Nov

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE
BUREAU OF PUBLIC ROADS

VOL. 12, NO. 9 ▽ NOVEMBER, 1931

APPLYING PRIME COAT TO SAND-CLAY BASE

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

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CERTIFICATE: By direction of the Secretary of Agriculture, the matter contained herein is published as administrative information and is required for the proper transaction of the public business

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

VOL. 12, NO. 9 NOVEMBER, 1931 G. P. St. CLAIR, Editor

TABLE OF CONTENTS

THE BUREAU OF PUBLIC ROADS

Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS

Mark Sheldon Building, San Francisco, Calif.

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Post Office Building, P. O. Box 3900, Portland, Oreg.

DISTRICT No. 2. California, Arizona, Nevada, and Hawaii.
Mark Sheldon Building, 461 Market St., San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
237 Customhouse, Nineteenth and Stout Sts., Denver, Colo.

DISTRICT No. 4. Minnesota, North Dakota, South Dakota, and Wisconsin.
410 Hamm Building, St. Paul, Minn.

DISTRICT No. 5. Iowa, Kansas, Missouri, and Nebraska.
8th Floor, Saunders-Kennedy Building, Omaha Nebr.

DISTRICT No. 6. Arkansas, Louisiana, Oklahoma, and Texas.
1912 Fort Worth National Bank Building, Fort Worth, Tex.

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

DISTRICT No. 8. Alabama, Georgia, Florida, Mississippi, South Carolina, and Tennessee.
Shepherd Building, P. O. Box J, Montgomery, Ala.

DISTRICT No. 9. Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.
Federal Building, Troy, N. Y.

DISTRICT No. 10. Delaware, Maryland, North Carolina, Ohio, Pennsylvania, Virginia, and West Virginia.
Willard Building, Washington, D. C.

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

DISTRICT No. 12. Idaho and Utah.
403 Fred J. Kiesel Building, Ogden, Utah.

Owing to the necessarily limited edition of this publication it will be impossible to distribute it free to any persons or institutions other than State and county officials actually engaged in planning or constructing public highways, instructors in highway engineering, and periodicals upon an exchange basis. Others desiring to obtain PUBLIC ROADS can do so by sending 10 cents for a single number or $1 per year (foreign subscription $1.50) to the Superintendent of Documents, United States Government Printing Office, Washington, D. C.

BITUMINOUS TREATMENTS ON SAND-CLAY AND MARL BASES IN SOUTH CAROLINA

Reported by H. C. JONES, Division Engineer, South Carolina Highway Department, and E. L. TARWATER, Assistant Highway Engineer, United States Bureau of Public Roads

A COOPERATIVE experimental project was constructed during the summer and fall of 1929 in Berkeley County, S. C., by the State highway department and the Bureau of Public Roads. This project, 4.5 miles in length, was built on State route No. 46 from its junction with United States Highway No. 17 at Moncks Corner to the village of Pinopolis.

The purpose of the experiments was to obtain information on the following subjects:

(*a*) The comparative value of sand-clay and marl as bases for bituminous surface treatment.

(*b*) The comparative value of various types of bituminous material for cold application.

(*c*) The effect of variously graded aggregates.

(*d*) Comparison of the wearing surfaces produced by the mixed-in-place method and by ordinary surface treatment.

The project embraced the construction of bituminous wearing surfaces by the mixed-in-place and surface-treatment methods, using crushed stone of different gradings and various bituminous materials. These surfaces were constructed upon sand-clay and marl bases which had been previously built.

The bituminous materials used were 8–13 viscosity tar, 60–70 and 85–100 penetration asphalts cut back with heavy naphtha, 25–35 viscosity tar, and an asphalt emulsion. The aggregate used was crushed granite graded as follows: 1¼ to ¼ inch, ¾ to ¼ inch, ⅝ to ¼ inch, and ¼ inch to dust. Table 1 gives the types and qualities of materials used in the construction of the sections. The analyses of the bituminous materials, aggregates, and mixes are given in Tables 2 to 7, inclusive.

The road upon which the experiments were built carries passenger cars and light trucks mainly but also some heavier trucks with trailers carrying relatively heavy loads of logs or merchandise. A traffic count at stations 13 and 92 taken shortly after construction showed a count of 587 and 320 vehicles daily, respectively.

The area through which the road passes is relatively low, and for this reason the water table is rather close to the surface of the ground. In spite of this condition, fair drainage of the roadway proper is provided. In several small areas where the grade is exceptionally low French drains were later constructed, extending from the edges of the treatments through the shoulders to the drainage ditches.

The marl and sand-clay bases were constructed by contract in the summer and fall of 1928. The bituminous wearing surfaces were built by State forces during the summer and fall of 1929.

CONSTRUCTION OF THE MARL BASE

Two miles of this project were constructed upon a marl base, the material for which was obtained from a local deposit about 1½ miles south of the project. Laboratory tests show it to have the following characteristics:

	Per cent
Calcium carbonate	86. 85 to 83. 85
Silica, alumina, and iron oxides	10. 40 to 14. 55
Magnesium carbonate	1. 33 to 1. 65

Cementing value, 133 to 500 plus.

As prepared for the above test it did not slake in 60 minutes.

When taken from the pit the marl is grayish white in color, contains considerable moisture, and in this condition can be easily broken down with picks or sledges and readily worked with a drag, disk, or blade machine. As it is homogeneous it compacts uniformly when moist and does not laminate but may develop small shrinkage cracks while drying or setting up. When dry it is white and in sunlight causes an objectionable glare. After it is compacted and set up it is very hard and can not be machined without wetting. It does not ravel or pothole under traffic, but does wear away, as some of the surface particles are whipped off as dust. Ordinary rains do not affect it, but continued rains or trapped water held on the surface soften it, allowing it to rut. Where the grade is low and where the subsoil is of a type permitting capillary moisture, softening of this material occurs and results in weakening and failure of the surfacing.

FIGURE 1.—CHARACTERISTIC SHRINKAGE CRACKS DEVELOPING IN THE MARL BASE AS IT DRIES OUT AND HARDENS

Surface irregularities can not be repaired by the ordinary patching method when the marl is dry and has set up. The new material will harden but will not bond to the old surface and will eventually scale off. Scarifying and reworking seems to be the most satisfactory method of surface repair.

In constructing the marl base side forms were used and were spaced 20 to 21 feet apart except for a distance of about 500 feet through the business section of Moncks Corner where the width was made about 30 feet. The forms were set to rough grade, to give a base thickness of approximately 8 inches compacted. The marl was dumped between the forms, broken into small pieces with picks and sledges, and then worked with the disk harrow and blade machine to develop a uniform mass. The material was rolled for compaction, and during this operation blading was continued to bring the roadway to the proper grade and cross section.

The marl base was constructed in the fall of 1928, which was an unusually wet season, and considerable rutting occurred under traffic, which was compelled to use the road during construction. The surface was machined, but some areas became so badly rutted that scarifying and reworking was necessary.

81677—31——1

Table 1.—*Types and quantities of materials used in the bituminous construction*

Experiment No.	Section No.	Stations: Beginning	Stations: End	Base: Type	Base: Average depth	Primer 8–13 viscosity tar	Bituminous mat: Stone: Coarse	Bituminous mat: Stone: Fine [1]	Bituminous mat: Bituminous material: Kind	Bituminous mat: Bituminous material: Rate of application	Bituminous mat: Average thickness compacted	Seal: Bituminous material: Description	Seal: Bituminous material: Rate of application	Seal: ⅝–¼ inch stone
					Inches	*Gals. per sq. yd.*	*Lbs. per sq. yd.*	*Lbs. per sq. yd.*		*Gals. per sq. yd.*	*Inches*		*Gals. per sq. yd.*	*Lbs. per sq. yd.*
1	A	0+00	13+28	Marl	9	0.27	[2] 154	38	60–70 penetration asphalt cut-back.	0.91	1.8	60–70 penetration asphalt cut-back.	0.42	30
	B	13+28	24+50	do	10	.27	[2] 156	36.5	85–100 penetration asphalt cut-back.	1.03	1.8	85–100 penetration asphalt cut-back.	.29	15
2	A	[3] 24+50	39+60	do	8.5	.31	[2] 180		do	.69	2.0	do	.30	18
	B	39+60	52+00	do	8	.29	[2] 175		25–35 viscosity tar	.89	2.0	25–35 viscosity tar	.23	15
	C	52+00	66+00	do	9	.28	[2] 165	37	Asphalt emulsion	1.27	2.3	Asphalt emulsion	.23	15
3		79+20	92+40	do	9	.30	[4] 162	38	85–100 penetration asphalt cut-back.	1.19	1.8			
4		92+40	105+84	do	9	.26	[4] 157		do	.72	1.8	85–100 penetration asphalt cut-back.	.22	15
5		66+00	79+20	do		.33	[2] 50		do	[5] .64				
6	A	105+84	119+99	Sand-clay	7	.33	[2] 171	40	60–70 penetration asphalt cut-back.	1.00	2.0	do	.34	15
	B	119+99	132+00	do	7	.39	[2] 170	42	85–100 penetration asphalt cut-back.	1.09	2.0	do	.23	15
7	A	132+00	144+20	do	6	.29	[2] 178		do	.77	2.0	do	.27	18
	B	199+70	212+90	do		.25	[2] 169		25–35 viscosity tar	.77	2.0	25–35 viscosity tar	.32	15
	C	144+20	158+40	do		.34	[2] 165	30	Asphalt emulsion	1.11	2.3	Asphalt emulsion	.25	15
8		212+90	226+10	do		.26	[4] 154	38	85–100 penetration asphalt cut-back.	1.25	1.8			
9		226+10	238+80	do		.27	[4] 152		do	.77	1.8	85–100 penetration asphalt cut-back.	.29	14
10		[6] 158+40	199+70	do	7	.29	[2] 52 and [4] 13		do	[7] .77				

[1] Stone screenings, ¼ inch to dust.
[2] 1¼-inch–¼-inch crushed stone.
[3] Deduct 36 linear feet for railroad crossing.
[4] ¾-inch–¼-inch crushed stone.
[5] Includes retreating stations 66+00 to 73+40.
[6] Deduct 170 linear feet for correction equation.
[7] Includes original treatment and retreatment.

Table 2.—*Analysis of asphalt cut-backs used in the construction*

Type material	85–100 penetration	85–100 penetration	85–100 penetration	85–100 penetration	60–70 penetration	60–70 penetration	60–70 penetration
Laboratory Number	31933	32529	32530	32531	31938	32532	32533
Sections on which used	1–B, 5, 10	1–B, 2–A, 3, 8, 10	2–A, 4, 6–A, 9, 10	3, 4, 6–B, 7–A, 10	6–A	1–A	6–A
Specific gravity, 25°/25° C	0.942	0.947	0.943	0.945	0.947	0.950	0.949
Flash point, ° C	29.8	28	29	25	31.4	29.60	28.4
Viscosity, Engler at 40° C	61.58	54.49	40.32	47.71	58.52	70.58	65.61
Viscosity Engler at 50° C	34.21	29.98	23.09	28.11	30.30	37.30	35.01
Percentage loss at 163° C., 5 hours, 50 grams	25.31	24.50	24.74	28.15	28.28	25.38	27.69
Penetration of residue, 25° C	104	114	119	117	84	101	85
Percentage loss at 163° C., 5 hours, 20 grams	25.89	24.92	25.59	25.80	29.84	26.30	28.58
Penetration of residue, 25° C	56	65	63	64	44	50	47
Bitumen soluble in CS_2, per cent	99.81	99.79	99.79	99.88	99.91	99.81	99.79
Organic insoluble, per cent	0.07	0.18	0.17	0.10	0.08	0.17	0.18
Inorganic insoluble, per cent	0.02	0.03	0.04	0.02	0.01	0.02	0.03
Bitumen insoluble in 86° Baumé naphtha, per cent	15.82	17.05	15.98	14.89	19.15	18.84	19.35
Residue of 100 penetration, per cent	73.9	74.7	74.9	74.4	72.9	72.1	72.4
Penetration of residue at 25° C	101	98	104	90	94	87	89
Penetration of residue at 0° C	12	22	22	22	14	22	23
Softening point of residue, ° C	48.4	45.4	45	46.8	52.2	46.8	46.4
Ductility of residue at 25° C	110+	110+	110+	110+	110+	110+	110+
Ductility of residue at 1.5° C	6.4	5.8	4.9	6.2	5.2	4.5	4.0
Distillation test, A. S. T. M. modified D 20[1] fractions, per cent by weight:							
0–170° C	4.24	1.08	0.25	1.27	0.42	1.06	0.05
170–225° C	12.32	14.02	15.83	15.66	18.80	15.67	17.81
225–315° C	6.57	5.32	8.05	6.26	8.24	7.62	8.53
315–360° C	2.05	3.27	1.54	1.48	1.67	1.87	1.91
Residue over 360° C	74.60	75.90	74.20	75.10	70.70	73.70	71.60
Penetration of residue at 25° C	133	151	128	137	108	1.30	117
Softening point of residue, ° C	40.8	43.8	42.2	42.4	44	43.8	46.6
A. S. T. M. modified D 20[2] fractions:							
0–190° C	[3] 7.93 [4] 10.0	[3] 0.49 [4] 0.8	[3] 5.55 [4] 8.2	[3] 8.04 [4] 11.5	[3] 7.75 [4] 9.8	[3] 4.79 6.02	[3] 5.52 [4] 7.08
190–225° C	[3] 7.31 [4] 10.4	[3] 15.11 [4] 19.2	[3] 10.48 [4] 13.4	[3] 8.57 [4] 11.0	[3] 11.44 [4] 15.2	[3] 10.38 [4] 12.97	[3] 11.73 [4] 14.58
225–360° C	[3] 8.80 [4] 12.2	[3] 9.17 [4] 9.7	[3] 9.81 [4] 12.0	[3] 8.23 [4] 9.9	[3] 9.99 [4] 12.4	[3] 9.61 [4] 11.60	[3] 9.95 [4] 12.06
Penetration of residue at 25° C	98	96	78	86	70	75	67
Softening point of residue, ° C	44.6	47.2	46.2	47.8	49.8	48.4	50

[1] Test specimen 100 grams; thermometer ½ inch from bottom of flask; flask cooled below 125° C. before pouring residue.
[2] Test specimen 100 cubic centimeters; thermometer ¼ inch from bottom of flask; residue poured immediately after reaching 360° C.
[3] Per cent by weight.
[4] Per cent by volume.

