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ROAD-MIX CONSTRUCTION IN CALIFORNIA

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EXPERIMENTS WITH ROAD-MIXES AND SURFACE TREATMENTS IN CALIFORNIA

Reported by T. E. STANTON, Materials and Research Engineer, Division of Highways, California, and J. T. PAULS, Senior Highway Engineer, U. S. Bureau of Public Roads

LIQUID asphaltic materials of the slow-curing type have been used extensively in the Western States during the last few years in the construction of the road-mix or mixed-in-place types of surfaces. In general, they have given satisfactory results in the arid and semiarid sections. However, these materials have not been entirely satisfactory in the more humid areas or with certain kinds of aggregates, and a need has been felt for some experimental work to determine the limitations of the materials and to obtain information as to other materials and methods of construction which might be used to better advantage under these special conditions.

The series of experimental sections described in this report included a wide range in the features commonly involved in the construction of the road-mix and surface-treatment types.

The experimental sections were built during 1929 and 1930 by the division of highways, California Department of Public Works, in cooperation with the Bureau of Public Roads. The 21 sections cover a length of 10 miles on U. S. 30, beginning at the California-Nevada State line and extending southwest toward Truckee.

EXPERIMENTS COVERED A NUMBER OF TYPES OF CONSTRUCTION

The experiments are grouped with respect to the type of construction and materials used as follows:

1. Road-mixes of crushed stone and gravel aggregates with different types and grades of bituminous materials.
2. Surface treatment of road-mixes.
3. Surface treatments on a traffic-bound stone base course.

The location of the different experiments and the details of their construction are given in tables 1 and 7.

The road on which the experimental sections were built had been graded and drained and surfaced with selected soil containing some granular material. In the summer of 1927, following this construction, an oil-mixed surface from 2 to 3 inches in thickness was built using local aggregate. On the westerly 3 miles a crushed red volcanic ash was used in the surface mix and this surfacing failed extensively. The remaining 7 miles, on which crushed granite had been used, was in better, condition but, in general, failure had developed on the whole project to such an extent that reconstruction of the surface was necessary at the time the experiments were begun. Figure 1 is an illustration of a condition typical of the old surface.

The road is in a section where the climate is severe and the moisture conditions are unfavorable. The average elevation is more than 5,000 feet and the range in temperature is from about 95° F. above zero to as low as −30° F. Considerable snow lies on the road until late in the spring and, as the road is located largely in heavy sidehill cuts, the moisture conditions during winter and spring are particularly bad, due to the heavy flow of water and sliding of earth which occur at this time of year. Figure 2 shows a typical condition during the spring. Yearly traffic counts over the period from 1929 to 1933 show a daily traffic on week days of 1,300 vehicles and as many as 3,500 vehicles are counted on Sundays.

Subgrade samples were taken at intervals under the edge of the old surface and the results of analyses are given in table 2.

The experimental sections were each approximately one-half mile in length, with the exception of sections 11, 12, and 13, which were one-third mile. Sections were numbered from east to west beginning at the State line and ending with section 21 at the west end of the project. The surface was made 20 feet wide in all cases and the compacted thickness of both the road-mix surfacing and also the traffic-bound stone course for surface treatment was 3 inches.

As a basis for correlation of data obtained on materials, methods of construction, and service behavior, two observation or test points were selected in each section, approximately 700 feet from each end. The locations of these points were marked in the field by 3- by 3-inch painted posts and identified by the number of the section and the letter A if near the easterly end, and B if near the westerly end. At these points samples were taken to determine the condition of the old surface and the character of the subgrade soil. Immediately prior to applying the bituminous material the aggregate was sampled to determine the moisture content and the mechanical analysis. Samples of the surface mixture were taken at these locations during compaction and at several intervals thereafter. Results of tests on these samples to determine the bitumen content, grading, and stability are given in table 3. Wherever the right or left portion of the roadway is mentioned in the report the reference is to the right and left of an observer facing in the direction of the stationing and the beginning of the project.

Except for the ¾- to ⅛-inch stone, the crushed stone used was produced locally at a roadside crushing plant shown in figure 3. The local material was a highly weathered granite, friable and very light, the crusher-run material weighing only about 2,300 pounds per cubic yard, and the open-graded material weighed 1,970 pounds. The ¾- to ⅛-inch stone was the same type of material but of somewhat better quality and was shipped in by rail from Oroville, Calif. The fine material, known locally as muck sand, which was added to the aggregate on several of the sections to increase the percentage passing the no. 200 sieve, was shipped in by rail from Sacramento. Washed gravel, 1 to ⅛ inch in size, and crushed gravel ranging from 5/16-inch to dust, were obtained from Fair Oaks, Calif. Combinations of these sizes were used on the road-mix sections and satisfactory mixing was obtained by depositing the materials on the subgrade in the proportions of 25 percent of the coarser uncrushed gravel to 75 percent of the finer crushed gravel and blading it in windrows.

Table 1.—*Materials used on road-mix experimental sections. All sections were surfaced with 3 inches of compacted material placed in 1929 and seal treatments were given to some sections in 1929 and 1930*

