





# PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH



UNITED STATES DEPARTMENT OF AGRICULTURE  
BUREAU OF PUBLIC ROADS



VOL. 10, NO. 8



OCTOBER, 1929



EXPERIMENTAL ROAD IN GROUNDS OF DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE

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R. E. ROYALL, Editor

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# BITUMINOUS SURFACE TREATMENT EXPERIMENTS IN DEPARTMENT OF AGRICULTURE GROUNDS

Reported by J. T. PAULS, Senior Highway Engineer, and PAUL F. CRITZ, Associate Highway Engineer, Division of Tests

**A** STUDY of the experimental bituminous roads in the grounds of the United States Department of Agriculture, at Washington, which have been maintained uninterruptedly for 16 years, and on which a careful record of cost and service behavior has been kept, provides interesting information on the bituminous surface treatment of plain and penetration macadams.

## EARLY HISTORY OF EXPERIMENTAL SECTIONS DISCUSSED

Before discussing the experiments it will be of interest to give some of the early history of the roads on which these experiments were built. Records available indicate that they were constructed during 1870 and 1871 with funds appropriated by Congress. The first of these appropriations was made in July, 1868, and in 1871, \$6,000 was authorized "for materials to complete the roads and sidewalks."

believed that the sandstone found there was waste from the construction of the terrace wall which was built in 1870 and indicates that this section was most likely built during the same year.

Overlying the conglomerate material, a wearing surface of pit-run gravel was found and, above this, a water-bound trap macadam surface. Indications are that the gravel was placed at the time of the original base construction and was maintained as the surfacing material until 1906 when the trap macadam was built.

The behavior of the macadam was characteristic of this type of construction in that it raveled badly and was extremely dusty. The importance of dust prevention and road preservation was generally recognized at this time, and led the bureau to select these roads for experiments in studying this subject.

These experiments were carried on from 1907 to 1912, using calcium chloride, crude and waste sulphite liquors, asphaltic oil emulsions, and a molasses-lime mixture as dust layers. These early experiments were reported a number of years ago<sup>1</sup> and will not be mentioned further in this report, which covers only the bituminous surface treatment experiments conducted subsequent to 1912.

## SURFACE TREATMENT EXPERIMENTS PLANNED USING TARS AND ASPHALTIC OILS

The later experiments were designed for the purpose of studying the behavior of cold-application tars and asphaltic oils of the types suitable for surface treating water-bound and penetration macadams. In general, the type of each section as well as the materials used in the subsequent maintenance treatments have remained unchanged. In a few instances, however, hot-application materials have been used in maintenance treatments instead of the lighter material used in the original construction. It also became necessary to reconstruct section 3 (fig. 2) as a penetration macadam. All of the sections have been maintained continuously since their construction and a record of their maintenance cost and behavior is given in this report.

Several of the more important roads traversing the grounds of the department and located as shown in Figure 1, were selected for treatment.<sup>2</sup> They were 16 feet wide and had been resurfaced with limestone macadam in the fall of 1911. In June, 1912, prior to applying the bituminous treatments they were treated with a molasses-lime mixture similar to that used on the Bradley Lane, Chevy Chase, Md., experiment in 1911. This treatment was followed by heavy rains covering a period of 10 days during which the mixture was entirely washed off and the surface soon became dusty. Although subjected to only a moderate traffic

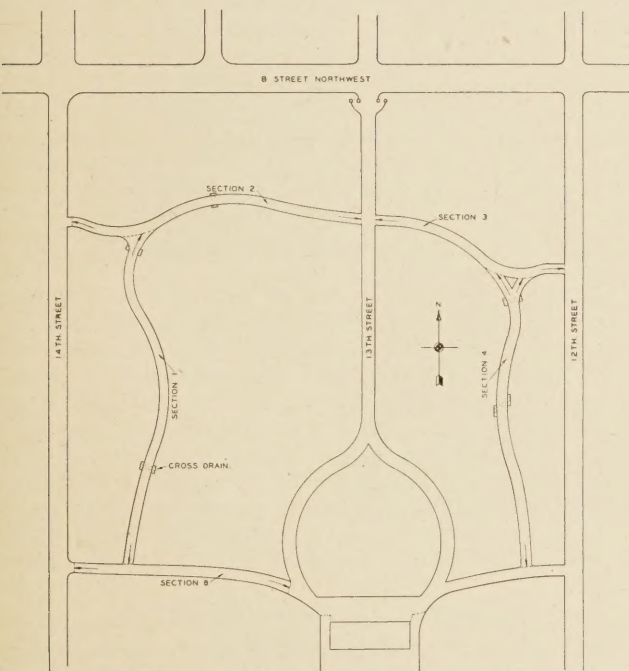


FIGURE 1.—LOCATION OF EXPERIMENTAL SECTIONS

Very little information is available as to the methods used on this early construction. However, a recent examination of the road structure shows it to have been built of several layers of different kinds of materials. In practically all cases the bottom layer consisted of conglomerate material such as cinders, oyster shells, brickbats, and sand mortar. In the foundation of the southern portion of section 1, "one-man" sandstone was found, similar to the material used in building a stone wall directly in front of the administration building of the department. As the topography of the section is such that natural drainage is good, it is

<sup>1</sup> Reported in Office of Public Roads Circulars 89, 90, 92, 94, and 98. These publications are no longer available for distribution but may be found in many libraries.  
<sup>2</sup> Descriptions of the original treatment together with the early behavior of the sections are included in Circular 99, Office of Public Roads, and Bulletins 105, 257, 407, 586 and Circular 77, U. S. Department of Agriculture. Only those publications listed on back cover page are now available for distribution.

of light delivery wagons, carriages, and automobiles, the surface had worn perceptibly during the few months intervening between the molasses-lime treatment and the bituminous treatments and the repair of numerous depressions was necessary before the latter treatments were applied.

In all cases the road surface was thoroughly cleaned, holes and depressions picked out to a depth of 2½ to 3 inches and filled with new stone and screenings which were hand tamped into place with sufficient water to bind the patch.

The bituminous materials were applied by means of a horse-drawn pressure distributor, and as the work was done in cold weather they required a slight amount of heating which would not have been necessary earlier in the season. The application was covered with screened and washed river gravel. Two grades were used, the mechanical analyses of which are given in Table 1. Tables 2 and 3 give the characteristics of the various bituminous materials used.

#### SECTION 1. REFINED WATER-GAS TAR PREPARATION

This section parallels Fourteenth Street and intersects sections 2 and 8 on the north and south, respectively, and is 766 feet long. Tar was applied at the rate of 0.43 gallon per square yard in a single application. The distribution was somewhat uneven, and it was thought best to defer spreading the gravel for a day to allow the tar to penetrate better and to be broomed more evenly when the sun had rendered it fluid. A heavy rain came on and the accompanying wind brought down large quantities of leaves which adhered to the sticky surface. After two days these were removed as much as was possible by raking and the gravel was spread, although the surface still held some small pools of water. Most of the gravel for the north half of the section was dried before spreading, but when rain came on again drying was discontinued.

TABLE 1.—Mechanical analyses of gravels used in original surface treatments, 1912

	Section 1	Sections 2, 3, and 4
	Per cent	Per cent
Retained on ¼-inch screen.....	16.0	2.2
Retained on ½-inch screen.....	67.0	56.2
Retained on ¾-inch screen.....	16.0	27.8
Retained on 10-mesh screen.....	.6	4.2
Passing 10-mesh screen.....	.4	9.6
Total.....	100.0	100.0

TABLE 2.—Analysis of refined water-gas tar<sup>1</sup> used in original treatment of section 1, 1912

Specific gravity, 25° C./25° C.....	1. 126
Specific viscosity, Engler, 50 c. c. at 50° C.....	29. 8
Free carbon, per cent.....	2. 43
Distillation, per cent, by weight:	
Water.....	0. 0
110° C. (clear).....	0. 5
110° to 170° C. (turbid).....	1. 6
170° to 270° C. (slightly turbid).....	18. 8
270° to 315° C. (clear).....	<sup>2</sup> 13. 1
Pitch residue.....	65. 9
Total.....	99. 9

<sup>1</sup> Rather viscous, sticky fluid.

<sup>2</sup> Showed 7.5 per cent insoluble in dimethyl sulphate. A 315° to 350° C. fraction showed 10 per cent and a 350° to 375° C. fraction showed 7.5 per cent insoluble in dimethyl sulphate. The material therefore contains a small percentage of oil asphalt.

TABLE 3.—Analyses of asphaltic materials used in the original treatment of sections 2, 3, and 4 in 1912

	Type of material		
	Section 2: Asphaltic petroleum <sup>1</sup>	Section 3: Residual petroleum <sup>2</sup>	Section 4: Asphaltic petroleum <sup>3</sup>
Specific gravity, 25° C./25° C.....	0. 947	0. 947	0. 926
Flash point, °C.....	32	167	27
Burning point, °C.....	68	198	46
Specific viscosity, Engler, 50 c. c. at 25° C.....	88. 1		
Specific viscosity, Engler, 100 c. c. at 25° C.....			41. 5
Specific viscosity, Engler, 50 c. c. at 50° C.....		43	
Loss at 163° C..... per cent.....	28. 06	7. 31	25. 83
Float test on residue at 50° C..... seconds.....	<sup>3</sup> 105	( <sup>4</sup> )	<sup>5</sup> 71
Bitumen soluble in CS <sub>2</sub> ..... per cent.....	99. 88	99. 92	99. 97
Organic matter, insoluble..... do.....	. 08	. 05	. 03
Inorganic matter, insoluble..... do.....	. 04	. 03	. 00
Bitumen insoluble in 86° B. naphtha..... do.....	8. 88	. 65	12. 59
Fixed carbon..... do.....	4. 84	1. 47	7. 23

<sup>1</sup> Thin fluid with strong naphtha odor.

<sup>2</sup> Slightly sticky fluid, semi-asphaltic.

<sup>3</sup> Soft with slight flow.

<sup>4</sup> Too soft for float test.

<sup>5</sup> Slightly sticky.

The coarser gravel was used on this section except for a small area on the south end where the finer grade was used. Approximately 27 pounds of gravel per square yard were spread. After rolling, the section was opened to traffic.

#### SECTION 2. ASPHALTIC PETROLEUM

Section 2 connects Thirteenth and Fourteenth Streets and is 635 feet long. The asphaltic petroleum was applied at the rate of 0.41 gallon per square yard and immediately covered with a very thin layer of fine gravel. However, more gravel was put on during the next few days and the total amount applied was approximately 27 pounds per square yard. In this section, as on the others, the gravel was wet when applied. The surface was rolled before opening to traffic.

#### SECTION 3. RESIDUAL PETROLEUM

Section 3 is an extension of section 2 and connects Twelfth and Thirteenth Streets and is 397 feet long. The residual petroleum was applied at the rate of 0.42 gallon per square yard and was immediately covered with fine gravel at the rate of 27 pounds per square yard. The surface was then rolled and opened to traffic. After a few days the oil began to bleed and when the nights became cold produced a sticky surface which resulted in small strips being picked up by automobile tires. As a remedy for this condition light applications of sand were made on three separate occasions.

#### SECTION 4. ASPHALTIC PETROLEUM

This section, which parallels Twelfth Street, extends south from the east end of section 3 and including the two arms at the north end is 743 feet in length.

