stability in both the roller-stability and the Hubbard-Field machines. The relative stabilities of bituminous-concrete mixtures of variable compositions, both prepared in the laboratory and taken from surfaces under traffic, were also determined with the roller-stability apparatus.

In this investigation the same kinds of materials were used throughout, that is, one asphalt cement, one limestone filler, and one type and grading of sand and coarse aggregate. The coarse aggregate in the bituminous concrete mixtures was a relatively soft limestone and was used for the purpose of determining whether crushing of the aggregate would occur either in molding or in testing specimens. Careful examination of the specimens showed that little or no crushing occurred. The Potomac River sand used was angular to subangular, consisting essentially of quartz, shale, and sandstone, and containing some grains of chert, schist, feldspar, mica, and clay.

The characteristics of the various materials used were as follows:

ASPHALT CEMENT

Specific gravity, 25°/25° C	1. 043
Flash point, °C	285
Penetration, 100 g, 5 sec., 25° C	50
Softening point, ° C	55
Ductility, 25° C., centimeters	110+
Loss on heating, 50 g, 5 hours, 163° C., percent	. 05
Penetration of residue after loss by heating	40
Total bitumen, soluble in CS_2, percent	99. 8
Organic matter insoluble in CS_2, percent	. 1
Inorganic matter insoluble in CS_2, percent	. 1
Total bitumen insoluble in 86° B. naphtha, percent	28. 5

LIMESTONE DUST

Specific gravity	2. 701
Percentage retained on no. 200 sieve	12. 0
Percentage of voids (Bureau vibrator method)	37. 6

CRUSHED LIMESTONE

Passing ¾-inch sieve, retained on ½-inch sieve, percent	52. 5
Passing ½-inch sieve, retained on no. 4 sieve, percent	22. 5
Passing no. 4 sieve, retained on no. 8 sieve, percent	25. 0
Specific gravity	2. 310
Percentage of wear	10. 4
Absorption, percent	6. 56

SAND

Passing no. 10 sieve, retained on no. 20 sieve, percent	7. 6
Passing no. 20 sieve, retained on no. 30 sieve, percent	7. 2
Passing no. 30 sieve, retained on no. 40 sieve, percent	11. 2
Passing no. 40 sieve, retained on no. 50 sieve, percent	17. 0
Passing no. 50 sieve, retained on no. 80 sieve, percent	25. 6
Passing no. 80 sieve, retained on no. 100 sieve, percent	8. 8
Passing no. 100 sieve, retained on no. 200 sieve, percent	15. 2
Passing no. 200 sieve, percent	7. 4
Specific gravity	2. 659
Percentage of voids (Bureau vibrator method)	33. 4

PREPARATION OF SPECIMENS AND METHODS OF TESTING

The proportions of the mixtures used are expressed as percentages by weight of the total and are shown in table 1. In the preparation of the test specimens the aggregates were proportioned by weight and then heated to about 184° C. The hot aggregates were then placed in a mixing pan that was indirectly heated by an oil bath. The asphalt cement, previously heated to about 168° C., was added and the mass mixed with trowels until all particles were uniformly coated. The amount of the mixture needed to make a specimen 2¼ inches thick and of the desired density was then placed in the molding machine form and rolled.

TABLE 1.—*Composition of the mixtures used in the stability determinations*

SHEET ASPHALT MIXTURES

Composition of bituminous mixtures				Composition of mineral aggregates		
Bitumen	Dust	Sand	Stone	Dust	Sand	Stone
Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
10	0	90	----------	0. 0	100. 0	----------
10	5	85	----------	5. 6	94. 4	----------
10	10	80	----------	11. 1	88. 9	----------
10	15	75	----------	16. 7	83. 3	----------
10	20	70	----------	22. 2	77. 8	----------
10	25	65	----------	27. 8	72. 2	----------
8	15	77	----------	16. 3	83. 7	----------
10	15	75	----------	16. 7	83. 3	----------
12	15	73	----------	17. 1	82. 9	----------

BITUMINOUS-CONCRETE MIXTURES

Bitumen	Dust	Sand	Stone	Dust	Sand	Stone
8	4	78	10	4. 3	84. 8	10. 9
9	4	77	10	4. 4	84. 6	11. 0
10	4	76	10	4. 4	84. 5	11. 1
11	4	75	10	4. 5	84. 3	11. 2
6	4	70	20	4. 2	74. 5	21. 3
7	4	69	20	4. 3	74. 2	21. 5
8	4	68	20	4. 4	73. 9	21. 7
9	4	67	20	4. 4	73. 6	22. 0
5	4	61	30	4. 2	64. 2	31. 6
6	4	60	30	4. 3	63. 8	31. 9
7	4	59	30	4. 3	63. 4	32. 3
8	4	58	30	4. 4	63. 0	32. 6
9	4	57	30	4. 4	62. 6	33. 0
5	4	51	40	4. 2	53. 7	42. 1
6	4	50	40	4. 2	53. 2	42. 6
7	4	49	40	4. 3	52. 7	43. 0
8	4	48	40	4. 3	52. 2	43. 5
5	4	41	50	4. 2	43. 2	52. 6
6	4	40	50	4. 2	42. 6	53. 2
7	4	39	50	4. 3	41. 9	53. 8

The required amount of rolling varied with the composition of the mixture, the load used, and the amount of compaction desired. After rolling the specimen was removed, allowed to cool to room temperature, and its density and voids were determined.

The specimens to be tested in the roller machine were placed in collapsible forms that supported the sides and prevented warping or other deformation. They were then transferred to a constant-temperature water bath at 60° C. and left until they were at a uniform temperature throughout, as determined with a thermometer embedded in a similar specimen prepared for temperature control. The time required to reach this temperature was about 3 hours. The specimens were then transferred to the testing mold and placed in the bath of the roller testing machine, the temperature of which was also maintained at 60° C. The revolving disk carrying the rollers was lowered until its full weight was carried by the specimen. A record was kept of the number of roller passages over the specimen and of the corresponding longitudinal deformations.

RESULTS OBTAINED WITH HUBBARD-FIELD AND ROLLER MACHINES COMPARED

In order to have a uniform basis for comparing the results obtained with the two testing machines, it was felt that the test specimens not only should have similar composition and physical characteristics but also

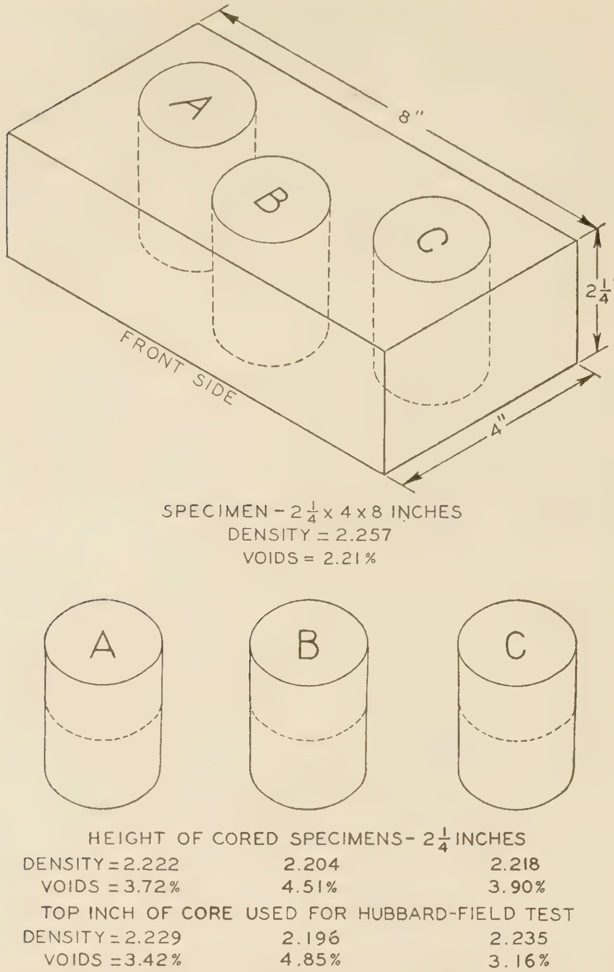

Figure 7.—Positions and Densities of Specimens Taken From Sheet-Asphalt Sample.

should be molded in the same manner. For these reasons the specimens used in the Hubbard-Field tests were obtained from the 4- by 8- by 2¼-inch blocks molded in the same manner as those tested in the roller machine. Cores of the exact test size were obtained by forcing a sharp-edged steel pipe through the specimen. The force required for cutting was obtained with a hydraulic jack. The blocks were warmed slightly to facilitate penetration with the minimum of distortion. The top 1 inch of the core was used as the specimen and the average of the test results from the three Hubbard-Field specimens taken from the molded block was reported as a single test result.