Section	Type of bituminous material and quantity applied in gallons per square yard	Type and size of aggregate	Bituminous material and cover used in seal treatment
13	95+L asphaltic emulsion 2.00 gals. Aggregate premixed with water at rate of 2.23 gals. per sq. yd.	Crushed stone, ¾ inch to dust	95+L2 asphaltic emulsion with ½ inch to ⅛ inch crushed stone cover. Right - .21 gal. emulsion; 11 pounds cover. Left - .18 gal. emulsion; 13 pounds cover. 95+L asphaltic emulsion, .3 gal; cover material, crushed stone, ¼ inch to ⅛ inch, 11 pounds.
12	95+M asphaltic emulsion, 1.84 gals. Premixed with 60-70 slow-curing oil, .70 gal. Enriched with 110-120 M asphaltic emulsion, .23 gal.	Crushed stone, ¾ inch to dust	95+L2 asphaltic emulsion, .21 gal. on right and .18 gal. on left; cover material, crushed stone, ½ inch to ⅛ inch, 11 pounds. Mixture of 95+M and 95+L asphaltic emulsion, .3 gal; cover material, crushed stone, ¼ inch to ⅛ inch, 11 pounds.
11	110-120 M asphaltic emulsion, 1.54 gals. Premixed with 60-70 slow-curing oil, .48 gal. Enriched with 95+M asphaltic emulsion, .48 gal.	Crushed stone, ¾ inch to dust	95+L2 asphaltic emulsion, .17 gal. on right and .18 gal. on left; cover material, crushed stone, ½ inch to ⅛ inch, 11 pounds. Mixture of 95+M and 95+L asphaltic emulsion, .3 gal; cover material, crushed stone, ¼ inch to ⅛ inch, 11 pounds.
10	94+ asphaltic oil cut back with kerosene, 1.58 gals. and 110-120 cut-back asphalt, .14 gal.	Crushed gravel, 75 percent ⅝ inch to dust, 25 percent 1 inch to ⅝ inch	
9	94+ asphaltic oil cut back with kerosene, 1.86 gals.	Crushed stone, ¾ inch to dust with 12.7 percent fines added	
8	70-80 slow-curing oil, 1.24 gals.	Crushed stone, ¾ inch to ⅜ inch	
7	70-80 slow-curing oil, 2.16 gals.	Crushed stone, ¾ inch to dust with 8.8 percent fines added	
6	60-70 slow-curing oil, 1.40 gals.	Crushed stone, ¾ inch to dust	94+ asphaltic oil, applied hot, .28 gal. on right and .22 gal. on left; cover material, crushed stone, ½ inch to ⅛ inch, 18.7 pounds.
5	60-70 slow-curing oil, 1.70 gals.	Crushed stone, ¾ inch to dust with 5.7 percent fines added	60-70 slow-curing oil, .17 gal. on right and .10 gal. on left; cover material, crushed stone, ½ inch to ⅛ inch, 19 pounds.
4	60-70 slow-curing oil, 1.78 gals.	Crushed stone, ¾ inch to dust with 6.4 percent fines added	540+44 = 0+00
3	60-70 slow-curing oil, 1.70 gals.	Crushed gravel, 75 percent ⅝ inch to dust, 25 percent 1 inch to ⅝ inch	
2	110-120 asphalt cut back with kerosene, 1.40 gals.	Crushed stone, ¾ inch to ⅛ inch	
1	110-120 asphalt cut back with kerosene, applied as follows: 2.47 gals. 1320'; 1.92 gals. 660'; 1.71 gals. 639'	Crushed stone, ¾ inch to dust; 6.5 percent fines added	

Stations: 306+23, 311+23, 326+19, 331+09, 340+69, 345+79, 349+69, 357+49, 361+39, 387+82, 414+25, 440+67, 467+07, 493+47, 520+55, 6+70, 33+10, 59+50, 65+69. STATE LINE

Table 2.—*Results of tests on subgrade soil samples*

Section and location	Mechanical analysis [1]: Particles larger than 2 millimeters	Particles smaller than 2 millimeters: Coarse sand, 2 to 0.25 millimeters	Fine sand, 0.25 to 0.05 millimeter	Silt, 0.05 to 0.005 millimeter	Clay, less than 0.005 millimeter	Colloids, less than 0.001 millimeter	Physical characteristics of material passing no. 40 sieve: Liquid limit	Plasticity index	Shrinkage limit	Shrinkage ratio	Moisture equivalent: Centrifuge	Field	Soil group
	Percent	Percent	Percent	Percent	Percent	Percent							
1, A	44	52	30	14	4	2	22	5	18	1.8	15	18	A-2, plastic.
B	27	42	32	19	7	1	36	16	19	1.8	34	25	A-4.
2, A	42	60	23	14	3	2	20				14	19	A-2, nonplastic.
B	42	60	28	10	2		23	5	20	1.7	17	20	A-2, plastic.
3, A	39	53	29	15	3	2	23	3			17	21	Do.
B	51	41	30	23	6	2	31	11	21	1.7	28	25	A-4.
4, A	39	62	22	13	3	2	26	6	19	1.7	19	22	A-2, plastic.
B	46	41	33	20	6	2	39	17	19	1.7	33	30	A-7.
5, A	28	37	27	14	13	6	38	16	18	1.8	35	29	Do.
B	50	54	26	14	6	2	31	10	21	1.7	23	26	A-2, plastic.
6, A	14	51	26	18	5	1	24	4			16	22	Do.
B	51	45	31	14	10	4	29	5	21	1.7	23	26	Do.
7, A	26	34	35	24	7	1	29	9	21	1.7	25	25	Do.
B	39	28	38	21	13	5	32	11	22	1.7	24	26	Do.
8, A	40	35	35	22	8	2	27	6	22	1.7	22	24	A-4.
B	41	22	41	25	12	5	36	14	21	1.7	32	30	Do.
9, A	30	38	28	27	7	1	39	19	20	1.7	33	30	A-7.
B	24	47	35	15	3	1	26	6	22	1.7	15	23	A-2, plastic.
10, A	30	51	30	16	3	1	23	4	22	1.7	19	21	Do.
B	29	20	17	33	30	13	52	23	26	1.6	49	43	A-7.
11, A	24	38	29	23	10	3	35	15	19	1.7	32	27	A-4.
12	45	27	24	34	15	5	46	19	23	1.6	48	39	A-7.
13	38	23	24	42	11	2	37	12	20	1.7	41	29	A-4.
15, B	43	35	33	20	12	5	19				17	22	A-2, nonplastic.
16, B	39	38	42	13	7	3	22				15	22	Do.
17, B	26	28	36	23	13	5	23	3	22	1.6	26	24	A-4.
18, A	27	27	31	24	18	8	27	8	24	1.6	30	27	A-4.
B	37	49	35	11	5	3	27				23	29	A-2, nonplastic.
19, A	28	25	31	23	21	8	31	7	27	1.6	39	31	Do.
20, A	4	17	25	28	30	16	51	27	17	1.8	56	39	A-7.
B	37	24	32	23	21	13	27	7	21	1.7	27	22	A-4.
21, A	46	11	24	39	26	11	48	17	34	1.4	58	41	A-5.
B	2	4	18	49	29	8	69	27	33	1.4	78	58	Do.

[1] Particles above 0.074 mm in diameter by sieve method; particles below 0.074 mm in diameter by the hydrometer method.

GENERAL METHOD OF CONSTRUCTING ROAD-MIX SECTIONS DESCRIBED

The road-mix type of construction was used on sections, 1 to 13, inclusive. The bituminous materials used on these sections included slow-curing oils of 60–70 and 70–80 asphalt content, medium-curing kerosene cut backs of 94+ asphaltic oil and of 110–120 penetration asphalt, and emulsions of 95+ asphaltic oil and 110–120 penetration asphalt designated as 95+ M, 95+ L and 110–120 M, respectively. Analyses of the bituminous materials are given in tables 4 and 5. Tests on these materials were made according to the methods used at the time of construction and are therefore not those now generally advocated. The approximate Saybolt-Furol viscosity values have, however, been included in the tables to facilitate comparison with present grades of asphaltic materials.

With the exception of the 70–80 slow-curing oil, the consistencies of the liquid asphaltic materials used in the road-mix sections, expressed as specific viscosity, Engler, at 122° F., ranged from 64 to 100. In terms of Saybolt-Furol viscosity, the range is from 255 to 400 seconds. For the medium-curing cut-back materials, 20 to 25 percent of kerosene was required in the manufacture to soften the base asphalt to the required consistency.

