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UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

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The Connecticut Avenue Experimental Road

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BUREAU OF PUBLIC ROADS

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REPORT ON CONNECTICUT AVENUE EXPERIMENTAL ROAD

A DISCUSSION OF CONSTRUCTION AND MAINTENANCE METHODS AND PRESENT CONDITION OF VARIOUS TYPES OF SURFACE LAID IN 1911, 1912, AND 1913

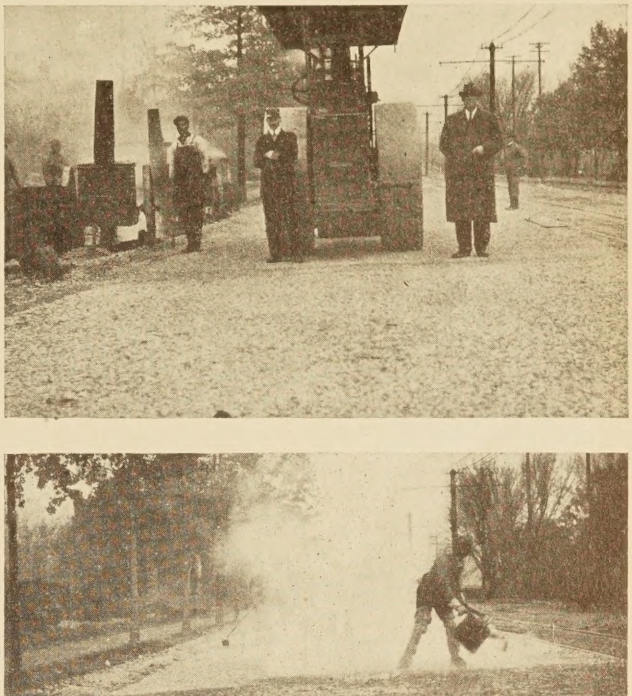
By the Division of Tests, United States Bureau of Public Roads

THE Connecticut Avenue experimental road extending from Chevy Chase Circle to Chevy Chase Lake in Montgomery County, Md., was constructed as two separate projects by the Bureau of Public Roads during the years 1911, 1912, and 1913. These two projects included a number of different types of construction which have since been subjected to a very heavy traffic and which have been maintained by the bureau. The behavior of each section has been closely observed and the cost of maintenance carefully recorded. This report summarizes the methods of construction employed on the 16 experimental sections,[1] their present condition, and the yearly cost of preserving their surfaces in serviceable condition.

The dividing line between the two groups of experiments is at Bradley Lane (fig. 1), the sections lying south of this intersecting road having been constructed as water-bound macadam with subsequent bituminous surface treatments or as bituminous macadam. The experiments north of Bradley Lane are characterized by use of Portland cement concrete as a wearing surface and as a foundation for bituminous and vitrified brick surfaces.

Figure 1 shows the location, grade, and nature of the experimental sections. As indicated, a double-track street railway divides the thoroughfare. At the time of construction the east side of Connecticut Avenue was not improved north of Bradley Lane, consequently the north experimental sections were subjected to traffic traveling in both directions, whereas, those lying south of Bradley Lane have carried only one-way traffic. In 1924, with the extension of the pavement on the east side from Bradley Lane to Woodbine Street, experiments 1, 2, and most of 3 of the north group were relieved of the northbound traffic. However, the remainder of experiment 3 and all of experiments 4, 5, and 6 still carry traffic in both directions.

Traffic counts were made periodically from the time of construction up to the end of 1921 on the sections south of Bradley Lane and up to the end of 1922 on the sections north of Bradley Lane. Observers were on duty for the full 24 hours of each thirteenth day, thus obtaining 28 counts, one of which was made on each day of the week four times during the year. From these data the average number of vehicles per day was obtained. Traffic counts were made again in 1927 and showed a tremendous increase in traffic over all the sections. This was found to be true also of those sections between Bradley Lane and Woodbine Street, in spite of the fact that they have been relieved of the northbound traffic.



Steps in Construction and Finished Pavement of Penetration Macadam, Experiment 3

The car-track area occupying the center of the street has never been paved with an impervious surface and has provided a means for water to gain entrance to the subgrade. Surface drainage afforded by the narrow cobble gutters on the sections south of Bradley Lane has not been entirely satisfactory. Automobiles frequently park with their wheels in the gutter and in some places the gutters are no longer at grade. The street is narrow for the traffic which it carries and without adequate side support for the road. Consequently the edges of the bituminous-treated surfaces present a rather ragged appearance.

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[1] Reports describing the construction and behavior of these experiments are included in Circulars 98 and 99, Office of Public Roads, U. S. Department of Agriculture Bulletins 105, 257, 407, and 586 and U. S. Department of Agriculture Circular 77.

BITUMINOUS MACADAM EXPERIMENTS DESCRIBED

The first experiments constructed on Connecticut Avenue were seven bituminous macadam sections of the penetration type built in 1911. Table 1 shows the extent of these sections and the nature of the bituminous materials entering into their construction. The characteristics of the bituminous materials, as indicated by laboratory tests, are shown in Table 2; and the quantity of application at the time of construction and in subsequent retreatments is shown in Table 3.

In preparation for the bituminous wearing course, the existing waterbound macadam was scarified, reshaped, and sufficient crushed limestone added to give a compacted foundation course 5½ inches thick. The improved roadway was approximately 19 feet wide. Originally the 2-foot strips adjacent to the street-car rails were left as waterbound macadam. About two years later those were scarified and treated with bituminous material by the street railway company, and subsequent surface treatments by the bureau flowed over them. A cobblestone gutter was constructed at the outer edge of the new pavement and, as required, French drains 2½ feet deep were installed under the gutters and next to the tracks, and some herringbone drains were laid under experiment 6.

The work was done in the fall of the year and conditions were unfavorable for bituminous construction. Much of the penetration work was done when the average air temperature was 45° to 50° F. In virtually all cases the stone chips and screenings were dried and heated before they were used. All of the bituminous binders were distributed by means of hand pouring cans, except on experiments 1 and 2, where the hand-operated pressure-nozzle method was used.

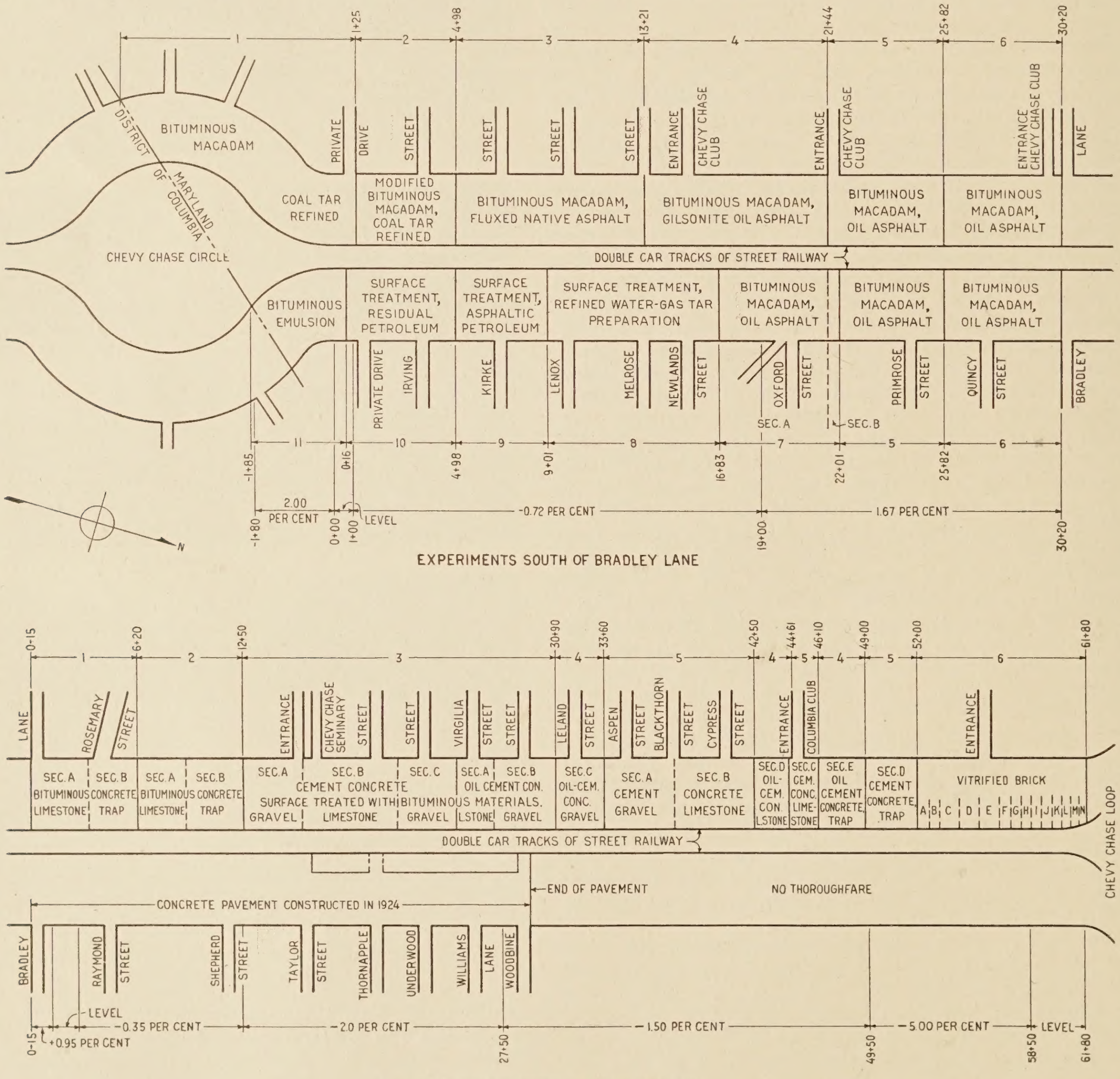
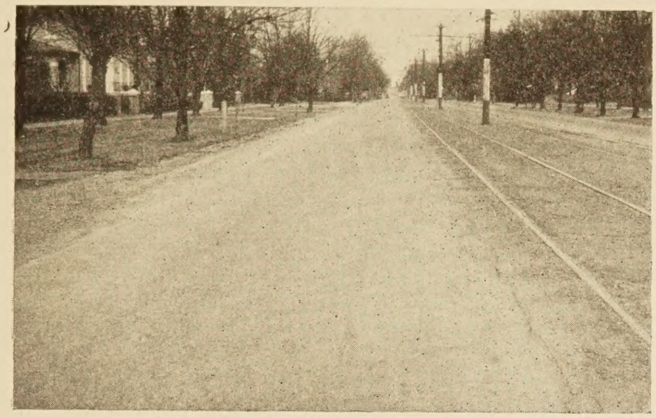
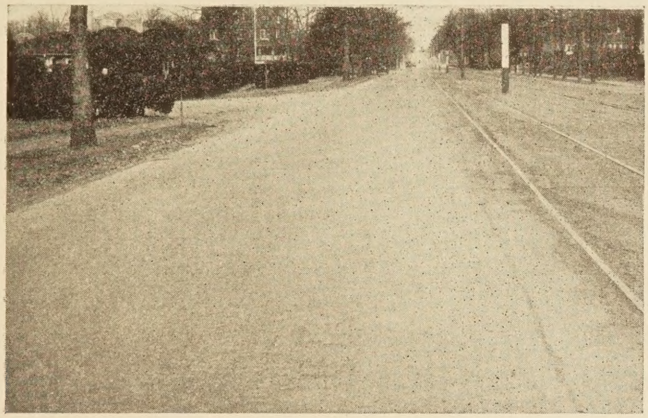


FIG. 1.—LOCATION OF VARIOUS EXPERIMENTAL SECTIONS. THE GRADES ARE APPROXIMATELY THE SAME ON BOTH SIDES OF THE TRACKS AND THOSE DESCENDING TOWARD THE NORTH ARE SHOWN AS NEGATIVE



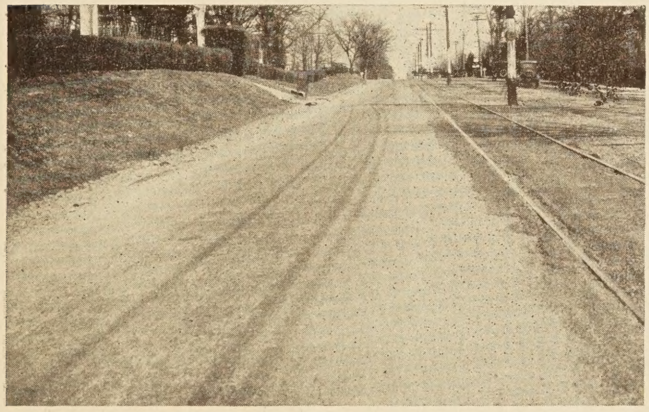
EXPERIMENT-1

EXPERIMENT-2

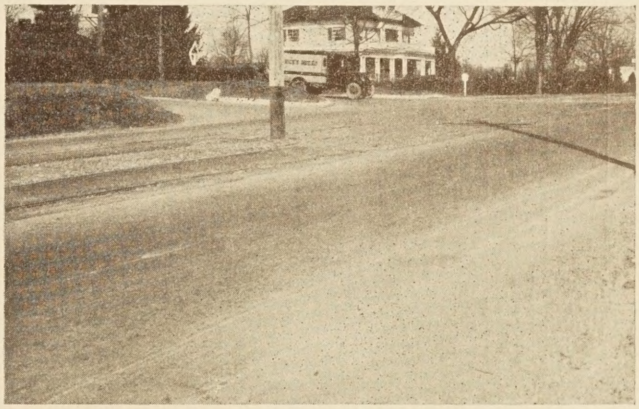


EXPERIMENT-3

EXPERIMENT-4



EXPERIMENT-5



EXPERIMENT-6

Condition of Surface-treated Sections in 1928

In some cases the construction procedure was varied slightly as will be noted from the following descriptions of the several sections:

Experiment No. 1.—The wearing course consisted of limestone, graded in size from 3 inches to 1 inch, laid to a depth of 3 inches loose measurement, and rolled lightly. Heated coal tar was then applied at the rate of 1.8 gallons per square yard, covered with screenings (three-fourths-inch to dust) and thoroughly rolled. After the excess screenings had been swept from the surface, a seal coat of tar was applied at the rate of 0.8 gallon per square yard, covered with screenings and the road completed by rolling.

The seal coat of this section wore off rather rapidly and was replaced by an application of crude coal tar in 1914. Following this treatment no more than normal wear took place. Some waviness developed adjacent to the gutter and occasional patching was required, but in general the appearance remained that of a uniform, well-bonded mosaic surface. In 1918 this section was given a surface treatment of 0.19 gallon of refined coal tar with a covering of ½-inch stone chips. A similar treatment consisting of 0.337 gallon of refined coal tar and sand was applied in 1924. This is the only section of this group of experiments which has required a surface treatment since 1918.

As this section is located on a curve, the more severe scouring action of traffic is probably the cause of the need for the additional maintenance treatment. At the present time this later treatment has worn off in the traveled area and some pitting and wear of the coarse stone is noticeable.

Experiment No. 2.—This section was constructed as a modification of the Gladwell method. A 1-inch cushion of sand was spread evenly over the foundation and given an application of 1.18 gallons per square yard of light refined coal tar. After the tar had been absorbed by the sand a layer of limestone (3 inches to 1 inch) was spread to a depth of 3 inches and thoroughly rolled. The surface was completed as in the case of experiment No. 1, using 1.95 gallons and 1.02 gallons per square yard of heavy refined coal tar for the penetration and seal applications, respectively.