Figure 7 shows the relative positions of the cores, *A*, *B*, and *C*, taken from the 8- by 4- by 2¼-inch blocks and also shows the variation in densities and percentages of voids between the Hubbard-Field specimens and the block from which they were cored. This variation is believed to be due to particle disarrangement that occurs along the cut surfaces of the core, since previous work with the molding machine has shown that the 8- by 4- by 2¼-inch blocks are quite uniform in density throughout.[6]

Two series of mixtures of the sheet-asphalt type were used in the comparison of the two machines. In one series the percentage of dust was held constant and the percentages of sand and asphalt cement were varied. In the other series the percentage of asphalt cement was held constant and the percentages of dust and sand were varied. The percentage composition by weight of the mixtures is given in table 1 and the test results are shown in figures 8 and 9.

Figure 8 shows an increase in stability with a decrease in the percentage of voids for all three bitumen contents, the change in stability being least for the mixtures containing 12 percent of bitumen. In this mixture, a change in percentage of voids has a greater effect upon the Hubbard-Field stability than upon the roller stability. With the mixture containing 10 percent of bitumen, however, the reverse appears to be true, while for the mixture containing 8 percent of bitumen the two curves have about the same slope.

Figure 9 shows the effect of percentage of voids on the stability of mixtures containing various percentages of dust. Here, as in figure 8, the general trend of the results is the same for both methods of test. For mixtures containing 15 percent or less of dust the stability increases with a reduction in percentage of voids, while with mixtures containing 20 and 25 percent of dust the stability increases as the percentage of voids increases.

These curves show a marked similarity in the general trend of results obtained by the two methods of test. However, there is no definite mathematical relation between the stabilities determined by the two methods.

ROLLER STABILITY TEST RESULTS FOR ASPHALTIC CONCRETE MIXTURES

Asphaltic-concrete mixtures of the compositions given in table 1 also were tested in the roller machine in the same manner as the sheet-asphalt mixtures. As shown in table 1 the percentage of dust was constant for all asphaltic-concrete mixtures, the principal variables being the amounts of stone and sand used. For each of the five percentages of stone, the asphalt-cement content was varied sufficiently to produce a series of mixtures having a range in plasticity. The test results showing the relation between roller stability and percentage of voids for the different mixtures are plotted in figures 10 and 11, and the effect of the percentage of asphalt cement for varying percentages of voids is shown in figure 12.

As was found for the sheet-asphalt mixtures, an increase in stability occurs as the voids percentages are decreased for a given asphalt-cement content; an increase in stability also occurs for a decrease in asphalt-cement content when the voids percentage is kept constant. These data indicate that the roller machine distinguishes between the factors affecting the stability of asphaltic-concrete mixtures, as well as for sheet-asphalt mixtures.

ACTUAL ROAD DISPLACEMENTS COMPARED WITH ROLLER-STABILITY VALUES

Few data are available for use in correlating actual field behavior with roller stability; however, some tests have been made upon samples from pavements of known behavior. Specimens from the asphaltic-concrete sections of circular track described in Public Roads, vol. 14, no. 11, January 1934, were tested for stability in the roller machine. The analyses of the sections tested are given in table 2, and the results of the test are shown graphically in figure 13. This curve

[6] A Machine for Molding Laboratory Specimens of Bituminous Paving Mixtures, by J. T. Pauls, Public Roads, vol. 10, no. 2, April 1929.

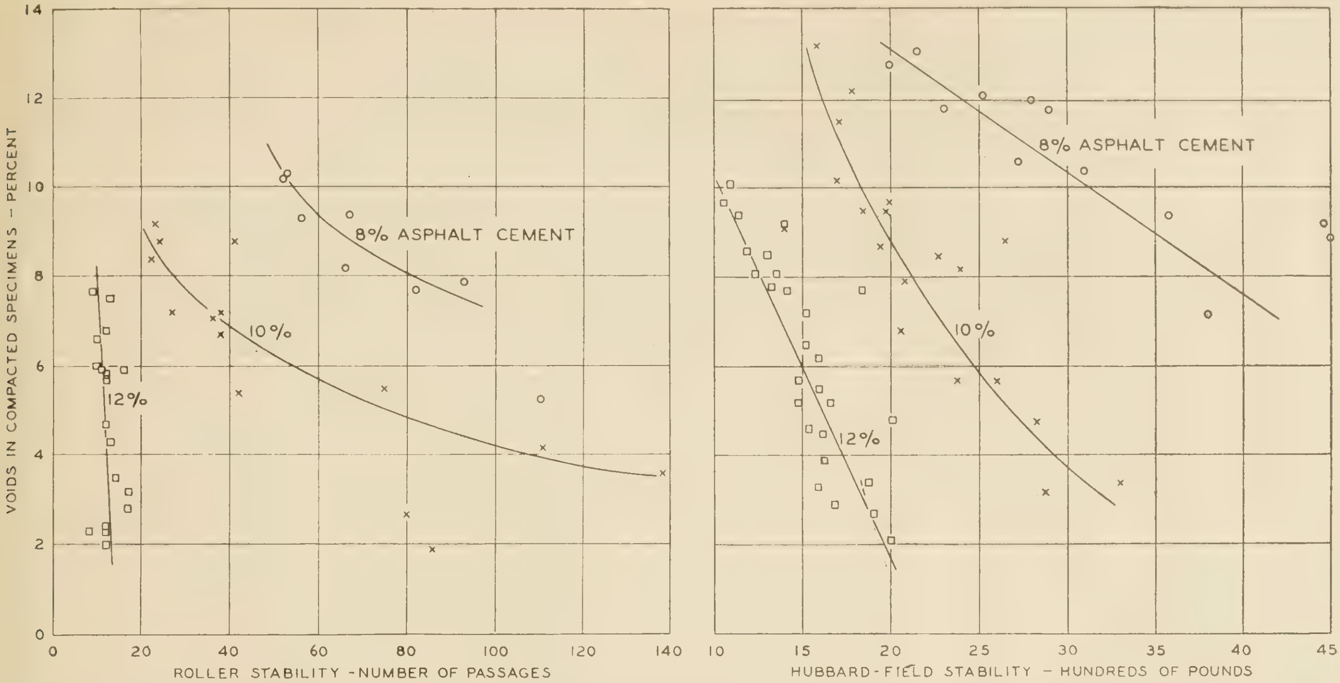

FIGURE 8.—RELATION BETWEEN STABILITY AND PERCENTAGE OF VOIDS IN SHEET-ASPHALT SPECIMENS CONTAINING 15 PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF ASPHALT CEMENT AND SAND.