FIGURE 1.—TYPICAL CONDITION OF THE OLD SURFACE AT TIME OF CONSTRUCTION.

The bituminous materials were delivered in tank cars which were heated to about 100° to 150° F.; the asphalt was pumped into tank trucks and hauled to the job. A detachable pressure distributor was used for spreading.

The aggregate was hauled in trucks and dumped in two windrows, one on each edge of the roadbed. The correct amount of aggregate was obtained by measuring the loads at the place of loading and spreading them over measured distances on the road. On those sections requiring the addition of fines, the procedure was to add this material to the top of the windrows and then mix the two together before applying the oil. The grading of the aggregate was determined by frequent sampling and testing at the loading plant and by later tests on the material in the windrows immediately before applying the oil. The amount of fines or filler to be added was determined from frequent mechanical analyses of the aggregate at the loading plant.

A typical grading of the fine muck-sand added to the crusher-run aggregate on a number of the sections to increase the percentage of material passing the no. 200 sieve was as follows:

Screen or sieve size:	*Percent passing*
¼ inch	100. 0
No. 10	99. 7
No. 20	99. 0
No. 30	98. 7
No. 40	98. 0
No. 50	97. 2
No. 80	89. 4
No. 100	82. 0
No. 200	57. 3

The amount of bituminous material required was determined largely from the appearance of the mix, the grading of the aggregate, and the results obtained during the progress of the work. The detailed descriptions of the sections show the grading of the aggregate and the amount of water determined at the time of mixing. Table 3 gives additional information from tests made on the mixes at different intervals following the construction. Comparisons, of the amount of oil used and that required according to various formulas based on the grading of the aggregate can be made from the data in table 6.

Prior to adding the bituminous material, one windrow of aggregate was moved to about midway between the edge and the center of the roadway and spread to a width of approximately 10 feet. The oil was then applied in three applications and disked in after each application. After the last application of oil, the materials were mixed with blade machines, using the usual turn-over method, until the aggregate had a uniform coating. It was then left in a windrow at the edge of the road and the same procedure was followed on the opposite windrow, after which the 2 were combined and mixed again 5 or 6 times to insure uniformity.

FIGURE 2.—DURING THE SPRING, SLIDES CAUSED POOR DRAINAGE AT NUMEROUS POINTS.

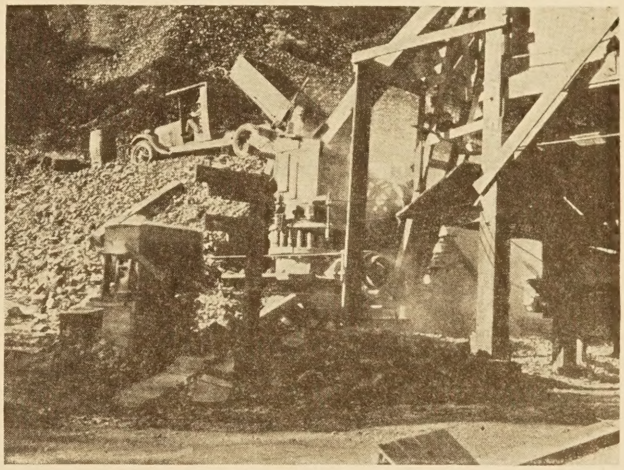

FIGURE 3.—THE ROADSIDE CRUSHING PLANT CONSISTING OF A JAW CRUSHER AND A GYRATORY CRUSHER.

In the construction of those sections where emulsions were used it was found advantageous to blade the material into a windrow following each application of oil and subsequent disking. Blade machines were used, one on each edge of the material, each turning toward the other, followed by a third machine which flattened the windrow thus formed in preparation for the next application. The arrangement of equipment is shown on the cover page.

Upon the completion of the mixing process the material was windrowed to the center of the road and spread by blading toward each edge. After spreading to the full width, a light power grader was used to smooth and maintain the surface.