The surface showed a tendency to bleed and the nonuniform application of chips made to correct this condition resulted in some surface irregularities. The surface was resealed in 1918, but no general treatment has been applied since that time. Next to the car tracks the unprotected edge has been broken by traffic and presents a ragged appearance. Some pitting of the aggregate has occurred, but the surface in general is in very good condition.

Experiment No. 3.—This section differed somewhat from experiment No. 1 in details of construction. Limestone from 2 inches to 1 inch was used in the surface course and was thoroughly compacted before the bitumen was poured. Clean chips, three-fourths to one-fourth inch in size were used both after the penetration and seal-coat applications. The initial pouring of fluxed native asphalt was at the rate of 1.46 gallons per square yard. One-half gallon per square yard was used for the seal coat. A shortage of material necessitated using a refined semiasphaltic oil on a small area.

During the early period of its life, this experiment developed the appearance of a sheet-asphalt pavement. Later, as the seal coat wore uniformly, as mosaic surface was presented. It was conspicuous for its uniform cross section and it is still the smoothest of the bituminous macadam sections. A seal-coat treatment of refined asphaltic petroleum and ½-inch stone chips was applied in 1918. Throughout its life maintenance costs on this section have been lower than on any other section of this series.

Experiment No. 4.—This section was constructed of 2-inch to 1-inch limestone, spread to a depth of 3 inches and lightly rolled. The first application of asphalt was at the rate of 1.65 gallons per square yard, and the second at the rate of 0.55 gallon per square yard. A light covering of stone chips was spread after the first application while after the second application, screenings from three-fourths inch to dust were used on a part of this section and clean chips on the remainder. The surface was completed by rolling with a 3-ton roller.

This section lies at a low point in the grade and drains experiments 3, 5, and 6 on the west side. The placing of the asphalt binder course was completed late in the evening, and rolling and pouring of the seal coat was

TABLE 1.—*Cost and description of experiments on Connecticut Avenue, Chevy Chase, Md.*

BITUMINOUS MACADAM (PENETRATION) EXPERIMENTS, SOUTH OF BRADLEY LANE, BUILT IN 1911

Experiment No.	Length	Area[1]	Original construction			Annual cost of surface treatments and maintenance in cents per square yard									
			Bituminous material or type	Gallons per square yard	Cost of surface, per square yard	1912		1913		1914		1915		1916	
						Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance
	Feet	*Square yards*			*Cents*										
1	513	1,581	Coal tar, refined	2.59	46.18					5.04	0.74		2.34		0.28
2	373	705	Coal tar, refined (modified)	4.15	64.42								2.29		.64
3	823	1,555	Fluxed native asphalt	1.96	64.69								.95		.38
4	823	1,555	Oil asphalt (Gilsonite)	2.19	57.18				0.26		.16		2.58		.67
5	819	1,447	Oil asphalt	2.25	58.27		17.98		.15		.06		2.91		.53
6	876	1,555	Oil asphalt	2.09	68.22				.22				2.07		.57
7A	449	130	Oil asphalt	2.26	59.96		1.09				.34		3.59		.29
7B	69	849	Oil asphalt	1.86	54.80	8.01					.15		2.89		
SURFACE TREATMENT EXPERIMENTS ON WATERBOUND MACADAM, SOUTH OF BRADLEY LANE, BUILT IN 1911															
8	782	1,477	Water-gas tar preparation	0.54	[2] 39.59			5.46					3.40	6.55	1.37
9	403	761	Asphaltic petroleum	.53	[2] 42.01			5.21		4.71	1.18	7.50	.88	8.76	1.48
10	482	1,013	Residual petroleum	.79	[2] 44.31				1.88	8.11	20.17	7.80	5.24	8.90	4.08
11	201	377	Native asphalt emulsion	3.32	[2] 81.51										1.56
EXPERIMENTS NORTH OF BRADLEY LANE, BUILT IN 1912															
1	635	1,498	Bituminous concrete (Topeka specification) 2 inches thick on 6-inch 1 : 3 : 7 cement concrete		186.62								0.22		
2	630	1,400	Bituminous concrete (District of Columbia specifications) 2 inches thick, on 6-inch 1 : 3 : 7 cement concrete and seal coat of 0.51 gallon fluxed native asphalt		195.65						0.29		.26		0.25
3	1,840	4,178	Cement and oil-cement concrete as in experiment No. 2, surface treated with various types of bituminous materials		154.95						.03		.06	7.81	.29
4	771	1,744	Oil-cement concrete, 1 : 1¾ : 3 and 5 pints residual petroleum per bag of cement		150.25						.12		1.05		1.02
5	1,339	3,013	Cement concrete, 1 : 1¾ : 3		142.29						.07		.68		.28
6	980	2,055	Vitrified brick, with base as in experiment Nos. 1 and 2, 2-inch sand cushion grouted with 1 : 1 sand-cement		258.21						.06		.02		.08

[1] Some of the sections were of varying widths.

[2] Includes cost of wearing course.

postponed. That night there was an extremely heavy rain, and water drained from experiments 3, 5, and 6 came up through the stone of experiment 4, so that it was necessary to tear out the cobble gutter at a number of places to drain the subgrade. About a week later an effort to resume work on the section was discontinued because the subgrade was still wet and soft, and it was not until some time later that the laying of the surface could be completed.

This surface gave early evidence of requiring repairs, but bleeding, which began with the advent of warm weather, caused the surface to seal itself. Some depressions occurred along the west edge and waviness and lack of stability in the surface were more apparent on that portion on which screenings containing dust were used in covering the original seal coat. In 1918 a surface treatment was applied consisting of 0.305 gallon per square yard of oil asphalt and a ½-inch stone cover. At the present time the section is in good condition, but in general the surface has worn more unevenly and has developed more waviness than that of experiment 3.

Experiment No. 5.—This is a divided section located on both sides of the car tracks. The stone of the wearing course, which was the same as that used in experiment 3, was thoroughly compacted before the application of the binder. The first application consisted of oil asphalt applied hot at the rate of 1.69 gallons per square yard. Chips from three-fourths to one-half inch in size were then spread sparingly and the surface thoroughly rolled. The second application consisted of 0.56 gallon per square yard of the same material and a covering of stone three-fourths to one-fourth inch. The surface was then rolled until firm and smooth.

During the first few years after construction this section required considerable maintenance due to unsatisfactory subgrade conditions. Weak places as they appeared were dug out and patched. With the gradual elimination of these weak places the condition of the section has been materially improved and the cost of maintenance decreased. In 1918 a light surface treatment consisting of 0.227 gallon per square yard of hot asphalt and ½-inch stone was applied. The surface at the present time is unbroken and in good condition except for some waviness.

Experiment No. 6.—This section also is located on both the east and west sides of the car tracks. The wearing course consisted of 3-inch to 1-inch limestone spread to a loose depth of 3½ inches. After a thorough rolling, the first application of asphalt was made at the rate of 1.56 gallons per square yard. This was covered with clean stone chips, three-fourths to one-half inch in size, the excess of which was swept off after rolling. The second application of 0.53 gallon per square yard of a harder grade of the same material was then made, covered with stone chips, and rolled.

Herringbone drains were laid on the west side of this section. Their installation, however, was apparently not entirely effective. Subgrade conditions were simi-

TABLE 1.—*Cost and description of experiments on Connecticut Avenue, Chevy Chase, Md.*—Continued

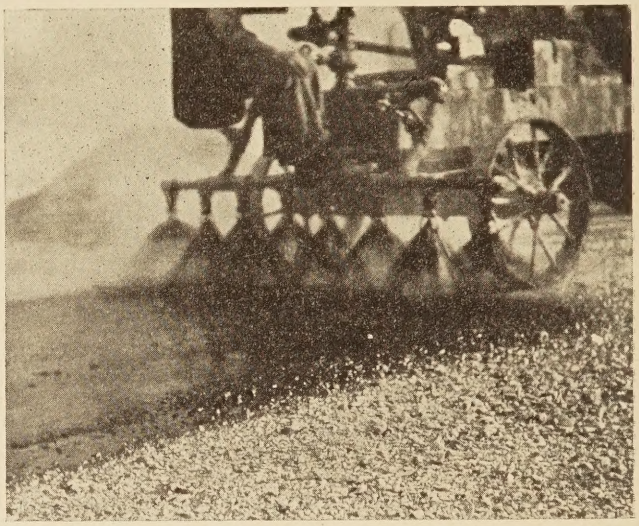
BITUMINOUS MACADAM (PENETRATION) EXPERIMENTS, SOUTH OF BRADLEY LANE, BUILT IN 1911

Experiment No.	Annual cost of surface treatments and maintenance in cents per square yard																						Total maintenance 1912 to 1927, inclusive
	1917		1918		1919		1920		1921		1922		1923		1924		1925		1926		1927		
	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	Treatment	Maintenance	
																							Cents per sq. yd.
1	------	0.29	19.12	1.47	------	------	------	------	------	0.04	------	------	------	------	9.68	1.37	------	------	------	1.90	------	0.72	43.01
2	------	1.49	22.42	2.95	------	------	------	------	------	.10	------	------	------	------	------	2.59	------	------	------	------	------	.89	33.37
3	------	.11	20.84	1.40	------	------	------	------	------	.04	------	------	------	------	------	1.37	------	------	------	3.39	------	.65	29.13
4	------	.78	19.40	1.63	------	------	------	------	------	.82	------	------	------	------	------	.99	------	8.96	------	3.51	------	3.29	43.05
5	------	.70	16.61	2.75	------	0.32	------	------	------	.05	------	------	------	------	------	3.38	------	6.33	------	4.82	------	------	56.59
6	------	.18	17.54	1.27	------	------	------	------	------	.04	------	------	------	1.51	------	3.77	------	1.34	------	2.37	------	------	30.88
7	------	.45	20.93	1.98	------	------	------	------	------	.07	------	------	------	1.32	------	6.22	------	4.05	------	8.84	------	3.36	57.76
SURFACE TREATMENT EXPERIMENTS ON WATERBOUND MACADAM, SOUTH OF BRADLEY LANE, BUILT IN 1911																							
8	5.59	0.37	------	1.31	11.96	0.57	------	------	------	0.05	------	------	------	6.21	9.55	3.61	------	5.79	11.41	11.94	------	0.33	85.48
9	5.93	.71	11.56	3.43	11.36	1.08	8.18	------	17.21	4.23	------	------	------	7.99	------	20.76	------	22.47	------	18.47	------	.65	163.75
10	5.36	1.39	9.11	2.04	10.49	.81	6.89	2.27	17.54	1.06	------	------	------	2.95	------	8.85	------	6.74	------	21.36	------	2.33	155.35
11	------	1.35	12.80	6.89	------	------	14.99	4.75	------	6.44	------	------	------	2.65	7.91	2.75	------	6.63	------	9.18	------	1.32	79.22
EXPERIMENTS NORTH OF BRADLEY LANE, BUILT IN 1912																							
1	------	------	------	------	------	0.29	------	------	------	0.61	------	2.67	------	1.00	------	1.68	------	0.56	------	1.33	------	1.18	9.54
2	------	------	------	------	------	.30	------	------	------	.65	------	2.47	------	.79	------	1.93	------	1.06	------	.39	------	1.86	10.25
3	------	0.04	------	0.07	------	.20	------	0.39	------	.16	10.45	1.38	------	3.52	------	1.54	------	1.74	------	7.58	------	2.53	37.79
4	------	.15	------	.29	------	.47	------	.94	------	1.93	10.46	3.31	------	4.23	------	4.99	------	1.68	------	11.90	------	4.86	47.40
5	------	------	------	.47	------	.27	------	.55	------	.22	10.45	1.69	------	3.49	------	1.55	------	.42	------	1.53	------	1.07	22.74
6	------	.06	------	.09	------	.66	------	.66	------	.03	------	.66	------	.55	------	------	------	.28	------	4.42	------	1.69	9.26

Hand Pouring the Seal Coat on One of the Penetration Macadam Sections

lar to those of the adjoining experiment 5, necessitating similar maintenance treatment. The extensive early repairs gradually eliminated the weak places and, as in experiment 5, lowered the maintenance costs during later years. The north end of this section on the west side is so located that it was subjected to much more traffic up to the year 1924 than the other sections. The highway up to that time was not improved beyond Bradley Lane on the east side, and north and west-bound traffic therefore crossed the tracks at this point to remain on pavement. During 1918 it was deemed desirable to smooth and seal the surface by adding a surface treatment of 0.293 gallon per square yard of hot asphalt and one-half inch stone. The east side of the experiment has continued generally better than the west side. Its present condition is similar to that of experiment 5.

Experiment No. 7.—This experiment was located entirely on the east side of the car tracks and comprises two tests designated as sections A and B. Section A was constructed with two applications of bitumen as in the other bituminous macadams of this group, but in section B the second treatment was omitted. The asphalt used was of a considerably harder grade than that used in other experiments.



Hot Application of Heavy Oil on a Penetration Macadam Section

Table 2.—*Analyses of bituminous materials used in original construction of the experiments south of Bradley Lane*

Experiment number	1 and 2	2	3	4	5	6	7	8	9	10	10	11
Material	Coal tar, refined	Coal tar refined (light)	Fluxed native asphalt	Gilsonite oil asphalt	Oil asphalt	Oil asphalt	Oil asphalt	Refined water-gas tar preparation	Asphaltic petroleum [1]	Residual petroleum [2] 1912	Asphaltic petroleum 1914	Native asphaltic emulsion
Specific gravity 25°/25° C	1.258	1.219	1.058	0.974	0.999	0.989	0.973	1.113	0.949	0.976	0.964	1.038
Specific viscosity, Engler:												
1. 100° C., 100 cc										13.1		
2. 50° C., 50 cc								15.5				
3. 25° C., 50 cc									118		113.3	
Float test:												
1. 50 ° C., seconds	150											
2. 32° C., seconds		47								205		
Flash point, °C									37		40	
Burning point, °C									68		85	
Melting point, °C			46	52	74	47	90					
Penetration, 25° C., 100 g., 5 seconds			128	146	73	94	55					
Per cent loss, 163° C., 5 hrs., 20 g			2.14	0.87	0.05	0.68	0.44		27.10	.13	26.46	[3] 3.35
Per cent loss, 105° C., 5 hrs., 20 g									16.71			52.54
Penetration on residue			[4] 56	[5] 99	[6] 65	[4] 79	[7] 50					[8] 195
Float test on residue, 50° C., seconds									[9] 100		81	[9] 72
Float test on residue, 32° C., seconds									[8] 32	229	226	
Per centage soluble in CS_2			94.51	99.81	99.46	99.59	99.82		99.88	99.74	99.92	36.30
Percentage organic insoluble			1.00	0.12	0.50	0.28	0.15		0.08	0.23	0.06	1.10
Percentage inorganic insoluble			4.49	0.07	0.04	0.13	0.03		0.04	0.03	0.02	3.30
Bitumen insoluble in 86° B. naphtha			20.78	21.13	24.68	20.10	26.20		9.10	9.93	7.43	
Fixed carbon, per cent			10.64	7.79	13.53	8.36	10.15		4.91	7.67	5.04	
Free carbon, per cent	29.60	23.35						3.04	Water			49.50
Distillation, percentage by weight:									Ammonia			.35
Water	0	1.0						0	Fatty and resin acids			9.45
Up to 110° C	[10] .2	[11] .7						0				
110 to 170° C	[10] .6	[12] .5						[11] .6				
170 to 270° C	[13] 10.2	[14] 16.8						[11] 24.8				
270 to 315° C	[10] 7.5	[15] 6.5						[11] 9.7				
Residue	[16] 81.4	[16] 74.3						[17] 64.9				
Total	99.9	99.8						100.0				

---

[1] Fairly thin fluid with strong naphtha odor.
[2] Viscous, sticky fluid.
[3] Loss in addition to loss at 105° C.
[4] Sticky, glossy surface.
[5] Mottled surface.
[6] Sticky, slightly mottled surface.
[7] Hard, fairly lustrous.
[8] Residue from percentage loss test at 105° C.
[9] Residue from percentage loss test at 163° C.
[10] Solid.
[11] Clear.
[12] Turbid.
[13] One-third solid.
[14] Two-thirds solid.
[15] One-sixth solid.
[16] Hard, dull, brittle.
[17] Sticky, semisolid. A 350-375° C. fraction showed 7.5 per cent insoluble in dimethyl sulphate.