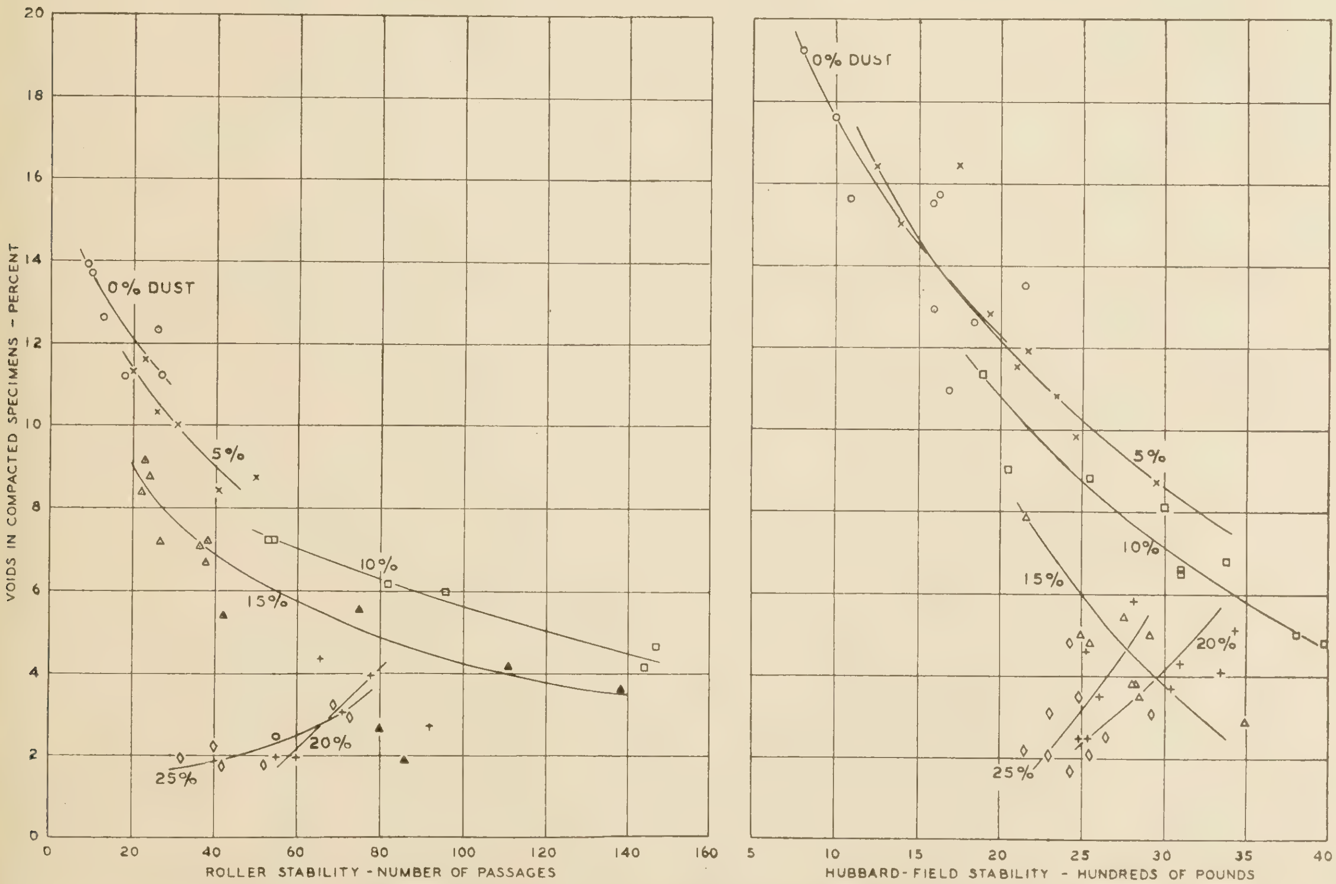

FIGURE 9.—RELATION BETWEEN STABILITY AND PERCENTAGE OF VOIDS IN SHEET-ASPHALT SPECIMENS CONTAINING 10 PERCENT OF ASPHALT CEMENT AND VARIOUS PERCENTAGES OF LIMESTONE DUST AND SAND.

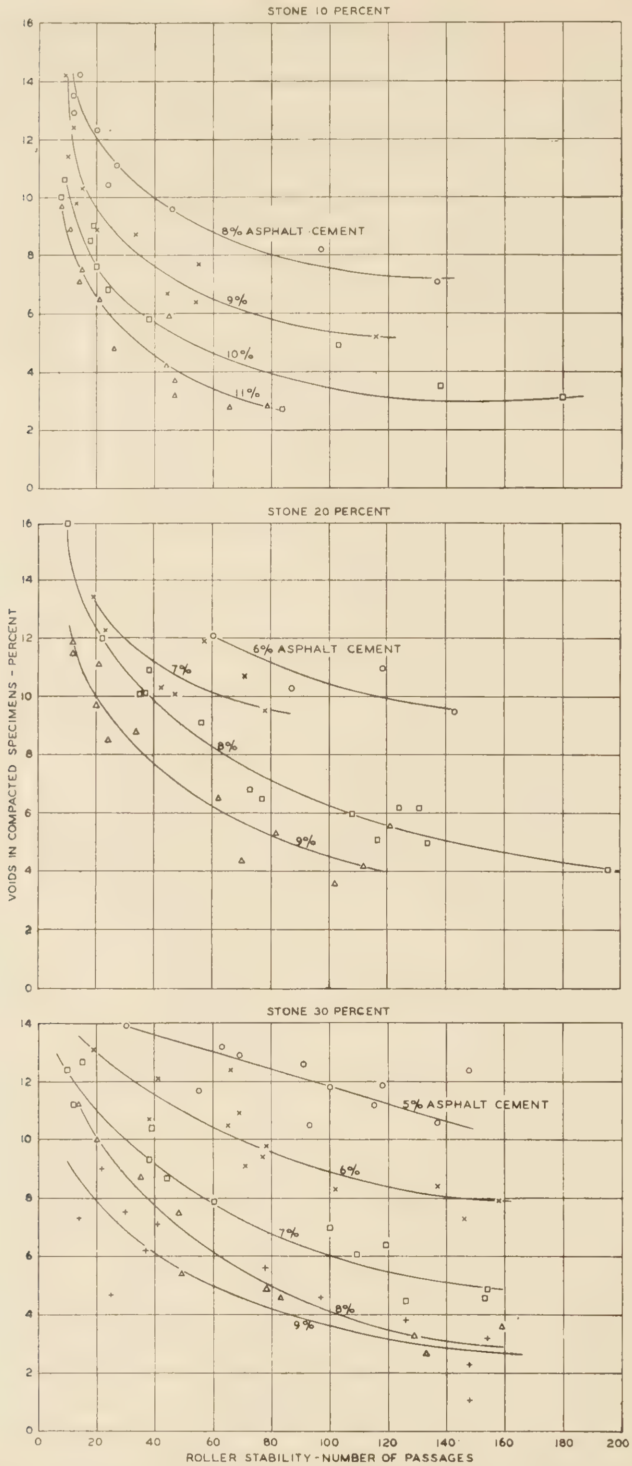

FIGURE 10.—RELATION BETWEEN ROLLER STABILITY AND PERCENTAGE OF VOIDS IN ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

shows longitudinal displacements of the bituminous concretes in inches plotted against roller-stability values. This longitudinal displacement was the total movement of 25 screws spaced 6 inches apart in a radial line on a circular test pavement and was derived by taking half of the total movement of 50 screws in two lines. The sections with the least displacement had the highest roller-stability values.

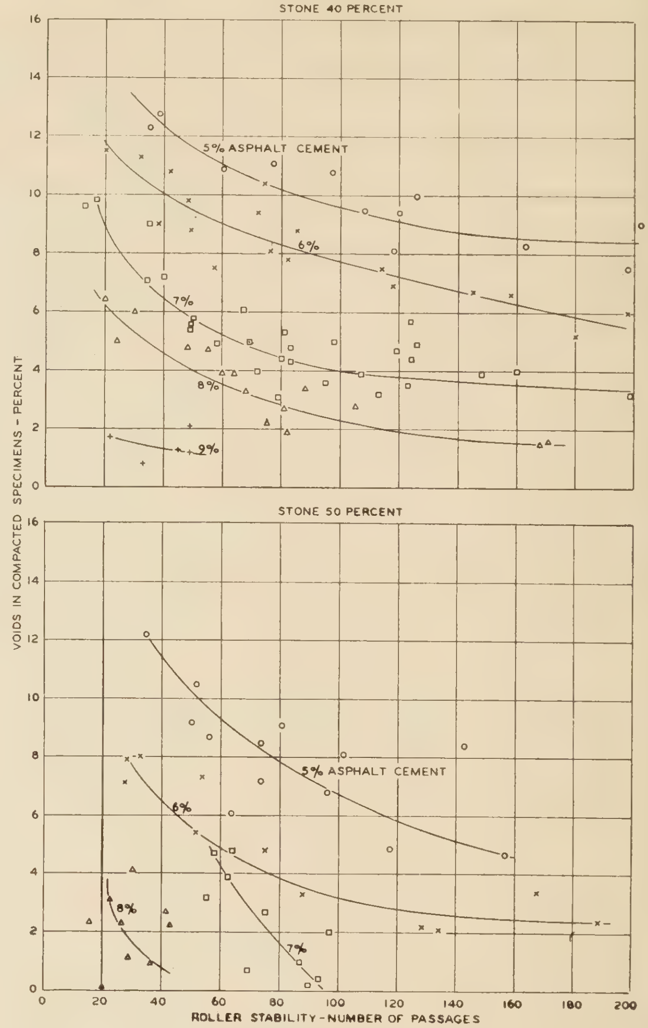

FIGURE 11.—RELATION BETWEEN ROLLER STABILITY AND PERCENTAGE OF VOIDS IN ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

ROLLER STABILITY METHOD PROVES PRACTICABLE

A study of the test data presented shows that, while no constant relation exists between stabilities as measured by the Hubbard-Field and roller-stability machines, both methods show the effects of various percentages of ingredients and voids, factors that influence the stability of sheet asphalt mixtures. Both methods show that variations in a given factor influence stability in the same way. In addition, the roller machine results show the effect of various percentages of ingredients and voids upon the stability of bituminous concrete mixtures, the results being comparable to those obtained on the sheet asphalt mixtures and are in agreement with commonly accepted theories. Although a considerable number of tests on pavements of known behavior will have to be made before roller stability results can be used as a measure of expected service behavior, it appears that the roller machine is a satisfactory device for determining the relative stabilities of both fine- and coarse-graded asphaltic mixtures.