TABLE 3.—*Results of tests of samples from mixed surfaces*

Section and location	Date sampled	Data on mix			Analyses of samples by weight						Results of tests on oiled material passing no. 10 sieve						
		Bituminous material		Aggregate	Grading of mineral aggregate after extraction. Dry aggregate passing—				Extracted bitumen	Water	Loss of volatile matter from binder in Hubbard-Field specimens cured at 60° C.[1]			Hubbard-Field stability at 25° C.			
		Type	Gallons per square yard		1-inch screen	¼-inch screen	No. 10 seive	No. 200 seive			1 day	5 days	10 days	As made	Cured at 60° C. 1 day	Cured at 60° C. 5 days	Cured at 60° C. 10 days
					Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Pounds	Pounds	Pounds	Pounds
1, A	Sept. 17, 1929 [2]	110-120 asphalt cut back with kerosene.	1.71	Crushed stone, ¾ inch to dust	100.0	36.7	24.7	4.4	4.0	0.2	[3] 10.16	[3] 17.22	[3] 18.89				
A	June 25, 1930				100.0	45.3	26.6	4.9	3.3	.7							
B	Sept. 17, 1929 [2]	do	1.92	Crushed stone, ¾ inch to dust with fines added.	100.0	41.5	28.8	6.3	3.9	.3	[3] 10.93	[3] 20.59	[3] 21.92				
B	June 25, 1930				100.0	46.1	29.8	7.0	3.6	.9							
C	Sept. 17, 1929 [2]	do	2.47	do	100.0	45.3	32.9	9.4	4.3	.4	[3] 11.73	[3] 19.57	[3] 20.74				
C	June 23, 1930				100.0	49.0	33.6	8.8	3.3	2.0							
2, A	Sept. 7, 1929 [2]	do	1.40	Crushed stone, ¾ to ⅛ inch	100.0	35.5	13.9	2.6	3.8	.1	[3] 5.21	[3] 9.01	[3] 11.02				
A	June 23, 1930				100.0	41.3	14.3	3.0	3.4	.1							
B	Sept. 7, 1929 [2]				100.0	35.6	14.7	3.2	4.0	.1	[3] 4.89	[3] 8.55	[3] 10.26				
B	June 23, 1930				100.0	39.7	14.8	3.8	3.7	.1							
3, A	Sept. 6, 1929 [2]	60-70 slow-curing oil	1.70	Gravel 1 inch to dust, 25 percent 1 to ⅛ inch uncrushed and 75 percent 5/16 inch to dust crushed.	95.0	44.7	33.8	6.7	2.9	.2	2.27	4.58	5.38	1,925	2,575	2,825	2,935
A	June 23, 1930				87.0	47.4	35.2	7.2	3.8	.2							
B	Sept. 6, 1929 [2]				94.7	51.7	43.7	8.5	4.2	.1	2.27	3.15	3.24		2,300	2,625	2,625
B	June 23, 1930				93.2	58.0	44.0	9.1	3.7	.8							
4, A	Sept. 3, 1929 [2]	do	1.78	Crushed stone, ¾ inch to dust with fines added.	100.0	39.1	30.7	7.8	2.8	1.0	4.37	9.76	11.18	2,575	3,625	4,375	4,150
A	Sept. 21, 1930				95.0	49.4	35.1	8.5	3.2	1.5							
B	Sept. 3, 1929 [2]				100.0	46.0	35.3	8.9	3.5	.8		9.07	11.85	2,375	3,610	4,300	4,075
B	June 21, 1930				100.0	41.7	29.4	7.7	2.9	.9					[4] 2,875		[4] 3,660
5, A	Sept. 3, 1929 [2]	do	1.70	do	100.0	54.9	40.6	10.3	2.7	1.3	5.32	10.33	11.59	2,675	3,575	4,175	4,125
A	May 21, 1930				100.0	53.9	39.4	10.4	[5] 3.2	1.2					[4] 2,975		[4] 3,560
B	Sept. 3, 1929 [2]				100.0	47.7	35.3	8.6	3.0	.7	6.75	12.08	12.76	2,800	4,100	5,175	4,075
B	May 21, 1930				100.0	55.6	37.7	9.9	[5] 3.6	.9							
6, A	Aug. 16, 1929 [2]	do	1.40	Crusher-run stone, ¾ inch to dust	100.0	46.7	34.0	6.9	3.5	.0	7.73		11.96	2,375	3,610	4,435	4,075
A	May 21, 1930				100.0	51.5	34.6	8.1	[5] 4.0	.8					[4] 3,400		[4] 3,450
B	Aug. 16, 1929 [2]				100.0	63.9	45.0	8.8			4.97	11.00	11.75		3,975	4,375	4,085
B	June 21, 1930				100.0	49.8	33.3	8.5	[5] 3.6	1.3							
7, A	Sept. 17, 1929 [2]	70-80 slow-curing oil	2.16	Crushed stone, ¾ inch to dust with fines added.	100.0	54.5	40.7	10.7	4.4	.8							
A	June 21, 1930				100.0	64.1	45.7	12.3	4.4	.6							
B	Sept. 17, 1929 [2]				97.5	42.0	32.8	8.8	5.3	.4	[3] 7.68	[2] 12.28	[3] 12.62				
B	June 21, 1930				100.0	55.5	39.1	11.6	5.8	.7							
8, A	Sept. 23, 1929 [2]	do	1.24	Crushed stone, ¾ inch to ⅛ inch	100.0	32.5	17.0	3.9	3.3	.0	[3] 4.48	[2] 5.38	[3] 6.05				
A	June 20, 1930				100.0	35.9	14.8	4.1	3.6	.2							
B	Sept. 23, 1929 [2]				100.0	36.5	18.3	4.9	3.2	.2	[3] 6.18	[2] 8.83	[3] 9.49				
B	June 20, 1930				100.0	46.6	18.0	5.0	3.4	.2							
9, A	June 23, 1929 [2]	94+ asphaltic oil cut back with kerosene.	1.86	Crushed stone, ¾ inch to dust with fines added.	100.0	43.5	32.4	9.2	4.1	.7	1.95		6.45		3,300		5,235
A	June 20, 1930				100.0	41.3	28.4	8.5	3.4	1.4							
B	Sept. 23, 1929 [2]				100.0	35.6	28.0	9.3	4.6	.4	1.66	5.12	6.09		3,675	4,435	4,135
B	June 20, 1930				100.0	45.7	31.6	10.6	3.5	.9							
10, A	Sept. 24, 1929 [2]	do	1.72	Gravel, 1 inch to dust, 25 percent 1 to ⅛ inch uncrushed, 75 percent 5/16 inch to dust crushed.	100.0	76.5	52.1	11.5	3.8	.0	1.70	5.18	5.89		3,575	5,265	6,000
A	May 19, 1930				100.0	66.7	46.0	9.8	4.0	.1							
B	Sept. 4, 1929 [2]				100.0	62.1	52.1	10.5	4.6	.1	2.17	4.65	5.80	3,075	3,650	4,700	5,075
B	June 19, 1930				97.0	64.3	49.8	11.1	4.0	.5							
11, A	Sept. 24, 1929 [2]	60-70 slow-curing oil and 110-120 M asphaltic emulsion.	(6)	Crusher-run stone, ¾ inch to dust	100.0	36.0	27.4	5.9	5.4	.4	[3] 12.54	[2] 14.67	[3] 14.67				
A	June 19, 1930				100.0	36.2	22.5	5.2	4.3	.2							
B	Sept. 24, 1929 [2]				100.0	33.8	24.0	4.9	4.6	.2	[3] 14.85	[2] 17.17	[3] 17.38				
B	June 18, 1930				100.0	34.5	21.0	4.9	3.4	.6							
12, A	Sept. 26, 1929 [2]	60-70 slow-curing oil and 95+ M asphaltic emulsion.	(6)	do	100.0	31.6	22.9	5.4	3.8	.6	[3] 13.60	[2] 15.90	[3] 16.85				
A	June 18, 1930				100.0	35.3	23.0	6.2	4.8	.8							
B	Sept. 6, 1929 [2]				100.0	43.2	30.5	8.1	4.8	.6	[3] 15.37	[2] 16.59	[3] 17.67				
B	June 18, 1930				100.0	47.4	32.9	8.1	4.6	2.1							
13	Sept. 30, 1929 [2]	Water and 95+ L asphaltic emulsion.	(6)	do	100.0	37.4	22.6	4.7	1.4	1.0	[3] 45.73	[2] 46.72	[3] 48.26				
	June 18, 1930				100.0	41.9	25.5	5.1	[5] 2.7	2.1							

1 Percentage loss based on amount of water and bitumen in the mix.
2 Sampled during compaction.
3 Tests on loose samples.
4 Tested at 60° C.
5 Includes seal.
6 See table 1.