At the time the bituminous wearing surfaces were constructed the base was, in general, in very good condition. Small shrinkage cracks had developed to a limited extent on nearly all the sections. The surface had worn unevenly in a number of areas which, after wetting, were lightly machined to restore the smooth cross section. The thickness of the marl base on the several sections was determined prior to surfacing and ranged from 7 to 10 inches, averaging about 9 inches.

CONSTRUCTION OF THE SAND-CLAY BASE

The sand-clay base upon which 2½ miles of the project were constructed was built on the old road except for a short relocated section. The sand-clay material was obtained from local pits and, although of only fair quality for this type of construction, largely because of lack of uniformity, it was considered the best available.

TABLE 3.—*Analysis of materials used in the cut-back asphalts*

BASE MATERIAL

Material	60–70 penetration	85–100 penetration
Laboratory number	32700	32701
Specific gravity 25°/25° C	1.021	1.020
Flash point, °C	310	305
Penetration at 25° C	67	100
Softening point, °C	51.5	47.4
Ductility at 25° C., centimeters	110+	110+
Percentage loss at 163° C., 5 hours, 50 grams	.01	.02
Penetration of residue at 25° C	58	82
Bitumen soluble in CS_2, per cent	99.88	99.88
Organic matter insoluble, per cent	.09	.09
Inorganic matter insoluble, per cent	.03	.03

DISTILLATE

Laboratory number	32702
Specific gravity, 25°/25° C	0.786
Flash point, °C	0.6
Distillation:	*°C.*
Initial boiling point	78
First 10 cubic centimeters over at	134
Second 10 cubic centimeters over at	154
Third 10 cubic centimeters over at	167
Fourth 10 cubic centimeters over at	174
Fifth 10 cubic centimeters over at	179
Sixth 10 cubic centimeters over at	183
Seventh 10 cubic centimeters over at	187
Eighth 10 cubic centimeters over at	192
Ninth 10 cubic centimeters over at	201
End point	272
	Cubic centimeters
Distillate	99.4
Residue	.1
Loss	.5

TABLE 4.—*Analysis of tar used in the construction*

Grade of material	8–13 viscosity		8–13 viscosity	
Laboratory number	31939		32534	
Sections on which used	1–A, 1–B, 5, 6–A, 6–B, 7–A, and 10		2–A, 2–B, 2–C, 3, 4, 7–B, 7–C, 8, and 9	
Material used as	Primer.		Primer.	
Specific gravity, 25°/25° C	1.142		1.148	
Viscosity, Engler at 40° C	11.74		11.05	
Bitumen soluble in CS_2, per cent	96.93		96.15	
Organic matter insoluble, per cent	2.65		3.81	
Inorganic matter insoluble, per cent	.02		.04	
Water, per cent	.40			
	Distillation, water-free basis			
Fractions:	*Character*	*Per cent by weight*	*Character*	*Per cent by weight*
Up to 170° C	Fluid	1.25	Fluid	1.05
170°–235° C	do	6.93	Trace of solids.	6.67
235°–270° C	do	11.89	½ solid	11.57
270°–300° C	¼ solid	8.40	Fluid	8.45
Residue		71.49		72.10
Softening point of residue, °C		43.2		42.8

Grade of material	25–35 viscosity		25–35 viscosity	
Laboratory number	32504		32528	
Sections on which used	2–B and 7–B		2–B and 7–B	
Material used as	Mix.		Mix.	
Specific gravity, 25°/25° C	1.165		1.165	
Viscosity, Engler at 40° C	28.52		27.49	
Bitumen soluble in CS_2, per cent	96.98		95.92	
Organic matter insoluble, per cent	2.04		3.61	
Inorganic matter insoluble, per cent	.02		.07	
Water, per cent	.96		.40	
	Distillation, water-free basis			
Fractions:	*Character*	*Per cent by weight*	*Character*	*Per cent by weight*
Up to 170° C	Fluid	0.53	Fluid	1.07
170°–235° C	¼ solid	5.29	do	4.71
235°–270° C	⅓ solid	8.89	½ solid	10.26
270°–300° C	⅓ solid	8.03	Trace of solids.	7.89
Residue		77.26		76.07
Softening point of residue, °C		41.8		41.4

Test results on samples taken from the finished sand-clay base are given in Table 8. In the construction the sand-clay from the pit was spread on the roadway, mixed with the surface material by means of disks and plows, and consolidated by traffic. In general the sand-clay failed to bond readily and necessitated considerable machining after rains. In a few areas where this material continually failed to bond it was necessary to plow and remix and, in some cases, to add additional material.

The sand-clay base prior to the construction of the bituminous surfacing was variable in appearance and composition. Some portions were well bonded and apparently in a suitable condition for surface treatment, while other portions showed a decided tendency to dust and ravel. On some areas where patching had been done, the patches peeled off for lack of bond. Attempts were made to better the surface condition by dragging but, on account of lack of uniformity in the underlying material, this effort did not entirely correct the defects. In general, the sand-clay base was in only fair condition when the experiments were built.

SIDE FORMS USED FOR BOTH TYPES OF CONSTRUCTION

In the construction of the mixed-in-place sections on both the marl and sand-clay bases side forms were used except where otherwise stated. Bridge plank, 3 inches by 8 inches by 16 feet long, laid flatwise, were used. They were laid loosely in place but were held to line by stakes. Before the stone was spread for mixing they were moved in about a foot on either side. The

TABLE 5.—*Analysis of asphalt emulsion*

Laboratory number	32505
Section on which used	2–C and 7–C
Specific gravity 25°/25° C	1.009
Viscosity, Engler, at 50° C	1.98
Distillation to 260° C.:	
Water, per cent by weight	47.3
Oil	Trace
Residue, per cent by weight	52.6
Tests on residue from distillation:	
Specific gravity, 25°/25° C	1.015
Penetration at 25° C	113
Softening point, °C	47.8
Ductility at 25° C. (centimeters)	96.5
Bitumen soluble in CS_2, per cent	98.94
Organic matter insoluble, per cent	.40
Ash (by ignition), per cent	.66

TABLE 6.—*Grading of the crushed stone used in the construction*

Laboratory number		31906	32520	31946	31947
Sections on which used		1–A, 1–B, 2A, 2–B, 2–C, 5, 6, 7–A, 7–B, 7–C, 10	1–A, 1–B, 3, 6–A, 6–B, 8	3, 4, 8, and 9	2–A, 2–B, 2–C, 4, 7–A, 7–B, 7–C
Size, inches		1¼ to ¼	¼ to dust	¾ to ¼	⅝ to ¼
SIEVE ANALYSIS					
Passing—	Retained on—	*Per cent*	*Per cent*	*Per cent*	*Per cent*
1¼-inch	1-inch	16			
1 Inch	¾-inch	23			
¾-inch	½-inch	24		6	1
½-inch	¼-inch	25	0.1	53	70
¼-inch	10-mesh	12	15.3	29	25
10-mesh	20-mesh		32.5	7	3
20-mesh	30-mesh		11 2	5	1
30-mesh	40-mesh		11.1		
40-mesh	50-mesh		8.5		
50-mesh	80-mesh		10.4		
80-mesh	100-mesh		3.1		
100-mesh	200-mesh		4.9		
200-mesh			2.9		

Table 7.—*Analysis of bituminous aggregates*

Laboratory number	Experiment and section No.	Sampled		Date tested (1929)	Sieve analysis of mix										Percentage lost on heating at 60° C. (based on percentage of bitumen)			Remarks
		Date (1929)	Time		Bitumen, per cent	1¼-inch to 1-inch	1-inch to ¾-inch	¾-inch to ½-inch	½-inch to ¼-incn	¼-inch to 10-mesh	10-mesh to 40-mesh	40-mesh to 80-mesh	80-mesh to 200-mesh	Passing 200-mesh	1 day	5 days	10 days	
31934	1-A	Aug. 17	Upon completion of mixing.	Nov. 4	2.2	13.0	25.2	28.7	16.8	2.8	5.5	4.3	0.2	1.3	4.76	6.09	7.41	
32515	1-A	Sept. 19	After opening to traffic	Nov. 11	3.0	------	6.4	34.6	26.5	9.0	10.8	4.1	2.9	2.7	-------	-------	-------	Sampled before sealing.
31905	1-B	Aug. 5	Upon completion of mixing.	Nov. 4	2.5	8.6	31.1	26.0	13.3	4.3	7.3	5.1	.2	1.6	2.21	3.41	4.81	
32516	1-B	Sept. 19	After opening to traffic	Nov. 11	3.8	------	10.3	44.8	16.4	7.1	8.9	3.6	2.5	2.6	-------	-------	-------	Sampled after sealing.
32524	2-A	Aug. 27	Upon completion of mixing.	Nov. 4	2.6	------	32.3	28.0	28.4	4.5	1.6	1.3	.2	1.1	17.15	20.79	22.42	
32506	2-A	Sept. 19	After opening to traffic	Nov. 11	2.3	16.9	25.2	19.2	21.0	7.7	3.1	1.5	1.2	1.9	-------	-------	-------	Sampled before sealing.
32523	2-B	Aug. 27	Upon completion of mixing.	Nov. 5	2.2	[1] 11.3	24.5	21.4	22.6	7.6	1.9	1.4	.2	1.1	20.54	21.31	22.59	
32507	2-B	Sept. 19	After opening to traffic	Nov. 12	3.4	13.5	17.5	19.0	23.6	9.6	5.2	2.3	2.7	3.2	-------	-------	-------	Do.
32508	2-C	---do----	-----do	---do----	4.8	2.7	6.2	15.2	26.8	22.7	12.2	3.6	3.3	2.5	-------	-------	-------	Sampled after sealing.
32525	3	Aug. 24	Upon completion of mixing.	Nov. 5	3.8	------	------	8.1	49.8	20.1	10.3	5.9	.2	1.8	5.67	7.01	7.68	
32511	3	Sept. 19	After opening to traffic	Nov. 12	3.7	------	------	6.0	43.8	23.9	13.2	4.0	2.7	2.7	-------	-------	-------	No seal used.
32522	4	Aug. 23	Upon completion of mixing.	Nov. 5	1.6	------	------	13.7	55.7	22.2	3.4	2.0	.2	1.2	8.41	9.46	12.16	
31936	6-A	Aug. 15	-----do	Nov. 6	1.6	25.6	34.4	13.4	10.0	3.2	5.6	4.5	.2	1.2	7.57	8.23	10.45	
32513	6-A	Sept. 19	After opening to traffic	Nov. 13	4.2	------	12.4	31.8	17.2	9.5	12.4	5.2	3.9	3.4	-------	-------	-------	Sampled after sealing.
31935	6-B	Aug. 14	Upon completion of mixing.	Nov. 6	2.8	20.8	24.4	20.2	13.3	5.0	7.1	5.1	.2	1.1	2.54	3.41	4.92	
32514	6-B	Sept. 19	After opening to traffic	Nov. 13	2.6	3.3	10.7	41.6	15.9	9.7	7.3	4.2	2.6	2.1	-------	-------	-------	Sampled before sealing.
31937	7-A	Aug. 14	Upon completion of mixing.	Nov. 6	1.9	6.6	47.9	27.7	9.6	1.2	1.5	2.5	.2	.9	2.74	4.42	5.47	
32512	7-A	Sept. 19	After opening to traffic	Nov. 13	2.9	------	17.6	43.6	16.6	5.7	3.8	4.1	2.9	2.8	-------	-------	-------	Sampled after sealing.
32526	7-B	Sept. 7	Upon completion of mixing.	Nov. 7	1.6	8.2	26.8	30.8	18.8	5.3	2.4	4.4	.2	1.5	7.57	11.49	15.16	
32527	8	Aug. 31	-----do	---do----	3.5	------	------	8.4	49.8	19.5	10.0	6.7	.2	1.9	6.95	9.37	10.25	
32509	8	Sept. 19	After opening to traffic	Nov. 14	4.1	------	------	6.9	34.0	23.1	14.7	7.9	6.0	3.3	-------	-------	-------	No seal used.
32521	9	---do----	Upon completion of mixing.	Nov. 7	2.4	------	------	12.8	56.3	21.4	3.8	2.2	.2	.9	6.92	11.49	12.77	
32510	10	---do----	After opening to traffic	Nov. 14	5.8	2.0	5.6	17.4	17.2	11.3	8.2	15.9	11.2	5.4	-------	-------	-------	Sampled before sealing.

[1] Sample contained 5.8 per cent passing the 1½-inch sieve and retained on the 1¼-inch.

Table 8.—*Analysis of sand-clay base*

Laboratory number	Location		Mechanical analysis [1] — Percentage of particles having diameters smaller than—						Liquid limit	Plasticity index	Shrinkage		Moisture eqivalent		Subgrade group [2]
	Experiment	Station	2 millimeters	0.5 millimeter	0.25 millimeter	0.05 millimeter	0.005 millimeter	0.001 millimeter			Limit	Ratio	Centrifuge	Field	
31915	6-A	113+43	99	93	82	30	19	15	26	12	17	1.8	16	22	A-2
31911	6-A	117+60	99	92	75	29	19	14	25	9	17	1.8	14	19	A-2
31909	6-B	107+54	99	89	70	27	16	11	21	8	17	1.8	19	17	A-2
31913	6-B	120+29	99	92	75	30	21	15	28	12	18	1.8	20	23	A-2
31908	6-B	124+06	100	90	70	24	16	12	22	8	--------	--------	14	19	A-2
31910	6-B	128+64	99	89	71	29	19	15	24	10	18	1.8	19	20	A-2
31916	7-A	135+15	100	92	78	18	11	7	17	0	--------	--------	9	16	A-3
31912	7-A	139+49	99	89	69	24	17	14	24	10	17	1.8	14	20	A-2
31914	7-A	139+96	100	93	79	20	12	10	19	5	--------	--------	13	17	A-2
32517	7-B	201+00	99	95	80	22	14	11	20	7	18	1.8	13	16	A-1
32519	7-B	205+00	99	95	80	22	14	11	21	7	17	1.8	16	17	A-1
32518	7-B	209+00	100	95	73	18	10	7	18	0	--------	--------	11	16	A-3
31901	10	166+50	100	95	80	30	21	16	30	16	18	1.8	18	19	A-2
31902	10	187+00	100	95	83	21	11	8	17	0	--------	--------	9	17	A-3
31903	10	193+00	100	95	85	28	17	14	23	9	17	1.8	15	19	A-2
31904	10	198+00	100	96	88	23	15	12	22	8	--------	--------	13	18	A-2

[1] Particles above 0.10 millimeter in diameter by sieve method; Particles below 0.10 millimeter in diameter by hydrometer method.