Additional advantages of the roller machine are that specimens of varying depth can be tested and that field specimens can be prepared without apparently disturbing the material within the specimen. This is

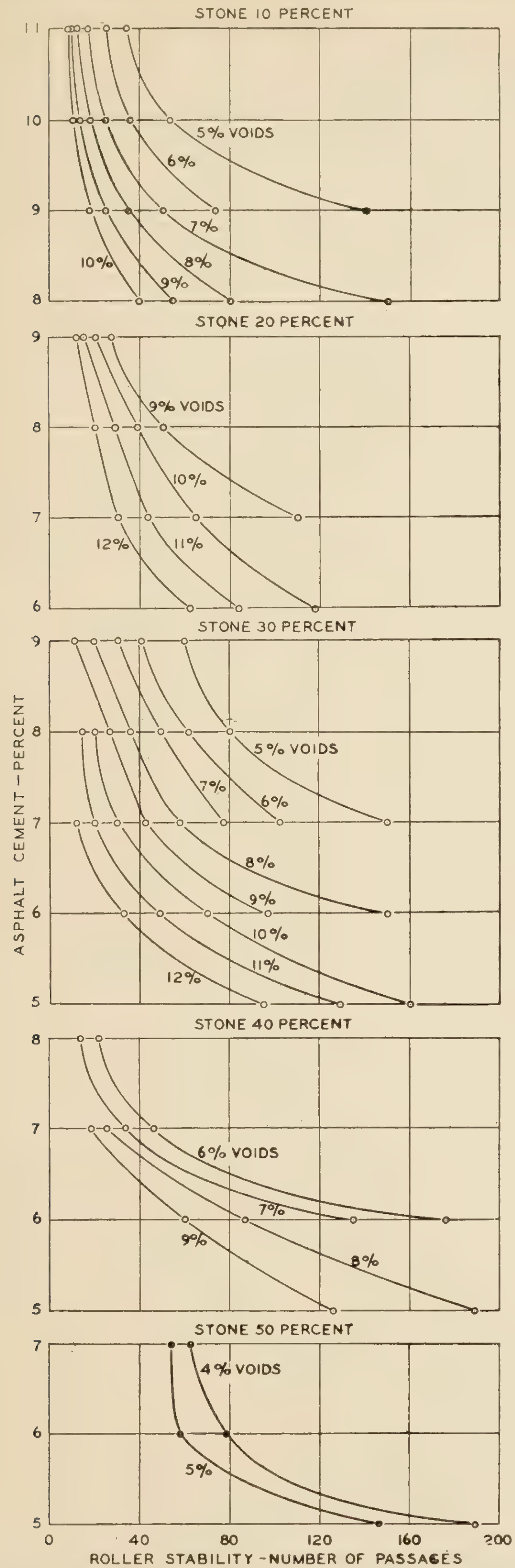

FIGURE 12.—EFFECT OF VARIATIONS IN PERCENTAGE OF ASPHALT CEMENT ON ROLLER STABILITY OF ASPHALTIC-CONCRETE SPECIMENS CONTAINING FOUR PERCENT OF LIMESTONE DUST AND VARIOUS PERCENTAGES OF STONE, SAND, AND ASPHALT CEMENT.

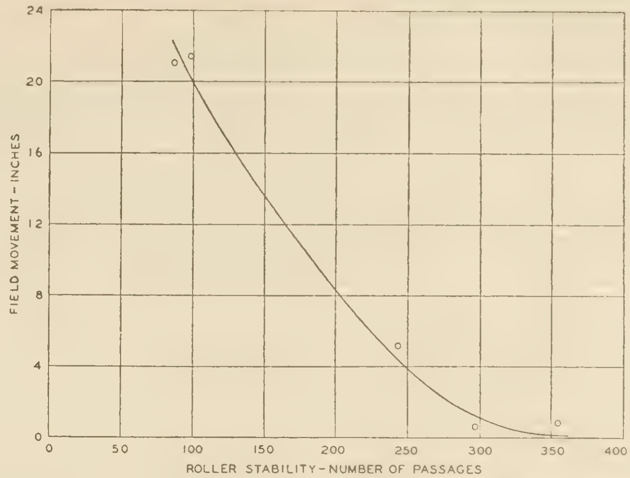

FIGURE 13.—COMPARISON OF FIELD MOVEMENT AND ROLLER STABILITY OF ASPHALTIC-CONCRETE SECTIONS FROM CIRCULAR TRACK.

TABLE 2.—*Laboratory analyses, field movement, and roller stability of sections of pavement from the experimental circular track*

	Section no. —				
	29	30	31	32	33
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
Bitumen	4.8	5.8	7.1	7.6	7.3
Passing 1¼-inch screen, retained on 1-inch screen	0.0	4.7	3.6	4.3	2.7
Passing 1-inch screen, retained on ¾-inch screen	14.6	12.7	9.6	10.0	11.8
Passing ¾-inch screen, retained on ½-inch screen	17.0	16.1	11.7	13.9	16.1
Passing ½-inch screen, retained on ¼-inch screen	8.6	10.4	10.9	10.9	9.1
Passing ¼-inch screen [1], retained on no. 10 sieve [2]	3.0	4.8	5.7	5.6	7.0
Passing no. 10 sieve, retained on no. 20 sieve	3.3	3.0	3.7	4.5	4.8
Passing no. 20 sieve, retained on no. 30 sieve	4.3	4.0	4.5	4.6	5.0
Passing no. 30 sieve, retained on no. 40 sieve	3.4	3.0	3.4	3.3	3.3
Passing no. 40 sieve, retained on no. 50 sieve	8.2	6.6	7.2	6.9	6.5
Passing no. 50 sieve, retained on no. 80 sieve	12.0	9.2	10.5	8.7	8.4
Passing no. 80 sieve, retained no. 100 sieve	6.8	5.2	6.2	6.1	4.8
Passing no. 100 sieve, retained on no. 200 sieve	8.5	8.6	9.1	7.6	6.5
Passing no. 200 sieve	5.5	5.9	6.8	6.0	6.7
Total	100.0	100.0	100.0	100.0	100.0
Field movement, inches	0.8	0.5	5.1	21.1	21.5
Maximum movement of single screw, inches	0.2	0.1	1.2	2.9	3.3
Roller stability	355	297	244	88	99

[1] Screens have circular openings. [2] Sieves have square openings.

done by cutting with a carborundum saw that apparently does not displace the material. The effect of slight displacement is lessened since the area of the test specimen is larger than the area subjected to load during the test.

By controlling the weight on the specimen during test, test values can be obtained for the more plastic types of mixture for which a comparison between test and service performances may be desired. It should also be possible to compare test and service performances of the cold-laid or liquefier type of surface.