Stone ranging in size from 2½ inches to 1 inch was spread to an uncompacted depth of 3½ inches. The first application of bitumen was made at the rate of 1.66 gallons per square yard for the two-coat test and was followed by 0.6 gallon per square yard, chips being spread sparingly following each application.

In the case of the single-application experiment stone chips 1 inch to one-half inch were spread over the coarser stone layer after it had been thoroughly compacted. The hot oil asphalt was then applied at the rate of 1.86 gallons per square yard, covered with chips, and rolled.

Within a year after construction the binder appeared to be lifeless. It was considered also that the asphalt used was too hard and had a melting point too high for this type of construction. A number of worn depressions occurred in both sections A and B, although to a much greater extent in the single-application area. These defects were repaired and a surface treatment of 0.29 gallon of cold asphaltic oil and one-half inch stone was applied to the patches on section A and to the whole of section B. This treatment undoubtedly saved section B from total failure.

From 1912 on, with the exception of the year 1915, this section required only light repairs up to 1918 at which time it received a surface treatment of 0.29 gallon of hot asphalt and ½-inch stone.

Subsequently section A required considerable patching and section B developed many short irregular waves. These waves have not, however, developed serious roughness although considerable cracking has occurred on a 3-foot strip adjacent to the car tracks. At the present time the appearance and condition of this section compares favorably with the other experiments of this group, although the maintenance costs for the past few years have been somewhat higher than the average.

BITUMINOUS MACADAM IN GOOD CONDITION AFTER 16 YEARS

Approximately 16 years have elapsed since these experiments were constructed. During this period they have carried very severe traffic and in their broken edges and repaired local failures they show the effect of the stresses to which they have been subjected. Nevertheless, all are still in serviceable condition and, with continued careful maintenance, should not require reconstruction for some years to come.

TABLE 3.—*Gallons of material per square yard and type of material used in the construction and retreatment of the experiments south of Bradley Lane*

Experiment No.	Year							
	1911	1912	1913	1914	1915	1916	1917	1918
1	Construction, 2.59 coal tar, refined.			0.316 coal tar, crude.[1]				0.190 coal tar, refined.[2]
2	Construction, 4.15 coal tar, refined.							0.255 coal tar, refined.[2]
3	Construction, 1.96 fluxed native asphalt.							0.299 residual asphaltic petroleum.[2]
4	Construction, 2.20 Gilsonite oil asphalt.							0.305 residual asphaltic petroleum.[2]
5	Construction, 2.25 oil asphalt.							0.227 residual asphaltic petroleum.[2]
6	Construction, 2.09 oil asphalt.							0.293 residual asphaltic petroleum.[2]
7	Construction, 2.26 and 1.86 oil asphalt.	0.290 residual asphaltic petroleum.[2]						0.290 residual asphaltic petroleum.[2]
8		Construction, 0.540 water-gas tar preparation.	0.250 water-gas tar, refined.[4]			0.149 water-gas tar, preparation.[5]	0.156 water-gas tar, preparation.[5]	
9		Construction, 0.530 asphalt petroleum.	0.204 asphaltic petroleum.[5]	0.209 asphaltic petroleum.[5]	0.197 asphaltic petroleum.[5]	0.289 asphaltic petroleum.[5]	0.213 asphaltic petroleum.[5]	0.204 asphaltic petroleum.[5]
10		Construction, 0.790 residual petroleum.		Reconstruction 0.476 asphalt petroleum.[5]	0.172 asphaltic petroleum.[5]	0.299 asphaltic petroleum.[5]	0.172 asphaltic petroleum.[5]	0.178 asphaltic petroleum.[5]
11		Construction, 3.32 native asphalt emulsion.						0.225 asphaltic petroleum.[5]

Experiment No.	Year							
	1919	1920	1921	1922	1923	1924	1925	1926
1						0.337 coal tar, refined.[3]		
2								
3								
4								
5								
6								
7								
8	0.339 water-gas tar preparation.[5]					0.348 coal tar preparation.[3]		0.406 coal tar preparation.[5]
9	0.140 asphaltic petroleum.[5]	0.118 asphaltic petroleum.[5]	0.453 asphaltic petroleum.[5]					
10	0.140 asphaltic petroleum.[5]	0.069 asphaltic petroleum.[5]	0.449 asphaltic petroleum.[5]					
11		0.133 asphaltic petroleum.[5]				0.132 asphaltic petroleum.[3]		

[1] ⅜-inch gravel cover material.

[2] ½-inch stone cover material.

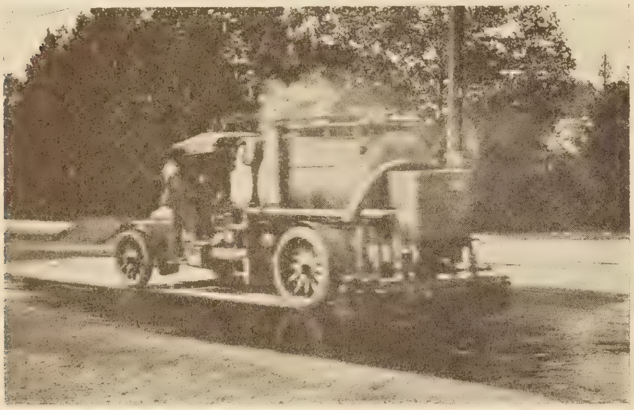
[3] Sand cover material.

[4] 1-inch screenings cover material.

[5] Torpedo sand cover material.

CONSTRUCTION OF SURFACE-TREATED SECTIONS DESCRIBED

Late in the year 1911 an 8-inch limestone water-bound macadam road was constructed for a distance of approximately 1,700 feet on the east side of Connecticut Avenue, beginning at the District line at Chevy Chase Circle. Cobblestone gutters were constructed along the east edge and drainage installations made as required. After being exposed to traffic for several months this highway was divided into sections for surface treatment with bituminous materials. These experiments are listed in Table 1. Laboratory tests of the bituminous materials used in the original applications are shown in Table 2.


Applying Bituminous Material for Surface Treatment

Experiment No. 8.—Surface treatment was applied under favorable weather conditions in August, 1912. The cold water-gas tar preparation was applied by means of an automobile distributor at the rate of 0.54 gallon per square yard after sweeping the bonded macadam surface. Several hours were allowed for the tar to penetrate into the road before the cover material of limestone, 1 inch to one-half inch in size, was spread at the rate of 1 cubic yard to 72 square yards of surface.

Under traffic the tar mat wore away rapidly, but it had penetrated well into the macadam surface and effectively bonded the upper layer of the stone. A year after construction several holes were patched and the whole section was given a surface treatment of 0.25 gallon of the same type of tar as used in the original treatment and a cover of 1-inch screenings. In 1915 the surface mat showed some signs of instability. Six retreatments have been required during the period between 1912 and 1926, the first four using a water-gas tar preparation similar to that constituting the original application. A cold-application coal-tar preparation was employed in the retreatments of 1924 and 1926. Torpedo sand was used as the mineral cover in all of the retreatments except in those of 1913 and 1924 when 1-inch screenings and sand were used, respectively. In August, 1927, this section presented a smooth fine-textured surface. In numerous small spots the last application of tar has picked up, revealing the underlying treatment. Indications of instability were very slight. This experiment at present is in better condition than the other surface-treated macadam sections which, however, have not received retreatments since 1921.

Experiment No. 9.—Surface treatment with cold asphaltic petroleum was applied in June, 1912, at the rate of 0.53 gallon per square yard. The macadam surface was well swept and application made with a street sprinkler and covered with 1-inch to ½-inch limestone at the rate of 1 cubic yard to 72 square yards of surface. Several hours elapsed between the distribution of the oil and the application of the mineral cover.

The oil mat withstood the abrasion of traffic better than the preceding section treated with tar. However, a tendency to become muddy in wet weather was noticeable and deterioration developed in the more lightly traveled areas of the section.

A very considerable amount of patching has been required on this experiment and treatments of asphaltic petroleum were applied annually from the time of construction until 1921. Retreatments were applied by pouring the oil on the road surface and obtaining distribution by hand brooming. Since 1921 maintenance has consisted only of patching.

The surface is fairly smooth and intact in the traveled way, but somewhat more uneven adjacent to the car track and the gutter. Fully 25 per cent of the south half of the section has been patched. Fewer patches have been required on the remainder of the section.

Experiment No. 10.—This section was treated with a hot residual petroleum applied under pressure. The process of application was hampered by the cold weather of late November and by a small amount of water contained in the oil. The application of 0.79 gallon per square yard was immediately covered with stone chips of the type used on the two preceding sections but in a somewhat greater amount.

This experiment gave promise of becoming troublesome from the beginning. The subgrade was soft and there was difficulty in bonding the macadam. With the advent of warm weather the thick mat began to bleed, necessitating the addition of more stone covering. It also proved unstable under traffic and developed a marked degree of waviness. Continued maintenance failed to correct this condition and in 1914 it was scarified, brought to grade by the addition of new stone and refinished as water-bound macadam. After being opened to traffic for a few days a new bituminous treatment of asphaltic petroleum was applied. This material was the same as that applied to the adjacent experiment, No. 9, in fact, constituted an extension of the same treatment. Unfortunately, the work of reconstruction was done late in the fall and numerous small potholes soon formed. Persistent waviness and the tendency to become muddy in wet weather were characteristic of this section during its early life.


Condition of Experiment 11 in February, 1928. Water-Bound Macadam Surface Treated with Asphalt Emulsion

Additional treatments of asphaltic petroleum were applied at the time such work was done on experiment

No. 9 and the two sections have similar records of service behavior and cost.

The surface of this experiment is now in good condition although heavily patched. The accumulation of material resulting from the several surface treatments constitutes a rough strip about 3 feet wide adjacent to the gutter and has pushed over the cobblestone edging in some places.

Experiment No. 11.—This section was originally intended as a part of experiment No. 10 but a shortage of oil necessitated the installation of an additional section which was constructed by a method of grouting.

The existing macadam was scarified and harrowed and new 2½-inch to 1-inch limestone was added to give a 3-inch layer of loose stone. A mortar prepared in the proportions of approximatley 4 cubic feet of trap rock screenings to 10½ gallons of native asphalt emulsion was mixed in a concrete mixer and spread to a thickness of 2½ inches over the stone. As soon as the emulsion began to dry out, screenings were scattered over the surface and a 10-ton roller forced the mortar into the voids of the loose stone until only a thin layer remained on the surface. It was intended to apply an emulsion flush coat in finishing this section, but, owing to adverse weather conditions, this operation was postponed until spring.


EXPERIMENT-7


EXPERIMENT-8


EXPERIMENT-9


EXPERIMENT-10

Condition of Penetration Macadam (Experiment 7) and Three Penetration Macadam Sections in 1928

For five years maintenance on this experiment was very slight and the first surface treatment was not required until 1918 when 0.225 gallon per square yard of asphaltic petroleum with a torpedo-sand cover was applied. Subsequently, a very considerable amount of patching has been necessary. This experiment, as in the case of experiment 1, is located almost entirely on a curve and consequently is subjected to the same scouring action of traffic. The condition of the pavement at present is fairly good although there are many cracks on the inside of the curve near the sidewalk.

MAINTENANCE COSTS MUCH LOWER ON BITUMINOUS MACADAM SECTIONS THAN ON SURFACE TREATED SECTIONS

Traffic carried by the east and west lanes did not differ widely up to 1921. Later traffic counts, made during 1927, show that this relationship still holds. Subgrade conditions are believed to have been reasonably uniform throughout the length of these experiments and the maintenance costs on the several sections may therefore, be regarded as fairly comparable.

As might be expected the cost of maintaining the bituminous macadam surfaces (shown in Table 1 and fig. 2), has proved to be far less than the costs on the three strictly superficial bituminous treatments on waterbound macadam. For the former the average yearly maintenance cost for the 16 years since construction has been 2.60 cents per square yard as compared to 8.30 cents per square yard on experiments Nos. 8, 9, and 10 over a period of 15 years. Experiment No. 8 of the surface-treated group has proved more economical than experiments Nos. 9 and 10, but nevertheless its average annual maintenance costs have been more than double the average of those on the bituminous macadams. The bituminous grouted section, No. 11, partakes more of the nature of the bituminous macadam than of the surface treatments. However, as it is not closely related to any type at present being constructed, its costs are omitted from this comparison. Yearly maintenance costs and traffic on the experiments south of Bradley Lane are shown graphically in Figure 2.

EXPERIMENTS WITH HIGHER TYPE SURFACES CONSTRUCTED NORTH OF BRADLEY LANE

The six experimental sections located north of Bradley Lane constitute a continuation of the work previously discussed, but are located only on the west side of Connecticut Avenue, as indicated in Figure 1. As previously stated, these sections carried traffic traveling in both directions up to the end of 1924, at which time that portion on the east side of the car tracks was paved from Bradley Lane to Woodbine Street thereby relieving experiments Nos. 1, 2, and most of 3 of the north-bound traffic. The average daily traffic carried by these experiments is shown graphically in Figure 2. Up to 1921 they carried slightly heavier traffic than did those sections south of Bradley Lane. However, during later years the continual development of the adjacent territory has greatly increased the traffic on the latter sections. The traffic counts made in 1927 show that the sections south of Bradley Lane carried approximately 50 per cent more traffic than did those north of Bradley Lane.

However, in comparing the effect of the traffic carried by the various experiments consideration should be given to the higher concentration necessarily obtaining on those sections carrying vehicles traveling in both directions.