TABLE 4.—*Analyses of bituminous materials used on various sections (asphalt emulsions excepted)*

Grade and type of material	110–120 penetration asphalt cut back with kerosene			60–70 slow-curing oil	60–70 slow-curing oil		60–70 slow-curing oil	60–70 slow-curing oil	70–80 slow-curing oil	
How and where used	Mix on secs. 1, 2, and 10			Mix on sec. 3	Mix on secs. 4 and 5		Seal on sec. 5, premix on secs. 11 and 12	Mix on sec. 6	Mix on secs. 7 and 8	
Specific gravity at 25° C	0.970	0.965	0.965	0.968	0.968	0.968	0.969	0.968	0.975	0.979
Flash point, C.O.C., °C	79	80	77	143	142	145	149	142	174	166
Specific viscosity Engler at 50° C	78.9	72.7	81.0	64.2	75.7	79.1	82.5	69.4		
Approximate Saybolt-Furol at 50° C., seconds	315	290	325	255	305	315	330	280		
Specific viscosity Engler at 100° C									9.3	12.1
Float test at 50° C., seconds									32.4	45
Loss 163° C., 5 hours, 50 centimeters, percent	13.28	14.00	13.00	6.5	11.0	10.2	9.5	6.6	1.9	1.9
Float on residue at 50° C., seconds	75.8	89	78	25.2	28.4	28.8	29.7	25.4	40.4	49.6
Loss at 163° C., 5 hours, 20 centimeters, percent	17.39	18.6	17.8	9.2	14.5	14.0	12.5	9.7	2.7	2.8
Float on residue at 50° C., seconds	153.6	207	188	35.8	35.4	34.8	39.6	35.2	41.8	53
Soluble in CS_2, percent	99.79	99.82	99.88	99.79	99.82	99.80	99.82	99.81	99.88	99.82
Organic matter insoluble, percent	.18	.13	.11	.18	.17	.18	.14	.16	.11	.16
Inorganic matter insoluble, percent	.03	.05	.01	.03	.01	.02	.04	.03	.01	.02
Bitumen insoluble in 86° B. naphtha, percent	8.05	8.93	9.71	3.87	3.03	4.17	4.44	4.29	3.61	6.47
Residue of 100 penetration, percent	75.3	76.2	75.7	61.0	60.9	61.7	65.4	61.8	72.7	77.2
Penetration on residue at 25° C., 100 centimeters, 5 seconds	103	112	102	109	104	113	112	89	89	92
Penetration on residue at 0° C. 200 centimeters, 60 seconds	19	25	22	23	20	27	21	19	17	19
Softening point of residue, °C	44.2	44.4	46.2	44.4	42.6	39.8	46.0	45.2	45.6	45.4
Ductility of residue at 25° C., centimeters	110+	110+	110+	110+	110+	110+	87	110+	110+	110+
Ductility of residue at 1.5° C., centimeters	7.0	5.2	4.6	[1] 1.8	7.2	[1] 2.0	[1] 1.6	[1] 2.2	6.0	1.8

Grade and type of material	94+ asphaltic oil cut back with kerosene		50–60 slow-curing oil	110–120 penetration asphalt cut back with kerosene	150–200 penetration asphalt	94+asphaltic oil	110–120 asphalt cut back with naphtha	50–60 slow-curing oil	50–60 slow-curing oil
How and where used	Mix on secs. 9 and 10		Priming on left lane of secs. 14, 15, 16, and 17	Priming on right lane of secs. 14, 15, 16, and 17	Surface treatment on sec. 14	Surface treatment on secs. 15 and 16	Surface treatment on sec. 17	Priming on sec. 18	Priming on secs. 18, 19, 20, and 21
Specific gravity at 25° C	0.971	0.966	0.945	0.943	1.004	1.011	0.958	0.948	0.945
Flash point, C.O.C., °C	88	85	117	68	262	243	38	123	115
Specific viscosity Engler at 50° C	100.2	92.2	18.8	17.2			51.9	20.7	17.6
Approximate Saybolt-Furol at 50° C., seconds	400	370	75	70			240	85	70
Float test at 50° C., seconds					265	248			
Penetration at 25° C., 100 centimeters, 5 seconds					181	199			
Softening point, °C					39.8	40.8			
Ductility at 25° C., centimeters					110+				
Loss 163° C., 5 hours, 50 centimeters, percent	12.6	12.9	8.4	23.1	0.29	0.25	17.7	11.2	8.6
Penetration on residue at 25° C					168	150	124		
Float on residue at 50° C., seconds	114	105	22.8	88				24	21.8
Loss at 163° C., 5 hours, 20 centimeters, percent	15.4	16.0	12.9	30.5			17.8	15.7	12.8
Penetration on residue at 25° C							92		
Float on residue at 50° C., seconds	202	192	49.2	204				45.6	51.2
Soluble in CS_2, percent	99.87	99.90	99.88	99.91	99.92	99.88	99.89	99.88	99.87
Organic matter insoluble, percent	.10	.08	.07	.07	.06	.08	.08	.07	.09
Inorganic matter insoluble, percent	.03	.02	.05	.01	.02	.04	.03	.05	.04
Bitumen insoluble in 86° B. naphtha, percent	9.97	9.85	5.45	13.2	8.08	9.81	7.92	6.14	4.92
Residue of 100 penetration, percent	76.8	76.5	58.8	65.5			78.8	58.8	58.8
Penetration on residue at 25° C. 100 centimeters, 5 seconds	98	87	94	102			91	98	103
Penetration on residue at 0° C. 200 centimeters, 60 seconds	17	16	23					19	21
Softening point of residue, °C	45.4	45	44.8					43	45.3
Ductility of residue at 25° C., centimeters	110+	110	86					110+	110+
Ductility of residue at 1.5° C., centimeters	4.0	4.2	4.0					4.5	5.0

[1] Material did not pull to a thread.

TABLE 5.—*Analyses of typical asphaltic emulsions used on the various sections*

Grade	95+L	95+M	95+L2	94+L2	90-95 L3	110-120 M	Standard	Standard
How and where used	Mix on sec. 13 and seal on secs. 12 and 13	Mix on secs. 11 and 12	Seal on secs. 11, 12, and 13	Surface treatment on sec. 19 and right lane on sec. 18	Surface treatment on left lane sec. 18	Mix on sec. 11	Surface treatment on secs. 20 and 21	Surface treatment on sec. 21
Specific gravity, 25°/25° C	1.008	1.009		1.009	1.006	1.010	1.007	1.011
Specific viscosity, Engler, at 50° C				2.8	2.9	1.9	1.7	2.7
Distillation to 260° C.:								
Water, percent by weight	41.9	40.1	48.4	42.8	42.4	50.9	43.2	42.3
Oil, percent by weight	.1	.1		.1	Trace	.2	Trace	.05
Residue, percent by weight	58.0	59.8	51.6	57.1	57.6	48.9	56.8	57.7
Tests on residue:								
Specific gravity, 25°/25° C	1.012	1.020		1.014	1.009	1.017	1.008	1.012
Penetration at 25° C	126	110	148	202	234	98	142	154
Softening point, °C	41.6	48.2		42.4	35.6	48.8	43.8	44.4
Ductility at 25° C	79	47		110+	81	50	92	110+
Bitumen soluble in CS_2, percent	99.04	94.87		96.67	98.05	94.69	99.00	98.73
Organic matter insoluble, percent	.05	2.54		.37	.55	2.54	.18	.44
Inorganic matter insoluble, percent	.91	2.59		2.96	1.40	2.77	.82	.83