Since the method of fabricating test specimens in the laboratory simulates the methods of compaction used in actual construction, it is believed that the use of the molding machine for fabrication and the roller machine for testing should furnish satisfactory laboratory evaluation of probable service performance for the various types of bituminous mixtures.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 1.—PROJECTS ON THE FEDERAL-AID HIGHWAY SYSTEM OUTSIDE OF MUNICIPALITIES

AS OF AUGUST 31,1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 7,059,832	$ 3,640,038	$ 333,151	388.0	$ 1,649,804	$ 305,142	$ 1,169,295	80.0		$ 210,259	11.8	$ 2,573	$ 417,216
Arizona	3,855,555	1,381,051	5,211,218	3,829,743	681,541	381.6	783,475	15,039	676,051	13.3				10,772	23,459
Arkansas	3,334,167	1,714,000	4,046,186	2,718,557	638,844	185.4	1,686,416	590,256	941,878	81.5		35,901	.2	25,354	97,377
California	7,912,928	3,713,643	11,785,341	7,790,341	841,365	380.9	3,465,799	121,228	2,724,900	67.3		11,203	.5	1,360	136,175
Colorado	3,437,265	2,424,504	5,778,807	3,359,612	2,188,123	280.4	335,942	68,649	236,046	12.4				9,003	335
Connecticut	1,404,213	607,500	1,592,908	1,398,014		30.8	670,946		554,726	7.2				6,199	52,774
Delaware	877,566	461,697	1,343,114	872,988	449,668	48.8	12,815	3,959	8,034					618	3,996
Florida	2,469,370	1,116,600	3,892,506	2,375,111	687,741	147.2	304,595	59,479	218,981	9.2		176,810	2.2	34,780	33,068
Georgia	5,045,592	2,556,745	5,640,255	4,306,527	1,089,849	369.3	1,374,629	585,971	705,634	59.1	$ 6,394	19,417	.3	146,700	741,845
Idaho	2,166,858	1,131,910	2,769,575	2,158,872	511,338	226.4	408,060		397,407	21.7		1,670	.1	7,986	221,495
Illinois	4,408,827	2,408,778	2,833,504	2,558,576	221,193	45.4	3,690,501	1,819,990	1,870,511	61.8		317,074		30,261	
Indiana	5,018,921	2,688,633	4,487,570	4,295,612	53,984	128.1	2,991,811	582,353	2,355,968	151.5	77,951	184,814	1.9	63,004	93,866
Iowa	5,027,830	1,963,361	6,293,748	4,978,830	890,386	374.6	1,204,882	49,000	1,058,290	64.8		13,700			985
Kansas	5,044,802	2,354,131	6,018,170	5,004,394	881,135	655.1	1,545,753	31,530	1,446,430	107.9		26,566	.9	8,878	
Kentucky	3,751,605	1,302,209	3,995,191	3,483,004	257,138	292.7	1,269,207	212,241	927,352	54.7		5,000	1.1	56,360	112,719
Louisiana	2,693,135	1,380,419	2,882,996	2,417,973	93,648	85.1	1,434,550	234,221	1,047,066	27.3	40,941		1.3		239,706
Maine	1,567,012	782,195	2,133,370	1,544,248	559,012	57.2	227,518	5,179	222,325	7.1				17,585	858
Maryland	1,782,263	289,609	1,013,261	888,200	123,550	18.6	933,521	803,850	129,671	19.2				90,213	36,389
Massachusetts	1,101,716	1,582,874	1,586,990	1,048,966	104,788	39.7	995,092	52,687	890,583	17.8				63	587,503
Michigan	6,051,533	3,226,284	6,166,972	5,398,945	402,775	259.4	3,317,075	648,450	2,647,561	142.7		112,825	3.6	4,137	63,123
Minnesota	4,561,011	2,533,733	6,581,228	4,254,660	2,131,650	1,022.0	627,791	247,577	338,500	69.2	30,000	3,773	7.5	28,775	59,809
Mississippi	3,489,337	2,832,182	5,887,700	2,776,095	748,044	308.3	2,645,950	620,984	1,584,553	146.1	23,588	210,437	12.6	68,670	289,148
Missouri	5,237,532	2,890,666	5,295,861	4,462,251	219,487	218.8	3,097,676	775,281	2,105,139	93.3		511,494	12.9		54,545
Montana	4,463,849	2,714,208	6,822,322	4,308,662	1,944,331	601.8	854,682	111,796	734,486	51.3	33,476	6,374	7.3	9,915	29,017
Nebraska	3,914,481	1,982,182	5,673,987	3,889,594	703,347	418.3	1,595,894	21,644	1,267,901	60.8				3,243	10,934
Nevada	2,909,387	1,350,356	3,744,024	2,664,314	1,003,444	391.6	602,129	204,263	336,320	88.7	17,734	2,850	2.6	23,075	7,742
New Hampshire	692,118	465,404	1,081,616	692,119	343,460	20.9	99,431		97,436	2.4					24,508
New Jersey	3,173,019	951,379	2,583,536	2,362,178	29,746	42.3	1,437,526	776,741	564,012	10.3		10,168		34,100	347,453
New Mexico	2,846,648	1,676,769	4,093,988	2,711,206	1,227,755	393.8	433,010		433,010	33.7	93,868		4.2	41,574	16,004
New York	10,465,672	3,673,231	12,889,156	9,648,179	719,730	236.4	6,116,780	567,625	2,777,952	116.2	23,000	4,000	.2	226,868	171,549
North Carolina	4,761,147	1,930,365	5,403,173	3,773,322	522,933	669.1	1,459,741	600,274	790,012	118.9	104,450	223,358	13.2	283,101	394,063
North Dakota	2,902,224	1,469,484	3,853,891	2,717,233	552,406	1,287.2	172,855	34,789	98,642	79.1	71,181	251,989	54.3	79,021	566,446
Ohio	7,277,758	3,539,255	8,378,196	7,036,716	751,074	217.2	2,691,104	225,551	2,290,333	51.2	1,500	191,561	3.1	13,991	306,287
Oklahoma	4,608,399	2,342,590	5,376,532	4,262,946	948,076	351.0	1,645,119	339,780	1,101,318	50.3		146,590	7.9	5,672	146,606
Oregon	3,053,448	1,426,910	3,844,042	2,905,698	520,378	205.8	1,035,973	102,555	866,114	43.4		1,000		45,195	39,417
Pennsylvania	6,641,194	4,554,082	9,242,739	6,494,210	2,269,261	179.8	2,297,256	136,292	2,116,286	41.0	2,126	114,109	3.4	8,566	54,426
Rhode Island	988,230	474,772	1,266,571	988,231	202,547	29.7	262,025		262,025	5.1		3,800			6,400
South Carolina	2,729,583	940,954	2,882,836	2,603,538	214,683	248.4	387,710	62,475	325,235	26.6	21,280	203,659	3.2	42,289	197,378
South Dakota	3,005,739	1,523,821	3,659,851	2,612,580	540,898	662.2	1,155,125	342,408	780,634	155.3	49,729	77,388	10.9	1,023	124,900
Tennessee	4,246,309	2,105,454	5,595,148	4,038,778	863,238	213.8	1,183,105	137,237	949,467	41.2	13,450	183,445	2.0	56,845	109,304
Texas	11,588,643	6,858,253	14,286,253	11,329,744	2,340,779	1,214.5	4,304,129	221,299	3,883,216	320.7	35,806	383,126	25.5	1,794	251,132
Utah	2,367,205	1,066,345	3,172,945	2,322,418	580,525	274.8	471,318	37,000	333,550	28.2		117,000	1.5	7,787	35,271
Vermont	928,184	466,042	1,272,427	912,376	250,743	59.2	221,414		207,151	8.2	4,042	4,307		11,766	3,841
Virginia	3,731,207	1,916,178	4,781,694	3,477,394	917,768	200.2	1,204,310	170,446	883,817	60.8	50,355	45,490	7.2	33,012	69,103
Washington	3,057,934	1,553,206	3,363,220	2,859,191	478,099	117.2	1,375,576	198,743	1,050,156	13.3		6,678			18,274
West Virginia	2,013,405	1,140,167	2,479,211	1,957,832	469,952	90.5	372,973	41,447	328,023	10.7	6,984	76,044	4.5	7,143	266,147
Wisconsin	4,697,518	1,818,970	5,257,273	4,386,938	637,071	245.6	1,520,748	298,603	1,088,097	62.9	7,300	70,839	1.2	4,678	22,963
Wyoming	2,250,663	1,686,368	3,051,863	2,105,140	782,549	584.4	996,922	141,021	829,741	149.0		69,397	1.1	4,502	4,681
District of Columbia															
Hawaii	1,693,344	598,778	1,326,739	952,902		27.3	940,719	681,972	98,893	12.3	20,973	183,992	1.4	37,497	315,893
TOTALS	185,194,099	93,698,168	229,679,536	169,574,996	33,923,203	14,926.8	69,511,382	13,287,027	48,750,728	2,956.7	736,128	4,213,107	211.6	1,595,948	6,806,130

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 2.—PROJECTS ON EXTENSIONS OF THE FEDERAL-AID HIGHWAY SYSTEM INTO AND THROUGH MUNICIPALITIES