The asphaltic petroleum was applied at the rate of 0.27 gallon per square yard, which was as much as the road surface would retain owing to the low viscosity of the material. A few hours later fine gravel was applied at the rate of 27 pounds per square yard. The surface was then rolled and the section opened to traffic.

#### BEHAVIOR OF SECTIONS UNDER REGULAR MAINTENANCE OBSERVED

One year after construction, section 1 was in the best condition of the group and had required no maintenance. It had a mosaic surface, which was smooth, hard, and well bonded.

The surface of section 2 showed some tendency to develop slight waves, especially along the south edge. Several worn depressions in the middle of the road had developed during the previous winter due, apparently, to poor bond between the macadam and the surface mat. It was believed that the section would be materially benefited by a light surface treatment, which was given later in the summer.

Shortly after the original treatment, section 3 showed a tendency to become muddy in wet weather and after periods of continued rain the surface was covered with a deep oily mud which gradually worked into ridges along the edges of the road. Figure 2 illustrates the condition of the surface during dry and rainy periods.

By the summer of 1914 all of the sections showed considerable wear. The surface mat on section 1 had become somewhat brittle, especially along the sides of the road, although it was still generally unbroken. Several holes had developed on section 2 but the surface was otherwise in excellent condition. The mat had largely worn off of section 3 and several small holes had developed. Although section 4 was smooth and well bonded, some of the large stone in the underlying macadam were exposed. The section, however, required no repairs except for a small area on the curved portion near Twelfth Street.

Preceding the retreatment given all the sections later in the summer the holes were repaired with water-bound

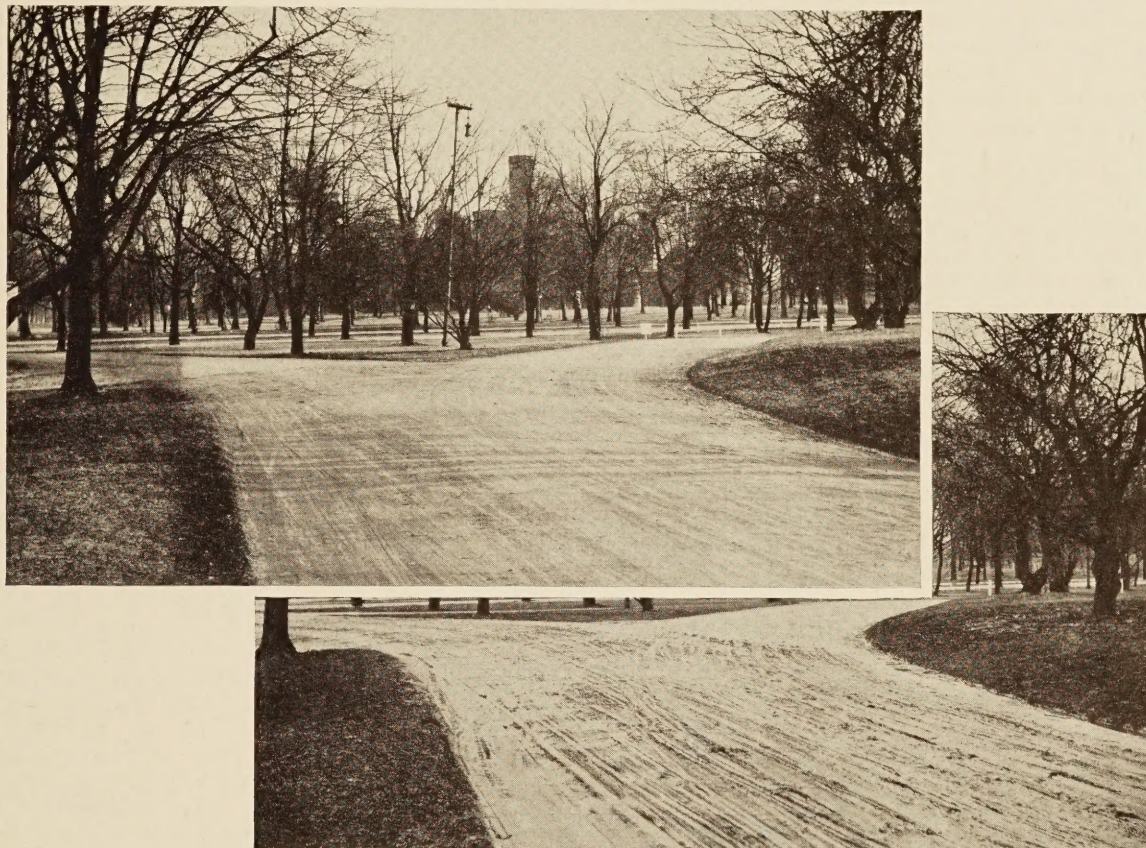


FIGURE 2.—APPEARANCE OF SECTION 3 (1912-1915) IN DRY AND WET WEATHER. NOTE STABLE CONDITION OF SECTION 4 ON THE RIGHT DURING WET WEATHER

By the early summer of 1913 the surface of the underlying macadam was exposed throughout the traveled area and the section was given a retreatment in July.

Section 4 gave excellent service in both wet and dry weather, but due to the light treatment originally applied the surface mat wore off, exposing the macadam in some areas. The surface mat was strengthened with a retreatment, given at the same time that sections 2 and 3 were retreated.

Before applying these treatments in 1913, the surfaces were swept. Such depressions as had developed were filled with limestone and screenings and all humps were removed. The treatment consisted of applying to the central portion of the roadway 0.10 gallon per square yard of the same bituminous materials as were used originally. Application was made by pouring the bituminous material on the road surface and spreading it with hand brooms. Torpedo sand was used as the covering material.

macadam and the surface swept with hand brooms. The same types of bituminous materials and cover as used in the original treatment were then applied.

During the following summer (1915) all of the sections, except No. 1, required a treatment. Section 1 was in excellent condition requiring neither repairs nor retreatment. Section 2 had raveled in some areas to a depth of 2 inches or more. The mat had worn unevenly and over a considerable portion of the section was entirely gone. The surface was repaired with penetration patches in which an oil asphalt and limestone were used and top-dressed with trap chips. The section was then lightly retreated with the materials originally used.

Section 3 had been persistently muddy during the preceding winter and spring as shown in Figure 2. The oily mud had been forced aside from the wheel tracks so that many bare places and depressions existed. One rut about  $1\frac{1}{2}$  inches deep and 8 to 10 inches wide

had developed along the north edge for some 75 or 80 feet near the west end. The section was patched in the same manner as section 2 and then retreated. Asphaltic petroleum of the same kind as used on section 4 was used in the retreatment to avoid, if possible, the winter and wet weather failure of the section.

Section 4 was in fairly good condition and had required no repairs but was given a retreatment to enliven the surface mat. The treatment given was the same as that originally applied.

All the sections were again retreated in the fall of 1916 using the same materials that were used the preceding year. During the summer of 1916 section 1 was subjected to much heavier steel-tired traffic than ever before owing to construction operations on the department grounds. By October the surface mat had become so thin that it was thought best to make some slight repairs and apply a retreatment.

At the same time section 2, although not subjected to the increased heavy steel-tired traffic, showed a greater degree of failure than ever before. With the exception of the central 100 feet, the section was spotted with small potholes from 1 to 1½ inches deep, but its surface was otherwise unbroken. It required considerable patching before the treatment was applied. Sections 3 and 4 were also repaired prior to retreating.

During 1917 the repairs required on sections 1 and 4 were very light but the maintenance on section 2 was

fairly heavy. Section 3, which had continued the least satisfactory, was resurfaced with 3 inches of penetration macadam using ¾-inch to 1¼-inch gravel and oil asphalt.

Since 1917 section 1 has required only moderate maintenance. During this period three light surface treatments have been applied, using in each case the same grade of tar as originally, with a covering of torpedo sand.

The maintenance on section 2 since 1917 has continued quite heavy. Retreatments were applied in 1918, 1923, and 1925. Previous to the treatment in 1918, the surface was scarified, reshaped, and recompact to eliminate the rich, unstable surface mat formed by the building up of the previous surface treatments. In the treatments applied in 1918 and 1925 a material heavier than that used previously was applied hot and covered with ½-inch stone chips. In 1923 a cut-back asphalt was applied cold and covered with torpedo sand. Up to the past year a considerable portion of the maintenance has been the repairing of the edges which have suffered severely because of the lack of pavement width for the volume of traffic. The extensive repairs thus made have resulted in a gradual widening of the traveled area with a corresponding decrease in edge failure.

Section 3, since its resurfacing as a penetration macadam in 1917, has remained in excellent condition. Except for a surface treatment applied in 1923, the

TABLE 4.—Cost and description of experiments

Section	Original construction			Annual cost of maintenance and surface treatments in cents per square yard															
	Type of surface and bituminous material	Amount of bituminous material (gals. per square yard)	Surface cost (cents per square yard)	1913		1914		1915		1916		1917		1918		1919		1920	
				Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance
1	Surface treatment on trap macadam using a refined water-gas tar (cold)	0.43	7.00			4.03				4.78			0.35		0.94	7.54	0.63		
2	Same as section 1, using an asphaltic petroleum (cold)	.41	7.57	1.89	0.44	3.33	0.19	3.05	1.55	4.42			2.93	17.78	3.17		1.82		0.85
3	Same as section 1, using a residual petroleum (cold)	.42	8.94	2.92		4.02	.20	4.98	1.82	4.64			(1)	(1)					
3	Penetration macadam with oil asphalt (hot)		<sup>2</sup> 240.13										4.93		9.72		2.60		1.31
4	Same as section 2	.27	5.67	1.56	.52	3.26	.12	3.26		4.64			.57	8.61	.94	6.73			
8	Penetration macadam on old "sheet" base using hot tar <sup>4</sup>	2.45	95.75																

Section	Original construction			Annual cost of maintenance and surface treatments in cents per square yard—Continued												Total cost of maintenance only (cents per square yard)	Average annual maintenance cost (cents per square yard)					
	Type of surface and bituminous material	Amount of bituminous material (gals. per square yard)	Surface cost (cents per square yard)	1921		1922		1923		1924		1925		1926				1927		1928		
				Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance			Treatment	Maintenance			
1	Surface treatment on trap macadam using a refined water-gas tar (cold)	0.43	7.00			3.33		4.38	5.82	3.92				6.73	1.68			3.10	47.26	2.95		
2	Same as section 1, using an asphaltic petroleum (cold)	.41	7.57			5.26		4.84	8.01	17.00			11.93	14.45	8.26			15.63	13.10	6.83	146.73	9.17
3	Same as section 1, using a residual petroleum (cold)	.42	8.94																		18.58	4.65
2	Penetration macadam with oil asphalt (hot)		<sup>2</sup> 240.13			2.47		3.21	8.47	2.07				2.00				3.24		.83	40.85	3.40
4	Same as section 2	.27	5.67			1.05		2.99	<sup>3</sup> 7.08	2.20				1.33				.35			39.86	2.49
8	Penetration macadam on old "sheet" base using hot tar <sup>4</sup>	2.45	95.75					6.94	1.28									2.11		3.21	14.73	1.84

<sup>1</sup> Rebuilt as penetration macadam in 1917.