[2] The classification of subgrade soils in groups is discussed in the article, Subgrade Soil Constants, Their Significance, and Their Application in Practice, Public Roads, vol. 12, No. 4, June, 1931, pp. 105-108. The characteristics of the 3 groups represented here are described as follows:

"*Group A-1.*—Well graded material, coarse and fine, excellent binder. Highly stable under wheel loads, irrespective of moisture conditions. Functions satisfactorily when surface treated or when used as a base for relatively thin wearing courses.

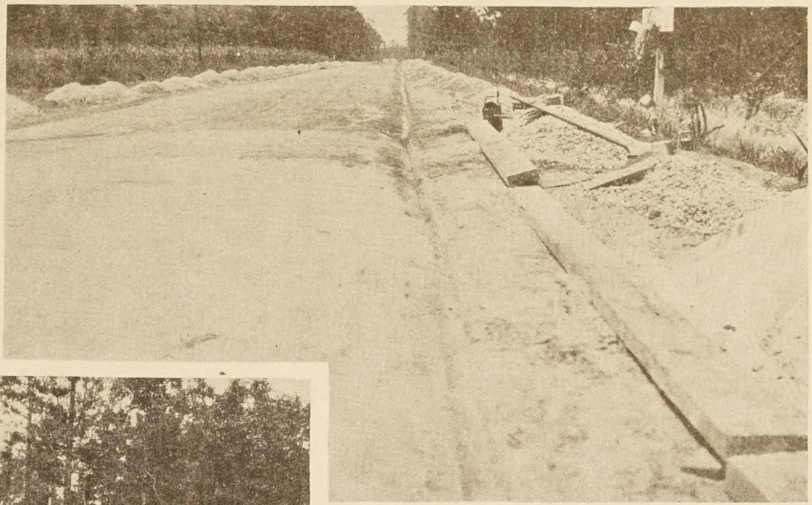
"*Group A-2.*—Coarse and fine materials, improper grading or inferior binder. Highly stable when fairly dry. Likely to soften at high water content caused either by rains or by capillary rise from saturated lower strata when an impervious cover prevents evaporation from the top layer, or to become loose and dusty in long-continued dry weather.

"*Group A-3.*—Coarse material only, no binder. Lacks stability under wheel loads but is unaffected by moisture conditions. Furnishes excellent support for flexible pavements of moderate thickness and for relatively thin rigid pavements."

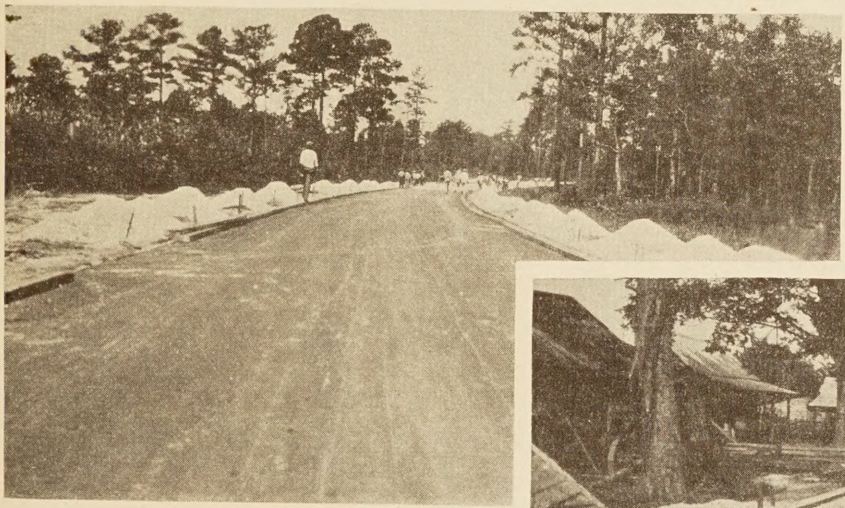
stone was then roughly leveled to the forms, the bituminous material applied, and the mixing operation carried out. Prior to spreading the mix the forms were set back in place and left there during the spreading, shaping, and rolling, after which they were removed. Immediately after their removal the shoulders were built up with earth to protect the edges of the treatments.

Five experiments, in which various bituminous materials and grades of aggregate were used, were constructed upon the marl base and duplicate experiments were built upon the sand-clay base. Some of the experiments were subdivided so that the project embraces a total of 16 sections, each of which is described in detail in the following pages.

Left: Appearance of Sand-clay Section During Machining and Compaction Under Traffic prior to Constructing the Bituminous Surface



Above: Sand-clay Surface Prior to Treatment. Side Trenches cut to Obtain a Thickened Edge



Below: Sand-clay Base Primed and Ready for the Stone to be Spread

Right: To Prevent Segregation, where Both Coarse and Fine Stone were Used in a Mix, the Coarse Aggregate was Spread First and Given an Application of Bituminous Material, after which the Fine Stone was Spread as Shown.

Figure 2.—Preparation for Mixed-in-Place Construction on Sand-Clay Base

EXPERIMENTAL SECTIONS CONSTRUCTED ON MARL BASE

Prior to the construction of the wearing surface, the marl base was thoroughly swept and given a prime coat of 8–13 viscosity tar applied at a temperature of 125° to 155° F. The amount used on each section is given in the text and in Table 1 and the analysis in Table 4. The tar was not absorbed by the marl as quickly as by the sand-clay, but a penetration of about ¼ inch was obtained. The primed surface presented a uniform, dull black appearance except for a few spots where clay balls appeared. These remained bright and glossy as the tar did not penetrate the dense clay. It did, however, penetrate around the clay so that upon its removal a completely primed surface was exposed. On unshaded areas traffic seemed not to affect the primed surface nor did the machine mixing appear to damage it to any great extent. On some areas which were partly shaded the prime coat penetrated more slowly and did not form such a firm crust, possibly because of the higher percentage of moisture present in the marl in these shaded areas. Traffic over these areas picked up the primed surface, necessitating considerable repriming by hand. Hauling over these portions of the primed surfaces was discontinued and during construction the stone was distributed by backing the trucks in over that previously spread. The wearing surfaces were not constructed until the primer had penetrated and thoroughly dried.

MIXED-IN-PLACE SECTIONS

Experiment 1, section B, stations 13+28 to 24+50.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 1.8 inches, compacted; 156 pounds of 1¼ to ¼ inch crushed stone, 36.5 pounds of ¼ inch to dust, and 1.03 gallons of 85–100 penetration asphalt cut back with naphtha.

Seal: 0.29 gallon of the same bituminous material was applied and covered with 15 pounds of ⅝ to ¼ inch stone chips.

Section 1–B was the first of the mixed sections constructed and was necessarily more experimental in character than the others. Considerable latitude was permitted by the outline, which did not specify the exact details of construction. As might be expected, some methods tried out were unsatisfactory and were modified or discarded.

The tar prime coat was applied at the rate of 0.27 gallon per square yard.

One hundred and fifty-six pounds of the 1¼ to ¼ inch stone per square yard were cast between the forms from stock piles at the sides and then leveled off with a drag, after which a single application of 0.46 gallon per square yard of cut-back asphalt was spread. Thirty-six and one-half pounds of the fine aggregate per square yard were then spread as uniformly as possible with shovels and followed by an application of 0.57 gallon of the same bituminous material.

Mixing was begun immediately with a heavy 4-way road drag pulled by a 10-ton tractor but the results obtained were not satisfactory. The amount of aggregate was more than the drag could handle, and when the blades were raised to lighten the load considerable material was necessarily dropped, so that after a few trips with the drag it was distributed very nonuniformly throughout the section. A 12-foot road machine was then substituted for the drag and was entirely satisfactory for the mixing operation. Because of the unevenness of the surface caused by the drag, it was impossible to redistribute the mix to a uniform thickness with the blade grader, and for this reason considerable work was done by hand and with trucks during the spreading operation. The rate of mixing on this section was somewhat slow due to the inexperience of the operators, with the result that mixing was not completed during the first day and the partly mixed material was left windrowed in the center over Sunday. By Monday morning a hard crust had formed on the outside of the windrow but during the mixing it broke up readily. Final shaping and smoothing was done very successfully with the drag. However, some handwork was necessary, particularly along the edges. This was required on practically all of the mixed sections.

During the mixing operation there was very littl tendency for the aggregates to segregate or for the fine aggregate to ball up. Because of the stiffness of the mix, some segregation did occur during the final shaping of the section, with the result that the center 7 or 8 feet presented a more porous and open appearance than the remainder of the surface.

Rolling with a 10-ton 3-wheel roller was begun immediately after final shaping was completed. As the operators were inexperienced and the roller was not in good mechanical condition, the rolling was not prosecuted as speedily or as efficiently as desirable but was carried on intermittently for several days. A reasonable degree of surface smoothness was obtained, but it was evident that better compaction would have resulted had the construction operation been more rapidly carried out.

After about three weeks under traffic it was apparent that a seal coat was necessary. The surface was porous and raveling of the larger stone had started in numerous places. A higher percentage of fines in the mix, with a corresponding increase in cut-back asphalt, would have given a more closed surface and would probably have eliminated the necessity for a seal. The seal treatment consisted of 0.29 gallon per square yard of the same type of bituminous material as was used in the mix and a cover of 15 pounds of ⅝ to ¼ inch crushed granite spread by hand and rolled.

The cost of constructing the bituminous surface on this section was 72.58 cents per square yard or $8,516 per mile for a 20-foot width. This cost was relatively high largely because of the methods and delays in mixing and rolling.

Experiment 1, section A, stations 0+00 to 13+28.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 1.8 inches compacted; 154 pounds of 1¼ to ¼ inch crushed stone, 38 pounds of ¼ inch to dust, and 0.91 gallon of 60–70 penetration asphalt cut back with naphtha.

Seal: 0.42 gallon of the same bituminous material and 30 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.27 gallon per square yard.

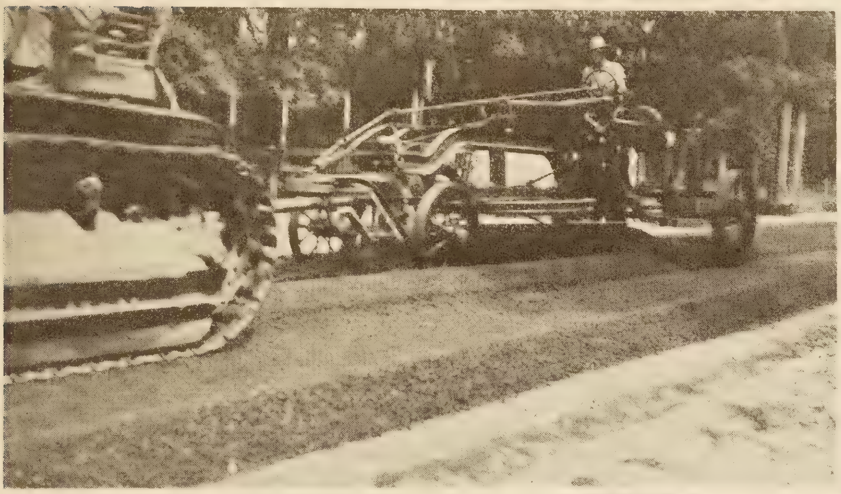
The mixed surface was constructed essentially in the same manner as that of section B. The amounts of bituminous material used in the mix were 0.43 and 0.48 gallon per square yard, respectively, for the two applications. Mixing was done entirely with the blade grader. Initial rolling was done approximately 18 hours after mixing was completed and, in contrast to the previous section, a closed surface was obtained. This early rolling, having sealed a greater portion of the naphtha in the mix, necessitated rolling only in the heat of the day to prevent cracking or checking and also to obtain maximum compression. This operation was continued for a week.

The section was then opened to traffic for one month, during which period the surface showed some signs of raveling and the need of a seal treatment. This was applied in the following manner: 15 pounds of ⅝ to ¼ inch stone per square yard were spread and subjected to traffic for two days, after which the loose stone was swept to the sides and 0.42 gallon per square yard of the same material as used in the mix was applied. The stone at the sides was then respread on the surface and thoroughly rolled. After 10 days under traffic it was apparent that more cover stone was needed and an additional 15 pounds were spread but not rolled.

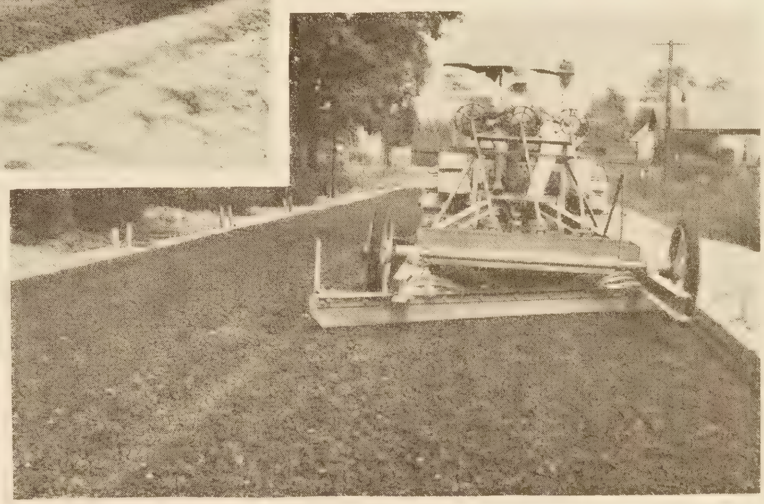
This method of first applying the stone and subjecting it to traffic prior to the application of the bituminous material was tried out experimentally with the view of developing some suitable type of seal treatment for surfaces that were in a raveled or very open condition. It proved very effective, in that the action of traffic over the loosely spread stone forced it into the larger voids, requiring less bituminous material for the seal and preventing its draining to the bottom because of the open surface texture. This method was used on some of the other sections where the surface conditions were similar to that mentioned above.

The cost of constructing this section was 66.12 cents per square yard or $7,758 per mile.