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,389,928	$1,064,960	$2,260,951	$2,063,926	$178,344	58.6	$533,590	$282,674	$250,916	15.5	$11,886	$170,985	3.9	$31,441	$464,716
Arizona	756,982	289,673	738,883	622,804	86,475	15.1	322,556	129,322	161,999	.5				4,857	41,199
Arkansas	1,964,534	857,025	2,094,157	1,736,222	255,906	49.8	475,446	100,471	373,470	10.3	101,076	190,076	3.0	26,765	37,572
California	4,213,986	2,219,360	5,438,684	3,849,724	901,933	68.8	2,806,815	356,840	1,084,144	7.2		119,500	3.3	7,422	113,784
Colorado	1,718,633	190,000	1,937,260	1,670,293	170,641	40.0	11,229	11,229		.8				37,111	19,359
Connecticut	802,407	426,500	838,564	802,407	9,362	10.2	193,692		142,521	1.6		261,170	1.8		13,447
Delaware	460,409	230,849	560,829	460,282	92,040	9.2								127	138,809
Florida	1,459,648	501,200	1,887,692	1,443,800	146,700	21.8	119,931		119,931	1.1		149,522	2.2	15,848	85,047
Georgia	2,724,620	1,278,373	2,444,140	2,239,781	170,784	76.8	671,956	266,401	382,267	16.1		31,607	1.2	218,438	693,715
Idaho	1,197,829	321,126	1,225,489	1,150,878	29,138	21.3	193,311		190,428	.6		67,000	2.4	46,951	34,560
Illinois	7,381,910	2,230,350	6,599,641	6,283,943	8,850	66.3	2,358,443	1,071,535	1,286,908	13.8	12,070	411,443	2.3	14,362	523,149
Indiana	4,287,050	2,248,858	3,901,542	3,475,607	257,159	74.8	2,269,612	656,654	1,612,780	28.3	99,241	89,457	2.2	55,548	289,462
Iowa	2,614,472	1,280,000	2,964,641	2,403,068	427,495	69.8	874,586	211,365	607,340	12.4				39	245,165
Kansas	2,522,401	1,432,949	3,068,016	2,473,483	437,821	47.5	999,451		984,148	9.6	48,918	10,980	1.2		
Kentucky	1,927,828	958,599	1,788,387	1,509,834	213,691	39.0	765,528	356,559	385,587	6.6	30,000	186,073	4.1	31,435	173,248
Louisiana	1,708,577	744,560	950,473	793,037	147,468	23.5	1,218,912	896,731	280,141	15.0	10,666	242,681	2.8	8,144	74,271
Maine	960,426	484,379	1,013,995	910,266	98,154	18.9	430,204	45,122	379,317	4.4				5,038	6,907
Maryland	891,132	452,515	429,154	423,149		3.8	1,293,376	467,982		2.2					452,514
Massachusetts	5,007,199	847,600	2,822,356	2,649,581	98,359	16.3	2,498,896	2,328,972	169,924	3.6				28,646	579,317
Michigan	3,500,637	1,613,142	3,696,148	3,148,517	360,400	43.7	1,416,400	310,450	1,093,450	14.1	19,400	140,875	2.6	22,271	18,417
Minnesota	3,719,143	1,421,494	3,710,274	3,129,589	512,534	119.8	1,087,338	515,071	476,784	13.6	2,310	4,758		72,174	427,418
Mississippi	1,744,669	354,022	1,309,979	1,161,617	129,121	40.6	692,091	511,031	110,022	20.3	27,791	12,352	1.7	44,230	102,527
Missouri	4,019,501	919,152	3,286,776	3,156,976	29,290	55.6	1,190,302	712,054	456,911	10.2		432,951	2.7	150,471	
Montana	1,115,962	113,092	1,148,381	1,047,354	58,596	40.3	49,405	35,858	13,547	3.2				32,750	40,949
Nebraska	1,957,240	991,091	2,570,127	1,915,583	618,581	46.5	230,593		230,593	3.3	41,657	39,225	1.9		102,692
Nevada	500,051	100,000	539,805	473,788	56,854	10.8	67,552	26,150	41,402	.6				112	1,744
New Hampshire	740,335	242,465	845,980	668,776	173,847	18.7	53,951		53,741	.5	22,006		.4	49,553	14,877
New Jersey	3,117,921	1,809,500	3,252,404	2,983,109	108,606	23.1	1,053,511	10,297	804,667	5.7		631,441	1.0	124,515	264,787
New Mexico	1,674,158	529,506	1,824,671	1,564,212	249,529	41.9	183,963		183,963	1.1				109,946	96,014
New York	8,255,661	3,961,690	8,793,499	7,695,002	617,300	67.3	3,279,225	392,401	2,731,390	19.0		219,150	.2	168,258	393,850
North Carolina	2,380,573	1,210,236	2,914,240	2,142,978	750,063	99.8	613,237	215,174	380,063	11.1		22,458	1.5	22,421	57,651
North Dakota	1,451,112	734,741	1,390,751	1,240,388	142,623	61.4	191,418	146,664	44,754	10.1	40,526	238,430	9.7	23,534	308,934
Ohio	4,335,686	2,359,504	5,229,990	4,238,314	490,826	70.2	1,589,580	93,352	1,370,390	12.9		197,100	1.3	4,020	301,188
Oklahoma	2,304,200	1,171,295	2,527,800	2,109,752	323,001	50.3	751,335	192,161	540,306	8.6		123,251	1.8	2,288	184,737
Oregon	1,526,724	778,728	2,004,562	1,445,150	498,190	38.2	354,145	37,135	280,538	4.1	518			43,921	
Pennsylvania	4,837,988	2,397,703	5,883,608	4,630,497	1,033,256	79.1	963,465	161,049	725,150	6.3		234,914	1.3	46,441	404,383
Rhode Island	512,665	285,760	651,165	508,370	141,760	8.9								4,295	144,000
South Carolina	1,364,791	488,000	1,298,762	1,233,572	53,000	40.6	349,221	121,504	222,167	10.4	9,715	28,372	.5		184,461
South Dakota	1,502,870	761,911	1,323,717	1,204,141	119,079	42.4	334,259	100,515	233,744	17.2		154,420	6.9	198,213	254,668
Tennessee	2,123,155	1,121,789	2,285,089	1,958,019	298,739	30.0	695,454	165,136	530,318	6.1		84,196	.5		208,537
Texas	6,642,863	1,795,000	6,133,580	5,704,645	297,191	136.1	1,821,755	686,110	959,454	24.7	2,192	503,148	6.7	249,916	35,206
Utah	778,826	533,173	812,143	649,146	97,066	20.8	645,051	129,130	436,107	13.5				550	
Vermont	500,509	240,611	681,403	489,021	114,046	16.6	119,530		114,011	2.0		8,129	.4	11,487	4,425
Virginia	1,948,780	956,021	2,335,087	1,678,448	417,818	35.0	739,044	245,204	438,009	12.2	13,975	66,642	2.4	11,153	33,551
Washington	1,977,260	776,603	2,543,866	1,974,863	547,931	45.6	196,551		196,551	1.9		1,415		2,397	30,706
West Virginia	1,342,270	570,085	1,178,195	1,112,989	28,109	18.6	466,966	200,578	266,388	6.7	28,643	186,097	2.0	61	89,491
Wisconsin	2,596,143	1,379,513	3,374,982	2,509,104	787,442	65.5	549,837	53,457	496,380	7.5		91,921	2.4	33,582	3,771
Wyoming	1,125,332	29,416	1,104,126	1,098,148	2,784	23.5	36,783	22,068	14,132	2.5		7,681		5,116	4,819
District of Columbia	946,445	181,051	1,127,496	946,445	181,051	6.6									
Hawaii															
TOTALS	115,533,441	47,885,170	118,743,460	100,780,598	12,968,953	2,129.0	37,759,496	12,264,406	21,856,753	399.0	522,590	5,359,420	78.3	1,965,847	7,700,044