TABLE 6.—*Amounts of bituminous material used on the different road-mix sections (exclusive of seal coat) and the amounts indicated by various formulas*

Section	Calculated amount of bitumen exclusive of solvent and water in mix (percent) [2] [3]	Average amount of bitumen 1 year after construction, by extraction	Amount of bituminous materials required according to various formulas [1]			Remarks on richness of the mix as indicated by service behavior
			Stanton, Calif.	Utah	Wyoming, N. Dak.	
1, A	4.2 [3]	3.3	2.7	3.1	2.9	Slightly lean without seal.
1, B	4.3 [3]	3.6	3.7	4.0	4.1	Do.
1, C	5.5 [3]	3.3	3.7	4.0	4.1	Satisfactory without seal.
2	3.6 [3]	3.6	2.1	2.5	2.1	Rich.
3	4.4	3.8	4.6	4.9	5.2	Satisfactory without seal.
4	5.0	3.1	4.0	4.2	4.3	Do.
5	4.8		4.2	4.5	4.8	Slightly lean without seal.
6	4.2		3.8	4.0	4.1	Very lean. Satisfactory with seal.
7	6.1	5.1	4.4	4.5	4.8	Satisfactory.
8	4.0	3.5	2.3	2.8	2.4	Rich.
9	4.2	3.5	4.5	4.8	5.0	Slightly lean without seal.
10	3.5	4.0	3.9	4.2	4.3	Satisfactory without seal.
11	2.6–3.5 emulsion [3] 1.5 slow-curing oil	3.9	3.7	3.8	3.9	Sufficient but poorly distributed.
12	3.3–3.6 emulsion [3] 1.5–2.2 slow-curing oil	4.7	2.8	3.1	2.9	Do.
13	3.5 [3]		2.7	3.0	2.8	Very lean.

[1] These formulas are all based on the division of the aggregate on the no. 10 and no. 200 sieves:
P = Percent of oil required.
a = Percent of aggregate retained on the no. 10 sieve.
b = Percent of aggregate passing to no. 10 and retained on the no. 200 sieve.
c = Percent of aggregate passing the no. 200 sieve.
Stanton, Calif.: $P=0.02a+0.045b+\begin{cases}0.15c \text{ for fine aggregate.}\\0.18c \text{ for average aggregate.}\\0.20c \text{ for coarse aggregate.}\end{cases}$
Utah: $P=0.02a+0.033b+0.195c+H$ (H is an absorption factor and is usually taken as 0.5).
Wyoming and North Dakota: $P=1.4\ (0.015a+0.03b+0.17c)$.

[2] The percentage of bituminous material by weight were calculated on the basis of the specific gravities of the bituminous materials as given in tables 4 and 5 and the following unit weights of loose aggregates:

	Pounds per cubic foot
Gravel	100
Close graded crushed stone	90
Crusher-run stone	85
Open graded crushed stone	80

[3] The quantities of cut back and emulsion have been corrected for solvent or water using 56 percent of bitumen for the emulsions and 80 percent residual bitumen for the cut backs.

An 8-ton tandem roller was used to obtain final compaction on the road-mixed emulsion sections and cut-back asphalt sections. The sections built with slow-curing oil were not rolled but were compacted entirely by traffic.

Obstructions, as shown in figure 4, A, were devised to guide the traffic so as to compact the full width of the surfacing. These were moved at frequent intervals to distribute traffic as required. The road-mix sections were built in 1929 and their behavior up to the final inspection in October 1932 is discussed in the following pages.

ROAD-MIX SECTIONS DESCRIBED IN DETAIL

Section 1.—The section consisted of a road-mix with medium-curing cut-back asphalt. The mix was composed of crushed rock and 110–120 penetration asphalt cut back with kerosene. The section was divided into three parts in order to investigate the use of differently graded aggregates and different amounts of binder.

Section 1–A, at eastern end of the project, was 639 feet long and was surfaced with crusher-run stone (three-fourths inch to dust) mixed with 1.71 gallons per square yard of cut-back asphalt. The aggregate contained 0.5 percent moisture and the mechanical analysis was as follows:

Passing—	*Percent*
¾-inch screen	100. 0
½-inch screen	76. 5
No. 3 sieve	46. 0
No. 10 sieve	13. 0
No. 200 sieve	2. 5

Section 1–B was 660 feet long and was surfaced with crusher-run stone (three-fourths inch to dust) with an admixture of fines to increase the percentage of dust and was mixed with 1.92 gallons per square yard of cut-back asphalt of the same grade as used on section 1–A. The aggregate contained 2.5 percent moisture and the mechanical analysis was as follows:

Passing—	*Percent*
¾-inch screen	100. 0
½-inch screen	72. 0
No. 3 sieve	49. 6
No. 10 sieve	28. 0
No. 200 sieve	7. 2

Section 1–C was 1,320 feet in length and was identical with section 1–B as to aggregate and type of binder. The section was mixed at the same time as 1–B using 2.26 gallons per square yard of the cut-back material. The mixed material was spread and compacted by traffic for 8 days. A wide spread in bituminous content was desired betwen sections 1–C and the other sections and at this time it was evident that a greater amount of bituminous material could be used without causing instability. The section was therefore scarified and remixed with the addition of 0.21 gallon per square yard.

No difficulty was encountered in handling, applying, or mixing the cut-back material. Less mixing seemed to be necessary than with the slow-curing oils of similar viscosity. The mixture on sections 1–B and 1–C, which contained added fines, compacted and bonded much more quickly under traffic than did section 1–A where fines were not added. The edges of these sections were rolled about 10 days after construction and were greatly improved in appearance. By that time the traveled portion of the roadway had compacted to such an extent that rolling of this portion was not considered necessary.

Cost of section 1:
1–A—46.94 cents per square yard or $5,507 per mile.
1–B—51.18 cents per square yard or $6,005 per mile.
1–C—58.57 cents per square yard or $6,872 per mile.