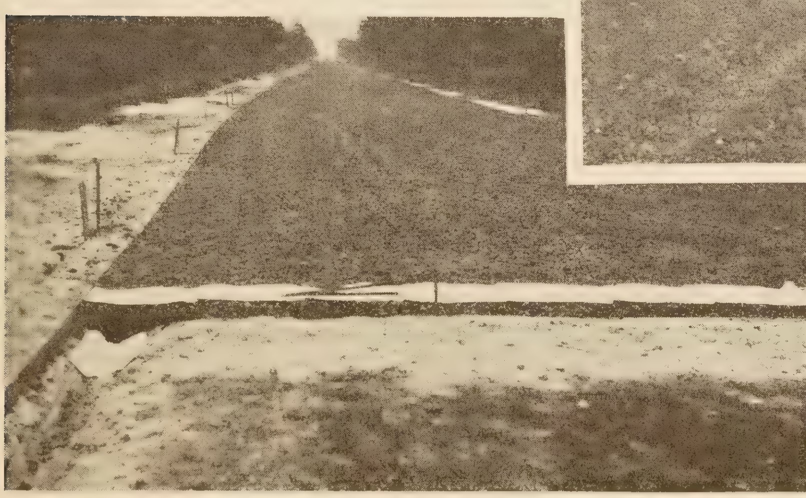
Right: Mixing with a Heavy Four-way Drag Did Not Prove Satisfactory



Above: Mixing with a Blade Grader Was Entirely Successful



Below: The Drag Proved Very Satisfactory for Smoothing the Surface After the Mixing Operation Was Completed



Left: Method of Obtaining Thickened Edge on the Sand-clay Mixed Sections by the Use of Both Forms and Trench

Figure 3.—Mixed-in-Place Construction

Experiment 2, section A, stations 24+50 to 39+60.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 2 inches compacted; 180 pounds of 1¼ to ¼ inch stone and 0.69 gallon of 85–100 penetration cut-back asphalt.

Seal: An average of 0.30 gallon of the same bituminous material was applied and covered with an average of 18 pounds of ⅝ to ¼ inch stone chips. This section was sealed in two separate portions.

The tar primer was applied at the rate of 0.31 gallon per square yard.

The details of construction were essentially the same as in the case of the preceding section, except that the aggregate used was 1¼ to ¼ inch in size with no fines added and the bituminous material was applied at the rate of 0.69 gallon per square yard in a single application.

The seal coat was applied three weeks later. On the portion from station 31+67 to 39+60 the same method of seal treatment was used as was employed on experiment 1, section A; that is, the stone was spread and subjected to traffic before applying the bituminous material. Twenty-three hundredths gallon of bituminous material per square yard and about 20 pounds of ⅝ to ¼ inch stone were used on this portion. The method of seal treatment used on the remainder of the section consisted of an application of 0.38 gallon of bituminous material per square yard and covering with 15 pounds of ⅝ to ¼ inch stone.

The cost of constructing the bituminous surface of this section was 70.34 cents per square yard or $8,253 per mile.

Experiment 2, section B, stations 39+60 to 52+00.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 2 inches compacted; 175 pounds of 1¼ to ¼ inch crushed stone and 0.89 gallon of 25–35 viscosity tar.

Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.29 gallon per square yard.

This section was constructed in essentially the same manner as the preceding section. The amount of coarse stone used was 175 pounds per square yard. An application of one-half gallon of 25–35 viscosity tar was spread on the stone but rain fell before mixing could be begun. On the following day when the materials were dried out and mixing was about completed it was evident that more bituminous material would be necessary to secure a bonded mix. Accordingly, a second application of 0.39 gallon was spread which, with additional mixing, produced a well bonded mix. The total amount in the mix was 0.89 gallon per square yard.

The seal coat was not applied until after about two months, during which traffic was permitted to use the section. No raveling occurred although the surface was fairly open. The seal consisted of an application of 0.23 gallon of the same tar as used in the mix and 15 pounds of ⅝ to ¼ inch stone. After the stone was spread the section was rolled.

The cost of constructing the bituminous surface of this section was 79.40 cents per square yard or $9,316 per mile.

Experiment 2, section C, stations 52+00 to 66+00.—The method of construction and the amounts of material per square yard used on this section were as follows:

Penetration course: 2.3 inches compacted; 165 pounds of 1¼ to ¼ inch stone; 37 pounds of ¼ inch to dust, and 1.27 gallons of asphalt emulsion.

Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.28 gallon per square yard.

It was planned originally to construct this section in the same manner as the two preceding sections but the producers of the emulsion objected and requested that a modified type of penetration construction be substituted. It was decided to construct this section according to their recommendations. The construction which is here described was done under their direction and with the approval of their representatives.

The side forms were kept to line during the construction of this section. Thirty-seven pounds per square yard of stone, ¼ inch to dust, were spread upon the primed base and leveled with a strike-off board to a uniform depth of approximately ½ inch. One hundred and sixty-five pounds of 1¼ to ¼ inch stone were then spread by hand, shaped with the drag to the proper cross section, sprinkled with water, and thoroughly rolled. A strip one foot wide at each edge was given an application of emulsion, after which the entire section received an application of 0.44 gallon per square yard. Water was applied immediately to wash the emulsion down into the fine aggregate and the section was again thoroughly rolled. The purpose of the second rolling was to force the mortar of fine stone and emulsion up part way through the interstices of the coarser stone and upon drying to leave them partially embedded. Actually, however, this did not occur. The water drained away to the side ditches carrying an undetermined amount of emulsion with it. During the rolling process approximately 8 pounds of ⅝ to ¼ inch stone were spread over the surface to fill the surface voids.

Figure 4.—Spreading the Coarse Stone on the Fine Stone Cushion. This Section, Experiment 2–C, Was Constructed with Asphalt Emulsion by a Modified Penetration Method

The following day a second application of the emulsion was spread at the rate of 0.83 gallon and followed immediately with 7 pounds of ⅝ to ¼ inch stone. The section was then thoroughly rolled.

The seal coat was applied one week later after the surface had been swept and loose or raveled places patched. The treatment consisted of an application of 0.23 gallon of emulsion and 15 pounds of ⅝ to ¼ inch stone.

An inspection of the section shortly after construction showed that the first application of emulsion had not penetrated the cushion course as intended, but had to a great extent been carried off with the water used to wash it down.

The cost of constructing the bituminous surface of this section was 84.62 cents per square yard or $9,928 per mile.

Experiment 3, stations 79+20 to 92+40.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 1.8 inches compacted; 162 pounds of ¾ to ¼ inch stone and 38 pounds of stone ¼ inch to dust with 1.19 gallons of 85–100 penetration asphalt cut-back.

Seal: No seal treatment was required.

The tar primer was applied at the rate of 0.30 gallon per square yard.

The mixed course was constructed in the same manner as experiment 1. The coarse stone was only ¾ to ¼ inch in size but there was no tendency of the mix to ball up or segregate. A total of 1.19 gallons of bituminous material, spread in two applications, was used. After initial rolling, but while it was still in a plastic condition, the surface was somewhat rutted by local traffic which could not be detoured. A drag was used to fill the ruts and some of the stone was thus left in a loose condition. However, it compacted under traffic and additional rolling without apparent damage to the section. The resultant mix was well closed and no seal treatment was given.

The cost of constructing the bituminous surface of this section was 61.07 cents per square yard or $7,165 per mile.

Experiment 4, stations 92+40 to 105+84.—The method of construction and the amounts of material per square yard used on this section were as follows:

Mix: 1.8 inches compacted; 157 pounds of ¾ to ¼ inch stone and 0.72 gallon of 85–100 penetration asphalt cut-back.

Seal: An average of 0.22 gallon of the same bituminous material was applied and covered with 15 pounds of ⅝ to ¼ inch stone chips. This section was sealed in two separate portions.

The tar primer was applied at the rate of 0.26 gallon per square yard.

The method of construction of this section was essentially the same as that of sections 2–A and 2–B except that the coarse stone was ¾ to ¼ inch. Seventy-two hundredths gallon of asphalt was spread in one application which apparently was not enough, as the mix did not compact and knead to any great extent under the roller. Upon opening to traffic the surface raveled but the approach of cold weather made remixing undesirable and it was decided to correct surface failures by means of a seal treatment. Two adjacent portions of the section, each about 100 feet long, were selected for trying out, in an experimental way, methods of treating the section. On one portion the loose stone was swept to the roadside and piled, while on the other it was uniformly redistributed on the surface. Both portions were then given an application of approximately one-third gallon of bituminous material per square yard. The stone was respread on the first portion with an additional amount to make about 15 pounds per square yard and both portions then thoroughly rolled. Rolling of the portion on which the stone was not removed and respread presented little difficulty. When the bituminous material became somewhat sticky, the use of kerosene on the roller wheels prevented picking up. It was noted on the following day that the bituminous material had penetrated the mix to approximately the same depth on both portions and that the area on which the loose stone was first removed showed a somewhat better surface appearance. Consequently this method was used to seal the remaining portion. Twenty-two hundredths gallon of bituminous material was used with a total of 15 pounds of stone.

The cost of constructing the bituminous surface of this section was 55.46 cents per square yard or $6,507 per mile.

SECTION GIVEN ORDINARY SURFACE TREATMENT

Experiment 5, stations 66+00 to 79+20.—The method of construction and the amounts of material per square yard used on this section were as follows:

Forty-four hundredths gallon of 85–100 penetration asphalt cut-back was applied and covered with 50 pounds of 1¼ to ¼ inch crushed stone.

Retreatment: (Stations 66+00 to 73+40).

Thirty-six hundredths gallon of the same bituminous material was applied and covered with 15 pounds of ⅝ to ¼ inch crushed stone.

The tar primer was applied at the rate of 0.33 gallon per square yard. The asphalt was applied at the rate of 0.44 gallon per square yard and immediately covered with 50 pounds of 1¼ to ¼ inch stone. The surface was then throughly rolled but was not opened to traffic until the following day. The rolling operation was continued intermittently for several days, during which the stone displaced by traffic was respread with brooms and shovels. Some early patching was required and the portion between stations 66+00 and 73+40 was sealed three months after the construction. For the seal coat, 0.36 gallon of the 85–100 penetration cut-back asphalt and 15 pounds of ⅝ to ¼ inch stone were spread and rolled.

The cost of constructing this surface treatment was 28.47 cents per square yard or $3,340 per mile.

EXPERIMENTAL SECTIONS CONSTRUCTED ON SAND-CLAY BASE

The experimental sections built on the sand-clay base were identical in type of construction and material used with those constructed on the marl base and are numbered correspondingly; i. e., Nos. 1 and 6 are identical, 2 and 7, etc.

Prior to applying the primer on the mixed sections, a triangular trench was cut with the grader on each side of the road to provide for a thickening of the edges. The trench was approximately 1 foot wide and 4 inches deep on the outside edge but was very irregular because of the nonuniformity of the sand-clay. The sections were swept and all loose material was removed, following which action the base was primed with 8–13 viscosity tar applied at a temperature of 125° to 155° F. As was expected, the penetration into the sand-clay base varied with the composition of the material penetrated. In general, the primer penetrated readily and appeared to be of considerable assistance in bonding the surface and forming a stable crust. During the mixing process the primed base was damaged considerably in some areas by the wheels of the road machines and the cleats of the tractors.

Side forms were used on some sections as noted. Edge protection was provided after construction by building up the shoulders with sand-clay.

81677 –31——2

MIXED-IN-PLACE SECTIONS

Experiment 6, section A, stations 105+84 to 119+99.—This section corresponds to Experiment 1, section A. The method of construction and the amounts of material used per square yard were as follows:

Mix: 2 inches compacted; 171 pounds of 1¼ to ¼ inch stone, 40 pounds of ¼ inch to dust, and 1 gallon of 60–70 penetration asphalt cut back with naphtha.

Seal: 0.34 gallon of 85–100 penetration asphalt cut-back was applied and covered with 15 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.33 gallon per square yard.

After the surface, including the area occupied by the trenches, was primed the side forms were placed inside the trenches to prevent the untreated stone from getting into them. The process of mixing was the same as that used on the corresponding section on the marl base. The bituminous material was applied in two applications at the rates of 0.41 and 0.59 gallon, respectively. The appearance and behavior of this mix was very similar to that of the corresponding section on the marl base, in that its surface appeared lean and raveled somewhat immediately following construction. A seal coat was deemed necessary and was applied one month after construction. It consisted of 0.34 gallon of 85–100 penetration asphalt cut-back and a cover of 15 pounds of ⅝ to ¼ inch stone which was spread by hand and rolled. Substitution of the 85–100 cut-back for the 60–70 material was done through error.

The cost of constructing the bituminous surface of this section was 72.53 cents per square yard or $8,510 per mile.

Experiment 6, section B, stations 119 + 99 to 132 + 00.—This section corresponds to experiment 1, section B. The method of construction and the amounts of material used per square yard were as follows:

Mix: 2 inches compacted; 170 pounds of 1¼ to ¼ inch crushed stone, 42 pounds of ¼ inch to dust and 1.09 gallons 85–100 penetration asphalt cut back with naphtha.

Seal: 0.23 gallon of the same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.39 gallon per square yard. In general, this quantity penetrated readily. However, on a portion of the section situated on a superelevated curve the amount was somewhat excessive as some of the material flowed to the side trenches.

An application of asphalt, 0.49 gallon, was made on the coarse aggregate late in the day and immediately covered with fines. The following morning the second application, 0.60 gallon, was spread and mixing was begun. During the mixing operation the primed surface of the base was damaged in a few places by the tractors and road machines. The sand-clay thus loosened was removed as much as possible. After mixing and spreading were completed but before the section was rolled a heavy rain fell, which penetrated the mix to the base. During the rolling process a number of spongy areas appeared where the softened base had worked into the mix. These were removed and replaced with good material.

Traffic was permitted on the section for about three months before it was sealed. During this time very little raveling had occurred although the surface appeared fairly lean.

The seal coat consisted of an application of 0.23 gallon of the same bituminous material as was used in the mix, covered with 15 pounds of ⅝ to ¼ inch stone and rolled.

The cost of constructing the bituminous surface of this section was 72.10 cents per square yard or $8,459 per mile.

Experiment 7, section A, stations 132 + 00 to 144 + 20.—This section corresponds to experiment 2, section A. The method of construction and the amounts of material used per square yard were as follows:

Mix: 2 inches compacted; 178 pounds of 1¼ to ¼ inch stone and 0.77 gallon of 85–100 penetration asphalt cut-back. Mixed, shaped, and rolled.

Seal: 0.27 gallon of the same bituminous material was applied and covered with 18.3 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.29 gallon per square yard. The penetration averaged ⅜ inch. Two days after priming the surface was dry and hard. The side forms were not used during the construction of this section.

The bituminous material was applied at the rate of 0.77 gallon in two applications. As in the case of experiment 6–B the primed base was damaged to some extent during the mixing. This section also was subjected to rain during mixing, the fairly open mix permitting the moisture to enter and penetrate to the base. The mix was already rather stiff and the base was softened so that additional mixing was not deemed advisable after the rain. When rolled the surface appeared in good condition except for considerable moisture which was retained in the mix. Traffic was not permitted on the section until it had dried out.

One week later the seal treatment was applied. The small stone was first spread and allowed to lie under traffic for a few days, after which the loose stones were broomed to the sides and 0.27 gallon of the same bituminous material as used in the mix was applied. The stone was then respread with an additional amount to make a total of about 18 pounds. Rolling of the surface completed the construction.