<sup>2</sup> Cost abnormal due to war prices on materials and labor.

<sup>3</sup> On a portion of the section only. Cost calculated on total area of section, 1.73 cents per square yard.

<sup>4</sup> Constructed in 1921.



maintenance has consisted almost entirely in repairing the edges as in section 2.

Section 4, also, has remained in excellent condition since 1917 and has received three light surface treatments which were applied in 1918, 1919, and 1923. Although it does not carry as large a volume of traffic as do sections 2 and 3, a considerable portion of the maintenance required has been the repair of the edges.

The cost of maintaining the sections to date is given in Table 4 and Table 5 shows the character and quantity of the materials used in construction and in the subsequent surface treatments.

**SECTION 8 RECONSTRUCTED AS A PENETRATION MACADAM**

Section 8 of the department grounds experiments is of special interest because of the nature of its construction. This section, which extends from Fourteenth Street almost to the front of the main building was, previous to 1920, a tar sheet pavement on a tar-binder course which had been laid on a pit-run gravel base. The surface had deteriorated to such an extent that the only remedy was reconstruction.

It was thought desirable to remove the old road structure and replace it with a new penetration mac-

adam, but sufficient funds were not available and this plan was abandoned. It was decided to lay a penetration macadam surface upon the old pavement as a base.

The old surface was brought to a true and uniform grade by patching with a tar and stone mix after which a paint coat of a light tar was applied at a rate of 0.34 gallon per square yard. Good quality, crushed granite, 1 3/4 inches to three-fourths inch in size was then spread to a depth sufficient to give 1 1/2 inches when compacted, and thoroughly rolled. Hot refined tar was then applied at the rate of 1 1/2 gallons per square yard, followed by 3/4-inch to 1/4-inch stone chips in sufficient quantity to key the surface which was then rolled. The seal coat consisted of an application of one-fourth gallon per square yard of the same tar and a light cover of stone chips. Rolling of the surface completed the operation. The analysis of the tar used is given in Table 6.

Since construction the section has remained in excellent condition, requiring very light maintenance and only one light surface treatment of asphaltic petroleum and torpedo sand.

The construction and maintenance cost of the section are given in Table 4.

TABLE 5.—Quantities and types of bituminous materials used in construction and retreatment

Section	Original construction		Gallons per square yard and type of material used in retreatments, years—						
	Type of construction and materials used	Material		1913	1914	1915	1916	1917	1918
		Bitumen	Gravel						
1	Surface treatment on trap macadam using refined water-gas tar (cold) and gravel (cold).	Gals. 0.43	Pounds 27	-----	0.18 gallon refined water-gas tar. <sup>1</sup>	-----	0.14 gallon refined water-gas tar. <sup>1</sup>	-----	-----
2	Surface treatment on trap macadam using an asphaltic petroleum (cold) and gravel.	.41	27	0.10 gallon asphaltic petroleum on central portion of road only. <sup>1</sup>	0.14 gallon asphaltic petroleum. <sup>1</sup>	0.05 gallon asphaltic petroleum. <sup>1</sup>	0.15 gallon asphaltic petroleum. <sup>1</sup>	-----	0.28 gallon hot asphaltic oil. <sup>2</sup>
3	Surface treatment on trap macadam using a residual petroleum (cold) and gravel.	.42	27	0.10 gallon residual petroleum on central portion of road only. <sup>1</sup>	0.18 gallon residual petroleum. <sup>1</sup>	0.23 gallons asphaltic petroleum. <sup>1</sup>	0.11 gallon asphaltic petroleum.	Penetration macadam surface constructed using oil asphalt.	-----
4	Same as section 2.	.27	27	do. <sup>1</sup>	0.15 gallon asphaltic petroleum. <sup>1</sup>	0.15 gallon asphaltic petroleum. <sup>1</sup>	do. <sup>1</sup>	-----	0.13 gallon asphaltic petroleum. <sup>1</sup>

Section	Original construction		Gallons per square yard and type of material used in retreatments, years—						
	Type of construction and materials used	Material		1919	1920	1922	1923	1925	1926
		Bitumen	Gravel						
1	Surface treatment on trap macadam using refined water-gas tar (cold) and gravel (cold).	Gals. 0.43	Pounds 27	0.14 gallon refined water-gas tar. <sup>1</sup>	-----	-----	0.16 gallon refined water-gas tar. <sup>1</sup>	-----	0.25 gallon refined water-gas tar. <sup>1</sup>
2	Surface treatment on trap macadam using an asphaltic petroleum (cold) and gravel.	.41	27	-----	-----	-----	0.22 gallon asphalt cut-back. <sup>1</sup>	0.31 gallon hot asphaltic oil. <sup>2</sup>	-----
3	Surface treatment on trap macadam using a residual petroleum (cold) and gravel.	.42	27	-----	-----	-----	0.25 gallon asphalt cut-back. <sup>1</sup>	-----	-----
4	Same as section 2.	.27	27	0.13 gallon asphaltic petroleum. <sup>1</sup>	-----	-----	do. <sup>1</sup>	-----	-----
8	-----	-----	-----	Penetration macadam surface constructed using 2.45 gallons hot tar.	0.15 gallon asphaltic petroleum. <sup>1</sup>	-----	-----	-----	-----

<sup>1</sup> Torpedo sand used as cover material.

<sup>2</sup> Stone chips used as cover material.

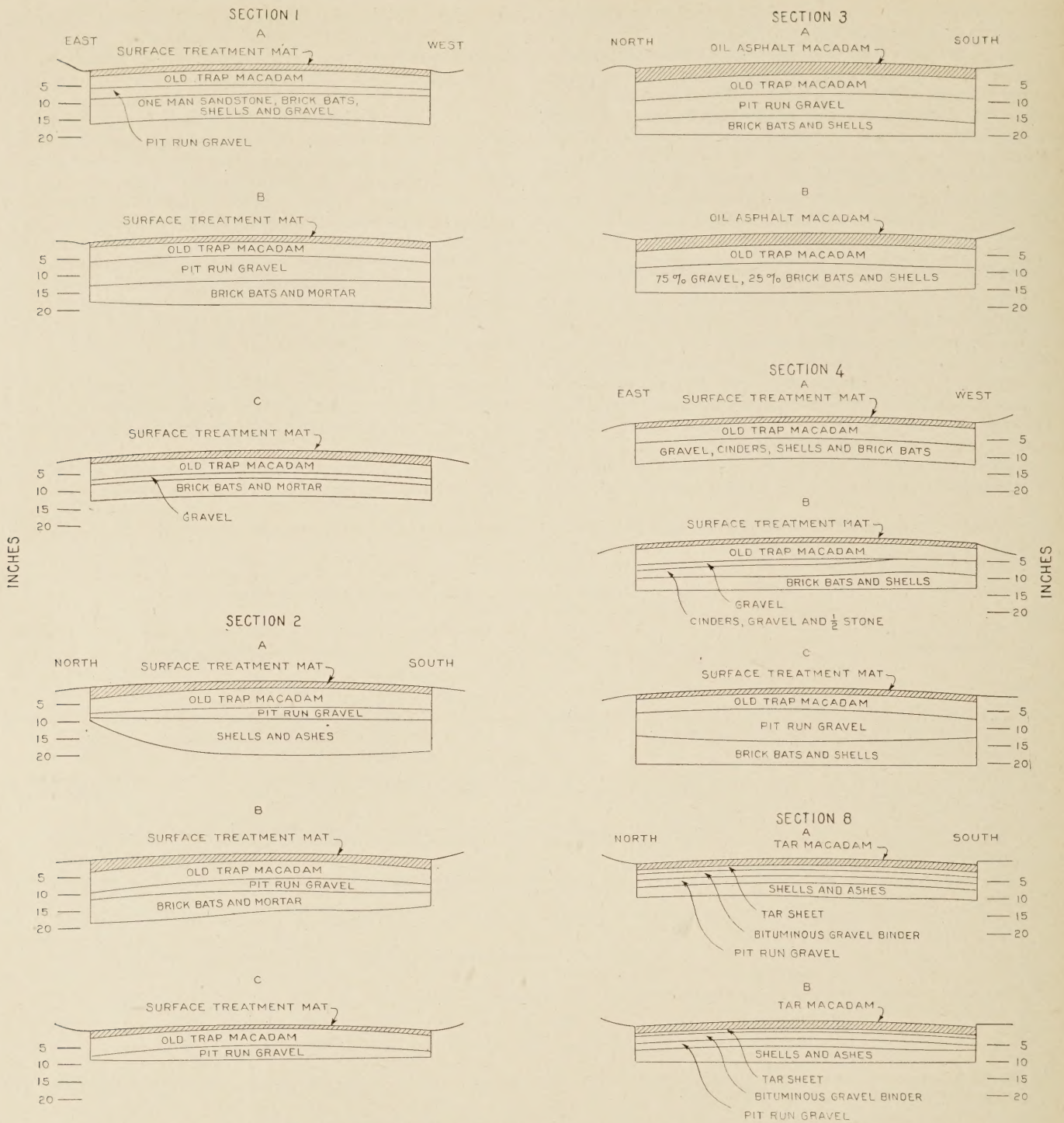


FIGURE 3.—CROSS SECTIONS OF EXPERIMENTAL SECTIONS

CAREFUL CONDITION AND TRAFFIC STUDY MADE IN 1928

A careful study of the sections was made in 1928 and included a survey of surface conditions, an examination of the road structure and of the subgrade and the taking of a traffic census. A series of test holes was dug through the pavement on the center line and at points 5 feet each way on each section. The nature and extent of the materials found are shown in the cross sections in Figure 3. Samples of the underlying soil were taken from each test hole and their analyses are given in Table 7. The traffic count of July, 1928,

is the only one taken on these sections since their construction. The results of the count are given in Table 8. The character of the traffic is the same throughout and is limited to passenger cars, busses, and light delivery trucks.