All three sections were in good condition when inspected 3 years after the construction. The surfaces were free from rich areas such as developed extensively on some of the slow-curing oil sections. Section 1–C which had the highest asphalt content, retained

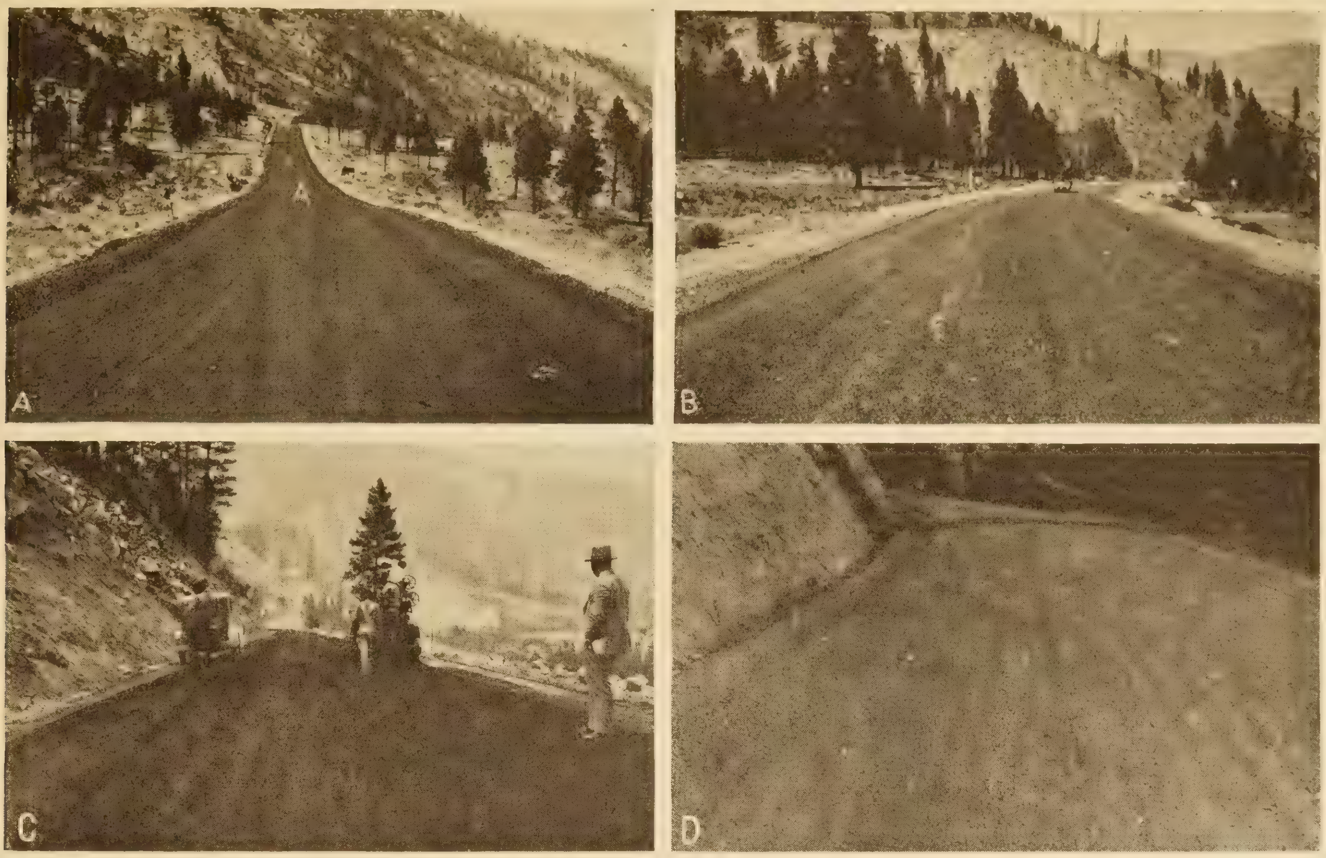

Figure 4.—A, Obstructions Used to Guide Traffic so as to Compact Entire Surface; B, The Relatively Quick-Breaking Emulsion Used on Sections 11 and 12 Produced a Mixture Which was Difficult to Compact; C, A Uniform Mix Which Compacted Readily Was Obtained on Section 13 by the Use of a Slow-Breaking Emulsion; D, The Leanness of Section 13 Resulted in Raveling Which Continued Until the Surface Was Sealed.

the most wear-resistant surface. Sections 1–B and 1–A began to show slight signs of surface raveling during 1932 and were given a light seal treatment of 0.15 gallon of 90–95 asphaltic oil applied hot and a cover of 11 pounds of ¼-to ⅛-inch crushed stone per square yard.

Except for the seal treatment, the only maintenance required had been the skin patching of a few small areas on section 1–A where the surface cracked due to movement in the subgrade.

Section 2.—The section consisted of a road-mix of cut-back asphalt and open graded crushed-stone aggregate. The aggregate was ¾- to ⅛-inch crushed stone bound with 1.4 gallons per square yard of 110–120 penetration asphalt cut back with kerosene.

The moisture content of the aggregate was 0.25 percent and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	100.0	100.0
½-inch screen	86.0	79.5
No. 3 sieve	55.5	41.0
No. 10 sieve	2.0	1.0
No. 200 sieve	.25	0

Mixing was completed on this section with considerably less effort than on section 1 where the aggregate included fines. The cut-back asphalt readily and thoroughly coated all of the stone particles. The mix, however, compacted and bonded slowly with the result that for several days some aggregate was displaced by traffic. Less displacement of aggregate would probably have occurred, not only on this section but also on section 1, had the mix been allowed to cure until somewhat tacky before being spread and compacted.

The cost of the surface was 66.50 cents per square yard, or $7,802 per mile.

As a result of the use of the medium-curing type of cut-back asphalt, instead of the rapid-curing type which would have been better suited to the open-graded aggregate, the mix did not develop high stability until about 2 years after construction. The surface of this section remained in excellent condition although the indications were that it was somewhat rich when constructed.

Probably a better design for this section would have been a leaner mix with a light seal treatment to provide the necessary resistance to displacement. Maintenance had been limited to a few small skin patches where the surface cracked or slight surface depressions had developed.

Section 3.—A slow-curing oil was mixed with a close-graded gravel. The surface was composed of 25-percent uncrushed, washed gravel 1 to ⅛ inch in size and 75 percent of crushed gravel 9/16 inch to dust, bound with a 60–70 oil applied at the rate of 1.70 gallons per square yard. The moisture content of the aggregate was 3 percent, and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1¼-inch screen	100.0	100.0
1-inch screen	98.0	97.0
¾-inch screen	91.0	88.0
½-inch screen	78.0	75.0
No. 3 sieve	62.0	60.0
No. 10 sieve	40.0	41.5
No. 200 sieve	11.0	11.5

The materials were mixed readily and the mixture, on being spread, appeared quite dark in color for a typical oil-mix. It seemed to compact more rapidly under traffic than did the other oil and crushed-stone mixes. The mix appeared richer than the stone mixes having the same grading of aggregate and amount of oil This was probably due to the relatively high percentage of moisture in the aggregate.

The cost of the surface was 69.68 cents per square yard or $8,175 per mile. Its high cost was due largely to the use of gravel aggregate which was shipped by rail.

The action of moisture on the mix seems to have been more pronounced than on section 4 where crushed stone aggregate was used. The surface, except for a small area on the west end where drainage and subgrade conditions were bad, remained generally hard and stable until the spring of 1931 when it softened quite generally, necessitating scarifying and remixing of about 500 lineal feet on the east end and 700 feet on the west end.