A few days later inspection of the section showed the base to be dry and the surface well sealed.

The cost of constructing the bituminous surface of this section was 62.86 cents per square yard or $7,375 per mile.

Experiment 7, section B, stations 199 + 70 to 212 + 90.—This section corresponds to experiment 2, section B. The method of construction and the amounts of material used per square yard were as follows:

Mix: Two inches compacted; 169 pounds of 1¼ to ¼ inch crushed stone and 0.77 gallon of 25–35 viscosity tar.

Retreatment: Stations 206 + 50 to 212 + 90, seal coat applied, using 0.42 gallon of the same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips. Station 199 + 70 to 206 + 50, remixed with 0.30 gallon of the same bituminous material. Sealed with 0.23 gallon of same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips.

The tar primer was applied at the rate of 0.25 gallon and the penetration averaged ⅜ inch.

The side forms were not used during the construction of this section. Seventy-seven hundredths gallon of tar was applied and the mixing operation carried out as in the preceding section. When the section was completed it was evident that an insufficient quantity of tar had been used in the mix, as it was not properly bonded and considerable raveling took place under traffic. Because of the cool weather remixing was not believed advisable and it was decided to apply a rather heavy seal to make up for the deficiency of tar in the mix. A tar seal was applied on the north portion (station 206 + 50 to 212 + 90) a few days after construction, at the rate of 0.42 gallon, and covered with 15 pounds of ⅝ to ¼ inch stone chips per square yard. The tar supply ran out at this point and the additional amount necessary to complete the job was not received for about 10 days. During this period the remainder of the section had become so raveled and displaced under traffic that remixing was considered necessary. This portion was first scarified or torn up with the blade grader and given an application of 0.30 gallon of tar per square yard. It was then remixed, spread, and rolled.

Approximately two months later it was necessary to give the portion of the section that had been remixed a light seal treatment in order to close the surface to prevent the entrance of moisture. Prior to applying the seal, 15 pounds per square yard of ⅝ to ¼ inch stone were spread on the surface, allowing traffic to force some of the particles into the mix. After two days the loose stone was swept to the sides and 0.23 gallon of tar applied. The stone was then respread over the surface and rolled.

The cost of constructing the bituminous surface of the section was 73.23 cents per square yard or $8,592 per mile.

Experiment 7, section C, stations 144 + 20 to 158 + 40.—This section corresponds to experiment 2, section C.

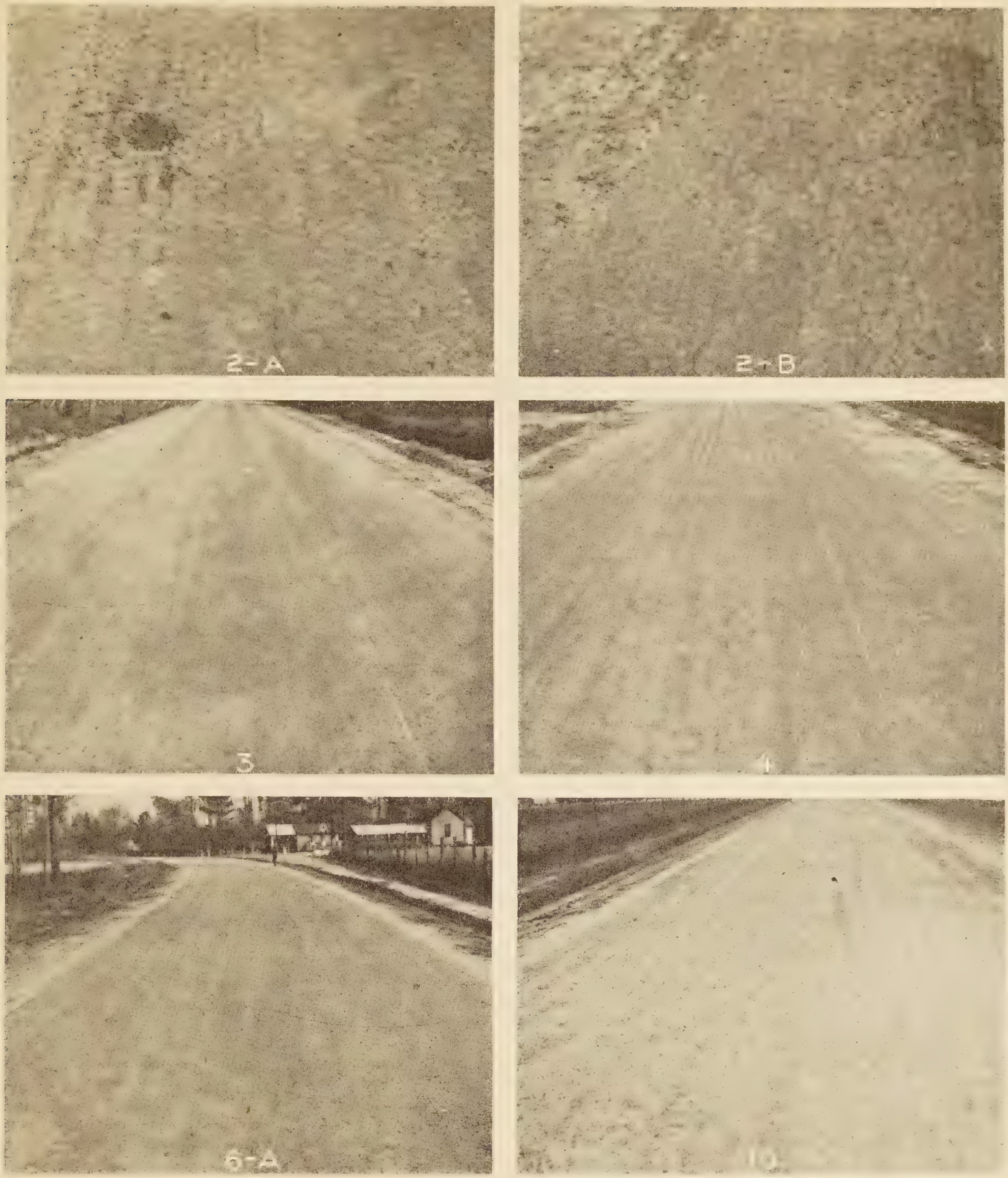


FIGURE 5.—EXAMPLES OF SURFACE APPEARANCE SIX MONTHS AFTER CONSTRUCTION. THE NUMBERS OF THE EXPERIMENTAL SECTIONS ARE GIVEN ON THE PHOTOGRAPHS. EXPERIMENTS 2-A AND 2-B: CRACKING AND RAVELING DURING SPRING OF 1930 WAS CAUSED BY SOFTENING OF THE MARL BASE AS A RESULT OF MOISTURE. EXPERIMENT 3: SECTION IN EXCELLENT CONDITION; MARL BASE, WHILE SLIGHTLY DAMP, HAD NOT SOFTENED AS IN EXPERIMENTS 2-A AND 2-B. EXPERIMENT 4: SURFACE IN GOOD CONDITION, EXCEPT FOR A FEW SMALL AREAS WHERE MARL BASE HAS SOFTENED. EXPERIMENT 6-A: IN EXCELLENT CONDITION; SAND-CLAY BASE MOIST, BUT ITS SUPPORTING VALUE APPARENTLY NOT AFFECTED. EXPERIMENT 10: GOOD CONDITION DUE TO EARLY RE-TREATMENT, WHICH NO DOUBT SAVED THE SECTION FROM COMPLETE DISINTEGRATION

The method of construction and the amounts of material used per square yard were as follows:

Penetration course: 2.3 inches compacted; 165 pounds of 1¼ to ¼ inch stone, 30 pounds of ¼ inch to dust and 1.11 gallons of asphalt emulsion.

Seal: 0.25 gallon of the same bituminous material and 15 pounds of ⅝ to ¼ inch stone chips.

The sand-clay base on this section was generally better than the average, as were the drainage conditions.

The tar primer was applied at the rate of 0.34 gallon and gave an average penetration of ⅜ inch.

Side forms were not used on this section. Otherwise the details of construction were essentially the same as those of the corresponding section on the marl base. As no mixing was done on this section the primed base was not disturbed during the construction of the bituminous mat. The emulsion was applied at the rate of 0.32 gallon per square yard for the first application and 0.79 gallon for the second. As on experiment 2, section C, where similar materials and methods were used, an appreciable amount of the first application was carried off by the water used to wash it down into the fine stone cushion. After rolling, the section was comparatively rough and, while under traffic for about 10 days, raveled considerably. Before the seal treatment was applied depressions and surface failures were repaired with emulsion and ½-inch stone. The surface was then swept and 0.25 gallon of emulsion applied and covered with 15 pounds of ⅝ to ¼ inch stone.

As on the other emulsion section, it was found that the emulsion had not penetrated the fine stone cushion.

The cost of constructing the bituminous surface of this section was 84.55 cents per square yard or $9,920 per mile.

Experiment 8, stations 212+90 to 226+10.—This section corresponds to experiment 3. The method of construction and the amounts of material used per square yard were as follows:

Mix: 1.8 inches compacted; 154 pounds of ¾ to ¼ inch stone, 38 pounds ¼ inch to dust, and 1.25 gallons of 85–100 penetration asphalt cut-back.

Seal: No seal treatment was required.

The sand-clay base on this section was very nonuniform and during construction compacted under traffic into strata which resulted in some scaling, especially near the edges. All loose material was removed before priming. The prime coat was applied at the rate of 0.26 gallon per square yard. The section was constructed similarly to the corresponding section on the marl base except that side forms were not used. The asphalt was spread in two applications at the rate of 0.51 and 0.74 gallon per square yard, respectively. Before mixing was completed a heavy rain occurred but the mix was windrowed in the center and was therefore partially protected. Mixing was not resumed until the base was thoroughly dry. After the mix was shaped and partially rolled, but before it hardened, it was badly rutted by local traffic on the following day. On the next day the surface was loosened with a disk harrow, reshaped, and again rolled. Although the mix had become somewhat stiff no difficulty was encountered in obtaining a well compacted, close surface. A seal was not considered necessary.

The cost of constructing the bituminous surface of the section was 59.53 cents per square yard or $6,985 per mile.

Experiment 9, stations 226+10 to 238+80.—This section corresponds with experiment 4. The method of construction and the amounts of material used per square yard were as follows:

Mix: 1.8 inches compacted; 152 pounds of ¾ to ¼ inch stone and 0.77 gallon 85–100 penetration cut-back.

Seal: 0.29 gallon of the same bituminous material was applied and covered with 14 pounds of ⅝ to ¼ inch stone chips.

One month preceding the construction of this section the sand-clay base was plowed and scarified, and additional clay binder was added. It was then machined and opened to traffic for compaction. At the time the surface was constructed it was in fair condition.

The tar primer was applied at the rate of 0.27 gallon and the penetration averaged about ⅜ inch. Side forms were not used.

The bituminous material was applied at the rate of 0.77 gallon per square yard. In the 1½ months following construction, during which time the section was under traffic before sealing, the surface raveled considerably, probably because of leanness as well as the lack of fine material necessary to give a well-graded mixture.

Before the application of the seal coat, the loose stone was swept to the sides of the road. The bituminous material was then applied at the rate of 0.29 gallon per square yard, and the stone respread with an additional amount to make a total of 14 pounds per square yard. Rolling completed the treatment.

The cost of constructing the bituminous surface of this section was 66.74 cents per square yard or $7,831 per mile.

SECTION GIVEN ORDINARY SURFACE TREATMENT

Experiment 10, stations 158+40 to 199+70 (less 170 feet).—This section corresponds to experiment 5. The method of construction and the amounts of material used per square yard were as follows:

Forty-six hundredths gallon of 85–100 penetration asphalt cut back with naphtha and 52 pounds of 1¼ to ¼ inch crushed stone.

Retreatment: 0.32 gallon of the same bituminous material covered with the loose stone that had been whipped off by traffic, plus 13 pounds of ¾ to ¼ inch crushed stone.

The sand-clay base on this section was in only fair condition. At the time of construction it had compacted under traffic in layers and, in many widely distributed areas, some peeling occurred during sweeping, preparatory to application of the primer.

Four days before the prime coat was applied the sand-clay surface was sprinkled with water and lightly machined. The tar primer was applied at the rate of 0.29 gallon per square yard. The primed surface was in good condition when surface treated except for a few local areas where traffic had caused some flaking of the laminated sand-clay. Before treatment, such loosened material was removed and the uncovered areas painted with 85–100 penetration asphalt cut-back. The surface treatment consisted of applying 0.46 gallon of the asphalt and 52 pounds of 1¼ to ¼ inch stone per square yard. The section was then thoroughly rolled. During rolling considerable failure of the sand-clay base occurred. On many widely scattered areas the upper portion of the base, which before treatment had appeared stable, separated from the lower portion and worked up through the cover stone. Under traffic these areas quickly disintegrated and whipped off leaving the base exposed.

As the number of areas failing in this manner was so numerous that it was deemed impractical to patch each one, a portion of the section was selected for experimentation to devise a satisfactory method of correcting the failure. The portion so selected was between stations 179+20 and 184+15, which was probably in the worst condition of any of the section. The loose stone, estimated at about 25 pounds per square yard, was swept to the sides and an application of 0.32 gallon of the asphalt cut-back applied, after which the stone was respread with 10 pounds additional. This treatment proved satisfactory and the remainder of the section was treated in the same manner, except that the new stone added was ¾ to ¼ inch, spread at the rate of 13 pounds per square yard, and the amount of bituminous material used was 0.31 gallon per square yard.

The cost of constructing this surface treatment, including the re-treatment, was 29.44 cents per square yard or $3,454 per mile.

DISCUSSION OF RESULTS OBTAINED

SEAL COAT NECESSARY WITH COARSER AGGREGATES

The open surface obtained on experiments 1 and 6, sections A and B, on which 1¼ to ¼ inch stone was combined with the stone screenings graded from ¼ inch down, indicated that the 20 per cent of fine aggregate used was not sufficient to close the voids in the large size stone and that a seal coat was necessary. On experiments 3 and 8, where the ¾ to ¼ inch stone was combined with the fine aggregate in the same proportion, a close mix was obtained which did not require a seal treatment. For the coarser stone it is believed that at least 30 per cent of fines would have been necessary in order to produce a surface similar to that obtained with the ¾ inch to dust.

On experiments 2 and 7, sections A and B, on which 1¼ to ¼ inch stone was used and on experiments 4 and 9 on which ¾ to ¼ inch stone was used without the addition of fines, the original plan was to close the surface with a key course, using ½ to ¼ inch stone. This was found to be impractical as the surfaces were not sufficiently open and the addition of stone of this size would not have filled the surface voids but would merely have added thickness to the mat. It was decided that, for this type of construction and size of aggregate, a better method would be to omit the key course and use a fine aggregate as a seal treatment in order to insure a closed surface. This type of treatment was therefore used on these sections.