Section 1 carries approximately 100 vehicles daily and in one direction only. Parking is permitted on the west side. The surface of the section, as illustrated in Figure 4, is somewhat mottled, due to the absence of the granular covering material in some areas and is very dull in appearance due to lack of traffic. How-

TABLE 6.—Analysis of refined coal tar used in constructing the penetration surface on section 8 in 1920

Specific gravity 25° C./25° C.....	1. 222
Float test at 50° C. (seconds).....	84
Total bitumen soluble in carbon disulphide (per cent)....	84. 8
Free carbon (organic matter insoluble) (per cent).....	15. 1
Inorganic matter insoluble (per cent).....	. 1
Distillation by weight (per cent):	
170° C.....	0. 00
170° C. to 235° C.....	1 4. 09
235° C. to 270° C.....	1 5. 29
270° C. to 300° C.....	2 5. 16
Residue.....	3 85. 40
Total.....	99. 94
Melting point of residue °C.....	59

TABLE 7.—Physical characteristics of the subgrade soils

Section	Inspection point	Description	Lower liquid limit	Plastic index	Shrinkage limit	Shrinkage ratio	Centrifuge moisture equivalent	Field moisture equivalent
1	A.....	Light brown silty loam, dry and powdery.	22	8	14	1.9	16	18
	B, 0 to 15 inches.	Brown clay loam, compact and dry.	26	10	15	1.9	21	21
	B, 15 to 24 inches.	Gray mottled silt, compact and dry.	27	10	18	1.8	24	20
	C.....	Brown clay loam, compact and dry.	27	12	15	1.9	21	20
2	A, B, and C.....	do.....	25	10	15	1.9	20	19
3	A and B.....	do.....	27	12	15	1.9	21	20
4	A and B.....	Brown sandy loam, compact and dry.	20	6	16	1.9	14	17
	C, 0 to 6 inches.	Brown clay loam, compact but damp.	26	10	17	1.9	23	20
8	C, 6 to 24 inches.	Light brown clay, mottled, soft, and water bearing.	34	15	20	1.8	25	23
	A.....	Brown clay loam, compact and damp.	30	14	15	1.9	21	21
	B.....	Brown sandy loam.....	21	7	14	1.9	17	17

TABLE 8.—Volume and character of traffic carried by the various sections as shown by the 1928 count

	Section 1	Section 2	Section 3	Section 4	Section 8
Average vehicles daily.....	104	4, 708	5, 213	305	3, 542
Passenger cars.....	104	4, 669	5, 171	303	3, 506
Busses.....	0	37	39	1	23
Light trucks.....	0	2	3	1	13

ever, it is smooth riding and intact and the edges are in good condition, free from breaking or raveling. Both ends of the section, where they intersect sections 2 and 8, are sharp curves and in making the turns traffic has continually encroached upon the lawn. In maintaining the section the surface has been gradually widened to correct this condition. The two cross drains shown in Figure 1, together with the natural slope, afford the section ample drainage.

Section 2 carries a heavy volume of traffic which travels in both directions. The traffic census showed an average daily traffic of 4,708 vehicles with as many as 592 passing over the section in a single hour. The tendency of traffic to encroach upon the adjacent lawn has necessitated a gradual widening throughout the section until its average width at present is now 19½ feet instead of 16 feet as originally constructed.

The section has always required heavy maintenance. The cross sections show a bituminous mat ranging in thickness from 1 to 3 inches and averaging 1.6 inches



FIGURE 4.—PRESENT APPEARANCE OF SECTION 1. PARKING OF CARS ON ONE SIDE LEAVES ONLY A SINGLE TRAFFIC LANE FOR THE ONE-WAY TRAFFIC

for the entire section. The central portion of the section has always required considerably more maintenance than the remainder and its condition at present, as illustrated in Figure 5, is probably worse than any other area included in the experiments. Its tendency to shove under traffic during very hot weather has recently required the extensive use of crushed stone in an attempt to stabilize the bituminous mat which is about 2 inches thick.

The surface on the remainder of the section although somewhat wavy is intact. It is mosaic in appearance where the coarse stone is exposed but shows no tendency to pothole or ravel. The eastern portion of the section, as shown in Figure 6, lies in a cut but the western portion is comparatively flat. Bituminous macadam gutters and cross drains where needed, together with the natural slope of the road, afford adequate drainage.

Section 3 is in excellent condition. Its surface is firm and smooth and shows no tendency to ravel although the coarse stone is exposed. Like section 2, it carries very heavy traffic traveling in both directions. The recent count showed a daily average of 5,213 vehicles. On several occasions the number of vehicles passing over the section exceeded 500 per hour. The gradual widening of the travel area along the edges has increased the width of the section to approximately 20 feet. Figures 7 and the cover page show the present condition of the section as well as its location which is mainly in a cut. The natural slope and the bituminous gutters provide satisfactory drainage.

Section 4, which carries traffic in both directions, is in very good condition. Its surface, although very dull in appearance, is smooth and intact. Some breaking along the edges has been caused by vehicles leaving or coming onto the surface from the adjacent parking areas. The average daily traffic carried by the section, as shown by the 1928 count, was 305

<sup>1</sup> Solid.

<sup>2</sup> Fluid

<sup>3</sup> Medium hard pitch.

vehicles. Natural and artificial drainage are adequate for the section, a part of which is in a cut on one side as shown in Figure 8. Two cross drains as shown in Figure 1 provide the artificial drainage.

Section 8, although in service for a considerably shorter period of time than the other sections, is giving excellent service at a remarkably low cost and to all appearances is suffering no deterioration from traffic. The 1928 count showed it to be carrying an average of 3,542 vehicles daily. The surface is smooth and intact save for a few small hair cracks which have been filled with bituminous material. Some large stones of the macadam course are showing but there is no tendency to crush or ravel. The section lies in a cut throughout its length but has a natural slope sufficient to carry off surface water satisfactorily. A concrete sidewalk on the south side and a slight embankment on the north side afford ample protection to the edges. Figure 9 shows the location and present condition of the section.

values than the clay loam above. In section 1, at point A, a light brown silty loam was encountered, probably a mixture of the two previously described soils.

In section 8, at point B, the soil is a brown sandy loam, compact and dry, and having low shrinkage and plastic properties.

In section 4, at points A and B, the soil is similar to that described for section 8, at point B. However, at point C, the first 6 inches below the bottom of the pavement were found to be a brown clay loam, compact but damp. Underlying this stratum was a bed of light brown mottled clay, soft and wet. In fact, one half hour after the borings had been made at this point free water was observed in the bottom of the auger hole. Laboratory tests on this soil show it to be the most plastic soil encountered.

None of the borings revealed an appreciable amount of coarse material in the subgrade, with the exception of section 8, at point B. At this one point rock frag-



FIGURE 5.—PRESENT CONDITION OF THE CENTRAL PORTION OF SECTION 2. NOTE HEAVY PATCHING AND SHOWING OF THE SURFACE MAT ALONG RIGHT SIDE

#### SURVEY OF THE SUBGRADE CONDITIONS INDICATES SATISFACTORY SUPPORT

Borings were made to a depth of 2 feet below the bottom of the pavement at each point where test holes were dug. In all cases it was found that the soil strata were the same at both sides and in the center of the roadway. Consequently the sample taken at each cross section was a composite of the three borings. Where more than one stratum was encountered, a sample was taken from each.

At all points of inspection in sections 2 and 3, and in parts of sections 1 and 8, the subgrade was found to be a dry, dense, brown clay loam very thoroughly compacted. This soil has low plastic and shrinkage properties as shown in Table 7.

In section 1, at point B, the brown clay loam is underlain at a depth of 15 inches below the bottom of the pavement by a gray mottled silt, very dry and compact, and which has slightly lower plastic and shrinkage

properties were encountered at 6 to 12 inches below the bottom of the pavement. It was possible to work the auger around the stone and penetrate to the full 2 feet, indicating that the rock fragments were small. This condition obtained at both sides and in the center of the road.

With the possible exception of section 4, at point C, the subgrade is uniform and furnishes adequate support both in the light of laboratory tests and field conditions.

#### RECENT IMPROVEMENTS IN SURFACE TREATMENT WOULD HAVE RESULTED IN LOWER MAINTENANCE COSTS

It is evident from the behavior of the sections that the pavement thickness was sufficient and that the underlying subgrade was satisfactory throughout. The behavior of the surface treatments can therefore be taken to show the merits of the various materials and methods used. In this respect, these surface treat-



FIGURE 6.—PRESENT APPEARANCE OF THE EAST END OF SECTION 2. ALTHOUGH LYING IN A CUT THE BITUMINOUS GUTTERS AND NATURAL SLOPE AFFORD AMPLE DRAINAGE



FIGURE 8.—LOCATION AND PRESENT CONDITION OF SECTION 4. THE SURFACE MAT, ALTHOUGH INTACT, IS VERY LIFELESS IN APPEARANCE, DUE TO INSUFFICIENT TRAFFIC

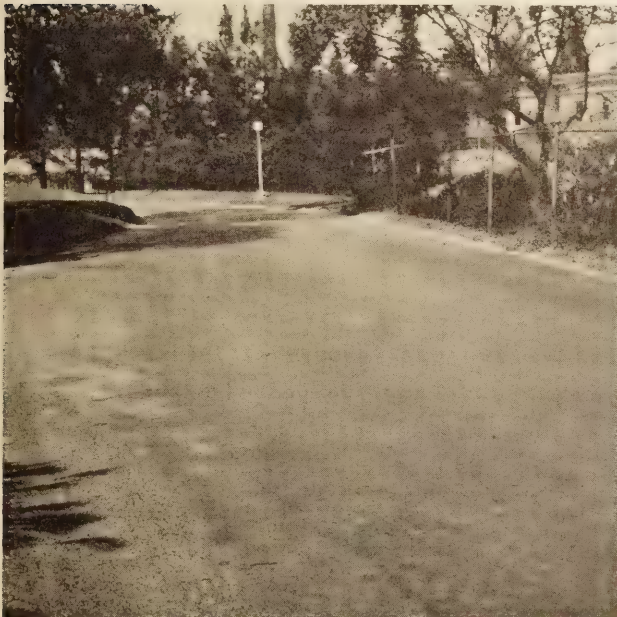


FIGURE 7.—EAST END OF SECTION 3. PRESENT CONDITION



FIGURE 9.—GENERAL VIEW OF LOCATION AND PRESENT CONDITION OF SECTION 8

ments differ from the average conditions generally found for this type of construction. Maintenance often involves patching and repair due to failure of the pavement structure because of lack of support and not to the failure of the surface treatment proper. A typical illustration of this point was the bureau's surface treatment experiment on Bradley Lane, Chevy Chase, Md.,<sup>3</sup> on which the service behavior and the cost of maintenance were greatly affected by failures due to insufficient foundation support.

An effort has been made to keep these sections in good condition and to maintain the type of treatment unchanged as nearly as possible by using in re-treatments materials similar to those used in the original construction. It should not be inferred, however, that because the types have remained unchanged except in a few cases the methods and materials used have been entirely satisfactory and represent what, to-day, would be considered good practice. On the contrary, it is evident that decided improvements could have been made, not only in some of the original construction but also in the subsequent maintenance treatments.

<sup>3</sup> Reported in Public Roads, February, 1929.

The light, slow-drying, residual petroleum, which was used in the construction and early maintenance of section 3, was decidedly lacking in cementing value and proved entirely unsatisfactory. An unstable mat was formed which was persistently muddy in wet weather. Additional maintenance treatments with the same material only added thickness to the mat and increased the difficulty of maintenance and its unsatisfactory condition. A section of the Connecticut Avenue experiments<sup>4</sup> on which the same type of material was used proved equally unsatisfactory, necessitating a change in type two years after construction.

Torpedo sand was used as the cover material on this section, but it was probably not responsible for or contributory to the failure of the section, as the use of coarse angular material proved of no additional benefit on the Connecticut Avenue experiment.

The excellent behavior of section 1 is probably due almost entirely to the exceedingly light traffic it carries rather than to the materials and type of construction. It is probable that had the section been called upon to carry such traffic as was carried by sections 2, 3, and 8 raveling of the surface would have occurred during its early life. Experience has shown that a single application of light tar such as was used does not have the body and binding quality to hold the cover material necessary to form a stable mat. This point is illustrated by the behavior of section 8 of the Connecticut Avenue experiments, on which a single application of a similar material was used with a cover of 1 inch to  $\frac{1}{2}$  inch stone. The tar penetrated readily, but it did not sufficiently bond the cover stone, which raveled badly, and it was only by the addition of timely and frequent maintenance treatments that a satisfactory surface mat was eventually formed.