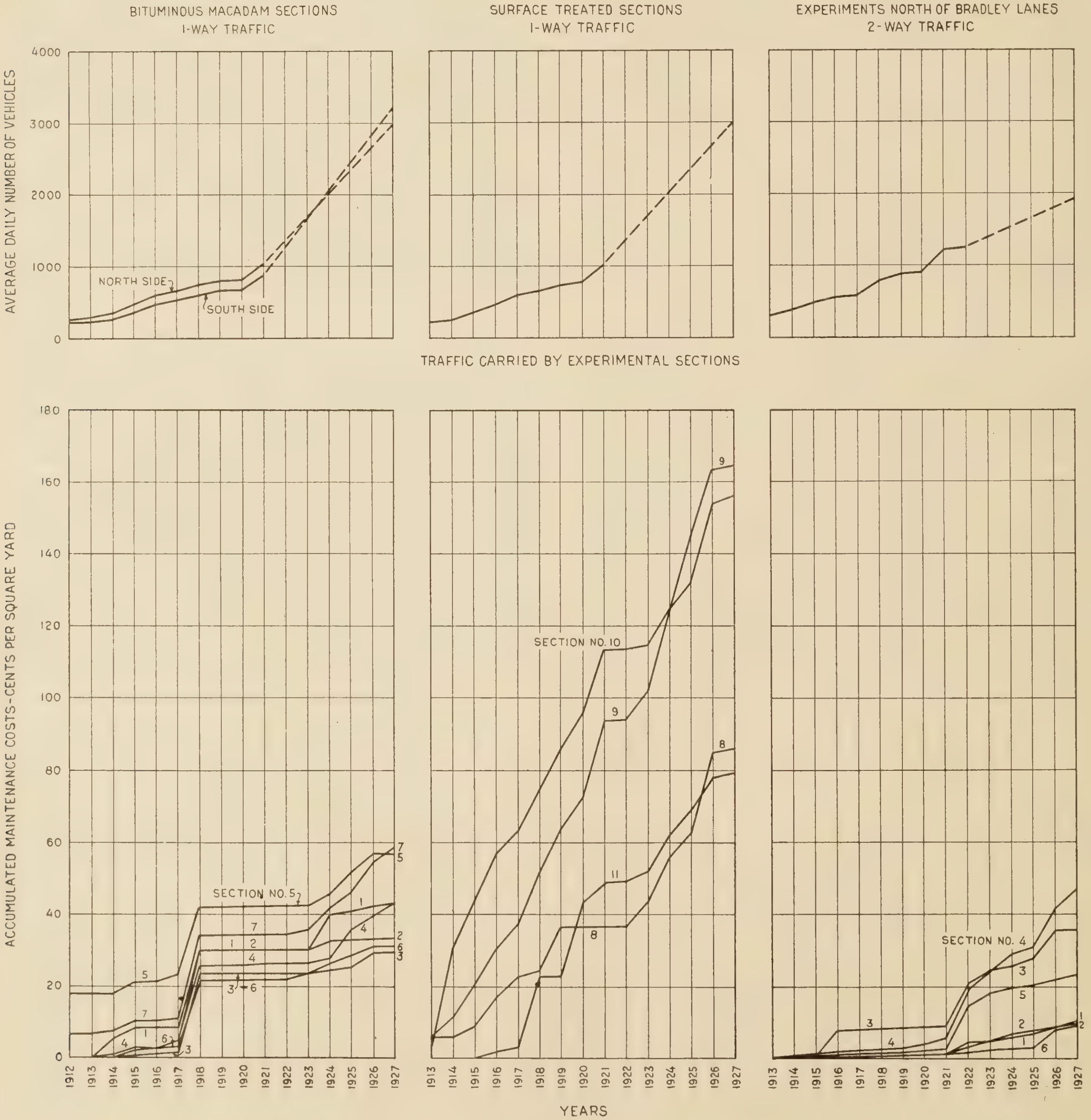


FIG. 2.—MAINTENANCE COSTS AND TRAFFIC ON EXPERIMENTAL SECTIONS

The construction of these sections was begun September 9, 1912, and continued until December 13, during which time experiments Nos. 1 and 2 and portions of Nos. 3, 4, and 5 were built. Due to the lateness of the season, the construction of the remaining portions of the latter experiments and all of No. 6 was postponed until the spring of 1913, and the road was finally completed May 17, 1913. Table 4 shows the character of the six experiments, and a summary of their construction details and subsequent service behavior follows.

TABLE 4.—*Character and extent of experimental sections constructed on Connecticut Avenue north of Bradley Lane*

Experiment		Location		Area	Type	Aggregate
No.	Section	From—	To—			
				Square yards		
1	A	0−15	3+19	1, 498	2 inches bituminous concrete (Topeka specification).	Limestone.[1]
	B	3+19	6+20		----do----	Trap.[1]
2	A	6+20	9+04	1, 400	2 inches bituminous concrete District of Columbia specification).	Limestone.[1]
	B	9+04	12+50		----do----	Trap.[1]
3	A	12+50	15+84	4, 178	Cement concrete surface treated with bituminous material.	Gravel.
	B	15+84	21+60		----do----	Limestone.
	C	21+60	25+03		----do----	Gravel.
	A	25+03	27+29		Oil-cement concrete, surface treated with bituminous material.	Limestone.
	B	27+29	30+90		----do----	Gravel.
4	C	30+90	33+60	1, 744	Oil-cement concrete	Do.
	D	42+50	44+61		----do----	Limestone.
	E	46+10	49+00		----do----	Trap.
5	A	33+60	37+85	3, 013	Cement concrete	Gravel.
	B	37+85	42+50		----do----	Limestone.
	C	44+61	46+10		----do----	Do.
	D	49+00	52+00		----do----	Trap.
6	------	52+00	61+80	2, 055	Vitrified brick	See Table 9.

[1] Aggregate used in the bituminous concrete. Gravel used in the cement concrete of the base.

Prior to the construction of the experimental sections the road surface was 8 inches of waterbound limestone macadam in very bad condition. This old surface was spiked, plowed, and scarified, and the suitable stone was reclaimed and used to backfill the trenches of French drains which were constructed at both sides of the new pavement. The installation of these drains was suggested by the character of the subgrade soil, which is a decomposed mica schist that absorbs water very readily. The drain along the east side was 3 feet deep and extended throughout the entire length of all experiments; that on the west side was laid under the gutter with the 4-inch tile at a depth of 2 feet below the subgrade. The latter extended through all sections except experiment 6, which lies on a fill.

The barrel-shaped concrete gutter which was laid along the west side of the experiments was built to a width of 3 feet with a depth of 4 inches at the center. The base of this gutter was 1 : 2 : 4 gravel concrete laid very dry and the top, immediately applied, was one-half inch of 1 : 2 mortar. The entire length of gutter was laid before any of the pavements were constructed, and the concrete surfaces and bases were struck off with a strike board which rested upon the gutter. There were no joints in the gutter except the joints at the ends of day's work. When the forms were removed the base was found to be very porous. By the time the concrete pavement sections were laid against this gutter it had attained considerable tensile strength, and, in contracting, had cracked at frequent intervals. When the pavement concrete was poured against the porous side of the base it apparently bonded to it; at any rate the majority of the first contraction cracks that appeared in the pavements were opposite the cracks in the gutter and were undoubtedly caused by the contraction of the stronger gutter.


CONCRETE BASE FOR ASPHALTIC CONCRETE SECTIONS

ASPHALTIC CONCRETE SECTIONS HAVE GIVEN GOOD SERVICE

Experiment No. 1.—A hot-mixed asphaltic concrete surface, 2 inches in thickness, was laid on a 6-inch 1:3:7 gravel concrete foundation. A curb of 1:2 mortar 6 inches wide and 2 inches high was constructed integrally with the foundation along the edge adjacent to the car track. The concrete base was compacted by tamping and its surface was slightly roughened by striking with a rattan broom. The bituminous wearing surface was not laid until a month after the completion of the foundation.

An effort was made to secure a composition conforming to the "Topeka" specification by using only crushed rock and limestone dust for the aggregate. This was found to be difficult without the addition of sand, but

TABLE 5.—*Analyses of bituminous concrete mixtures*

Coarse aggregate	Experiment No. 1		Experiment No. 2	
	Topeka specification		District of Columbia specification	
	Limestone	Trap	Limestone	Trap
Bitumen soluble in CS_2	7. 1	8. 7	6. 7	6. 7
Sieve analysis of aggregate:				
Pass 1¼-inch screen, retained 1-inch screen	-------	-------	2. 1	0
Pass 1-inch screen, retained ¾-inch screen	-------	-------	13. 2	6. 5
Pass ¾-inch screen, retained ½-inch screen	1. 8	2. 0	16. 7	15. 2
Pass ½-inch screen, retained ¼-inch screen	11. 3	14. 0	13. 5	19. 2
Pass ¼-inch screen, retained ⅛-inch screen	20. 5	13. 0	12. 7	13. 5
Pass ⅛-inch screen, retained 10-mesh sieve	14. 5	8. 8	6. 5	7. 4
Pass 10-mesh sieve, retained 20-mesh sieve	15. 8	17. 0	7. 6	8. 7
Pass 20-mesh sieve, retained 30-mesh sieve	5. 8	7. 3	3. 5	4. 0
Pass 30-mesh sieve, retained 40-mesh sieve	3. 8	4. 0	3. 3	3. 3
Pass 40-mesh sieve, retained 50-mesh sieve	1. 6	2. 3	2. 0	1. 9
Pass 50-mesh sieve, retained 80-mesh sieve	3. 3	4. 4	4. 1	4. 0
Pass 80-mesh sieve, retained 100-mesh sieve	1. 5	1. 8	1. 1	1. 2
Pass 100-mesh sieve, retained 200-mesh sieve	2. 9	4. 6	2. 0	2. 6
Pass 200-mesh sieve	10. 1	12. 1	5. 0	5. 8
Total	100. 0	100. 0	100. 0	100. 0

owing to impending winter conditions and the consequent necessity for completing the pavement as quickly as possible, the mixtures were laid as indicated by the analyses of Table 5. From station 0 – 15 to 3 + 19 limestone screenings were used and from 3 + 19 to 6 + 20 trap rock was used. The binder was a fluxed native asphalt of the characteristics shown in Table 6.

The mixture arrived upon the road at a temperature of about 280° F. Initial compression was obtained by a 3-ton roller and completed by means of a 10-ton tandem roller. The surface between stations 4 + 26 and 6 + 20 was laid during a drizzling rain.

This pavement in general has remained in good condition throughout its 15 years of service and has required remarkably low expenditures for maintenance. Depressions have occurred from time to time along the west edge of section A and to some extent on the north end of section B, due, apparently, to the tendency of heavy trucks to follow the line of the gutter. Shortly after construction slight indications of waviness were observed, especially near the north end in the trap-rock section adjacent to the curb. This condition has not increased to a marked degree, although in a few places transverse cracks have developed in the base, resulting in a slight bulge in the wearing surface.

On a number of scattered areas in the limestone section, especially near the west edge, the surface has been broken by the formation of fine irregular cracks. These areas have remained firm and smooth and have required no additional maintenance up to this time. However, it may be reasonably expected that they will eventually affect the life of the pavement and will require more maintenance.

Some pitting has occurred, which is more noticeable in the limestone section, and the section on which trap rock was used appears richer and more plastic. A study made on the base showed the condition of the concrete was fairly well reflected in the appearance of the wearing surface. Cores were drilled in both good and poor areas. On those areas over which the wearing surface was cracked, the concrete base was found to have suffered pronounced deterioration, in some cases to such an extent that it could be removed with little difficulty with a shovel. On the other hand, where the surface was intact and free from cracks, the concrete base was also in good condition.

Experiment No. 2.—This is an asphaltic concrete surface proportioned in accordance with District of Columbia specifications laid 2 inches thick on the concrete foundation described in connection with experiment No. 1.

This experiment was also divided into two sections, stations 6 + 20 to 9 + 04 and 9 + 04 to 12 + 50, upon which limestone and trap-rock screenings, respectively, were used in the surface mixture. In this case, however, the finer particles of the stone were augmented by the addition of a coarse sand. Limestone dust as filler and the fluxed native asphalt binder were used as in the Topeka mixture. The south 80 feet of this pavement was laid in a drizzling rain. Analysis of the mixture as laid appears in Table 5.

After a delay of one week, due to unfavorable weather, a seal coat of fluxed native asphalt was applied at the rate of 0.51 gallon per square yard and covered with clean stone chips. The temperature at the time was only 35° F., and the asphalt hardened as soon as

TABLE 6.—*Analyses of bituminous materials used in original construction of experiments north of Bradley Lane*

	Experiment Nos. 1 and 2: Bituminous concrete—Fluxed native asphalt	Experiment No. 3 (surface treatments)							Experiment Nos. 3 and 4: Oil-cement concrete—Residual petroleum
		Sections A and G: Refined coal tar	Sections D and F: Water-gas tar preparation	Sections B and H: Water-gas tar preparation	Section E: Fluxed native asphalt	Sections C, D and I: Fluxed native asphalt	Section F: Oil asphalt	Section J: Oil asphalt	
Specific gravity, 25°/25° C	1.074	1.219	1.108	1.144	1.045	1.043	1.031	1.012	0.933
Specific viscosity, Engler:									
1. 50° C., 100 cc									27.8
2. 50° C., 50 cc			14.0						
Penetration, 25° C., 100 g., 5 sec	60				184	148	[1] 26	147	
Float test, 32° C., seconds		83		207					
Float test, 50° C., seconds		40		75					
Melting point, °C	53				39	48	92	52	
Loss 163° C., 5 hrs., 20 g., per cent	2.86				3.50	2.73	0.32	0.59	2.63
Penetration on residue	29				63	64	18	103	
Float test on residue at 32 °C., seconds									95
Per cent soluble in CS_2	93.56				94.70	96.56	99.74	99.72	99.90
Per cent insoluble in CS_2	1.86				1.23	1.35	.17	.17	.08
Per cent inorganic insoluble	4.58				4.07	2.09	.09	.11	.02
Per cent bitumen insoluble in 86° B., naphtha	23.83				19.60	21.87	34.84	21.72	2.31
Per cent fixed carbon	11.20				9.83	11.17	15.62	10.92	3.01
Per cent free carbon		16.29	0.25	0.95					
Distillation, per cent by weight:									
Water		0.0	0.0	0.0					
Up to 110° C		[2].5	[3]1.4	[3].1					
110 to 170° C		[4].2	[3].4	[3].2					
170 to 270° C		[5]14.7	[3]16.3	[3]6.4					
270 to 315° C		[6]8.7	[7]17.0	[8]10.4					
Residue		75.8	64.8	82.8					
Total		99.9	99.9	99.9					

[1] Penetration at 0° C. (200 g., 1 min.) 14; penetration at 46° C. (50 g., 5 sec.) 58.

[2] One-half solid.

[3] Clear.

[4] Cloudy.

[5] Two-thirds solid.

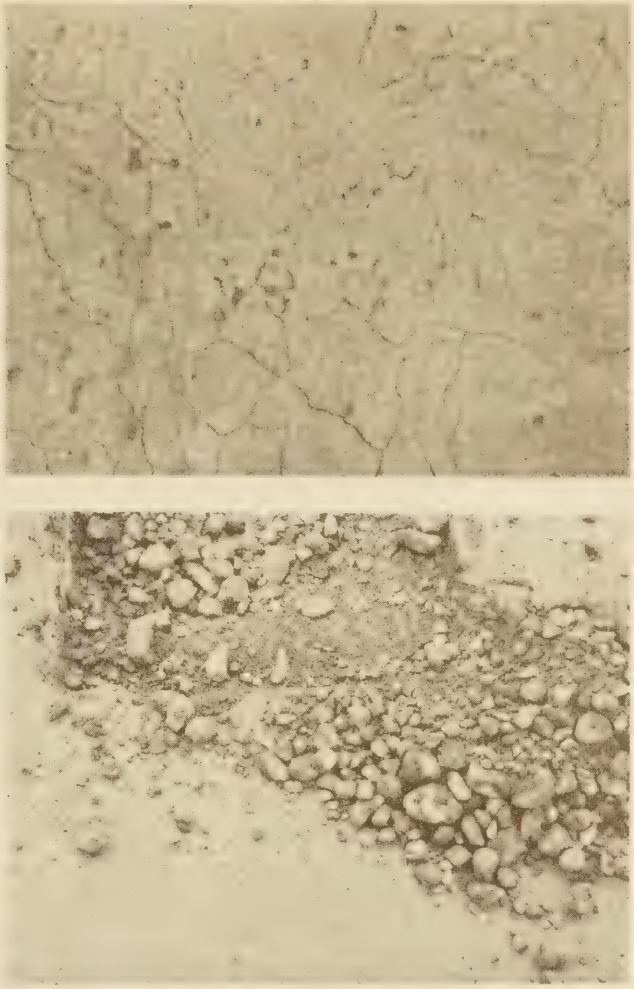
[6] Solid.

[7] Clear. Showed 7.5 per cent insoluble in dimethyl suphate. A 315 to 350° C. fraction showed 7.5 per cent, and a 350 to 375° C. fraction showed 17.5 per cent insoluble n dimethyl sulphate.