MIXING METHODS DISCUSSED

In the original design no mention was made of the method of mixing. It was thought that in those sections where the fines were to be added to the coarse aggregate some difficulty might be encountered because of segregation, particularly if a drag were used in the mixing. To prevent this it was decided to treat the coarse stone with a light application of bituminous material before adding the fines. Although this method of applying the fines was thought necessary for the drag mixing, it would have not been necessary where mixing was done with a blade machine. For this method of construction a crusher-run stone could probably have been used equally as well and at less cost.

The cut-back asphalt used in this work was manufactured under the same specification as that used for surface treatment work and mixed-in-place construction where sand-clay and topsoil material are used as aggregates. Although no construction difficulty was encountered in the use of this material, there are reasons to believe that had it been of higher viscosity it would have proved more satisfactory in that a greater film thickness of bitumen on the stone would have been obtained, a condition which is probably desirable with the coarser aggregates. Another advantage of using the higher viscosity is that less distillate would be required, resulting in a somewhat cheaper material. The viscosity of the material used on this work ranged from about 23 to 37, Engler, at 50° C. From experience in other States on similar work, it is believed that a material of at least 50 viscosity could have been used.

In building a surface mat by the mixed-in-place method it is very important, particularly when using asphaltic materials of the cut-back type, to have the mix in a condition of tackiness before compacting it either by traffic or by rolling. This is best accomplished by spreading and shaping the mix immediately after mixing and allowing sufficient time to lapse before rolling in order that the light distillates may evaporate. Another method commonly used is that of windrowing the material immediately after mixing and leaving it to cure before spreading and rolling. This latter method requires a longer curing period, is likely to cause segregation at the time of spreading and, in general, has not proved as satisfactory as the first method, as well as being somewhat more costly. There is also a possibility of some of the bituminous material draining to the bottom of the windrow, causing the mix to be nonuniform and resulting in fat and lean streaks in the surface after the roadway is opened to traffic.

Experience has shown that a smoother and more stable surface can be obtained in the early life of the pavement by either of these two plans than can be obtained when the mix is laid and rolled before the proper tackiness has developed. Rolling the mix before an appreciable amount of the light distillate has volatilized results in this material being trapped in the mix, causing it to remain unstable for some time. It is believed that on a considerable amount of mixed-in-place construction with cut-back asphalt, compacting the mix immediately after mixing without sufficient time for curing has resulted in early shoving and often in unsatisfactory surface behavior of the mat.

The ⅝ to ¼ inch stone used as cover material was not altogether satisfactory. A smaller size stone would have proved more satisfactory from the standpoint of waterproofing the surface. However, the larger size cover resulted in added thickness and in the formation of a somewhat rough mat with some of the larger stone projecting, rendering the pavement more skid proof.

ALTERNATIVE METHODS OF SURFACE TREATMENT DESCRIBED

In view of the difficulty experienced during construction of the surface treatment on the sand-clay because of the scaly, raveled condition, it is probable that a better method of applying a surface treatment, particularly for this base condition, would be to apply the heavy binding material in two applications so that the second application would heal any breaks in the first. The treatment might consist of spreading 0.2 gallon of binder over the prime coat and covering with stone, rolling, and then spreading the remaining 0.3 gallon, followed by a covering of key stone and rolling. A seal coat treatment could be applied later as required.

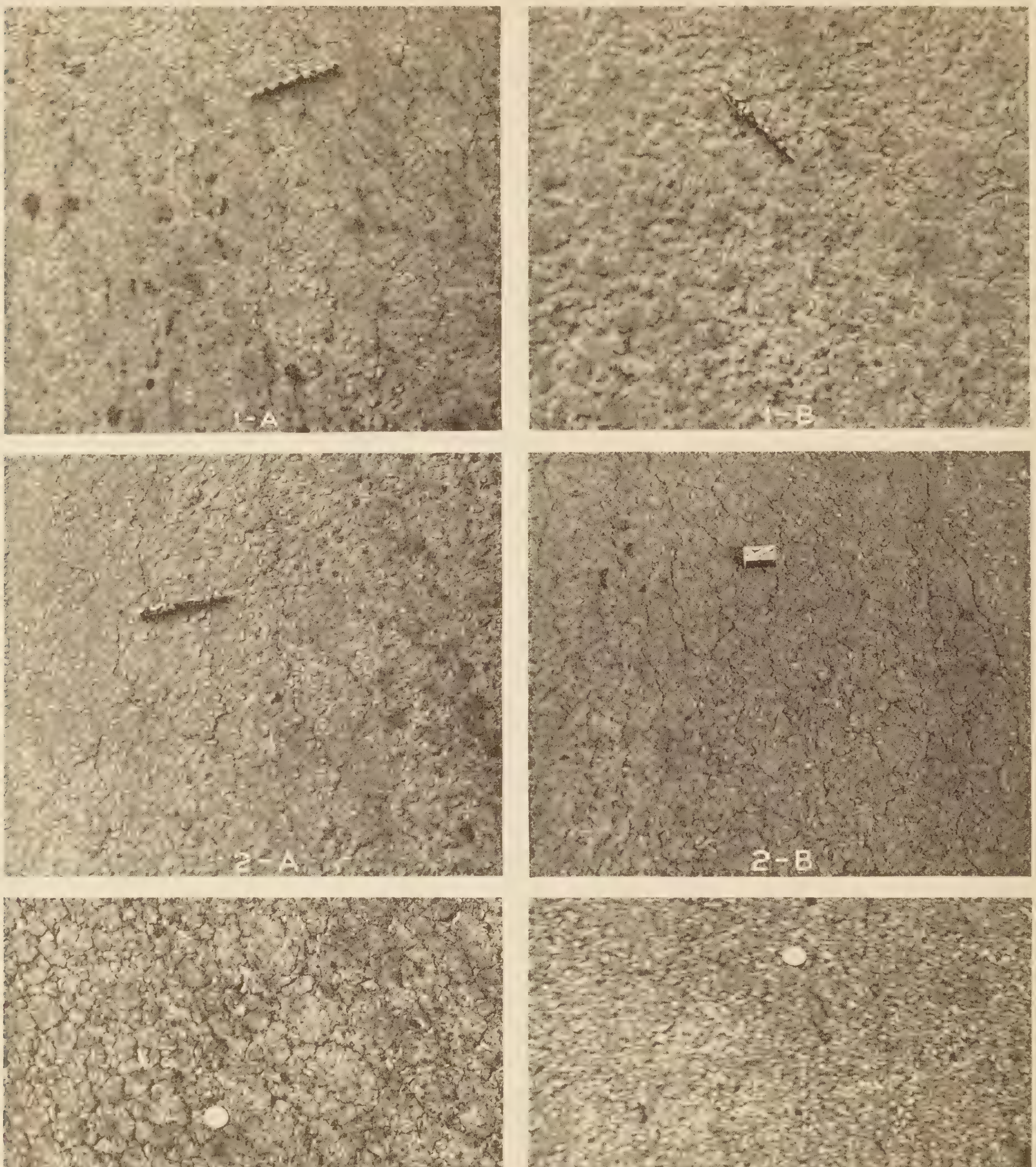


Figure 6.—Typical Examples of Surface Condition During the Spring of 1931. The Numbers of the Experimental Sections Are Given on the Photographs

TABLE 9.—*Cost of construction*

[Cost in cents per square yard]

Experiment number	1		2			3	4	5	6		7			8	9	10
Section	A	B	A	B	C				A	B	A	B	C			
Area, square yards	2,951	2,493	3,275	2,755	3,111	2,933	2,987	2,933	3,144	2,669	2,711	2,933	3,156	2,933	2,822	8,800
Type of base	Marl								Sand-clay							
Type of construction	Mix	Mix	Mix	Mix	Penetration	Mix	Mix	Surface treatment	Mix	Mix	Mix	Mix	Penetration	Mix	Mix	Surface treatment
Bituminous materials used	60–70 cut-back	85–100 cut-back	85–100 cut-back	25–35 tar	Asphalt emulsion	85–100 penetration cut-back			60–70 cut-back	85–100 cut-back	85–100 cut-back	25–35 tar	Asphalt emulsion	85–100 penetration cut-back		
ITEMS OF CONSTRUCTION																
Preparation of base	0.31	1.28	1.36	0.40	0.39	0.45	0.62	1.60	1.60	2.70	0.89	2.76	0.84	1.64	12.49	1.24
Prime treatment in place	3.65	3.63	4.10	3.88	3.69	4.01	3.54	4.48	4.39	5.16	3.92	3.35	4.58	3.41	3.62	3.92
Mixed material:																
Aggregate in place	35.05	36.77	32.66	33.50	37.34	34.96	29.96	-------	38.00	38.52	34.10	31.64	40.07	34.95	29.46	-------
Bituminous material in place	7.96	7.69	5.13	14.72	21.31	8.90	5.36	-------	8.74	8.13	5.74	12.69	18.73	9.32	5.76	-------
Mixing and shaping	2.00	5.28	3.30	7.86	1.42	2.78	2.55	-------	3.34	3.27	3.12	5.29	.65	2.32	1.95	-------
Rolling	1.49	2.50	3.12	1.42	4.85	1.40	2.00	-------	1.30	2.10	2.69	2.27	4.69	1.15	1.78	-------
Total cost of mixed material	46.50	52.24	44.21	57.50	64.92	48.04	39.87	-------	51.38	52.02	45.65	51.89	64.14	47.74	38.95	-------
Surface treatment:																
Aggregate in place	-------	-------	-------	-------	-------	-------	-------	10.12	-------	-------	-------	-------	-------	-------	-------	12.45
Bituminous material in place	-------	-------	-------	-------	-------	-------	-------	3.28	-------	-------	-------	-------	-------	-------	-------	5.84
Rolling	-------	-------	-------	-------	-------	-------	-------	.50	-------	-------	-------	-------	-------	-------	-------	.53
Total cost of surface treatment	-------	-------	-------	-------	-------	-------	-------	13.90	-------	-------	-------	-------	-------	-------	-------	18.82
Seal treatment:																
Bituminous material in place	3.66	2.17	3.51	3.80	3.80	-------	1.69	1.52	2.50	1.67	1.98	5.36	4.18	-------	2.13	-------
Aggregate in place	2.89	2.89	2.23	2.74	2.89	-------	2.90	1.39	2.89	2.89	3.52	2.89	2.89	-------	2.89	-------
Rolling	.93	1.20	-------	-------	1.09	-------	-------	.07	.20	.14	-------	-------	.87	-------	-------	-------
Total cost of seal treatment	7.48	6.26	5.74	6.54	7.78	-------	4.59	2.98	5.59	4.70	5.50	8.25	7.94	-------	5.02	-------
Incidentals:																
Forms	.05	.78	.07	.22	.32	.95	.15	-------	2.04	.16	-------	-------	-------	-------	-------	-------
Shoulders	1.82	1.91	8.44	4.21	.74	1.44	.65	.16	1.05	.90	.67	.49	.27	.60	.33	.08
Demurrage	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75	.75
Engineering	1.68	1.85	1.79	2.02	2.15	1.55	1.41	.72	1.85	1.83	1.60	1.86	2.15	1.51	1.70	.75
Miscellaneous	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88
Total cost of incidentals	8.18	9.17	14.93	11.08	7.84	8.57	6.84	5.51	9.57	7.52	6.90	6.98	7.05	6.74	6.66	5.46
Total cost per square yard	66.12	72.58	70.34	79.40	84.62	61.07	55.46	28.47	72.53	72.10	62.86	73.23	84.55	59.53	66.74	29.44
Cost per mile, 20-foot width	$7,758	$8,516	$8,253	$9,316	$9,928	$7,165	$6,507	$3,340	$8,510	$8,459	$7,375	$8,592	$9,920	$6,985	$7,831	$3,454

Another method of meeting the difficulty of loose subgrade in the case of light surface treatment would be to treat the surface of the base. For example, a heavier prime coat might be used, followed by light surface mixing and rolling if necessary. It is probably often the case that the soil can be so treated or the treatment of soil roads can be so modified that light bituminous wearing surfaces can be constructed without expensive rebuilding of the subgrade.

Because of the experimental character of the sections and their relatively short lengths, the cost as shown in Table 9 naturally was higher than that of constructing any one section of a considerable length. The type of construction used on these experiments offers an opportunity for the use of mechanical equipment, thereby reducing hand labor to a minimum with a corresponding reduction in cost. As indicated in the description of the various sections, considerable hand labor was employed.

MAINTENANCE AND EARLY BEHAVIOR

A record of the maintenance costs on the different sections of this project are given in Table 10. Inspection of the project has been made at various intervals and the comparative behavior is shown by the illustrations accompanying this article and in the following discussion.

During the spring following the construction all the sections on the marl base, excepting experiment No. 5, the plain surface treatment, experiment No. 3, ¾ to ¼ inch stone plus fines, and experiment No. 4, ¾ to ¼ inch stone without the fines, had developed extensive cracking and presented, to a considerable extent, an "alligator-hide" appearance. This condition was found to be due to the softening of the marl base caused by capillary as well as surface moisture. The presence of the prime coat on the marl did not seem to prevent the upward movement of moisture through the base. The upper surface of the marl which had been penetrated by the primer was also softened and contained a high percentage of moisture.

All of the experiments on the sand-clay were found to be in excellent condition. Examination of this base showed that it contained as much moisture as the marl, and sometimes more, but the primed surface had not been affected by the moisture. The stable crust formed by the primer had to a large extent prevented the upward movement of the base moisture into the bituminous wearing surface.