The plan used in these experiments of making a single application fulfill the purpose of both a priming coat and binding material has long since proved unsatisfactory. A more suitable method of treatment for this section would have been to apply a prime coat followed by a heavier bodied material. The priming would have stabilized the macadam and produced a bonded surface to which the mat would have readily adhered. A heavy material in the second application would have held the stone and provided a more stable and wear-resisting mat.

#### EXPERIMENTS INDICATE NECESSITY OF FORMING A STABLE MAT

Sections 2 and 4 were practically the same as regards the asphaltic petroleum used in their original construction. The effect of the slight difference in their characteristics was not perceivable, due to the great difference in volume of traffic carried by the sections. Their behavior was more satisfactory than that of section 3, in that a fairly stable mat was formed which held the cover material and which showed no tendency to become soft and muddy in wet weather.

The scarifying and reshaping of section 2 preceding the re-treatment of 1912 was necessary to eliminate the thick, unstable mat which had developed. This trouble was not due to the character of the bituminous material used, but rather to the frequent maintenance treatments with the invariable use of a fine covering material.

In maintaining by surface treatment it is important to guard against the development of an unstable mat.

It is essential not only that the bituminous material selected be suitable but the cover material as well, and their selection depends upon the purpose of the treatment—whether it is to enrich the surface or to form a mat. Section 2, with its thick, unstable mat is an illustration of the result of improper selection of materials for certain conditions.

Present practice favors a lean appearing surface mat having a granular texture rather than a richly sealed surface having a smooth, glossy appearance. Experience has shown that the former is more stable and safer under present day traffic.

The bituminous material used in the maintenance of section 2 was a type which would readily hold coarse covering material and there is no doubt that the surface behavior would have been decidedly better had fewer treatments been applied and coarse cover material been used with some of them. The section will soon have to be reconstructed to stabilize the surface and again eliminate the thick, rich mat.

In view of the present condition of all the sections, excepting section 2, it can be reasonably expected that they will continue indefinitely to give excellent service at a moderate cost with the present type of maintenance.

Table 4 shows that the cost of maintaining the water-bound macadam surface by surface treatment and patching ranged from 2.49 cents per square yard annually for section 4 to 9.17 cents for section 2, while for the penetration macadams the cost ranged from 1.84 cents for section 8 to 3.40 cents for section 3.

#### MAINTENANCE COSTS DISCUSSED

In comparing the maintenance cost of the two types, sections 1 and 4 should not be included, as the traffic carried by them is not comparable with that of sections 2, 3, and 8. Considering only sections 2, 3, and 8, the average annual cost per square yard was 2.78 cents for the penetration type as compared with 8.26 cents for the surface treatment of plain macadam. Table 9 shows that these costs agree closely with these of maintaining similar sections of the Connecticut Avenue experiments. However, in comparing the costs of the two groups of experiments, some account should be taken of the difference in traffic conditions. On the department grounds traffic ranged from 3,500 to 5,300 daily and traveled in both directions. Heavy trucks were excluded, but any advantage accruing in this respect was probably offset by the numerous heavy busses. On the Connecticut Avenue experiments the

TABLE 9.—Comparison of surface treatment maintenance costs of the Connecticut Avenue and department grounds experiments

PENETRATION MACADAM SECTIONS			
	Years of service	Average annual maintenance cost	Average daily traffic
Connecticut Avenue.....	16.....	Cents per square yard 2.62	3,000 (1927)
Department grounds.....	8 to 12.....	1 2.78	4,400 (1928)
SURFACE-TREATED, WATER-BOUND MACADAM SECTIONS			
Connecticut Avenue.....	15.....	Cents per square yard 8.37	3,000 (1927)
Department grounds.....	4 to 16.....	1 8.26	4,700 (1928)

<sup>4</sup> Reported in Public Roads, May, 1923, vol. 9, No. 3.

<sup>1</sup> Cost weighted in proportion to time in service.

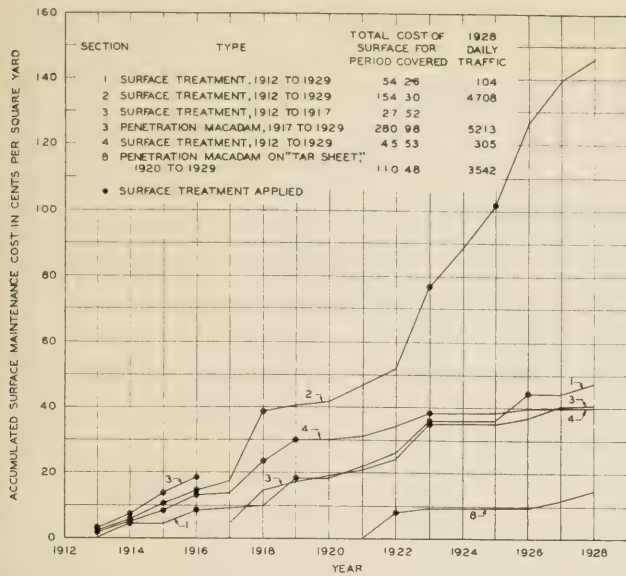


FIGURE 10.—COMPARISON OF COST OF MAINTAINING EXPERIMENTAL SECTIONS EXCLUSIVE OF CONSTRUCTION COSTS

traffic was unrestricted, traveled in one direction only and averaged 3,000 vehicles daily.

The wide difference in the cost of maintaining the two types, based on a study of these two groups of experiments, would indicate a decided economical advantage of the penetration macadam over the surface treatment of water-bound macadam. However, since there has been little change in the method of constructing and maintaining penetration macadam as compared with the decided improvement in surface treatment work in recent years, it is not believed that this difference in maintenance cost would be as large on more recent construction.

Although the maintenance costs of sections 1 and 4 are not comparable with the others, they are of interest in showing that a certain amount of maintenance is necessary regardless of traffic, if the surface is to be protected from deterioration from natural causes. The maintenance cost per vehicle carried, for these two sections, is many times higher than that of the more heavily traveled sections. Similarly, section 4, has carried three times as much traffic as section 1, but its actual maintenance cost has been materially less. Indications are that section 1 has suffered consistently from lack of traffic and it is believed that this accounts for its higher maintenance cost.

CONCLUSIONS

Briefly, a study of the experiments shows:

1. On a nonrigid pavement, an adequate, wear-resisting bituminous surface mat capable of carrying almost unlimited traffic can be economically maintained provided it has adequate subgrade support.
2. Sufficient foundation support materially lessens the cost of maintenance and is reflected in the freedom from patching and absence of settlement of the surface.
3. A prerequisite to a successful surface treatment of the mat type is a stable, well-bonded surface to which the applied treatment will readily adhere. In the surface treatment of a penetration macadam these conditions are found, but where the surface of the road to be treated is not well bonded a prime coat is essential.
4. Successful maintenance by surface treatment requires that the materials used be such that their combination will produce a stable mat.

5. A surface can be indefinitely maintained in a stable condition by surface treatment provided materials are selected which are suited to the purpose of the treatment.

6. A surface mat which has become unstable may be reclaimed as a penetration macadam at a comparatively low cost, and made to produce a stable surface that can be economically maintained.

7. Thin surface mats carrying very light traffic require a certain amount of maintenance to offset the deterioration due to weathering. The amount of such maintenance is decreased with a corresponding increase in traffic.

TRAFFIC SURVEY NOW UNDER WAY IN WESTERN STATES

In order that the Federal Government and the Western States may know what the flow of traffic is throughout the year on the main transcontinental highways and on other roads in the Federal-aid highway system in the West, the highway departments of Washington, Oregon, California, Idaho, Nevada, Wyoming, Utah, Arizona, Colorado, New Mexico, and Nebraska and the Bureau of Public Roads of the United States Department of Agriculture began a traffic survey in September which will extend over a period of one year. Among the routes on which traffic will be measured are the historic Oregon Trail, over its entire length from Omaha to Portland, parts of the Santa Fe and Overland Trails, and the long-distance motor-bus routes from Omaha to Denver, Salt Lake City, and San Francisco, and from Denver to Los Angeles by way of Santa Fe, and from Seattle to Los Angeles.

Data compiled by the State highway department of New Mexico in 1927 and 1928 indicate that more than 30 per cent of the vehicles using the roads of that State in those two years were from other States, and on many routes the so-called "foreign" traffic was more than half the total. The foreign traffic on many of the New Mexico highways was 50 per cent greater in 1928 than in 1927, and the total traffic was 22 per cent greater in 1928 than in 1927. A similar situation is believed to exist in the other Western States.

In the Western States traffic has reached the point where it is necessary for the States to know the flow, density, and composition of the traffic on their roads, so they can plan their highway systems on a good economic basis and plan for the removal of snow in winter.

The survey will show the number of vehicles using each of the main highways throughout the year, by days of the week and hours of the day, and the number of vehicles passing a given point at certain times of the day. It will classify the traffic according to types of vehicles, whether passenger cars, motor trucks, or motor busses, and the number of passengers in passenger cars. The importance of cities, towns, and sections of the State as the source and destination of traffic will be ascertained, and the number of vehicles from other States using the highways, and other information required by State and Federal highway officials, will be obtained. The data will be useful in solving traffic regulation and safety problems. Surveys are being conducted simultaneously in each of the States.

# THE FREYSSINET METHOD OF CONCRETE-ARCH CONSTRUCTION

By ALBIN L. GEMENY, Senior Structural Engineer, Division of Tests, Bureau of Public Roads

The hingeless concrete arch, when built by the customary method, has certain disadvantages which limit its use to comparatively short spans and to locations where practically incompressible foundations are available. Due to various causes, deformations of the concrete occur and produce what may be called parasitical stresses because they do no useful work in carrying load and therefore reduce the load capacity of the arch.

These parasitical stresses are due to elastic shortening of the rib under load, shrinkage of the concrete, and a change in temperature from that which exists in the concrete when arch action begins. The deformations due to shrinkage of the concrete and to temperature variations are independent of the depth of rib except in so far as the mass of a member affects the rate at which drying out proceeds and the speed with which

these stresses and reducing others to a minimum.<sup>1</sup> In addition, his method, even for spans of moderate length, makes the construction of an arch a simpler and more certain procedure than the usual method. The usual provisions for striking centers are not necessary and the centers and falsework can be built more rigidly and economically. In addition, the arch axis can be adjusted so that the maximum dead and live load stresses can be considerably reduced.

Freyssinet has built in France many arches by his method and has gradually increased the span to 612 feet without any difficulty. Such a span would be impracticable by the old method. He believes that spans of 1,500 for plain concrete and 2,000 feet for reinforced concrete are entirely practicable where economic conditions otherwise warrant the use of such spans.



AN ARCH CONSTRUCTED BY THE FREYSSINET METHOD

the atmospheric and rib temperatures are equalized. Therefore, as the depth of rib is increased for dead and live load stresses, the parasitical stresses increase rapidly and definitely limit the span length which may be constructed by the method of striking centers in the usual way.

Various efforts have been made to eliminate these parasitical stresses by the use of such expedients as temporary hinges, but they have been only partly successful. These methods do not furnish the means of definitely controlling the amount of adjustment.