[8] Clear. This fraction and also a 315 to 350° C. fraction and a 350 to 375° C. fraction each showed 7.5 per cent insoluble in dimethyl sulphate.

Condition of Bituminous Concrete Sections in 1928. The the Upper Pictures are of Experiment 1 and the Lower is of Experiment 2

it touched the surface. As a consequence the asphalt was unevenly distributed and the chips were not properly bedded, so that most of the stone was swept off by the traffic during the winter and when spring came the surface was very soft. A reapplication of chips in the amount of 0.011 cubic yard per square yard was made in July, 1913, and this greatly stiffened and improved the surface.



A Badly Cracked Area of Bituminous Concrete in Experiment 1, North of Bradley Lane. The Lower Picture Shows the Condition of the Concrete Base Which Could Be Removed with a Shovel

The service record of this experiment is virtually the same as that for experiment No. 1. The surface has a mottled appearance and seems richer than the Topeka mixture. Wear and depressions near the gutter have developed and have been maintained with cold patch mixtures of tar and stone chips. The surface is generally smooth and unbroken excepting for a few transverse cracks which are reproductions of base cracks. The trap-rock section, as in experiment No. 1, appears richer and more plastic than does the limestone section. Specimens taken from the base show the concrete to be in good condition generally.

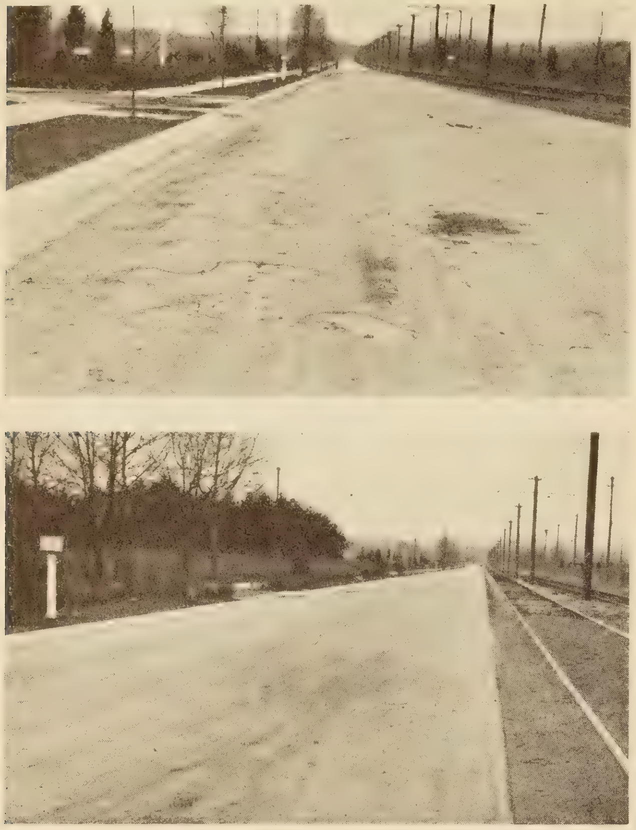
BITUMINOUS SURFACE COAT EXPERIMENTED WITH ON CONCRETE PAVEMENT

Experiment No. 3.—This section consists of 4,178 square yards of 6-inch Portland cement concrete pavement which it was desired to surface coat with a number of bituminous materials.

In mixing the concrete for 1,341 square yards of this experiment there was added a light fluxed residual petroleum in the proportion of 5 pints to each sack of cement, The analysis of this material is shown in Table 6.

The proportions of the concrete throughout this experiment were 1 part of Portland cement, 1¾ parts of sand and 3 parts of coarse aggregate. The experiment was divided into sections as shown in Figure 1, and Table 4. Both plain and oil-cement concrete were laid with limestone and with gravel coarse aggregate, the analyses of which are given in Table 7.

The concrete was mechanically mixed to a "quaky" consistency, shoveled and raked into place, shaped by means of a strike board, and finished from a bridge by hand with wooden floats. Expansion joints were purposely omitted and no joints of any other kind were constructed except those between the several day's work. These were placed at an angle of 80° to the center line of the road; and before work was continued, the exposed face of the concrete was washed with a 10 per cent solution of muriatic acid, followed by water. The mixer was of the rotary-distributor type, now obsolete; and there was probably a considerable segregation of the aggregates.



Condition of 2 of the Surface-treated Portland Cement Concrete Sections in 1914

Table 7.—*Mechanical analyses of coarse aggregates used in concrete Experiments 3, 4, and 5, north of Bradley Lane*

Size	Gravel	Limestone	Trap
Pass 2½-inch, retained on 1½-inch screen	2. 3		
Pass, 1½-inch, retained on 1¼-inch screen	10. 8		
Pass 1¼-inch, retained on 1-inch screen	24. 0	13. 2	6. 6
Pass 1-inch, retained on ¾-inch screen	25. 8		19. 5
Pass ¾-inch, retained on ½-inch screen	26. 4	34. 2	40. 6
Pass ½-inch, retained on ¼-inch screen	9. 8	47. 4	24. 9
Pass ¼-inch	. 9	5. 2	8. 4
Total	100. 0	100. 0	100. 0

The fresh concrete was covered with canvas as soon as practicable and, after it had set, a 2-inch layer of loam or sand was spread, kept wet for a period of 8 days, and removed after 15 days.

The bituminous surface treatments were omitted from the original construction on account of the cold weather and were not applied until the following year. In preparation for the application of the bituminous mat, the concrete surface was washed, swept, and allowed to dry. Table 8 indicates the nature of the materials which were applied as protective coatings and Table 6 shows the results of laboratory tests made upon the bituminous materials used in original construction.

In certain instances it will be noted that two applications of bituminous materials were made, the first being in the nature of a paint or priming coat to facili-

Table 8.—*Materials used in bituminous surface treatments on the concrete experiments Nos. 3, 4, and 5, north of Bradley Lane*

Experiment No.	Location		Original treatments			Maintenance treatments			
						1916		1922	
	From—	To—	Paint coat	Carpet coat [1]	Amount	Materials [2]	Amount	Material [3]	Amount
					Gallons		*Gallons*		*Gallons*
3-A	12+50	15+00	None	Coal tar, refined	0. 33	Water-gas tar preparation	0. 307	Coal tar, refined	0. 385
3-B	15+00	17+50	do	Water-gas tar preparation No. 2.	. 33	do	. 307	do	. 385
3-C	17+50	20+00	do	Fluxed native asphalt No. 2.	. 50	Residual asphaltic petroleum.	. 275	do	. 385
3-D	20+00	21+25	Water-gas tar preparation No. 1.	do	. 70	do	. 275	do	. 385
3-E	21+25	22+50	Native asphalt emulsion [4]	Fluxed native asphalt No. 1.	. 60	do	. 275	do	. 385
3-F	22+50	25+00	Water-gas tar preparation No. 1.	Oil asphalt No. 1	. 60	do	. 275	do	. 385
3-G	25+00	26+50	None	Coal tar, refined	. 33	Water-gas tar preparation.	. 307	do	. 385
3-H	26+50	28+00	do	Water-gas tar preparation No. 2.	. 33	do	. 307	do	. 385
3-I	28+00	29+50	do	Fluxed native asphalt No. 2.	. 50	Asphaltic petroleum	. 499	do	. 385
3-J	29+50	30+90	do	Oil asphalt No. 2.	. 50	do	. 499	do	. 385
4	30+90 42+50 46+10	33+60 44+61 49+00	do	None	None.	None	None.	do	. 260
5	33+60 37+85 44+61 49+00	37+85 42+50 46+10 52+00	do	do	None.	do	None.	do	. 260

[1] Cover consisted of limestone screenings or pea gravel.

[2] Torpedo-sand cover.

[3] Pea-gravel cover.

[4] Same type of bituminous material used in experiment No. 11.

tate the adhesion of the heavier carpet material. The first application was broomed over the concrete without heating. The heavier products were heated in kettles and spread by means of a hand-drawn distributor. The treatments were covered with pea gravel or limestone grit and immediately opened to traffic.

The bituminous mats were purposely permitted to wear without maintenance and in February of 1916 were reported to be in the following condition:

(A) Refined coal tar. Twenty to twenty-five per cent of the treatment worn off. The west side showed more exposed concrete than the east side.

(B) Water-gas tar preparation, No. 2. Slightly better than A, but deteriorating.

(C) Fluxed native asphalt, No. 2. Eighty-five per cent of the mat was gone on the west half but only about 1 per cent had disappeared from the east half.

(D) Fluxed native asphalt No. 2 over water-gas tar preparation No. 1. About 85 per cent had disappeared from the west side and about 5 per cent from the east side.

(E) Fluxed native asphalt over native asphalt emulsion. About 85 per cent worn off of the west half and about 10 per cent from the east half.

(F) Oil asphalt No. 1 over water-gas tar preparation No. 1. Only a few scattered patches of the treatment remained.

(G) Refined coal tar. Surface treatment was worn off to a great extent over the entire section.

(H) Water-gas tar preparation No. 2. Seventy-five per cent of mat had worn off of the west half of the pavement. The east half remained almost intact.

(I) Fluxed native asphalt No. 2. About 60 per cent of the treatment was gone from the west half. The east half remained almost intact.

(J) Oil asphalt No. 2. About 35 per cent of the surface treatment had disappeared from the west quarter of the pavement. The remaining three-quarters was almost intact.

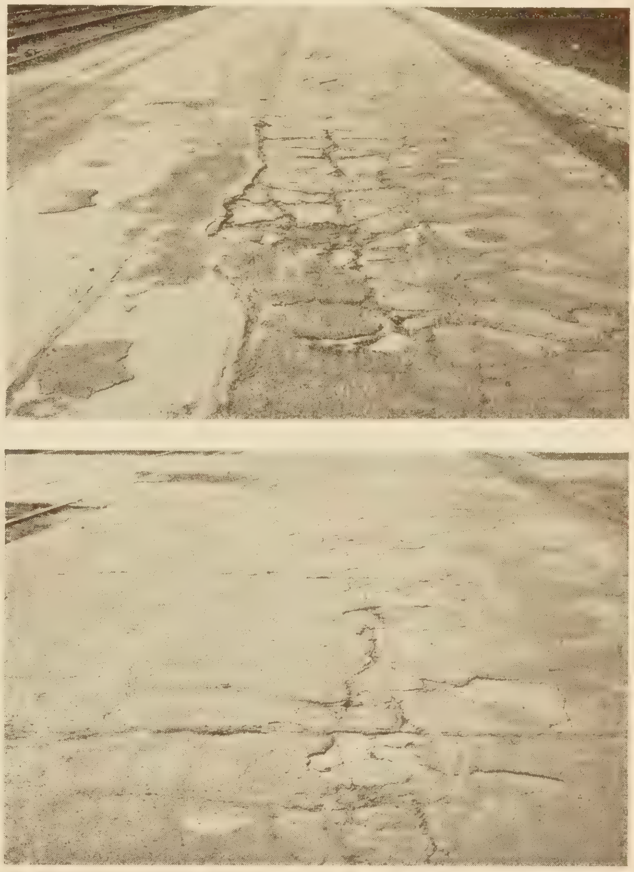
The mats of sections A to F, inclusive, were laid on plain concrete. The concrete of sections G to J contained oil as previously described. Although earlier observations had indicated that oil-cement concrete was not better adapted to bituminous surface treatment than cement concrete, a comparison of these groups, on the basis of observations made three years after construction, leads to the conclusion that the asphaltic materials at least, proved somewhat more durable on the former.

The west half of the pavement carried much heavier traffic than did the east half, and this condition is clearly reflected in the behavior of the bituminous treatments.

During the fall of 1916 the entire experiment was once more surface treated with bituminous materials. Sections A, B, G, and H, which originally had tar mats, were at this time treated with a hot water-gas tar preparation. A residual asphaltic petroleum was applied to sections C, D, E, and F, upon which materials of an asphaltic nature had been previously used. Sections I and J received a carpet coat of cold asphaltic petroleum applied at the rate of one-half gallon per square yard in two applications. Torpedo sand was used as the top-dressing for all of these treatments.

By 1922 these mats had virtually disappeared and refined coal tar with pea gravel was applied to the whole experiment at the rate of 0.385 gallon per square yard. Inspections made in 1926 and again in 1927 showed that the last treatment had for the most part worn off, although on the east side considerable areas remained intact, especially in the gravel oil-cement section, and small patches were scattered over the remainder of the surface.

All the sections in this experiment are in poor condition and will require heavy maintenance from now on. Very little difference in appearance is noted between the gravel and crushed-stone aggregate and between the cement and oil-cement sections.



Condition of Surface-Treated Concrete Sections in 1928, Experiment 3-B. The Upper Picture Shows Concrete Not Containing Oil and the Lower Picture Shows Oil-Cement Concrete

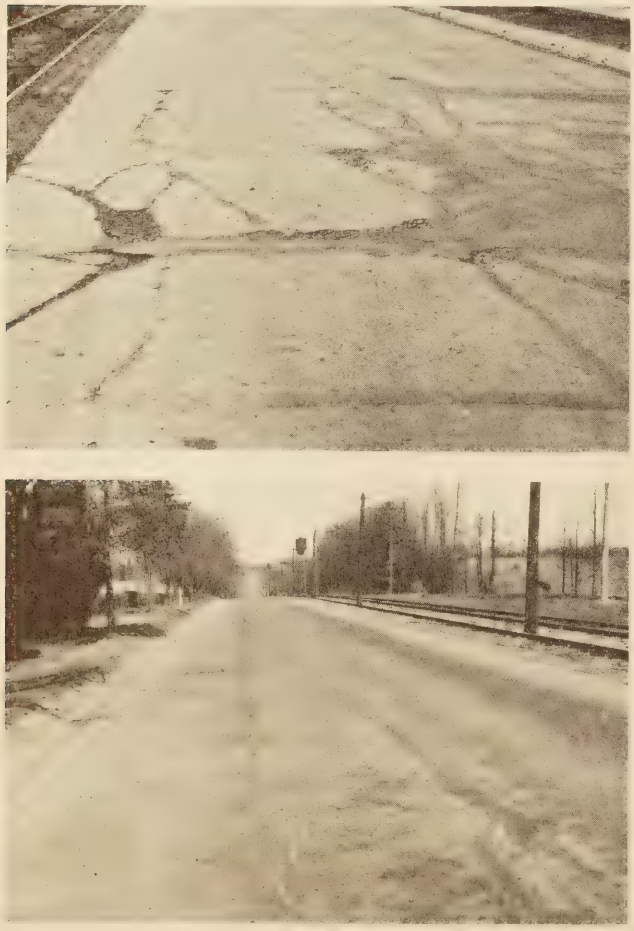
PORTLAND CEMENT CONCRETE TEST SECTIONS DESCRIBED

Experiment No. 4.—This was a test of Portland cement concrete mixed with oil as a wearing surface. Gravel, limestone, and trap rock were used as the coarse aggregate and, due to irregularity in the delivery of these materials, it was necessary to separate the sections in which they were used, as shown in Table 4.

The concrete mixture was composed of 1 part Portland cement, 1¾ parts of sand, and 3 parts of coarse aggregate. After the cement, aggregates, and water were partially mixed, 5 pints of light residual oil was added for each sack of cement and the mixing completed. The analysis of the oil is given in Table 6. The construction details of this experiment were identical with those of experiment No. 3 which has been described.

Hydrated lime was also added to the concrete constituting 153 linear feet at the northern end of the section containing trap-rock coarse aggregate. The

Steps in the Construction of the Concrete Sections and Condition of a Portion of the Finished Pavement in 1914



Condition of Concrete Sections in 1928. The Upper Picture Shows Experiment 5-A and the Lower Picture Shows Experiments 4-E and 5-D

Badly Cracked Concrete Pavement in 1928 Which Produced Cores of Fairly High Strength

proportions of this mixture were as follows: Hydrated lime, 20 pounds; cement, 188 pounds; sand, 4 cubic feet; coarse aggregate, 7½ cubic feet; oil, 10 pints.