A later inspection, made during the summer of 1930, showed that both the marl and the sand-clay bases had to a great extent dried out and that the marl had hardened considerably. It was thought possible that, as the base support of the sections constructed

TABLE 10.—*Cost of maintenance from October, 1929, to December, 1930*

Experiment No.	Section No.	Type of base	Original construction August–September, 1929					Maintenance costs		
			Bituminous material	Type of surface	Size of aggregate	Cost per square yard	Cost per mile 20 feet wide	October–December, 1929—Per square yard	January–December, 1930—Per square yard	Per mile per year
					Inches	*Cents*		*Cents*	*Cents*	
1	A	Marl	Asphalt, cut-back	Mixed	1¼–dust	66.12	$7,758	0.00	0.82	$77
1	B	do	do	do	do	72.58	8,516	.12	1.48	150
2	A	do	do	do	1¼–¼	70.34	8,253	.05	1.10	108
2	B	do	Tar	do	do	79.40	9,316	.10	1.74	173
2	C	do	Asphalt emulsion	Penetration	1¼–dust	84.62	9,928	.00	4.21	395
3		do	Asphalt cut-back	Mixed	¾–dust	61.07	7,165	.15	.23	37
4		do	do	do	¾–¼	55.46	6,507	.00	1.64	154
5		do	do	Surface treatment	1¼–¼	28.47	3,340	.10	4.29	413
Average [1]										177
6	A	Sandclay	do	Mixed	1¼–dust	72.53	8,510	.08	.44	49
6	B	do	do	do	do	72.10	8,459	.11	1.09	113
7	A	do	do	do	1¼–¼	62.86	7,375	.10	1.31	132
7	B	do	Tar	do	do	73.23	8,592	.00	1.18	111
7	C	do	Asphalt emulsion	Penetration	1¼–dust	84.55	9,920	.19	1.05	117
8		do	Asphalt cut-back	Mixed	¾–dust	59.53	6,985	.09	.33	39
9		do	do	do	¾–¼	66.74	7,831	.00	.92	86
10		do	do	Surface treatment	1¼–¼	29.44	3,454	.22	1.69	179
Average [1]										111

[1] Average weighted for lengths of experimental sections.

on the marl base increased, the cracks which had developed during the winter would heal under the summer traffic. During the fall it was evident that little or no healing had occurred, although no new cracks had developed during the summer.

During the following winter of 1930–31 a repetition of the same conditions occurred on the marl base and an inspection of the project made during the spring of 1931 showed that the cracking had increased, the old cracks had become wider and, in some few areas, raveling had started to a limited extent. The surface of the three experiments on the marl base that were not affected during the first winter were still in good condition and comparable with those on the sand-clay base.

A comparison of the various experiments, based on their past behavior and their condition in the spring of 1931, shows that those constructed on the sand-clay base are far better than those on the marl, except for experiments Nos. 5, 3, and 4, which compare favorably with those on the sand-clay base. A rating of the experiments based on their present surface condition is given in Table 11.

The surface maintenance of the various experimental sections has consisted of hand patching in certain local areas where failures have occurred. Prior to the summer of 1931 no re-treatments had been made on any of the experiments. The data given in Table 10 show the average maintenance costs for the experiments on the marl base to be $177 per mile per year while the maintenance cost for those on the sand-clay base has been $111 per mile per year. Although these costs indicate a distinct superiority on the part of the sand-clay base, the true merits of the two types of base are not fully shown by these figures, as the experiments constructed on the sand-clay will require no great amount of maintenance in the near future while the experiments constructed on the marl base, with the exception of experiments 3, 4, and 5 will probably require some type of re-treatment.

Two types of re-treatment of these surfaces were considered and were tried out experimentally during the summer of 1931. Under one of these methods the present surface is scarified and remixed with additional bituminous material, after which the mixture is again spread and rolled. Under the other method a light surface treatment is applied to the surface of the existing experiment. From the early results of these two types of treatments the better method will be selected for re-treating the remainder of the experiments on the marl base which are in need of re-treatment.

The unsatisfactory condition of the majority of the experiments constructed on the marl base has been caused by the softening of this material during the wet winter months. Evidently this material, the analysis of which is given on page 217, is not suitable for base construction where the moisture conditions are as unfavorable as they are in the locality in which this project was constructed. It is possible that with a higher elevation of the road surface and deeper drainage ditches, which would no doubt reduce the capillary moisture, the be-

TABLE 11.—*Relative ratings of experimental sections*

MIXED-IN-PLACE ON SAND-CLAY BASE

1—Experiment 8, ¾ to ¼ inch stone plus fines, 85–100 penetration asphalt cut-back.
2—Experiment 6, Section B, 1¼ to ¼ inch stone plus fines, 85–100 penetration asphalt cut-back.
3—Experiment 6, section A, 1¼ to ¼ inch stone plus fines, 60–70 penetration asphalt cut-back.
4—Experiment 9, section A, ¾ to ¼ inch stone, no fines, 85–100 penetration asphalt cut-back.
5—Experiment 7, section B, 1¼ to ¼ inch stone, no fines, 25–35 viscosity tar.
5—Experiment 7, section A, 1¼ to ¼ inch stone, no fines, 85–100 penetration apshalt cut-back.
6—Experiment 7, section C, 1¼ to ¼ inch stone plus fines, asphalt emulsion.

MIXED-IN-PLACE ON MARL BASE

1—Experiment 3, same as experiment 8.
2—Experiment 4, same as experiment 9.
3—Experiment 1, section A, same as experiment 6, section A.
3—Experiment 1, section B, same as experiment 6, section B.
4—Experiment 2, section A, same as experiment 7, section A.
4—Experiment 2, section B, same as experiment 7, section B.
5—Experiment 2, section C, same as experiment 7, section C.

SURFACE TREATMENT

Experiment No. 5, on marl base, and experiment No. 10, on sand-clay base, were both in excellent condition. There was no noticeable difference in the condition of the two experiments.

Figure 7.—Typical Examples of Surface Condition During the Spring of 1931. The Numbers of the Experimental Sections Are Given on the Photographs

FIGURE 8.—TYPICAL EXAMPLES OF SURFACE CONDITION DURING THE SPRING OF 1931. THE NUMBERS OF THE EXPERIMENTAL SECTIONS ARE GIVEN ON THE PHOTOGRAPHS

havior of the marl base would have been more satisfactory. The application of the tar prime coat was not effective in preventing the movement of moisture through the marl base, as that portion of the base which had been penetrated by the prime was softened by moisture the same as the untreated material.

In the case of the sand-clay the condition was strikingly different, as that portion of the base which had been penetrated by the prime remained firm and hard and apparently was not affected by the action of moisture. Although the base underneath the primed surface contains a high percentage of moisture during the winter months, it has thus far retained its supporting power, so that no surface failures have occurred.

Considerable difficulty was experienced during construction because of the poorly bonded surface of this sand-clay. This material probably would not have been suitable for a sand-clay road during dry weather. However, upon application of the prime and construction of the bituminous wearing surface, enough moisture was retained in the sand-clay to bond it properly and render it entirely suitable as a base.

During recent years it has been the belief that for a clay-bonded material to serve satisfactorily as a base, the proportions of clay and granular material should be such that, as a wearing surface, it would remain stable in wet weather and have the minimum amount of raveling in dry weather. In view of the results thus far obtained from this and other similar experiments, definite indications are that the amount of clay required to prevent raveling in dry weather is excessive when used as a base for bituminous surfacing and that no more clay should be used than that amount which will produce a stable surface in wet weather.

The behavior of these experiments to date has shown conclusively that, where a surface mat is constructed on a low-type nonrigid base, a richer and more plastic mat is required than for a more rigid type. At this time there are also indications that under these same conditions a thin mat has an advantage over a thicker mat. The good behavior of the surface treatments on both types of base may not be entirely due to the thickness, as this type of surface is considerably higher in bitumen than the mixed sections. Although the percentage of bitumen used in the mixed sections would in no case equal the amount used in the surface treatment, it is believed that a higher percentage of bitumen would have resulted in more favorable behavior of these mixed sections.

Although the results thus far obtained from these experiments show little or no difference between the different grades of asphalt used, it is believed that a preference should be given to those of higher penetration where a nonrigid type base is used.

CONCLUSIONS SUMMARIZED

Although these experimental sections have not been in service long enough to warrant drawing definite conclusions, their early behavior and present surface conditions appear to justify the following statements.

1. The minimum amount of clay binder is desirable in sand-clay and gravel material when used for base construction for bituminous wearing surfaces, except under arid conditions, when a larger percentage of this material may be used. The bonding of the immediate surface of a base composed of granular material to make it suitable for the construction of the bituminous wearing surface may be accomplished by the use of a heavier prime application, together with such mixing, smoothing, and rolling as may be necessary, rather than by the addition of clay material. The maximum percentage of clay in bases for these types of surfaces should be limited to that amount which will produce a good wearing surface in wet weather.

2. Although there is considerable difference in the composition of marl, which affects its resistance to moisture, the general use of this material for base construction should be limited to areas where moisture conditions are most favorable.

3. A thin rich mat of the surface-treatment type seems to offer advantages over the thicker mat when used on a nonrigid base, because of its ability to adjust itself more readily to such movements as may occur in the base.

For a wearing surface consisting of a relatively thick bituminous mat, such as was used on the majority of these experiments, a richer, more plastic mixture is necessary than is required when the base is of a more rigid type. On this project an insufficient amount of bituminous material was used in the mixed sections.

GASOLINE TAXES FIRST HALF OF 1931

Tax earned on motor vehicle fuel, etc., disposition of fund, 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 motor fuel vehicles	Other receipts under tax law (licenses)	Grand total earnings (tax and other receipts)	Disposition of grand total earnings: Collection costs	Construction and maintenance of rural roads: State highways	Construction and maintenance of rural roads: Local roads	State and county road bond payments [1]	On city streets	For miscellaneous purposes	Tax rates, 1931: Cents per gallon Jan. 1	Cents per gallon June 30	Date of rate change	Gasoline taxed: Net gallons	Percentage increase [2]
Alabama	$3,200,225		$3,200,225		$3,200,225	$9,118	$555,605	$1,596,732	$1,038,770			4	[3] 4		80,005,626	−6.5
Arizona	1,788,502	$163,776	1,624,726	$501,446	2,126,172	([4])	1,627,867	498,305				4	5	Jan. 30	33,194,313	−1.1
Arkansas	3,267,935	212,416	3,055,519		3,055,519	67,500		378,255	[5] 2,558,919	$50,845		5	6	Feb. 26	54,037,015	−6.3
California	20,723,606	2,212,544	18,511,062	[6] 735,000	19,246,062	38,898	12,804,776	6,402,388				3	3		617,035,384	14.0
Colorado	3,365,278	310,862	3,054,416		3,054,416	[7] 30,358	2,116,840	816,496		90,722		4	4		76,360,389	3.4
Connecticut	2,097,423	2,483	2,094,940	49,130	2,144,070	([8])	2,144,070					2	2		104,746,999	3.2
Delaware	518,976	29,611	489,365		489,365	([9])	489,365					3	3		16,312,162	4.1
Florida	7,623,982		7,623,982	[10] 14,232	7,638,214	14,232	2,541,327	423,555	[11] 2,541,327		[12] 2,117,773	6	[13] 6		127,066,367	5.4
Georgia	6,365,601		6,365,601		6,365,601	[14] 4,200	4,240,934	1,060,234			[15] 1,060,233	6	6		106,093,343	−1.0
Idaho	1,331,087	118,503	1,212,584	388	1,212,972	8,019	1,051,386		[16] 153,567			5	5		24,251,680	−1.0
Illinois	13,990,088	593,733	13,396,355		13,396,355	42,601	8,902,503	4,451,251				3	3		446,545,165	3.6
Indiana	8,997,330	532,454	8,464,876	37	8,464,913	29,047	6,326,899	1,581,725		527,242		4	4		224,413,636	12.3
Iowa	5,946,968	649,830	5,297,138		5,297,138	17,000	3,128,138	2,152,000				3	3		176,571,279	6.0
Kansas	4,854,587	1,206,815	3,647,772		3,647,772	([17])	2,747,772	900,000				3	3		121,592,400	−18.8
Kentucky	4,054,046		4,054,046		4,054,046	15,501	4,038,545					5	5		81,025,634	4.7
Louisiana	4,462,153	222	4,461,931		4,461,931	31,000	1,653,564		1,891,181		[18] 886,186	5	5		89,238,632	−.7
Maine	1,771,037	170,450	1,600,587		1,600,587	34,448	783,070	783,069				4	[19] 4		[20] 38,594,253	11.1
Maryland	3,389,018	144,346	3,244,672		3,244,672	13,573	2,584,879			[21] 646,220		4	4		81,116,787	1.8
Massachusetts	6,060,946	80,452	5,980,494		5,980,494	([22])	3,209,744	902,267		1,868,483		2	3	May 1	247,720,983	4.2
Michigan	11,065,515	1,064,407	10,001,108	18,231	10,019,339	24,558	5,492,615	2,950,000	1,500,000	35,000	[23] 17,166	3	3		[24] 333,370,258	.3
Minnesota	5,703,938	546,863	5,157,075		5,157,075	([25])	3,438,050	1,719,025				3	3		171,902,484	10.3
Mississippi	2,774,770		2,774,770	67,755	2,842,525	[26] 6,920	1,342,365	1,386,950			[27] 106,290	5	5		55,495,393	−17.7
Missouri	4,463,803	112,422	4,351,381		4,351,381	22,712	4,328,669					2	2		217,569,048	8.3
Montana	1,689,546	267,817	1,421,729		1,421,729	13,711	1,408,018					5	5		28,434,580	4.5
Nebraska	4,452,430	32,357	4,420,073		4,420,073	3,750	3,312,242	1,104,081				4	4		110,501,811	4.0
Nevada	406,645	43,191	363,454		363,454		363,454					4	4		9,086,441	21.6
New Hampshire	1,065,412	27,464	1,037,948		1,037,948		778,461		259,487			4	4		25,948,689	5.7
New Jersey	9,802,250	1,887,223	7,915,027	6,599	7,921,626	9,500	5,367,126			2,500,000	[28] 45,000	3	3		263,834,202	6.2
New Mexico	1,253,516		1,253,516	4,742	1,258,258	25,146	784,163		444,000		[29] 4,949	5	5		25,070,315	−1.8
New York	14,219,976	307,131	13,912,845	27,351	13,940,196	[30] 142,199	10,310,998	2,749,599			[31] 737,400	2	2		695,642,265	6.0
North Carolina	6,104,821	232,255	5,872,566		5,872,566	5,165	[32] 2,567,401	[32] 1,500,000	[32] 1,800,000			5	6	Apr. 1	97,876,102	−17.9
North Dakota	1,301,035	516,764	784,271		784,271	([33])	522,847	261,424				3	[34] 3		26,803,554	2.7
Ohio	18,506,660	856,906	17,649,754	400	17,650,154	([9])	9,928,212	4,412,538		3,309,404		4	4		441,243,859	−.6
Oklahoma	5,757,592	7,786	5,749,806		5,749,806	22,779	3,698,331	1,232,777			[35] 795,919	4	5	Mar. 25	134,170,623	−13.1
Oregon	3,408,036	314,435	3,093,601		3,093,601	9,409	2,395,080		689,112			4	4		77,581,843	10.8
Pennsylvania	14,281,909	83,197	14,198,712	193,367	14,392,079	117,971	10,395,090	2,379,018	1,500,000			3	3		473,131,367	18.6
Rhode Island	883,334	29,177	854,157	2,486	856,643	([36])	642,482		214,161			2	2		42,707,822	7.3
South Carolina	3,484,195	16,693	3,467,502		3,467,502	([37])	2,889,585	577,917				6	6		57,791,696	2.7
South Dakota	2,301,562	1,005,592	1,295,970		1,295,970	7,500	875,825		376,748		[38] 35,897	4	4		32,399,255	2.5
Tennessee	4,969,312		4,969,312		4,969,312	49,693	1,967,847	983,924	[39] 1,967,848			4	[40] 5		99,386,235	.6
Texas	16,004,109	862,840	15,141,269		15,141,269		11,355,952				[41] 3,785,317	4	4		378,531,742	7.7
Utah	1,070,643	21,413	1,049,230	93	1,049,323	2,309	660,064		386,950			3½	4	May 12	28,774,682	.7
Vermont	751,806		751,806		751,806		751,806					4	4		18,789,365	4.9
Virginia	5,458,080	327,315	5,130,765		5,130,765		3,591,535	1,539,230				5	5		102,581,754	4.6
Washington	5,487,693	615,033	4,872,660		4,872,660	([42])	3,120,863	1,560,431			[43] 191,366	3	5	Apr. 1	117,506,219	7.5
West Virginia	2,463,954	99,002	2,364,952	4,525	2,369,477		831,375		1,538,102			4	4		59,123,817	.9
Wisconsin	6,420,208	413,330	6,006,878		6,006,878	4,598	3,793,492	1,956,722		252,066		2	4	Apr. 1	187,172,128	6.6
Wyoming	627,866		627,866		627,866		470,900	156,966				4	4		15,696,651	12.5
District of Columbia	881,646	5,087	876,559		876,559					876,559		2	2		43,827,986	17.4
Total			244,746,853	1,625,782	246,372,635	823,415	158,332,132	48,416,879	18,860,172	10,156,541	[44] 9,783,496	Average rate 3.44 cents			7,117,874,233	4.5