## THE FREYSSINET METHOD HAS A NUMBER OF ADVANTAGES

In 1908 Mr. E. Freyssinet, a noted French engineer, introduced an ingenious and extremely simple method of almost totally eliminating the most troublesome of

Articles on this method have appeared in American technical literature at various times, but it apparently has never been used in this country in spite of its obvious merit and simplicity.

The Freyssinet method is applicable to any type of concrete arch, but we will discuss here only the symmetrical rib arch, the most common type in highway work.

The ribs are separated into two halves at the crown by a transverse joint without thickness. (See figs. 1 and 2.) A group of jacks is placed at this joint in each rib and in emplacements provided for the purpose. By exerting a horizontal jack pressure equal to or a little greater than the thrust of the arch the joint is opened and the arch is lifted off the centers. The

<sup>1</sup> According to Mr. Freyssinet this method is not patented.



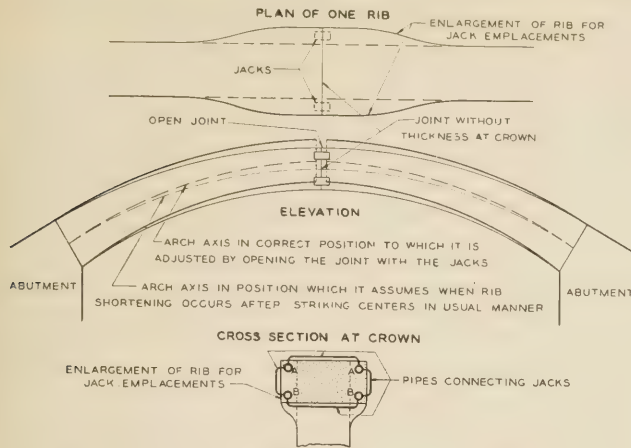


FIGURE 1.—SKETCH SHOWING POSITION OF HYDRAULIC JACKS FOR ADJUSTMENT OF ARCH AXIS

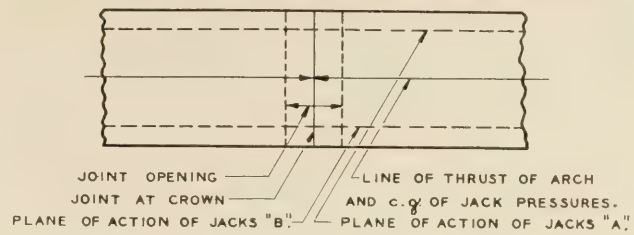
axis may thus be put in the position anticipated in the design. The amount by which the joint must be opened to accomplish this purpose is a measure of the combined rib shortening which has occurred, due to all causes.

Final keying may be done when the joint opening indicates that nearly all of the shrinkage is complete and when the rib temperature is at the mean value chosen for keying. As the joint is opened, steel plates are inserted covering the entire area of the section and kept tight, so that in case of accident to the jacks the thrust would be taken by the shims. The final keying may be accomplished by filling the joint with mortar or, in case of a large opening, by means of a precast concrete slab of the necessary size and shape to produce the required elongation and rotation of the axis at the crown. The exact shape and thickness of this slab may be determined by estimating the total shortening due to the various causes or it may be determined by a trial loading.

Freyssinet has found it possible to rekey an arch several years after completion in order to correct for delayed shrinkage or movements of the supports. Where it is observed that shrinkage is probably not complete, the arch can be temporarily keyed with steel plates until the fall of the crown indicates further shrinkage has occurred. The jacks can be replaced with practically no interruption to traffic and the axis raised to its theoretical position and the final keying accomplished. It is of course necessary to select a time when the temperature of the ribs is the chosen mean temperature.

Freyssinet used specially made jacks of 500 metric tons capacity, about 6 inches long and 16 inches in diameter with a maximum stroke of 3 inches. The jack emplacements may be a part of the section of the rib or the rib may be widened at the crown so as to preserve the entire section for arch thrust. In case the emplacements reduce the section of rib, high strength concrete with special reinforcement should be used on each side of the joint for a short distance so as to increase its bearing strength. The same is true of the jack bearings. On several large spans Freyssinet used four jacks in each rib, two near the intrados and two near the extrados. By connecting the jacks so that they could be operated separately or together he was able to shift the center of gravity of jack pressures in a vertical plane to produce any desired rotations of the joint surfaces. Accurate gauges measured the jack pressures.

UNIFORM JOINT OPENING WHEN LINE OF THRUST AND C. G. OF JACK PRESSURES COINCIDE.



JOINT OPENING WHEN THE C. G. OF JACK PRESSURES IS SHIFTED TO A POSITION ABOVE THE LINE OF THRUST, PRODUCING A ROTATION OF THE FACES OF THE JOINT. THE C. G. OF THE JACK PRESSURES IS LIFTED BY MAKING THE PRESSURE IN JACKS "A" GREATER THAN IN "B".

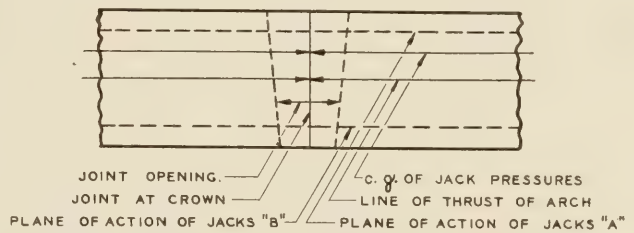


FIGURE 2.—SKETCH SHOWING OPENING OF JOINT AT CROWN OF ARCH

The combined live, dead and temperature stresses at critical sections may be reduced to a minimum by creating counterstresses with the jacks. Care must be exercised to avoid the creation of injurious strains by this operation.

A further aid to complete control of the stresses may be obtained by the use of strain gauges attached at the sections of high stress. In this way the strains may be noted as the jacks are operated and the desired adjustment accurately made.

**CORRECTION CAN BE MADE FOR ELASTIC RIB SHORTENING**

The amount of correction for elastic rib shortening can be accurately calculated by determining the modulus of elasticity from test cylinders made during construction. This correction will depend upon the modulus of elasticity of the concrete and the stresses in the rib. In most cases it will be of less importance than the other corrections.

**CORRECTION FOR SHRINKAGE OF THE CONCRETE SHOULD BE MADE PROGRESSIVELY**

Shrinkage of concrete due to setting and drying has a wide range of values depending upon the richness of the mix, the amount of mixing water used, the percentage and location of reinforcement and climatic conditions. A rich mix, within certain ranges of proportions, has the advantage of greater strength but this is counterbalanced in the usual construction methods by greater shrinkage and high resulting parasitical stresses. The Freyssinet method eliminates, to a great extent, this disadvantage of a rich mix.

Full shrinkage may not occur for a considerable period after the concrete is placed. Recent tests in Georgia<sup>2</sup>

<sup>2</sup> Described by Searcy B. Slack, bridge engineer, State Highway Board of Georgia, in Engineering News Record for August 29, 1929, pp. 336 to 339.

on an arch under construction showed that arch action started about four days after the last concrete was placed in the rib. Due to the moisture retained by the forms, it is not likely that any great amount of shrinkage had taken place in this short time. A period of wet weather after the arch is finished may delay any appreciable shrinkage for months. Correction for shrinkage should be made progressively as the shrinkage is observed so as to avoid overcorrection and the creation of dangerous counterstresses in the rib.

Because of this delayed shrinkage, it does not seem probable that the method of placing the rib in alternate sections and leaving out key sections for several days is effective in eliminating stresses due to shrinkage. The efficacy of the method depends on weather conditions and is always in doubt. Because of the uncertainties as to the rate and final amount of shrinkage, it is difficult to determine the correction except by trial loadings and the measurement of the variations in the joint opening. Laboratory experiments and observation by Freyssinet on actual structures indicate a range of shrinkage coefficients from 0.0004 to 0.0008 for concretes used in bridges.

#### UNCERTAINTY AS TO TEMPERATURE STRESSES REMOVED

It is customary, in designing for temperature stresses, to select a mean temperature and make stress calculations for fluctuations above and below this mean, covering the range of temperatures for the location in which the structure is built. It seldom, if ever, happens that the atmospheric temperature is at the selected mean temperature when the structure begins to act as an arch and becomes subjected to temperature stresses. The construction season is generally in warm weather when the temperature is considerably above this mean. Therefore, if the concrete of the rib were at atmospheric temperature the variation would be almost altogether a drop, producing a rib shortening. But the Georgia tests referred to above indicate that the condition is even worse than this. In the structure tested, arch action began four days after completion of the ribs while the rib temperatures due to chemical action of setting were from 20° to 35° F. higher than atmospheric temperature. It is therefore not improbable that a drop in temperature of as much as 100° F. will occur and create large temperature stresses. This condition adds greatly to the value of the Freyssinet method, because the keying can be delayed, without delaying the progress of the work, until a chosen mean temperature has been reached and the greater part of the temperature stresses eliminated with great precision. A few resistance coils distributed in the rib concrete during construction would facilitate the selection of the rib temperatures suitable for keying.

#### ADJUSTMENT CAN BE MADE FOR FOUNDATION MOVEMENTS AND COMBINED DEAD AND LIVE LOAD STRESSES

The Freyssinet method permits correction of foundation movements which would, by the usual method, be a serious matter. Foundation movements without rotation of the supports are equivalent to a rib shortening due to the other causes and can be corrected for in the same way. If there is reason to suppose that rotation of the supports may occur the correction can best be

made by joints near the skew backs where counter-rotations may be produced with the jacks.

After the parasitical stresses have been eliminated or greatly reduced, the arch axis may be adjusted so as to materially reduce the combined stresses due to dead load and the worst condition of live load. We have two variables, the length of the arch axis and the rotation of the axis at the crown, which can be adjusted to any desired value. It may be mathematically determined in any of the usual ways how much change in the length of arch axis and how much rotation at the crown is necessary to produce counterstresses which, when added to the live, dead, and remaining parasitical stresses, will reduce the total at critical sections to a minimum. Freyssinet, by this means, has been able to pass the thrust line very close to the axis of the rib and reduce the bending moments to a minimum. In this manner reinforcing can be greatly reduced in quantity.

This adjustment of dead and live load stresses can be accurately controlled by the use of strain gauges at the critical sections of the rib, so that the strains can be observed as the jacks are operated.

#### SUMMARY

The advantages of the Freyssinet method may be summarized as follows:

1. The parasitical stresses, which limit the concrete arch to comparatively short spans of high rise may be almost entirely eliminated thereby making practicable much longer spans and smaller rise ratios. Temperature stresses which are probably much higher than have been usually allowed for in design may be reduced to a minimum.
2. Combined dead and live load stresses may be adjusted so as to reduce the bending moments to a minimum and consequently reduce the amount of reinforcing steel and concrete required in the ribs.
3. Special provisions for striking centers in the usual manner may be eliminated and the centering and falsework built more rigidly and economically.
4. Correction may be made for small foundation movements.
5. Because of the above reasons, the concrete arch is adapted to a greater range of location conditions and the entire process of arch construction is made simpler and safer.

It is anticipated that, in the near future, the great possibilities of this method will be thoroughly explored by its use in this country in conjunction with provisions for making accurate measurements of the arch deformations incident to the process.