Table 7 shows mechanical analyses of the coarse aggregates employed in the concrete experiments.

Experiment No. 5.—This section was identical with experiment No. 4, except that oil was omitted from the mixture. The same coarse aggregates were used and the experiment was constructed in separate sections, as shown in Table 4.

Hydrated lime was added to the concrete of the trap section adjacent to the oil-concrete area in which hydrated lime was included. The proportions were the same as in experiment No. 4, except, of course, for the omission of the oil.

The wearing quality of the concrete seems not to have been affected by the presence of the oil. Both types have worn uniformly and disintegration has not developed except where the pavement has cracked so badly that the small slabs have been progressively broken into still smaller pieces.

In the sections using trap rock the abrasion of the mortar has left the more resistant coarse aggregate prominently exposed.

At the present time nearly all of the sections are badly cracked and certain areas are maintained with the greatest difficulty. The sections located north of Blackthorn Street are in the best condition of the concrete group, with transverse cracks frequently located at greater than 25-foot intervals. This may be due to the better drainage conditions existing at this point.

In 1922 these experiments were surface treated with a hot application of 0.26 gallon refined coal tar and pea gravel. This mat surface has now entirely disappeared except for two small isolated areas.

The presence of hydrated lime in portions of the trap rock sections of experiments No. 4 and No. 5 apparently has not affected the behavior of the concrete. Cores were taken both from the badly cracked portions and from the larger areas of the various sections of the concrete experiments. The compressive strengths of the two types of cores are approximately the same and consequently are not indicative of the true condition of the pavement.

In the summer of 1914 and subsequently at other times, expansion of concrete sections resulted in a blow-up at station 12 + 50, the junction of the second bituminous concrete and the first concrete section, and a point at which there is a convex vertical curve. Removal of a strip of concrete on each of the several occasions finally put a stop to the phenomenon.

Steps in the Construction of the Brick Experiment and One of the Finished Sections

BRICK TEST SECTION SHOWS BUT LITTLE WEAR

Experiment No. 6.—This section included tests of vitrified brick wearing surfaces on a Portland cement concrete foundation. The foundation was constructed of 1:3:7 gravel concrete as in experiments No. 1 and No. 2, except that in this case the curb was made 8 inches wide and 6 inches high of $1:1\frac{3}{4}:3$ gravel concrete placed integrally with the base.

On the foundation a cushion of sand was spread and rolled with a 300-pound hand roller and struck off to a true depth of 2 inches. The brick were laid in straight courses at right angles to the curb and no driving was permitted to straighten the courses. After the brick were laid and imperfect ones replaced, the surface was rolled with a 5-ton tandem roller until they were firmly bedded in the sand cushion. Portland cement grout, composed of 1 part cement to 1 part of sand, was applied in two applications. The first was of such consistency that it would flow freely and was swept into the joints. After the first application had settled well into the joints, the second application of the consistency of thick cream was squeegeed over the pavement, leaving the joints well filled. Immediately after the grouting was completed, sand was spread over the pavement to a depth of one-half inch and kept wet for seven days.

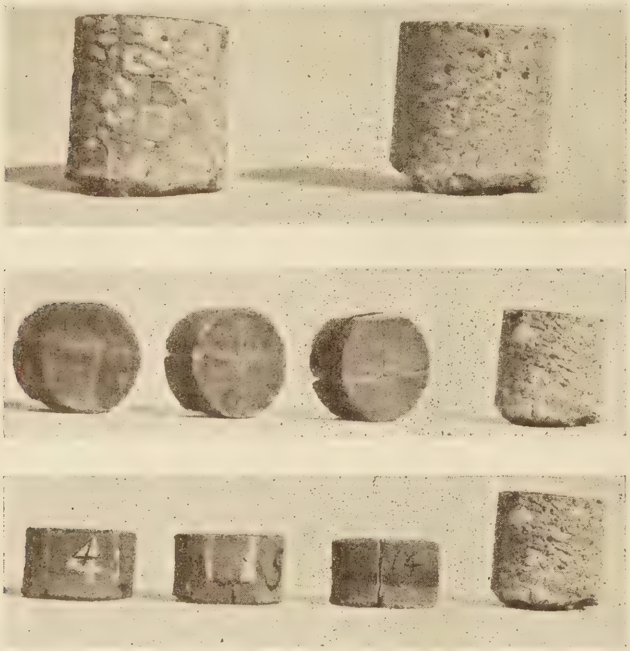
Longitudinal joints were provided along each curb, but no transverse expansion joints were constructed, and the ends of the pavement were practically fixed.

The experiment was constructed with brick obtained from many sources and possessing widely different test characteristics. Results of tests made upon samples of the brick laid in each section are listed in Table 9.

Table 9.—*Tests on vitrified brick used in experiment No. 6 north of Bradley Lane*

[Length of section, 978.1 feet]

Section	Length	Type of brick	Rattler loss	Water absorption	Description
	Feet		*Per cent*	*Per cent*	
A	51.5	Shale, wire-cut lug	21.12	1.39	Hard-burned brick having a good structure.
B	67.5	do	16.36	1.31	Medium hard-burned brick having a very good structure.
C	108.7	Shale, re-pressed	25.57	.88	Brick well vitrified; losses in rattler mainly due to chipping.
D	105.0	do	17.67	1.65	Brick molded from coarsely ground shale; had a fairly good structure and was hard burned.
E	111.4	do	22.04	1.10	Brick very hard burned; losses in rattler due to chipping.
F	69.4	do	18.80	1.81	Brick molded from coarsely ground clay; had a good structure.
G	60.5	do	27.92	2.29	Medium hard-burned brick which wear evenly though excessively in the rattler test.
H	67.9	do	22.68	3.74	Medium hard-burned brick made from finely ground clay and having a fairly good structure.
I	50.0	do	22.59	2.86	Medium hard brick made from coarsely ground clay and wearing down uniformly in the rattler.
J	61.3	Fire clay, re-pressed	19.11	1.56	Brick made from coarsely ground fire clay; had an excellent structure, free from laminations; not burned very hard.
K	54.7	do	37.68	2.38	Comparatively soft-burned brick made from coarsely ground fire clay; wear in rattler excessive though uniform.
L	58.8	Shale, re-pressed	38.89	4.04	Comparatively soft-burned brick made from coarsely ground clay; wear in rattler excessive though uniform.
M	60.1	Fire clay, re-pressed	24.31	3.73	Fairly soft-burned brick made from medium finely ground clay; worn down evenly by rattler.
N	51.3	Fire clay, wire-cut lug	31.19	3.68	Losses in rattler due mainly to open laminations; brick burned hard.



The Upper Picture Shows Cores Taken from the Concrete Sections and the two Lower Pictures Show Cores from the Brick Sections

Sections K, L, M and part of N were constructed over a heavy fill which some years ago settled to a considerable extent, causing failures in the overlying pavement necessitating heavy repair during 1919, 1920, and 1922. The cost of such repair is not properly chargeable to surface maintenance and therefore has not been included in the accumulated cost data of Figure 2 and Table 1. A foundation failure occurred also at the junction of this experiment and the adjoining concrete pavement. This was apparently due to expansion of the concrete, and the brick on a strip 2 feet wide across the section are cracked and worn. The brick of section N are rough and badly broken.

The mortar grout is generally in good condition, and in several sections, notably those of wire-cut brick, the joints are filled to the top. In no case is the mortar disintegrated, but directly in the traffic lanes some joints are unfilled to a depth of about one-quarter inch. This is particularly true of the sections paved with re-pressed brick.

No transverse cracks exist in the experiment although a considerable number of fine longitudinal cracks have developed and sometimes extend through several consecutive sections. However, they seem not to have affected the bahavior of the wearing surface which still remains in excellent condition and shows no evidence of raveling. Except for the repair of defects directly caused by subgrade and foundation failure, maintenance on this experiment has been confined to the filling of these cracks with bituminous material.

A slight amount of pitting is noticeable in sections L and N in the traveled areas but on a major portion of the sections the surface has the same smooth unworn appearance as originally.

At the time of construction two courses of brick from each section were measured before laying and a record made of their thickness and location in the pavement. In February, 1928, a number of these brick were removed from the heavily traveled areas and measured. The results of these measurements are given in Table 10. Sections not appearing in the table gave indications of no wear and consequently were not measured.

Table 10.—*Loss in thickness of brick taken from portions of pavement subjected to greatest wear*

Section	Type of brick	Rattler loss	Water absorption	Measured wear
		Per cent	*Per cent*	*Inch*
A	Shale, wire-cut lug	21.12	1.39	0.08
B	do	16.36	1.31	.00
G	Shale, re-pressed	27.92	2.29	.06
K	Fire clay, re-pressed	37.68	2.38	.12
L	Shale, re-pressed	38.89	4.04	.20
N	Fire clay, wire-cut lug	31.19	3.68	.70

In a few isolated cases individual bricks show circular scaled areas indicative of internal laminated structure, while some other bricks have cracked but have not spalled and would not be noticeable to the casual observer.

With the exception of section N and the sections located over the unstable fill, whose failure can not be attributed to the nature of the surface, this experiment is in excellent condition.

No deterioration in the concrete base was found such as was noticed on certain portions of experiment 1–A although that portion over the fill was badly broken.

COMPARATIVE DATA ON TEST SECTIONS PRESENTED

The accumulated maintenance costs of the six sections north of Bradley Lane are given in Table 1, and the costs by years are shown graphically in relation to the traffic in Figure 2.

The results of a crack survey of all sections made in February, 1928, are plotted in Figures 3 and 4, and digested in Table 11.

Table 12 gives the result of tests of cores taken from the concrete pavements and bases, and Table 13 shows the results of analyses of samples of bituminous concrete taken from experiments 1 and 2, the samples of both materials having been taken in February, 1928.

The two bituminous-concrete experiments and the brick experiment, exclusive of that portion over the fill, have required the least maintenance up to this time and are still in excellent condition and to all appearances should continue to give economical service for some time to come.

On the other hand, the concrete experiments have required comparatively heavy maintenance and, with the exception of the north 1,400 feet, are in very bad condition. To what extent the deterioration of these sections has been caused by the impact resulting from the rough condition of the surface which was developed when the surface mats were allowed to wear off in patches, is problematical. That the lack of maintenance of these mats has to some extent caused cracking of the pavement, is a probability. The maintenance work now being done does not improve the condition of these experiments as concrete pavement but serves somewhat to keep them serviceable. In spite of the badly cracked condition of these sections there is no appearance of settlement or subgrade failure and, for this reason, those areas which seem to have reached their service limit as a concrete pavement might economically serve as a base for some type of surfacing.

TABLE 11.—*Digest of condition survey made in February, 1928*

BITUMINOUS CONCRETE

Section No.	Per cent of section in—			Cracking per 100 feet		
	Class 1[1]	Class 2[2]	Class 3[3]	Transverse	Longitudinal	Corner
				Feet	*Feet*	*Number*
1-A	60	8	32	109	29	0.7
1-B	93	----------	7	66	3	.7
2-A	77	3	20	37	5	----------
2-B	93	6	1	----------	----------	----------

PORTLAND CEMENT CONCRETE

Section No.	Covered with surface treatment	Not covered with surface treatment	Broken	Cracking per 100 feet			
				Transverse		Longitudinal	
				Covered	Not covered	Covered	Not covered
	Per cent	*Per cent*	*Per cent*	*Feet*	*Feet*	*Feet*	*Feet*
3-A	----------	98	2	----------	424	----------	391
3-B	9	89	2	23	277	----------	388
3-C	7	90	3	----------	296	----------	437
3-A	----------	95	5	----------	215	----------	371
3-B	62	26	12	106	405	76	187
4-C	1	91	8	----------	270	----------	517
5-A	3	89	8	----------	369	----------	430
5-B	----------	99	1	----------	219	----------	290
4-D	----------	100	----------	----------	127	----------	252
5-C	----------	100	----------	----------	127	----------	277
4-E	----------	100	----------	----------	40	----------	126
5-D	----------	100	----------	----------	57	----------	125

BRICK

Section	A	B	C	D	E	F	G	H	I	J	K	L	M	N
Longitudinal cracks per 100 feet (in feet)	550	332	195	620	73	606	496	723	480	196	403	735	800	488
Per cent of section broken or replaced	----	----	----	----	----	----	----	----	----	----	21	7	21	31

[1] Smooth, without surface cracking.
[2] Moderate surface cracking and slightly uneven.
[3] Excessive surface cracking, marked unevenness, maintained or patched areas in combination or separately.