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$2,032,452	$1,064,961	$2,309,887	$1,924,006	$365,643	161.7	$589,857	$61,735	$528,122	37.6		$152,197	3.5	$46,711	$18,998
Arizona	599,423	971,211	1,145,732	530,962	510,676	96.1	483,106	59,762	407,341	38.2				8,699	53,194
Arkansas	1,449,634	857,024	1,423,425	1,286,905	127,674	185.1	709,585	107,334	600,076	76.1	$21,408	120,645	11.8	33,988	8,628
California	3,480,440	1,999,203	4,321,313	3,249,065	342,800	193.1	1,761,849	227,850	1,418,828	49.3		104,000	3.5	3,525	133,575
Colorado	1,718,632	871,502	2,638,722	1,608,632	578,638	275.6	516,993	110,000	292,864	36.2					
Connecticut	659,120	420,868	697,300	659,120	12,889	14.9	222,880		222,880	4.5					185,099
Delaware	481,113	230,849	499,966	277,564	208,650	63.9	224,924	201,248	18,000	7.5				2,301	4,198
Florida	1,302,816	1,043,543	1,630,914	1,279,756	329,467	81.4	693,466		641,918	41.3		49,595	2.8	23,060	22,562
Georgia	2,320,973	1,278,373	1,921,821	1,839,506	53,108	139.0	838,794	399,219	439,575	60.9				82,248	785,691
Idaho	1,121,562	824,450	1,739,651	1,094,530	467,436	201.8	177,969		177,969	22.0		70,000	.4	27,032	109,044
Illinois	5,780,033	4,282,273	4,345,064	4,109,658	180,491	242.9	4,953,938	1,661,465	3,292,473	249.3		456,948	7.1	8,910	352,361
Indiana	731,872	151,472	479,826	417,905	15,004	49.7	369,094	274,972	94,122	50.2				38,996	42,346
Iowa	2,413,358	1,875,000	3,101,720	2,390,624	622,021	513.4	1,255,840	22,027	1,132,425	184.6		5,600	2.3	707	114,955
Kansas	2,522,401	1,330,595	2,757,547	2,478,902	275,787	253.5	1,098,307	43,499	1,054,808	60.6					
Kentucky	1,837,926	1,557,503	2,383,120	1,772,049	468,003	281.1	1,133,012	46,363	1,018,988	128.0		65,505	3.0	19,513	5,006
Louisiana	1,426,879	838,953	1,241,210	1,085,083	143,710	51.6	942,203	337,357	604,846	44.5	3,135	74,211	2.4	1,303	16,186
Maine	842,479	445,012	1,393,835	842,403	429,831	105.7	13,424		13,424	.8				75	1,757
Maryland	891,132	1,067,934	1,053,153	860,196	134,642	72.3	334,765	16,123	318,642	13.8	9,800	176,376	4.1	5,012	438,275
Massachusetts	488,185	920,000	482,233	474,504		15.2	837,333		837,333	20.4				13,681	82,667
Michigan	3,184,057	1,613,142	3,543,656	3,025,292	278,850	222.2	1,417,119	117,227	1,299,892	78.0		34,400	.4	41,538	
Minnesota	2,376,415	1,470,324	3,288,661	2,179,075	913,228	368.2	681,095	133,323	466,017	48.0		70,503	.1	64,017	20,576
Mississippi	1,744,669	354,023	1,325,531	1,309,031	16,500	148.1	514,312	407,501	106,811	38.6		197,261	17.9	28,137	33,451
Missouri	2,923,273	2,363,922	3,395,026	2,686,006	622,066	740.1	1,867,235	235,551	1,586,431	307.1		155,425	14.4	1,716	
Montana	1,859,937	942,434	2,543,443	1,739,224	794,388	305.7	208,613	68,564	140,049	21.2				52,149	7,998
Nebraska	1,957,240	991,091	2,558,346	1,953,891	581,497	441.7	329,975		329,975	51.5		16,708	8.0	3,349	62,911
Nevada	1,136,479	852,000	1,722,864	1,110,208	573,169	208.8	221,262	8,443	212,819	23.7				17,828	66,012
New Hampshire	477,386	261,593	609,099	448,098	111,779	29.9	169,438	29,000	137,633	4.3				287	12,181
New Jersey	55,099	460,000	56,528	55,099		.5	107,525		107,525	1.7		170,412	1.1		182,063
New Mexico	1,272,129	735,425	1,918,265	1,272,129	646,136	296.8	73,332		73,332	2.6					15,956
New York	3,608,768	3,693,000	4,948,637	3,211,646	977,299	160.7	3,380,382	397,122	2,635,040	223.2					80,661
North Carolina	2,380,573	1,700,340	3,127,385	2,246,077	876,509	346.9	908,856	90,285	818,571	82.7				44,211	5,260
North Dakota	1,451,112	734,742	1,372,712	1,267,358	104,721	430.1	154,081	66,752	87,329	30.6	102,670	370,379	96.3	14,332	172,313
Ohio	3,871,148	1,966,253	4,338,414	3,749,696	336,650	349.6	1,277,466	49,860	1,178,223	64.9		92,250	9.6	71,592	359,130
Oklahoma	2,304,199	1,171,295	2,471,681	2,154,542	87,815	282.8	1,164,794	147,071	908,286	50.8		29,343	.3	2,586	145,852
Oregon	1,526,724	892,176	2,276,898	1,494,881	581,851	163.8	252,915	19,526	194,540	10.1				12,317	115,785
Pennsylvania	7,411,822	2,639,003	7,321,815	6,430,741	674,466	593.0	2,772,178	854,159	1,824,964	157.9		115,431	7.0	126,923	24,142
Rhode Island	497,813	254,040	497,631	447,809	39,789	34.2	211,374		211,374	7.1	50,003		3.0		2,876
South Carolina	1,364,791	1,342,000	1,337,533	1,103,131	233,769	141.2	1,318,840	249,891	1,030,599	156.3		70,760	3.6	11,769	6,872
South Dakota	1,502,870	761,911	1,683,466	1,432,735	248,645	485.6	461,370	69,046	392,324	126.3		120,455	28.0	1,090	486
Tennessee	2,123,155	1,075,748	2,202,088	1,805,582	316,213	158.2	668,645	253,999	414,646	28.8	3,663	121,178	4.6	59,912	223,710
Texas	6,012,518	3,638,000	7,736,424	5,969,309	1,297,109	911.5	2,358,413	18,000	2,331,340	135.5		1,000	14.1	25,209	8,551
Utah	1,048,677	533,173	1,627,473	1,041,002	306,173	224.7	269,854		227,000	36.6				7,675	
Vermont	438,880	241,354	785,232	435,360	221,418	51.7	19,034		19,034	1.4				3,520	903
Virginia	1,736,770	893,188	1,894,027	1,555,179	284,724	231.8	519,211	98,691	412,254	52.9	59,804	137,213	14.9	23,097	58,998
Washington	1,080,673	776,603	1,573,597	1,080,673	457,193	113.3	318,146		318,146	11.6					1,265
West Virginia	1,118,559	570,083	900,874	856,050		46.7	647,996	257,170	390,826	31.9		77,781	4.3	5,338	101,477
Wisconsin	2,431,220	1,743,354	2,853,674	2,190,729	476,109	187.1	1,552,806	219,020	1,146,210	49.7		3,553		21,471	117,483
Wyoming	1,125,332	571,928	1,355,150	1,122,742	214,464	213.5	357,466		357,464	63.7				2,590	
District of Columbia	972,024	792,791	1,290,053	971,729	318,324	11.3	263,975		263,975	1.6		75,395	.6	296	135,097
Hawaii	177,718	351,000	178,209	177,718		4.9	150,713		143,867	4.6					207,133
TOTALS	93,272,460	58,416,662	108,300,831	84,704,112	17,857,324	10,902.6	41,775,760	7,359,155	32,881,130	3,030.7	250,483	3,134,524	269.1	958,710	4,543,684

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SEPARATE REPRINT FROM THE YEARBOOK