A complete description of this method first appeared in *Le Genie Civil* in 1921, volume 79, pages 97, 124, and 146. Since then, articles have appeared periodically in the same magazine, as the use of this method has extended in France and interest in it has increased.

A cooperative project embodying the Freyssinet method of arch construction has been proposed to the Bureau of Public Roads by the Oregon State Highway Commission. Such a project would include strain measurements and other data which would be useful in studying the possibilities of this method.

# ACCURACY OF SPECIFIC GRAVITY AND ABSORPTION TESTS OF COARSE AGGREGATE INVESTIGATED

Reported by D. O. WOOLF, Assistant Materials Engineer, Division of Tests, United States Bureau of Public Roads

THE ACCURACY of the results of certain absorption tests of coarse aggregate of variable composition was recently questioned in the course of routine tests made in connection with a research project. Comparison of the results with previous tests on the same material disclosed many apparent errors in the test which were attributed to the method of procedure. It was considered advisable to make a brief investigation of the absorption test to determine the cause of the erroneous results and to devise a method of improving the test.

The method of test for apparent specific gravity and absorption of coarse aggregate is described as follows:<sup>1</sup>

The apparent specific gravity shall be obtained by weighing the water displaced by a sample of the material weighing approximately 1,000 grams, broken into pieces about 1¼ inches in diameter. The vessel to be used consists of a galvanized-iron cylinder closed at one end and measuring 5 inches in diameter by 8 inches high. A brass spout one-half inch in diameter is soldered into the side of the cylinder 6 inches from the bottom. The spout is inclined at an angle of 2° with the horizontal and is 2½ inches long. A notch is filed across its lower end to stop the drip from the displaced water. To determine the specific gravity and absorption, the dried and cooled sample shall be weighed to the nearest 0.5 gram and immersed in water for 24 hours. The pieces shall then be surface dried individually with a towel, the sample reweighed and immediately placed in the cylinder, which has been previously filled to overflowing with water at room temperature.

The weight of water displaced by the sample shall be used to calculate its apparent specific gravity. The difference between the original weight of the sample and its weight after 24 hours shall be used to determine the absorption.

## TESTS ON DIFFERENT SAMPLES OF SAME MATERIAL SHOW INCONSISTENT RESULTS

The apparatus used is shown in Figure 1. The wire basket is used to immerse the sample in water in the cylinder when the volume of the aggregate is being determined. It was formerly the practice to drop the pieces of aggregate into the overflow apparatus; but even with the greatest of care, sufficient wave action was caused to prevent accurate results.

Six or seven individual samples were selected from each of seven different materials, six of which were gravels and one rock. These samples were tested for absorption and apparent specific gravity. Two to four samples of each material were then retested by the same operator and also by two other operators. The results of these tests will be found in Tables 1 to 4.

The repeated tests on the same sample were made to determine the error in the test which could be attributed to the operator. The results in Tables 1 and 3 show that in general the concordance between tests by different operators on the same sample is very good. The mean deviation of the percentage of absorption

from the average is 0.02, and the maximum variation between the tests of any sample averages 0.07. The results of the apparent specific-gravity tests show even smaller variations, the mean deviation from the average being 0.01 and the maximum variation between the tests of any sample averaging 0.02.

The tests of different samples given in Tables 2 and 4 show marked variations in the test results, especially those for absorption. In four cases out of the seven the maximum variation between tests for absorption on a single material exceeds the average percentage of absorption for all the tests on the same material. Sample No. 1, for example, has an average absorption of 0.79 per cent and minimum and maximum test values of 0.41 per cent and 1.45 per cent, respectively. The results of the tests for specific gravity on different samples of the same material also show a wide variation, but not to the same extent as for absorption.

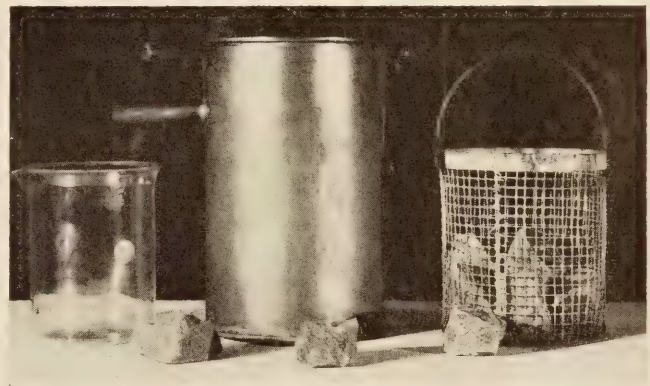


FIGURE 1.—APPARATUS USED IN DETERMINING APPARENT SPECIFIC GRAVITY

TABLE 1.—Variation in results of tests for absorption when made on same samples

Sample No.	Material	Absorption, per cent					Maximum variation between tests
		Test by operator				Average	
		A	B	B	C		
1A	Massachusetts gravel	0.51	0.55	0.56	0.57	0.55	0.06
1B		.88	.90	.93	.94	.91	.06
1C		.53	.56	.59	.60	.57	.07
2A		.15	.18	.20	.19	.18	.05
2B	New York limestone	.04	.06	.08	.06	.06	.04
2C		.18	.20	.22	.20	.20	.04
3A		.40	.43	.44	.43	.42	.04
3B		1.24	1.26	1.31	1.32	1.28	.08
3C	Pennsylvania gravel	.67	.70	.74	.73	.71	.07
3D		.94	.98	1.04	1.01	.99	.10
4A		1.33	1.25	1.32	1.33	1.31	.08
4B		2.53	2.40	2.51	2.50	2.48	.13
4C	Ohio gravel	2.08	1.92	2.05	2.04	2.02	.16
5A		.65	.63	.68	.63	.65	.05
5B		.58	.56	.59	.59	.58	.03
5C		.87	.84	.88	.87	.86	.04
6A	Virginia gravel	1.15	1.09	1.16	1.14	1.14	.07
6B		1.37	1.31	1.37	1.35	1.35	.06
6C		1.13	1.05	1.13	1.09	1.10	.08
7A		Alabama gravel	.46	.43	.46	.47	.46
7B	1.02		.98	1.03	1.04	1.02	.06

<sup>1</sup> U. S. D. A. Bulletin 1216, Tentative Standard Methods of Sampling and Testing Highway Materials, method No. 14.

TABLE 2.—Variation in results of tests for absorption when made on different samples of same material

Sample No.	Absorption, per cent								
	Test number							Average	Maximum variation between tests
	1	2	3	4	5	6	7		
1	1.14	1.45	0.41	0.47	0.55	0.91	0.57	0.79	1.04
2	.09	.48	.26	.18	.06	.20		.21	.42
3	.94	.76	.42	1.28	.71	.99		.85	.86
4	1.85	.97	2.26	2.26	1.31	2.48	2.02	1.88	1.51
5	.47	.51	.70	.65	.58	.86		.63	.39
6	2.12	1.74	1.35	1.14	1.35	1.14		1.47	.98
7	.34	1.02	.32	.18	.46	1.02		.56	.84

TABLE 3.—Variation in results of tests for specific gravity when made on same sample

Sample No.	Material	Specific gravity					Average	Maximum variation between tests
		Test made by operator						
		A	B	B	C			
1A	Massachusetts gravel	2.67	2.66	2.66	2.67	2.66	0.01	
1B		2.61	2.61	2.60	2.60	2.60	.01	
1C		2.68	2.67	2.66	2.69	2.68	.03	
2A	New York limestone	2.66	2.66	2.66	2.67	2.66	.01	
2B		2.67	2.67	2.68	2.68	2.68	.01	
2C		2.68	2.68	2.68	2.68	2.68	.00	
3A	Pennsylvania gravel	2.63	2.62	2.63	2.63	2.63	.01	
3B		2.54	2.53	2.54	2.55	2.54	.02	
3C		2.65	2.64	2.63	2.66	2.64	.03	
3D		2.58	2.57	2.59	2.59	2.58	.02	
4A	Ohio gravel	2.65	2.61	2.64	2.64	2.64	.04	
4B		2.54	2.52	2.52	2.52	2.52	.02	
4C		2.63	2.56	2.57	2.59	2.59	.07	
5A	Virginia gravel	2.59	2.58	2.57	2.58	2.58	.02	
5B		2.59	2.58	2.58	2.59	2.58	.01	
5C		2.59	2.56	2.56	2.58	2.57	.03	
6A	Illinois gravel	2.69	2.67	2.68	2.69	2.68	.02	
6B		2.66	2.62	2.62	2.65	2.64	.04	
6C		2.67	2.63	2.66	2.66	2.66	.04	
7A	Alabama gravel	2.61	2.58	2.60	2.61	2.60	.03	
7B		2.56	2.52	2.55	2.57	2.55	.05	

USE OF AVERAGE RESULT OF A NUMBER OF TESTS RECOMMENDED

It is apparent from the results shown here that the selection of the test sample, and not the test method,

is responsible for the great variation in test results obtained on a single material. Each of the samples tested was considered to be representative of the entire material. Since these tests demonstrate that test samples selected by the customary laboratory methods are not representative of the entire material, it is recommended that in future practice a number of samples be tested for a given material and that the average of all the test results be considered instead of those of a single sample. It is probable that a larger sample—say of 25 to 30 pounds weight—would furnish a representative test sample and therefore give equally accurate results, but the difficulties of handling such a sample without special apparatus favors the testing of a number of the smaller samples.

TABLE 4.—Variation in results of tests for specific gravity when made on different samples of same material

Sample No.	Specific gravity								
	Test number							Average	Maximum variation between tests
	1	2	3	4	5	6	7		
1	2.54	2.58	2.66	2.72	2.66	2.60	2.68	2.63	0.18
2	2.67	2.66	2.67	2.66	2.68	2.68		2.67	.02
3	2.56	2.64	2.63	2.54	2.64	2.58		2.60	.10
4	2.54	2.61	2.50	2.56	2.64	2.52	2.59	2.57	.14
5	2.62	2.53	2.54	2.58	2.58	2.57		2.57	.09
6	2.60	2.77	2.62	2.68	2.64	2.66		2.66	.17
7	2.60	2.58	2.61	2.63	2.60	2.55		2.60	.08

INDEX TO VOLUME 6 OF PUBLIC ROADS AVAILABLE

An index to volume 6 of PUBLIC ROADS which included the issues from March, 1925, to February, 1926, is now available for distribution, and copies may be obtained without charge from the Bureau of Public Roads, United States Department of Agriculture, Washington, D. C.

It is planned to issue an index for each of volumes 7, 8, and 9 in the near future and when requested names will be listed to receive these as they appear.

## ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

*Applicants are urgently requested to ask only for those publications in which they are particularly interested. The Department can not undertake to supply complete sets nor to send free more than one copy of any publication to any one person. The editions of some of the publications are necessarily limited, and when the Department's free supply is exhausted and no funds are available for procuring additional copies, applicants are referred to the Superintendent of Documents, Government Printing Office, this city, who has them for sale at a nominal price, under the law of January 12, 1895. Those publications in this list, the Department supply of which is exhausted, can only be secured by purchase from the Superintendent of Documents, who is not authorized to furnish publications free.*

### ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.  
 Report of the Chief of the Bureau of Public Roads, 1925.  
 Report of the Chief of the Bureau of Public Roads, 1927.  
 Report of the Chief of the Bureau of Public Roads, 1928.