CONDITION OF BRICK SECTIONS IN 1928

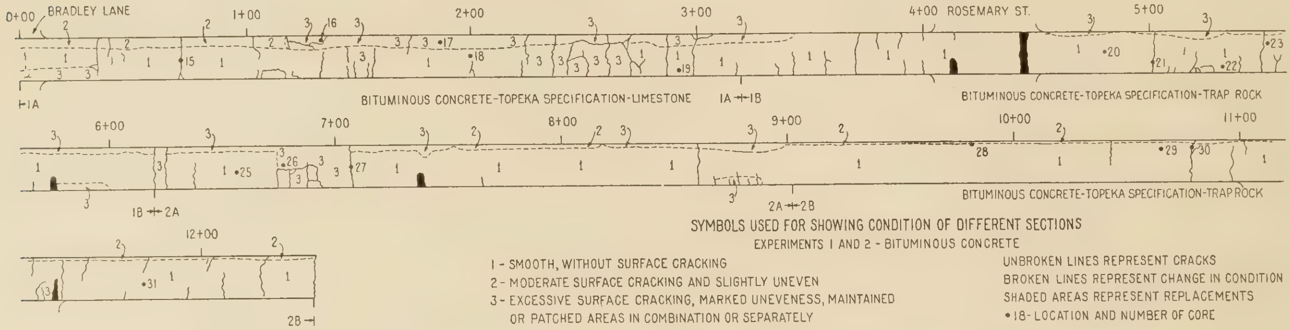


Fig. 3.—Condition Chart of Bituminous Concrete Experiments in February, 1928

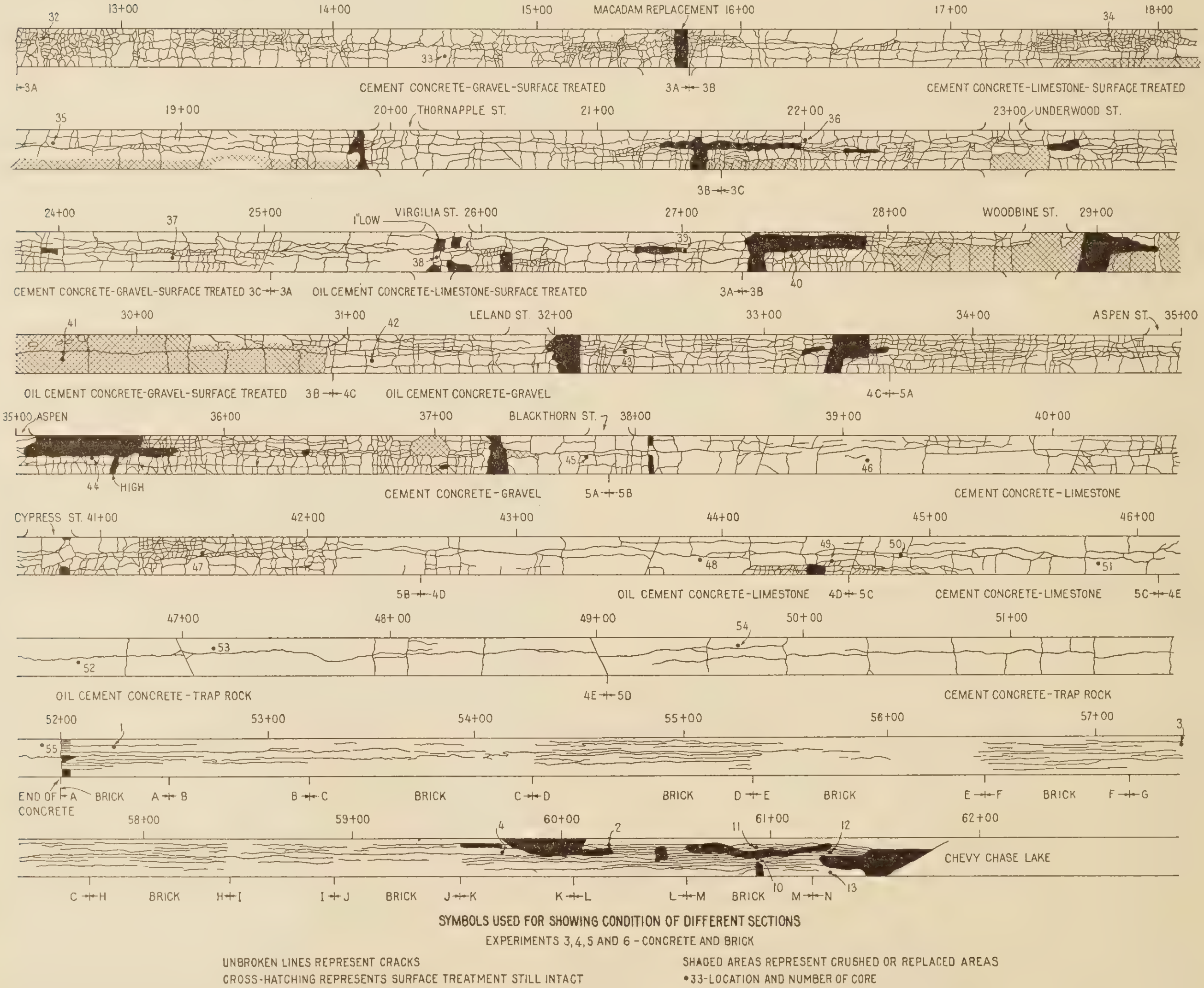


Fig. 4.—Condition Chart of Cement Concrete and Brick Experiments in February, 1928

TABLE 12.—*Tests on concrete specimens taken from experiments north of Bradley Lane during February, 1928*

Specimen No.	Experiment and section	Station	Distance from west edge	Type	Depth of concrete	Compression strength	Remarks
			Feet		*Inches*	*Pounds per square inch*	
15	1-A	0+57	9.5	1:3:7 concrete base			Taken directly over transverse crack; concrete base sound though cracked transversely.
16	1-A	1+34	2.0	do			Taken from badly cracked area; concrete badly crushed; no core obtainable.
17	1-A	1+88	2.0	do			Same as No. 16.
18	1-A	2+00	12.0	do			Base cracked horizontally with no surface indication of failure.
19	1-A	2+89	16.0	do	6.0	3,140	Sound structurally.
20	1-B	4+79	9.5	do	5.5	3,380	Taken from good section of pavement.
21	1-B	5+00	15.0	do	6.0		Taken from transverse crack; concrete shattered.
22	1-B	5+29	17.0	do	4.75		Top surface not cracked but badly shoved; concrete appeared to be weak and disintegrating.
23	1-B	5+51	3.0	do			Top surfacing good; concrete base apparently sound on top 3½ inches; bottom portion disintegrated.
25	2-A	6+55	14.0	do	5.0		Top surface good; base appears to be somewhat crushed.
26	2-A	6+79	11.0	do	5.5		Top surface badly cracked and wavy; concrete crushed and cracked in all directions.
27	2-A	7+05	9.5	do	5.0		Taken on transverse crack; surface good; concrete specimen taken in small pieces; base crushed.
28	2-B	9+85	2.0	do	5.4		General appearance of top good, but cracked where specimen was taken; concrete crushed.
29	2-B	10+67	4.0	do	5.0		Top good; concrete solid for first 4 inches; crushed and loose below.
30	2-B	10+87	4.0	do	4.0		Taken on transverse crack; concrete shattered.
31	2-B	11+75	13.0	do	6.5	3,400	Top and concrete in good condition.
32	3-A	12+67	6.0	1:1¾:3, 6-inch gravel concrete	6.0	[1] 5,430+	Taken from badly cracked area.
33	3-A	14+53	15.0	do	7.0	6,315	Taken from uncracked slab 7 by 15 feet.
34	3-B	17+77	5.0	1:1¾:3, 6-inch limestone concrete.	5.5	[1] 5,610+	Taken from badly cracked area.
35	3-B	18+37	9.5	do	6.0	5,550	Taken from good section; uncracked slab 9 by 51 feet.
36	3-C	22+03	7.5	1:1¾:3, 6-inch gravel concrete	6.0	[1] 5,280+	Taken in nest of cracks; general appearance bad; core taken from slab not over 18 inches square.
37	3-C	24+55	13.5	do	5.5	[1] 5,750+	Taken from uncracked slab 5 by 18 feet
38	3-A	25+75	15.0	1:1¾:3, oil-cement concrete, 6 inches thick (limestone).	5.5	5,100	Taken from uncracked slab 8 by 33 feet.
39	3-A	26+99	8.0	do	5.5	[1] 5,130+	Taken in nest of cracks; slab measured 10 by 24 inches.
40	3-B	27+51	12.0	1:1¾:3, oil-cement concrete, 6 inches thick (gravel).	5.5	4,290	Taken in nest of cracks; slab measured 12 by 24 inches.
41	3-B	29+63	13.0	do	6.0	2,960	General appearance in vicinity of specimen good; core porous.
42	4-C	31+12	13.0	do	6.0	3,240	Taken from slab 4½ by 15 feet; core porous.
43	4-C	32+34	12.0	do	5.5	4,500	Taken in nest of cracks.
44	5-A	35+35	9.5	1:1¾:3, 6-inch gravel concrete	5.5	[1] 5,330+	Taken in nest of cracks; surface cracked in all directions.
45	5-A	37+71	12.0	do	6.0	[1] 5,380+	Taken from slab 6 by 6 feet.
46	5-B	39+14	13.0	1:1¾:3, 6-inch limestone concrete.	5.5	4,520	Taken from slab 10 by 20 feet.
47	5-B	41+50	9.5	do	5.5	[1] 4,880+	Taken in nest of cracks; surface cracked in all directions.
48	4-D	43+91	13.0	1:1¾:3, oil-cement concrete 6 inches thick (limestone).	5.75	4,050	Taken from slab 8 by 38 feet; adjacent surface not so badly cracked.
49	4-D	44+54	14.0	do	5.75	3,610	Taken in nest of cracks from slab 1½ by 3 feet; surface badly cracked; core porous.
50	5-C	44+93	9.5	1:1¾:3, 6-inch limsetone concrete.	4.75		From small slab; road badly cracked in network; core too short for test.
51	5-C	45+81	13.0	do	6.75	5,040	Surface generally good; core from slab 9½ by 15½ feet.
52	4-E	46+47	12.0	1:1¾:3, oil-cement concrete, 6 inches thick (trap).	7.00	3,870	Surface generally good; core from slab 7 by 69 feet; core slightly porous
53	4-E	47+15	7.5	do	6.75	4,630	Surface generally good; core 1 foot from transverse crack.
54	5-D	49+71	6.0	1:1¾:3, 6-inch trap concrete	6.75	4,800	Surface generally good but slightly pitted.
55	5-D	51+92	4.0	do	6.0	4,530	Surface generally good
1	6-A	52+25.1	4.0	1:3:7, base under brick	5.5	3,380	Base concrete in the brick sections did not show indications of disintegration excepting on the west side of sections K, L, M, and N where it was badly broken over the fill.
3	6-G	57+40.3	4.0	do	5.3	3,835	
4	6-K	59+75.4	7.3	do	5.5	3,790	
9	6-L	60+25.5	7.3	do	5.0	3,660	
10	6-M		7.0	do	6.5	3,360	
11	6-M		4.0	do	4.5		
12	6-N	61+34.9	7.0	do	7.0	2,170	
13	6-N	61+34.9	16.7	do	6.8	3,210	

[1] Maximum load applied and specimen not broken. Variation in maximum-load value due to factor applied to correct for height of specimen.

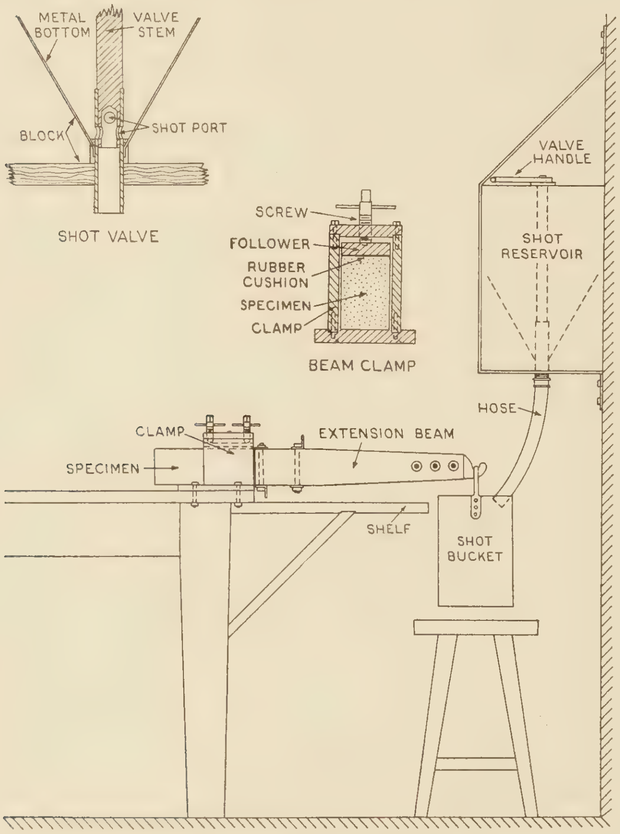
TABLE 13.—*Results of analyses of samples taken during February, 1928, from the bituminous concrete Experiments 1 and 2, north of Bradley Lane*

Laboratory No.	29947	29948	29949	29950	29951	29952	29953	29954	29955
Identification	No. 16	No. 18	No. 20	No. 23 (thin)	No. 23 (thick)	No. 24	No. 26	No. 28	No. 29
Taken from section	1-A	1-A	1-B	1-B	1-B	2-A	2-A	2-B	2-B
Condition	Poor (cracked)	Good	Good	Shoved	Shoved	Good	Poor (cracked)	Poor (cracked)	Good
Thickness of sample	Average 1½ inches	1¾ to 2$\frac{1}{16}$ inches	2⅛ to 2$\frac{7}{16}$ inches	1 to 1½ inches	2½ to 3 inches	2¼ to 2¾ inches	Average 1½ inches	Average 2 inches	2 to 2½ inches
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
Bitumen extracted	6.8	6.8	8.0	8.2	7.6	6.0	5.6	5.4	5.2
Pass 1¼-inch screen, retained on 1-inch screen									6.9
Pass 1-inch screen, retained on ¾-inch screen						9.2	0.8	17.2	11.7
Pass ¾-inch screen, retained on ½-inch screen			4.0	2.6	4.0	16.5	5.0	9.9	6.4
Pass ½-inch screen, retained on ¼-inch screen	9.0	10.8	14.2	12.0	11.8	16.6	19.6	18.2	18.6
Pass ¼-inch screen, retained on 10-mesh sieve	21.0	22.0	15.0	13.7	16.4	15.6	25.4	15.2	15.4
Pass 10-mesh sieve, retained on 20-mesh sieve	22.6	21.4	17.8	17.7	18.0	9.6	13.8	9.4	9.6
Pass 20-mesh sieve, retained on 30-mesh sieve	7.0	6.4	6.2	6.2	6.4	3.4	4.0	3.1	3.3
Pass 30-mesh sieve, retained on 40-mesh sieve	5.5	5.0	4.8	5.2	5.2	3.8	4.2	3.0	3.2
Pass 40-mesh sieve, retained on 50-mesh sieve	4.0	3.6	4.0	4.5	4.2	4.0	4.0	3.0	3.2
Pass 50-mesh sieve, retained on 80-mesh sieve	4.8	4.3	5.3	6.0	5.8	5.0	4.7	3.8	4.2
Pass 80-mesh sieve, retained on 100-mesh sieve	2.3	2.0	2.0	2.2	2.0	1.2	1.4	1.4	1.2
Pass 100-mesh sieve, retained on 200-mesh sieve	3.5	3.5	3.7	6.6	5.9	3.0	2.8	3.0	3.7
Pass 200-mesh sieve	13.5	14.2	15.0	15.1	12.7	6.1	8.7	7.4	7.4

A CANTILEVER TESTING APPARATUS FOR MORTAR BEAMS

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

THE Division of Tests of the Bureau of Public Roads has recently designed an apparatus for testing cement mortar beams under cantilever loading which is similar in a general way to that developed by the Illinois Department of Public Works for tests of concrete and described by H. F. Clemmer in the May, 1926, issue of Public Roads. The apparatus was designed to furnish a more rapid method of testing mortar beams in flexure and which could be employed in laboratories not equipped with a universal testing machine of sufficient sensitivity to test such beams.



Apparatus for Testing Beams as Cantilevers

The apparatus consists of a clamping device to hold the beam securely and an extension arm which fastens on the end of the beam and transmits the load as shown in Figure 1. The beam may be loaded by any means that is at hand. In the bureau laboratory, No. 12 lead drop shot are used to apply the load. The shot are fed from a reservoir fastened to the wall, and equipped with a quick-action valve which opens completely by moving the control handle through a 60° arc.

The two thumbscrews shown in the clamping device bear on a steel plate three-eighth inch thick, which rests on the specimen. The beam is tested in the same position that it is molded, i. e., with the troweled surface up. Slight irregularities in the troweled surface have prevented an even distribution of stress over the surface exposed to restraint, and have consequently given poor breaks with an accompanying wide variation in test results. To overcome this, a piece of sheet rubber one-eighth inch thick is placed between the bearing plate and the specimen. This has given very good results.

The test specimens, 2 by 3 by 12 inch beams, are made in steel molds. The use of such molds, with carefully machined surfaces, is considered highly advisable.

Computations of the modulus of rupture are made using the formula

$$S=\frac{Mc}{I}$$

where

S = modulus of rupture, in pounds per square inch,
M = bending moment in inch-pounds, $=W_1l_1+W_2l_2$

where

W_1 = test load, in pounds
l_1 = distance of load from support = 18.12 inches,
W_2 = weight of arm,
l_2 = distance of center of gravity of arm from support,
c = distance of extreme fiber from neutral axis, or $1\frac{1}{2}$ inches,
I = moment of inertia of cross section of beam about its central horizontal axis.

Substituting the particular constants which applied for these tests, and neglecting the weight of the overhanging beam we have,

$$S=12.4+6.04W_1 \text{ (pounds per square inch)}$$

Neglecting the weight of the overhanging section of the beam is in accordance with the usual practice in testing beams for flexure under center loading.

To demonstrate the suitability of this apparatus for testing beams, four series of beams were prepared for comparative tests in the cantilever apparatus and in a universal testing machine under center loading. Each series included five or six 18-inch beams for test under center loading, and an equal number of 12-inch beams for test in the cantilever apparatus. Series B, C, and D were made of a 1 : 3 mix and series A of a 1 : 2 mix using Potomac River sand in all series. Series A was tested at an age of 14 days, series B at 28 days, and series C and D at 7 days.