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

TRANSPORTATION SURVEY REPORTS

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

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

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

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

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

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

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

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF AUGUST 31, 1935

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 8,370,133	$ 4,259,842	$ 11,630,670	$ 7,627,970	$ 877,139	608.3	$ 2,773,252	$ 649,552	$ 1,948,333	133.1	$ 11,886	$ 533,440	19.2	$ 80,726	$ 900,930
Arizona	5,211,960	2,641,935	7,095,833	4,983,509	1,278,692	492.9	1,589,137	204,122	1,245,391	52.0				24,328	117,852
Arkansas	6,748,335	3,428,049	7,563,768	5,741,684	1,022,424	420.2	2,871,447	798,060	1,915,425	167.9	122,484	346,622	15.0	86,107	143,578
California	15,607,354	7,932,206	21,545,339	14,889,130	2,086,098	642.8	8,034,462	705,918	5,227,872	123.8		234,703	7.4	12,306	383,534
Colorado	6,874,530	3,486,006	10,354,789	6,638,538	2,937,403	596.0	864,165	189,878	528,910	49.4				46,114	19,694
Connecticut	2,865,740	1,454,868	3,128,771	2,859,541	22,251	56.0	1,087,518		920,127	13.3		261,170	1.8	6,199	251,320
Delaware	1,819,088	923,395	2,403,909	1,610,834	750,358	121.8	237,738	205,207	26,034	7.5				3,047	147,003
Florida	5,231,834	2,661,343	7,411,112	5,098,667	1,163,909	250.3	1,117,992	59,479	980,830	51.5		375,927	7.2	73,688	140,677
Georgia	10,091,185	5,113,491	10,006,216	8,385,814	1,313,741	585.1	2,885,379	1,251,592	1,527,475	136.1	6,394	51,025	1.6	447,386	2,221,250
Idaho	4,486,249	2,277,486	5,734,715	4,404,280	1,007,912	449.5	779,340		765,804	44.3		138,670	2.9	81,969	365,100
Illinois	17,570,770	8,921,401	13,778,209	12,952,177	410,534	354.6	11,002,882	4,552,990	6,449,892	324.9	12,070	1,185,465	9.3	53,533	875,510
Indiana	10,037,843	5,088,963	8,868,938	8,189,125	326,147	252.7	5,630,517	1,513,978	4,062,871	230.0	177,192	274,271	4.1	157,548	425,674
Iowa	10,055,660	5,118,361	12,360,109	9,772,522	1,939,902	957.7	3,335,308	282,392	2,798,055	261.8		19,300	2.3	746	361,104
Kansas	10,089,604	5,117,675	11,843,733	9,956,779	1,594,743	956.1	3,643,512	75,029	3,485,387	178.0	48,918	37,546	2.2	8,878	
Kentucky	7,517,359	3,818,311	8,166,698	6,764,887	938,832	612.8	3,167,747	615,163	2,331,928	189.3	30,000	256,578	8.1	107,309	290,973
Louisiana	5,828,591	2,963,932	5,074,680	4,296,094	384,825	160.2	3,595,666	1,468,309	1,932,052	86.8	54,742	316,892	6.5	9,447	330,163
Maine	3,369,917	1,711,586	4,541,201	3,296,917	1,086,998	181.8	671,146	50,301	615,066	12.2				22,699	9,522
Maryland	3,564,527	1,810,058	2,495,568	2,171,546	258,191	94.7	2,561,662	1,287,956	448,312	35.2	9,800	176,376	4.1	95,225	927,179
Massachusetts	6,597,100	3,350,474	4,891,578	4,173,052	203,147	71.3	4,331,320	2,381,659	1,897,840	41.9				42,389	1,249,487
Michigan	12,736,227	6,452,568	13,406,776	11,572,754	1,042,025	525.3	6,150,594	1,076,127	5,040,903	234.8	19,400	288,100	6.6	67,946	81,539
Minnesota	10,656,569	5,425,551	13,580,163	9,563,323	3,557,413	1,510.0	2,396,224	895,970	1,281,301	130.8	32,310	79,034	7.6	164,966	507,803
Mississippi	6,978,675	3,540,227	8,523,210	5,246,743	893,665	496.9	3,852,353	1,539,517	1,801,386	205.0	51,379	420,050	32.2	141,037	425,126
Missouri	12,180,306	6,173,740	11,977,662	10,305,233	870,844	1,014.4	6,155,213	1,722,886	4,148,481	410.5		1,099,870	30.1	152,187	54,545
Montana	7,439,748	3,769,734	10,514,145	7,095,240	2,797,315	947.9	1,112,700	216,219	888,081	75.7	33,476	6,374	7.3	94,813	77,964
Nebraska	7,828,961	3,964,364	10,802,460	7,759,068	1,903,424	906.6	2,156,462	21,644	1,828,469	115.6	41,657	55,933	9.8	6,592	176,537
Nevada	4,545,917	2,302,356	6,006,692	4,248,311	1,633,467	611.3	890,943	238,856	590,542	112.9	17,734	2,850	2.6	41,016	75,497
New Hampshire	1,909,839	969,462	2,536,695	1,808,993	629,086	69.5	322,820	29,000	288,810	7.3	22,006		.4	49,840	51,566
New Jersey	6,346,039	3,220,879	5,892,469	5,400,386	138,352	65.9	2,598,562	787,038	1,476,203	17.6		812,020	2.1	158,615	794,303
New Mexico	5,792,935	2,941,700	7,836,924	5,547,547	2,123,420	732.5	690,305		690,305	37.4	93,868		4.2	151,520	127,974
New York	22,330,101	11,327,921	26,631,292	20,554,827	2,314,329	464.4	12,776,387	1,357,148	8,144,382	358.4	23,000	223,150	.4	395,126	646,061
North Carolina	9,522,293	4,840,941	11,444,798	8,162,377	2,149,505	1,115.9	2,981,834	905,732	1,988,646	212.7	104,450	245,816	14.7	349,733	456,975
North Dakota	5,804,448	2,938,967	6,617,353	5,224,979	799,750	1,778.7	518,354	248,205	230,726	119.8	214,377	860,798	160.3	116,887	1,047,693
Ohio	15,484,592	7,865,012	17,946,600	15,024,726	1,578,550	637.0	5,558,150	368,763	4,838,946	129.0	1,500	480,911	13.9	89,603	966,605
Oklahoma	9,216,798	4,685,180	10,376,013	8,527,239	1,358,892	684.1	3,561,248	679,013	2,549,910	109.8		299,184	10.0	10,546	477,195
Oregon	6,106,896	3,097,814	8,125,503	5,845,729	1,600,419	407.8	1,643,033	159,216	1,341,192	57.7	518	1,000		101,434	155,202
Pennsylvania	18,891,004	9,590,788	22,448,162	17,555,448	3,976,984	851.9	6,032,899	1,151,500	4,666,399	205.2	2,126	464,454	11.7	181,930	482,951
Rhode Island	1,998,708	1,014,572	2,415,367	1,944,409	384,096	72.8	473,399		473,399	12.2	50,004	3,800	3.0	4,295	153,276
South Carolina	5,459,165	2,770,954	5,519,131	4,940,242	501,451	430.2	2,055,771	433,870	1,578,001	193.3	30,995	302,791	7.2	54,058	388,710
South Dakota	6,011,479	3,047,643	6,667,034	5,249,456	908,622	1,190.1	1,950,754	511,969	1,406,702	298.8	49,729	352,264	45.9	200,326	380,055
Tennessee	8,492,619	4,302,991	10,082,325	7,802,379	1,478,189	402.0	2,547,204	556,371	1,894,432	76.2	17,113	388,819	7.1	116,756	541,551
Texas	24,244,024	12,291,253	28,156,257	23,003,698	3,935,080	2,262.1	8,484,297	925,409	7,174,011	480.9	37,998	887,274	46.4	276,919	294,888
Utah	4,194,708	2,132,691	5,612,562	4,012,566	983,763	520.4	1,386,222	166,130	996,657	78.3		117,000	1.4	16,011	35,271
Vermont	1,867,573	948,007	2,739,062	1,836,757	586,207	127.5	359,978		340,196	11.6	4,042	12,436	.4	26,774	9,169
Virginia	7,416,757	3,765,387	9,010,808	6,711,020	1,620,310	466.9	2,462,565	514,341	1,734,079	126.0	124,134	249,346	24.5	67,262	161,652
Washington	6,115,867	3,106,412	7,480,683	5,914,727	1,483,222	276.0	1,890,273	198,743	1,564,853	26.8		8,093		2,397	50,244
West Virginia	4,474,234	2,280,335	4,558,280	3,926,871	498,061	155.8	1,487,935	499,195	985,236	49.4	35,626	339,922	10.8	12,541	457,116
Wisconsin	9,724,881	4,941,837	11,485,930	9,086,770	1,900,621	498.2	3,623,391	571,080	2,730,687	120.0	7,300	166,312	3.6	59,731	144,217
Wyoming	4,501,327	2,287,712	5,511,139	4,326,029	999,797	821.4	1,391,171	163,089	1,201,337	215.2		77,078	1.1	12,208	9,500
District of Columbia	1,918,469	973,842	2,417,548	1,918,173	499,375	17.9	263,975		263,975	1.6		75,395	.6	295	135,097
Hawaii	1,871,062	949,778	1,504,948	1,130,620		32.2	1,091,432	681,972	242,760	16.9	20,973	183,992	1.4	37,497	523,026
TOTALS	394,000,000	200,000,000	456,723,827	355,059,706	64,749,480	27,958.4	149,046,638	32,910,588	103,488,611	6,386.4	1,509,201	12,712,051	559.0	4,520,505	19,049,858