1 For State highway bonds, except as noted.
2 Column shows percentage increase, or decrease (−), over same period last year.
3 Increased to 5 cents on July 28, 1931.
4 From State appropriation, $8,936.
5 Includes $1,601,626 payments on county bonds.
6 Refund reserve released and returned to gasoline tax fund.
7 Includes all expenses of inspector of oils.
8 Paid from motor vehicle license receipts, $15,000.
9 Paid from State treasury.
10 Includes $12,015 from dealer's licenses and $2,217 from reserve fund to cover collection cost.
11 For county and town bonds.
12 Includes $200,000 to permanent building fund under State board of control for buildings of higher learning, remainder to schools under county boards of public instruction.
13 Emergency tax of 7 cents passed, and becomes effective Aug. 1, 1931, to July 1, 1933.
14 Clerk's salary for full year taken from first collections of year.
15 To an equalization school fund for public schools.
16 State treasury note payment.
17 From State general fund, $7,500.
18 Includes $443,093 for State Board of Education, and $443,093 for Boards of Commissioners of Port of New Orleans and Lake Charles Harbor.
19 Referendum petition postponed 5 cent tax until election in September, 1932.
20 Excludes 5,681,678 gallons taxed 1 cent for uses other than in motor vehicles.
21 Baltimore city only.
22 State appropriation $10,000.
23 For aviation fund; from taxes collected from gasoline sold for airplanes, included in "other receipts."
24 Includes 572,205 gallons sold for airplanes, tax for which is shown in "other receipts."
25 State appropriation, $7,146.
26 Includes expenses of State audit of accounts, $4,220.
27 For financing sea wall to protect road, partly paid by extra gasoline taxes in tide-water counties.
28 For inland waterways under State Department of Commerce and Navigation, partly paid for by 2 cent gas tax for motor boats.
29 Undistributed suspense fund.
30 Allowance of 1 per cent on gross receipts for loss in handling, and in addition $37,505 paid for collection cost from State treasury.
31 Includes $687,400 to New York city general funds, and $50,000 to reserve for refunds.
32 Disposition of funds approximate.
33 From State appropriation, $12,500.
34 Referendum petition prevented collection of 4 cent tax which will be voted upon in March, 1932.
35 Includes $756,241 to special emergency relief fund, and $39,678 to suspense accounts.
36 From motor-vehicle fees.
37 From State tax commission appropriation.
38 Reserve for refunds.
39 On State highway bonds, $983,924 and same amount for county bonds.
40 Increased to 6 cents on July 1, 1931.
41 For free-school fund, according to State constitution.
42 From motor-vehicle fund, $5,000.
43 Reserve for refunds.
44 Includes $7,406,416 for schools, $2,055,190 for special purposes (as noted) and $321,890 for suspense and reserve accounts.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

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

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1924.
Report of the Chief of the Bureau of Public Roads, 1925.
Report of the Chief of the Bureau of Public Roads, 1927.
Report of the Chief of the Bureau of Public Roads, 1928.
Report of the Chief of the Bureau of Public Roads, 1929.
Report of the Chief of the Bureau of Public Roads, 1930.

DEPARTMENT BULLETINS

No. *136D Highway Bonds. 20c.

*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.

*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.

*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.

*660D. Highway Cost Keeping. 10c.

1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.

1486D. Highway Bridge Location.

DEPARTMENT CIRCULAR

No. 331C. Standard Specifications for Corrugated Metal Pipe Culverts.

TECHNICAL BULLETIN

No. 55T. Highway Bridge Surveys.

SEPARATE REPRINT FROM THE YEARBOOK

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

MISCELLANEOUS CIRCULARS

No. 62MC. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.

*93MC. Direct Production Costs of Broken Stone. 25c.

109MC. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

MISCELLANEOUS PUBLICATION

No. 76MP. The Results of Physical Tests of Road-Building Rock.

TRANSPORTATION SURVEY REPORTS

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

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

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

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

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

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. 11, No. 10, D-15. Tests of a Large-Sized Reinforced-Concrete Slab Subjected to Eccentric Concentrated Loads.

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

OCTOBER 31, 1931

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,357.4	$ 2,752,593.91	$ 1,341,440.01	98.9	12.2	111.1						$ 5,323,972.91	Alabama
Arizona	1,043.4	4,428,904.52	3,106,398.60	216.8	72.3	289.1	$ 215,102.75	$ 161,950.85	20.0	19.8	39.8	1,685,377.32	Arizona
Arkansas	1,860.0	4,717,650.89	2,343,177.54	114.4	85.6	200.0	362,032.53	181,016.26	17.3		17.3	1,957,501.16	Arkansas
California	2,022.1	12,971,335.22	5,255,603.52	353.6	79.6	433.1	1,486,749.49	283,776.96	25.5	3.6	29.1	4,147,203.88	California
Colorado	1,436.1	5,590,381.33	2,916,061.48	249.3	82.0	331.3	944,874.75	479,281.34	28.3	4.5	32.8	2,302,759.11	Colorado
Connecticut	276.8	3,948,540.61	1,426,527.04	34.5		34.5						687,401.80	Connecticut
Delaware	353.4	521,793.00	260,142.00	12.5		12.5						569,728.08	Delaware
Florida	554.4	6,147,898.61	2,872,456.15	174.4		174.4						3,046,471.31	Florida
Georgia	2,975.2	6,995,889.51	3,192,097.75	160.1	160.0	320.1	620,396.25	230,315.46	9.2	15.7	24.9	2,871,344.42	Georgia
Idaho	1,421.9	2,190,639.09	1,310,813.68	139.7	82.7	222.4	468,908.90	232,896.59	13.6	7.4	21.0	1,475,512.52	Idaho
Illinois	2,537.5	22,638,753.74	10,446,811.19	680.1	28.7	708.8	5,135,028.04	2,332,334.60	164.3	4.7	169.0	3,544,043.42	Illinois
Indiana	1,630.9	11,116,667.28	5,484,158.40	345.6		345.6	1,729,695.47	824,485.40	62.5	12.5	75.0	2,548,193.74	Indiana
Iowa	3,314.8	2,376,684.14	850,411.47	55.4	22.3	77.7						2,842,419.77	Iowa
Kansas	3,567.0	4,283,194.25	2,010,573.24	230.5	28.8	259.3	16,608.05	8,304.02	2.8		2.8	3,065,290.49	Kansas
Kentucky	1,711.6	4,103,393.25	1,897,832.32	238.9	60.0	298.9	112,797.25	56,398.61	3.2	4.0	7.2	2,017,274.55	Kentucky
Louisiana	1,455.0	8,005,957.77	3,691,415.08	189.1	20.3	209.4	2,567,840.55	135,581.56	1.0		1.0	1,580,926.58	Louisiana
Maine	666.8	3,624,948.75	1,512,185.42	70.7		70.7	37,546.34	14,085.00	.9		.9	1,285,660.42	Maine
Maryland	762.2	806,057.95	331,912.28	21.3		21.3						911,088.46	Maryland
Massachusetts	754.8	11,923,157.53	3,579,081.86	94.6		94.6	1,766,074.36	463,330.15	17.6		17.6	1,260,102.69	Massachusetts
Michigan	1,865.6	11,117,448.45	4,858,444.98	375.1	50.3	425.4	564,678.15	282,339.07	37.0		37.0	4,385,828.30	Michigan
Minnesota	3,957.6	8,514,289.67	3,684,152.47	79.5	318.0	397.5	789,974.64	246,000.00	38.1	14.3	52.4	2,734,307.67	Minnesota
Mississippi	1,782.2	4,025,405.52	1,973,890.24	184.3	70.6	254.9	242,383.87	119,760.39		12.6	12.6	5,694,583.56	Mississippi
Missouri	2,867.3	4,961,993.49	2,049,321.87	135.6	20.8	156.4						3,544,718.24	Missouri
Montana	2,381.0	8,409,258.95	4,719,276.84	533.8	72.1	605.9	1,045,177.24	587,946.47	98.3	28.0	126.3	2,940,090.52	Montana
Nebraska	3,899.1	8,493,691.01	4,012,001.98	295.1	146.4	441.5	25,464.82	12,727.40		18.3	18.3	2,575,697.73	Nebraska
Nevada	1,155.7	2,772,153.01	1,885,134.85	98.4	212.9	311.3	4,951.87	4,399.73		.5	.5	1,553,866.48	Nevada
New Hampshire	407.4	1,101,793.55	407,090.45	21.7	4.3	26.0						529,375.00	New Hampshire
New Jersey	573.9	6,227,244.82	2,160,299.27	67.6	.6	68.2	560,151.74	275,075.87		.2	.2	1,699,922.94	New Jersey
New Mexico	2,245.9	1,625,133.61	1,065,552.06	67.4	11.7	79.1	127,281.76	80,452.98	2.4		2.4	1,845,211.88	New Mexico
New York	2,871.7	30,638,380.33	12,188,747.50	631.3		631.3	1,624,800.00	644,000.00	36.5		38.5	5,439,782.04	New York
North Carolina	2,184.0	2,321,261.35	1,141,703.19	71.6	4.0	75.6	413,800.68	196,212.82	19.2	11.5	30.7	3,954,388.61	North Carolina
North Dakota	4,949.4	2,355,013.05	1,181,109.96	237.8	264.7	502.5	780,313.54	405,639.84	102.1	138.7	240.8	2,242,271.96	North Dakota
Ohio	2,665.3	13,394,647.41	4,806,622.57	233.3	35.1	268.4	1,383,489.96	463,111.27	30.6	5.7	36.3	4,555,650.28	Ohio
Oklahoma	2,138.7	6,082,187.53	2,978,239.98	170.4	105.1	275.5	4,489.14	2,482.49				2,552,189.41	Oklahoma
Oregon	1,467.0	4,603,523.94	2,586,858.52	163.1	35.6	198.7						2,141,009.20	Oregon
Pennsylvania	2,863.3	8,807,507.76	3,872,892.56	194.8		194.8	15,183.78	7,040.14	.1		.1	5,101,432.42	Pennsylvania
Rhode Island	249.7	1,087,677.93	309,140.62	14.3		14.3						662,607.52	Rhode Island
South Carolina	1,951.8	3,226,699.25	1,417,073.56	66.7	65.8	132.5	564,458.79	150,042.23	19.7	9.0	28.7	1,489,704.30	South Carolina
South Dakota	3,940.1	3,755,472.01	2,134,989.03	232.1	210.7	442.8	158,622.23	93,635.86	2.9	12.7	15.6	1,612,467.40	South Dakota
Tennessee	1,670.7	548,910.76	274,452.78	9.3		9.3	508,641.04	231,532.60	8.6	15.1	23.7	4,043,659.50	Tennessee
Texas	7,300.1	16,462,467.16	7,737,071.86	779.8	244.1	1,023.9	2,756,672.19	1,206,709.59	141.3	51.3	192.6	7,807,980.58	Texas
Utah	1,177.2	1,055,941.05	641,880.37	57.1	29.6	86.7	234,316.57	157,222.73	18.9	.2	19.1	1,466,306.01	Utah
Vermont	313.9	976,900.81	412,307.19	29.6		29.6						540,222.52	Vermont
Virginia	1,775.0	3,903,338.22	1,807,530.75	176.9	22.0	198.9	779,512.29	389,622.19	39.5	7.4	46.9	2,081,876.71	Virginia
Washington	1,140.2	2,761,555.50	1,274,313.58	77.1	18.2	95.3	491,468.47	264,400.00	17.1		17.1	2,074,145.27	Washington
West Virginia	624.1	3,702,648.67	1,610,166.06	101.2	13.8	115.0	97,329.39	40,854.05	.6		.6	1,256,505.76	West Virginia
Wisconsin	2,517.1	7,283,713.53	2,830,850.92	228.8	73.1	301.9	46,991.91	16,000.00	2.6		2.6	2,663,746.75	Wisconsin
Wyoming	1,944.3	2,423,476.72	1,360,830.38	181.9	107.9	289.8	419,067.23	234,960.95	48.8	15.2	64.0	1,350,546.63	Wyoming
Hawaii	59.3	1,094,751.98	481,061.26	31.6		31.6	82,324.99	22,869.00	1.5		1.5	2,044,877.80	Hawaii
TOTALS	96,959.9	292,868,928.39	131,690,106.68	9,027.5	2,871.9	11,899.4	29,174,171.02	11,538,774.45	1,032.0	412.9	1,444.9	125,577,242.80	TOTALS

[1] The term stage construction refers to additional work done on projects previously improved with Federal-aid. In general, such additional work consists of the construction of a surface of higher type than was provided in the initial improvement.

U. S. GOVERNMENT PRINTING OFFICE: 1931