The various series were made in the laboratory as time permitted. Because of the small number of molds available, no effort was made to tie the four series together. In series A, each specimen was made from a separate batch, the 18-inch beams being made first. Inspection of the test results of this series indicates that the water-cement ratio may not have been exactly constant for the two sizes of beams. When tested as cantilevers, the halves of the original 18-inch beams check the center loading tests, whereas the 12-inch beams tested as cantilevers show somewhat lower values. To guard against this, and to furnish a better comparison between the two methods of testing, in series B, C, and D each 18-inch and the corresponding 12-inch beam were molded simultaneously from the same batch.

The 18-inch beams were tested in an Olsen universal testing machine of 40,000 pounds capacity. A small beam rider was used which decreased the machine ratio by 10, and permitted accurate reading of the applied load to the pound. A span of 15 inches was used and the beams were mounted on rockers in accordance with approved practice. The rate of application of the load was such that the modulus of rupture developed at an average rate of about 100 pounds per square inch per minute. The broken halves were then tested in the cantilever apparatus to serve as a check. These last tests are shown in Tables 3 and 4.

The 12-inch beams were tested in the cantilever apparatus, applying the load at a rate of 15 pounds per minute. This produced a stress increasing at the rate of 102 pounds per square inch per minute. Two breaks were made on each beam. The beam was inserted in the clamping device and the extension arm hung on the free end of the beam. The beam was then so adjusted that the base of the extension arm was one-sixteenth of an inch from the clamping device. This space is the minimum sufficient to permit flexure without binding. The beam was then firmly fastened and loaded to failure. The breaking load was weighed to the nearest tenth of a pound.

Tables 1 to 3 give the breaking load and computed moduli of rupture for each individual specimen. Table 4 presents a summation of the strengths, together with the mean variation from the average for each series.

There appears to be little variation between the test results obtained by the two methods of testing. The strengths obtained are essentially the same and the variation found between individual breaks averages the same in each case. It may be said that the testing of mortar beams can be performed as accurately with this cantilever device as by the customary method in the universal machine.

The retests of the 18-inch beams are of interest since they demonstrate that specimens broken under center loading may be checked by test of the two halves in the cantilever apparatus. In a series of tests extending over several periods of testing, one 18-inch beam could be tested at three different ages, the first test being by the center-loading method, and the other two by cantilever action. Such a method would furnish a more accurate index of the effect of age than could be obtained with three different specimens with the accompanying uncertainty of identical preparation.

TABLE 1.—*Results of tests under center loading in universal machine using 15-inch span*

Series A, mix 1:2, age 14 days		Series B, mix 1:3, age 28 days		Series C, mix 1:3, age 7 days		Series D, mix 1:3, age 7 days	
Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture
Pounds	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*
487	608	415	519	320	400	308	385
435	544	420	525	316	395	363	454
416	520	420	525	315	394	345	431
396	495	379	474	320	400	332	415
438	547	----------	----------	383	476	318	398
Average--- 543		Average---- 511		Average---- 413		Average---- 417	

TABLE 2.—*Results of tests of 12-inch beams in cantilever apparatus*

Series A, mix 1:2, age 14 days		Series B, mix 1:3, age 28 days		Series C, mix 1:3, age 7 days		Series D, mix 1:3, age 7 days	
Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture
Pounds	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*
85.0	526	86.3	533	69.5	432	72.0	447
82.0	508	84.5	522	74.0	459	69.5	432
86.5	535	76.7	475	63.5	396	67.0	417
88.5	547	84.0	519	63.5	396	68.5	426
77.5	481	85.0	525	63.5	396	66.0	411
85.0	526	81.3	503	59.2	370	73.2	455
79.0	490	79.0	489	66.0	411	61.0	381
87.0	538	81.3	503	68.5	426	58.5	366
78.5	487	77.5	480	64.5	402	76.0	472
78.0	484	----------	----------	64.0	399	64.0	399
90.0	556	----------	----------	----------	----------	----------	----------
82.0	508	----------	----------	----------	----------	----------	----------
Average--- 516		Average---- 505		Average---- 409		Average---- 421	

TABLE 3.—*Results of tests of 9-inch beams in cantilever apparatus*

Series A, mix 1:2, age 14 days		Series B, mix 1:3, age 28 days		Series C, mix 1:3, age 7 days		Series D, mix 1:3, age 7 days	
Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture	Breaking load	Modulus of rupture
Pounds	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*	*Pounds*	*Lbs. per sq. in.*
84.0	518	82.0	507	62.5	389	63.0	393
87.0	538	88.3	545	62.5	389	72.0	447
87.5	541	83.3	515	74.0	459	71.0	441
91.0	562	71.3	442	65.0	405	70.0	435
88.5	547	87.3	539	61.5	384	72.0	447
89.0	550	89.0	549	65.2	406	63.5	396
100.0	616	83.7	518	58.0	363	73.0	453
80.0	496	81.3	503	58.0	363	66.0	411
96.5	595	76.5	474	72.5	450	69.0	429
94.0	570	----------	----------	67.5	420	71.5	444
Average--- 553		Average---- 510		Average---- 403		Average---- 430	

TABLE 4.—*Average results of tests of each series and mean deviation from average*

Series	Center loading		Cantilever, 12-inch beams		Cantilever, 9-inch beams	
	Average modulus of rupture	Mean deviation from average	Average modulus of rupture	Mean deviation from average	Average modulus of rupture	Mean deviation from average
	Lbs. per sq. in.	*Per cent*	*Lbs. per sq. in.*	*Per cent*	*Lbs. per sq. in.*	*Per cent*
A	543	5.2	516	5.2	553	4.7
B	511	3.5	505	3.4	510	5.0
C	413	6.1	409	4.6	403	6.2
D	417	5.0	421	6.2	430	4.2
Mean	----------	5.0	----------	4.8	----------	5.0

Working drawings of the cantilever apparatus may be obtained upon request.

GASOLINE TAXES, 1927

Total taxes earned on motor-vehicle fuel, etc., refunds, disposition of funds, and gallons taxed

[From reports of State authorities]

State	Gross tax assessed prior to deduction of refunds	Exemption refunds: (Deducted from gross tax)	Total tax earnings on fuel for motor vehicles [1]	Other receipts under tax law (licenses)	Grand total earnings (tax and other receipts)	Disposition of grand total earnings					Tax rates, 1927			Net gallons of gasoline taxed, and used by motor vehicles
						Collection costs [2]	Construction and maintenance on rural roads		State (S) and county (C) road bond payments	Miscellaneous purposes	Cents per gallon		Date of rate change	
							State highways	Local roads			Jan. 1	Dec. 31		
Alabama	$5,908,986		$5,908,986		$5,908,986	$23,542	$2,618,865	$2,962,829	(S) [3] $303,750		2	4	Jan. 25	149,620,507
Arizona	1,646,375	$257,545	1,388,830		1,388,830		620,691	768,139			3	4	Aug. 12	40,216,927
Arkansas [4]			4,338,737		4,338,737		1,041,297	564,036	[5] 2,733,404		4	5	June 9	[6] 94,345,820
California	24,453,585	1,986,502	22,467,083		22,467,083	41,762	13,158,714	9,266,607			2	3	July 29	928,748,702
Colorado	3,272,537	132,943	3,139,594		3,139,594	[7] 21,221	2,160,745	957,628			2	3	May 1	122,493,107
Connecticut	3,054,906		3,054,906	$42,522	3,097,428	(8)	3,097,428				2	2		152,745,302
Delaware	681,466	19,307	662,159		662,159	(9)	662,159				2	3	Mar. 24	23,486,804
Florida	10,980,586		10,980,586	27,955	11,008,541	2,800	7,552,018	2,513,401		[10] $940,322	4	5	July 1	251,410,081
Georgia	7,066,109		7,066,109	11,394	7,077,503	4,200	4,799,581	1,919,833		[11] 353,889	3½	4	Sept. 1	192,103,248
Idaho	1,669,057	97,308	1,571,749		1,571,749	11,966	1,436,096			[12] 123,687	3	4	Mar. 1	40,876,738
Illinois [13]	6,248,009	48,500	6,199,509		6,199,509	25,000	3,087,255	[14] 3,087,254	(14) (C)		0	[15] 2	Aug. 1	309,975,466
Indiana	10,500,307	366,739	10,133,568		10,133,568	15,184	6,745,589	2,529,596		[16] 843,199	3	3		337,769,317
Iowa	7,612,106	363,892	7,248,214		7,248,214	57,755	1,833,000	3,666,000		[17] 1,691,459	2	3	July 4	288,619,674
Kansas	5,093,617	498,967	4,594,650		4,594,650	(18)	3,850,720	743,930			2	2		229,732,510
Kentucky	5,913,396		5,913,396		5,913,396	11,700	5,901,696				5	5		118,267,918
Louisiana	3,034,056		3,034,056		3,034,056		3,034,056				2	2		151,702,807
Maine	2,344,347	55,414	2,288,933		2,288,933	12,952	2,275,981				3	4	Oct. 29	[19] 72,007,253
Maryland	4,314,297	144,900	4,169,397		4,169,397	2,500	2,973,416			[20] 1,193,481	2	4	Apr. 1	118,335,211
Massachusetts	No tax.										0	0	No tax.	(21)
Michigan	15,327,752	1,067,188	14,260,564		14,260,564	43,797	8,409,937	2,806,830	(S) 3,000,000		2	3	Sept. 4	561,144,507
Minnesota	5,510,257	335,377	5,174,880		5,174,880		5,174,880				2	2		258,743,986
Mississippi	[22] 4,890,686		4,890,686		4,890,686	3,600	2,302,347	2,378,311	[23] (C) 206,428		4	4		119,342,686
Missouri	6,449,655	118,672	6,330,983		6,330,983	48,488	6,282,495				2	2		316,549,141
Montana	1,601,621	165,223	1,436,398		1,436,398	(24)	1,436,398				3	3		47,879,927
Nebraska	3,685,318	20,399	3,664,919		3,664,919	8,013	3,656,906				2	2		183,245,970
Nevada	509,936	38,312	471,624		471,624		235,812	235,812			4	4		11,790,615
New Hampshire	1,291,499	22,592	1,268,907		1,268,907		1,268,907				2	[25] 3	May 1	44,897,901
New Jersey	4,775,137	692,277	4,082,860	15,125	4,097,985	25,000	3,982,985			[26] 90,000	0	2	July 1	204,142,900
New Mexico	1,415,690		1,415,690	16,502	1,432,192	30,975	1,295,217		(S) 106,000		3	5	Mar. 7	30,117,191
New York	No tax.										0	0	No tax.	(27)
North Carolina	9,111,297	324,615	8,786,682		8,786,682	[28] 47,288	[28] 6,444,313		[28] (S) 2,295,081		4	4		219,667,060
North Dakota	1,673,633	398,068	1,275,565	858	1,276,423	25,000	1,210,000			[29] 41,423	2	2		63,778,243
Ohio	20,475,688	565,207	19,910.681		19,910,481		11,998,452	7,912,029			2	3	May 25	752,028,064
Oklahoma	7,224,276	26,320	7,197,956		7,197,956	(30)	4,798,637	2,399,319			3	3		239,931,866
Oregon	3,879,393	236,202	3,643,191		3,643,191	8,386	3,634,805				3	3		122,822,563
Pennsylvania	17,296,333		17,296,333		17,296,333		13,838,523	3,457,810			2	3	July 1	691,562,015
Rhode Island	915,959		915,959		915,959	(31)	736,447		(S) 179,512		1	2	June 1	56,144,687
South Carolina	5,086,899	6,514	5,080,385		5,080,385	5,000	3,045,231	1,522,616	(C) 507,538		5	5		101,607,700
South Dakota	3,074,595	681,003	2,393,592		2,393,592	4,760	2,074,669		(S) 242,243	[32] 71,920	3	4	July 1	65,965,089
Tennessee	4,476,180		4,476,180		4,476,180		4,476,180				3	3		149,206,016
Texas	15,650,841		15,650,841		15,650,841		11,738,131			[33] 3,912,710	1	3	Mar. 16	594,592,077
Utah	1,461,261		1,461,261	428	1,461,689	5,375	943,814		(S) 512,500		3½	3½		41,773,659
Vermont	905,244		905,244		905,244		905,244				2	3	June 1	33,167,246
Virginia	7,515,859	376,152	7,139,707		7,139,707		4,759,805	2,379,902			4½	[34] 4½		158,423,951
Washington	4,086,891	265,453	3,821,438		3,821,438	(35)	3,821,438				2	2		191,071,925
West Virginia	3,897,644	103,576	3,794,068	13,254	3,807,322		3,807,322		[36] (S)		3½	4	July 1	99,917,717
Wisconsin	6,271,738	244,624	6,027,114		6,027,114	9,982	2,214,939	3,368,279		[37] 433,914	2	2		301,355,684
Wyoming	756,049		756,049		756,049	3,687	752,362				2½	3	Mar. 1	25,884,393
District of Columbia	1,156,104	7,310	1,148,794		1,148,794					[38] 1,148,794	2	2		57,439,721
Total			258,838,813	128,038	258,966,851	499,933	182,095,503	55,440,161	10,086,456	10,844,798	Aver. 2.76			[39] 9,366,651,892

[1] This is the net tax after deduction of refunds because of exemptions.

[2] Collection costs in many States are paid from other State funds and when amounts and sources are reported notes are entered below.

[3] On State highway bonds, series G only.

[4] Tentative data, as accounts are to be audited.

[5] Includes $216,937 on State highway bonds and $2,516,467 on local road bonds.

[6] Estimate based on rates and amounts received.

[7] Excludes $31,547 from gasoline inspection fee fund.

[8] Approximately $46,000 charged to motor vehicle department.

[9] Approximately $60 charged to State treasury.

[10] For free public school fund $616,125; for permanent building fund $308,057; and balance of $16,140 in State treasury.

[11] For State treasury.

[12] Unallotted balance.

[13] Earnings for last 5 months of year only.

[14] County bond payments included in local road allotments.

[15] Tax discontinued Feb. 25, 1928.

[16] For city streets.

[17] Special refunds for rights of way and bridges.

[18] From State general fund.

[19] Includes 2,770,705 gallons not consumed by motor vehicles but taxed 1 cent per gallon.

[20] Baltimore city $743,042; grade crossing elimination $450,439.

[21] Estimated consumption based on motor-vehicle registration, 310,000,000 gallons.

[22] Includes $131,206 from extra tax in Harrison and Hancock counties for sea wall to protect State highway

[23] Sea-wall bonds.

[24] State appropriation of $12,000.

[25] Gasoline tax became 4 cents on Jan. 1, 1928.

[26] For Department of Commerce and Navigation.

[27] Estimated consumption based on motor-vehicle registration, 920,000,000 gallons.

[28] Allocation of fund estimated.

[29] General State fund.

[30] State appropriation of $5,700 from general revenue.

[31] State appropriation of $5,000.

[32] Reserve for refunds.

[33] For free school fund.

[34] Increased to 5 cents on Mar. 19, 1928.

[35] From motor vehicle fund, $5,000.

[36] Payments on State road bonds charged to gasoline fund; amount not stated.

[37] For city streets.

[38] Receipts expended on Washington streets for improvement and repairs.

[39] For approximate total of all States, add estimated amounts given in notes 21 and 27 for Massachusetts and New York to total here given and also add 530,000,000 for untaxed gasoline in Illinois and New Jersey, making a grand total of 11,130,000,000.

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.

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*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.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
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.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
463D. Earth, sand-clay and gravel.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
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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.

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.
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* Department supply exhausted.