### DEPARTMENT BULLETINS

No. \*136D. Highway Bonds. 20c.  
 220D. Road Models.  
 257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.  
 \*314D. Methods for the Examination of Bituminous Road Materials. 10c.  
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 387D. Public Road Mileage and Revenues in the Southern States, 1914.  
 388D. Public Road Mileage and Revenues in the New England States, 1914.  
 390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.  
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 \*691D. Typical Specifications for Bituminous Road Materials. 10c.  
 \*724D. Drainage Methods and Foundations for County Roads. 20c.  
 1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.  
 1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.

### DEPARTMENT BULLETINS—Continued

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 1486D. Highway Bridge Location.

### DEPARTMENT CIRCULARS

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 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

### TECHNICAL BULLETIN

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### MISCELLANEOUS CIRCULARS

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 93M. Direct Production Costs of Broken Stone.  
 \*109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails. 10c.

### SEPARATE REPRINTS FROM THE YEARBOOK

No. 914Y. Highways and Highway Transportation.  
 937Y. Miscellaneous Agricultural Statistics.

### TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Connecticut.  
 Report of a Survey of Transportation on the State Highway System of Ohio.  
 Report of a Survey of Transportation on the State Highways of Vermont.  
 Report of a Survey of Transportation on the State Highways of New Hampshire.  
 Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio.  
 Report of a Survey of Transportation on the State Highways of Pennsylvania.

### REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

Vol. 5, No. 17, D- 2. Effect of Controllable Variables upon the Penetration Test for Asphalts and Asphalt Cements.  
 Vol. 5, No. 19, D- 3. Relation Between Properties of Hardness and Toughness of Road-Building Rock.  
 Vol. 5, No. 24, D- 6. A New Penetration Needle for Use in Testing Bituminous Materials.  
 Vol. 6, No. 6, D- 8. Tests of Three Large-Sized Reinforced-Concrete Slabs Under Concentrated Loading.  
 Vol. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

\* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE  
BUREAU OF PUBLIC ROADS  
**CURRENT STATUS OF FEDERAL AID ROAD CONSTRUCTION**

AS OF

**SEPTEMBER 30, 1929**

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION				BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE	
		Estimated total cost	Federal aid allotted	MILEAGE		Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage <sup>1</sup>			Initial	Stage <sup>1</sup>			Total
Alabama	2,642.8	3,245,413.51	1,605,991.23	127.9	35.3	153.2	137,029.35	68,514.67	6.4	6.4	1,907,502.32	Alabama
Arizona	1,823.1	2,754,462.44	2,312,350.58	100.4	94.9	195.3	421,958.91	335,351.26	15.3	33.9	2,000,921.05	Arizona
Arkansas	1,749.3	3,295,752.41	1,551,011.58	151.2	13.8	155.0	950,094.10	374,530.54	41.7	25.6	1,429,796.95	Arkansas
California	1,719.1	8,959,490.76	4,037,247.59	213.8	20.2	234.0	1,087,886.57	590,030.67	44.6	44.6	12,993.89	California
Colorado	1,140.8	3,313,614.59	2,093,911.70	129.0	43.5	172.5	1,072,609.47	350,315.67	69.9	70.5	1,208,972.85	Colorado
Connecticut	229.3	1,458,404.69	483,708.57	15.4		15.4	772,115.51	321,350.81	4.2	4.2	841,978.71	Connecticut
Delaware	213.3	1,282,731.90	563,526.96	46.2	5.7	46.2	43,822.00	21,911.00	6.3	6.3	22,613.12	Delaware
Florida	449.0	3,204,952.11	1,370,445.52	91.1	24.3	96.8	464,596.33	232,233.15	18.3	18.3	1,436,421.35	Florida
Georgia	2,597.1	3,021,937.64	1,381,657.56	142.4		166.7	484,596.33	232,233.15	18.3	18.3	2,031,949.55	Georgia
Idaho	1,169.3	898,780.80	521,405.17	61.8		61.8	420,276.39	253,083.74	25.9	24.1	601,986.97	Idaho
Illinois	1,977.0	17,118,635.96	7,612,173.66	497.3	24.4	497.3	710,000.00	355,000.00	24.4	24.4	2,539,619.77	Illinois
Indiana	1,304.0	8,390,045.38	4,215,572.38	273.4		273.4	359,700.00	179,850.00	12.0	12.0	9,440.05	Indiana
Iowa	2,272.2	5,306,238.55	2,692,711.21	60.9	132.1	193.0	97,271.59	32,303.31	4.4	1.7	67,313.11	Iowa
Kansas	2,914.5	5,440,791.48	2,444,323.51	329.9	22.9	352.8	992,545.82	450,040.66	62.9	4.4	153,992.35	Kansas
Kentucky	1,315.8	5,295,191.93	2,541,198.49	282.7	25.1	307.8	358,329.99	176,041.03	32.3	10.3	389,931.24	Kentucky
Louisiana	1,345.2	3,304,293.92	1,644,398.34	128.0		128.0	172,458.47	66,214.22	17.7	17.7	1,139,643.56	Louisiana
Maine	485.4	2,668,472.44	975,265.59	54.8	1.9	56.7	276,342.23	107,143.03	10.7	10.7	995,128.47	Maine
Maryland	609.5	1,373,639.05	639,321.73	46.1	17.7	63.8	556,560.40	93,973.54	15.4	15.4	172.41	Maryland
Massachusetts	801.5	3,984,464.24	1,109,145.44	62.1	3.4	65.5	806,395.41	285,221.99	6.0	6.0	1,489,159.28	Massachusetts
Michigan	1,517.5	10,533,721.40	4,443,578.23	248.0	13.3	261.3	1,654,000.00	782,323.31	55.3	3.2	517,873.37	Michigan
Minnesota	3,957.2	6,594,362.71	2,133,916.23	328.2	112.0	440.2	539,225.82	66,110.00	15.9	17.4	297,890.00	Minnesota
Mississippi	1,720.0	3,740,204.04	1,625,158.55	147.0	17.5	164.5	79,957.35	30,000.00	.1	.1	1,326,565.63	Mississippi
Missouri	2,251.5	10,822,371.11	4,126,594.50	175.4	139.1	314.5	302,331.51	115,512.11	3.7	7.8	123,145.50	Missouri
Montana	1,602.0	5,859,735.92	4,095,557.93	474.1	7.4	481.5	1,829,402.04	896,795.04	141.3	26.2	2,339,295.83	Montana
Nebraska	3,562.6	5,727,678.76	2,777,931.04	324.0	157.9	481.9	1,668,302.93	747,619.01	33.3	76.3	997,656.77	Nebraska
Nevada	1,111.5	1,109,044.45	975,265.59	192.2	129.1	221.3	82,143.01	72,960.04	.5	13.5	50,379.25	Nevada
New Hampshire	344.6	465,940.92	154,324.67	9.7	1.0	10.7	194,155.42	45,710.00	.9	2.1	108,010.22	New Hampshire
New Jersey	477.9	4,460,194.70	900,915.00	60.1		60.1	553,057.51	123,840.00	6.2	6.2	317,700.08	New Jersey
New Mexico	1,993.3	2,913,025.79	1,845,681.24	153.3	.7	154.0	258,926.23	150,362.58	23.4	23.4	399,123.79	New Mexico
New York	2,269.4	25,272,017.76	5,499,605.55	367.8		367.8	6,009,119.02	1,749,300.00	78.2	78.2	3,619,979.01	New York
North Carolina	1,755.9	941,486.42	489,904.71	68.1	2.9	71.0	494,338.86	243,085.42	10.7	17.5	1,407,757.35	North Carolina
North Dakota	3,935.1	2,659,790.40	1,020,322.82	405.4	121.6	527.0	1,142,935.71	532,239.40	193.8	176.2	336,683.96	North Dakota
Ohio	2,091.3	12,614,187.54	4,191,544.15	240.2	9.4	249.6	6,221,817.81	1,705,357.02	66.9	29.5	1,033,378.42	Ohio
Oklahoma	1,815.6	3,499,827.79	1,604,787.52	108.2	29.6	137.8	1,201,362.32	546,885.74	32.1	31.9	52,323.91	Oklahoma
Oregon	1,135.2	1,659,073.59	912,341.37	99.0	35.8	134.8	1,293,118.00	784,971.96	70.1	27.3	653,170.95	Oregon
Pennsylvania	2,145.3	14,959,990.24	3,947,377.59	240.9	14.1	255.0	4,458,222.99	1,355,435.43	82.4	82.4	45,197.00	Pennsylvania
Rhode Island	172.1	1,232,152.80	323,386.55	13.5		13.5	192,450.06	90,722.15	2.5	2.5	475,976.33	Rhode Island
South Carolina	1,859.6	3,959,647.76	1,093,695.51	106.7	37.3	144.0	19,353.44	4,000.00			465,550.48	South Carolina
South Dakota	3,357.9	4,123,642.76	2,624,911.03	491.2	43.9	535.1	606,712.69	335,951.66	76.7	70.8	1,939.50	South Dakota
Tennessee	1,178.4	3,527,015.27	1,661,658.09	117.7	295.7	413.4	208,835.70	104,417.85	10.8	10.8	829,294.78	Tennessee
Texas	6,171.6	19,217,231.43	8,064,859.55	641.2		641.2	1,806,714.97	798,563.03	49.6	37.3	158,506.14	Texas
Utah	921.2	1,922,194.83	829.9	82.9		82.9	333,167.35	194,453.82	10.5	10.5	202,854.65	Utah
Vermont	240.9	1,324,835.05	494,989.54	26.3		26.3	679,545.61	275,154.46	20.3	22.2	62,872.48	Vermont
Virginia	1,373.6	2,222,585.89	1,010,757.50	103.8	10.9	114.7	511,571.85	301,551.16	25.9	25.9	381,297.08	Virginia
Washington	887.2	4,489,918.79	1,610,600.00	96.6	18.1	114.7	1,185,132.51	382,000.00	20.3	48.1	462,176.16	Washington
West Virginia	653.0	4,055,014.57	1,649,057.16	90.9	34.7	125.5	244,451.54	99,798.00	7.8	7.8	5,861.19	West Virginia
Wisconsin	2,126.7	7,805,647.69	3,389,859.25	252.9	26.7	279.6	970,243.05	399,565.00	21.3	2.3	17,096.70	Wisconsin
Wyoming	1,696.3	3,247,484.09	1,051,599.17	153.9	30.5	184.4	126,327.89	126,283.23	9.9	24.4	19,861.91	Wyoming
Hawaii	391.3	422,261.10	131,426.62	6.5		6.5	552,699.38	247,269.61	15.6	15.6	1,072,664.16	Hawaii
<b>TOTALS</b>	<b>79,494.0</b>	<b>265,740,729.95</b>	<b>104,097,210.71</b>	<b>8,594.1</b>	<b>1,730.4</b>	<b>10,314.5</b>	<b>44,117,422.27</b>	<b>16,938,765.47</b>	<b>1,462.4</b>	<b>582.9</b>	<b>2,165.3</b>	<b>TOTALS</b>

<sup>1</sup> Term stage construction refers to additional work on projects previously improved with Federal aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.