It should be noted that the portions which failed first on this section, as well as on section 4, were those where the mix appeared somewhat rich in oil at the time of construction. Poor drainage and subgrade conditions, which prevailed on several small portions of the section, also seemed to greatly hasten the softening of the surface.

During the summer of 1932 a seal treatment of one-fourth gallon of 90–95 hot asphaltic oil and a cover of 16.5 pounds of one-fourth- to one-eighth-inch crushed stone was added to several portions of the section on which the mix had not softened appreciably. The area treated was mostly over fills and totaled 3,111 square yards, or slightly more than half of the entire section.

Section 4.—A slow-curing oil was mixed with a close-graded crushed stone. The mix was composed of crusher-run stone, three-fourths inch to dust, with fines added as filler, and 60–70 oil applied at the rate of 1.78 gallons per square yard. The aggregate contained from 2.75 to 3 percent of moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	94.0	92.0
½-inch screen	79.5	79.0
No. 3 sieve	64.0	64.0
No. 10 sieve	37.0	38.0
No. 200 sieve	7.5	7.5

Sections 4, 5, and 6 were designed to have practically identical mixes except as to percentage of oil used. Sections 5 and 6, however, were surface treated while section 4 was not.

The cost of the surface was 44.57 cents per square yard or $5,229 per mile.

The surface remained in good condition generally. The mix appeared somewhat lean at the time of construction but no appreciable raveling occurred. Softening of the mix did not develop to the extent that it did on section 3 although it was necessary to scarify and remix about 500 feet on the east end during the summer of 1931. This portion was almost entirely in a cut where the drainage and subgrade were not satisfactory. A seal treatment, similar to that used on section 3, was applied in 1932 to several short portions totaling 666 square yards where the surface was beginning to ravel, particularly along the edges.

Section 5.—A slow-curing oil was mixed with a close-graded crushed stone and followed with a light seal. The mix was composed of crusher-run stone, three-fourths inch to dust, with fines added and 1.7 gallons of 60–70 oil. After compaction a light seal treatment of 60–70 oil and a cover of ¼- to ⅛-inch screenings was applied. The aggregate contained from 2.75 to 3.25 percent of moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	95.0	93.0
½-inch screen	72.0	80.0
No. 3 sieve	54.0	69.0
No. 10 sieve	33.0	44.0
No. 200 sieve	9.0	9.25

After the surface had been down about 35 days and had become thoroughly compacted, it was swept clean with a power broom and a light seal treatment of 60–70 oil was applied. The oil was heated to about 140° F. and was applied at the rate of 0.17 gallon per square yard on the right half of the surface and at the rate of 0.10 gallon on the left half. A cover of about 19 pounds of ¼- to ⅛-inch screenings was then spread, following which the surface was rolled with an 8-ton tandem roller. The major portion of this cover material was thrown to the sides by traffic due to the inability of the slow-curing oil to hold the aggregate cover.

The appearance of the surface before applying the seal treatment seemed to indicate a slight deficiency in oil which would probably have resulted in some raveling had not the seal treatment been applied. The principal effect of the treatment was to enrich the surface and make it more resistant to the wear of traffic. The cost of the surface was 52.03 cents per square yard or $6,105 per mile.

In general, this section had remained in better condition than either sections 3 or 4. Although there were some indications of softening of the mix in a few small local areas, failures did not develop sufficiently to affect the generally good condition of the surface.

Maintenance, except for some skin patching, had consisted of scarifying and remixing in the summer of 1931 of about 200 feet of surface on the east end and the application of an additional seal treatment during the summer of 1932 to 751 square yards of the surface which was beginning to show some signs of wear. This treatment was similar to that applied to sections 3 and 4 except that one-fourth gallon of bituminous material and 16.4 pounds of cover were used per square yard.

Section 6.—The section consisted of slow-curing oil mixed with crushed stone with a light surface treatment. The mix was composed of crushed stone, three-fourths inch to dust, without the addition of fines, and 60–70 oil at the rate of 1.40 gallons per square yard. A light surface treatment was applied late in the fall. The aggregate contained 2.5 percent moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	Percent	Percent
¾-inch screen	96.0	94.0
½-inch screen	85.5	81.3
No. 3 sieve	71.5	64.5
No. 10 sieve	38.2	34.1
No. 200 sieve	6.8	5.8

The mix in this experiment was purposely made lean as a surface treatment was to be applied later. Some raveling and pot-holing occurred during the period of about 2 months which intervened between the placing of the mix and the applying of the surface treatment and it is doubtful if the untreated oil-mix surface could have gone through the first winter without considerable failure.

Previous to the application of the surface treatment the surface was swept and all holes patched. A 94+ grade of asphaltic oil heated to about 400° F. was applied at the rate of 0.28 gallon on the right half of the roadway and 0.22 gallon on the left half. It was immediately covered with 18.7 pounds per square yard of ½- to ⅛-inch stone and then rolled. A different amount of oil was used on each half of the road width in order to obtain information as to the most economical amount to use. As the treatment was not applied until late in the fall, cold weather prevented complete cementing of the cover stone and, as a result, some of the aggregate was displaced by traffic. It was not until the following summer that the oil warmed sufficiently to come up through the stone and at that time some additional cover had to be added to stop bleeding.

The cost of the mix and surface treatment was 47.17 cents per square yard or $5,534 per mile. The mix alone cost 37.88 cents per square yard or $4,444 per mile.

This section had remained in excellent condition. The surface was free from soft spots such as occurred on some of the other sections with light oil mixes. Such little maintenance as had been required consisted of applying a few small seal patches.

Section 7.—A slow-curing oil was mixed with a close-graded crushed stone. The mix was composed of crushed stone, three-fourths inch to dust with which fines were added, and 70–80 oil at the rate of 2.16 gallons per square yard. The aggregate contained from 1.5 to 3 percent moisture and the mechanical analyses were as follows:

	Sample A	Sample B
Passing—	Percent	Percent
¾-inch screen	100.0	100.0
½-inch screen	79.5	84.5
No. 3 sieve	65.0	70.0
No. 10 sieve	45.5	41.0
No. 200 sieve	11.0	6.5

Considerable difficulty was encountered in mixing the 70–80 oil because of cold weather during construction. The quantity of oil first tried was 1.93 gallons per square yard. Since this did not appear to be sufficient an additional 0.23 gallon was used. The mix compacted rapidly and developed an excellent nonskid surface texture. The oil seemed to have better adhesive properties than did the 60–70 oil but was less adhesive than the cut-back asphalts.

The cost of the mix surface was 47.82 cents per square yard or $5,611 per mile.

Softening of the mix developed early on about 600 feet on the west end and on about 200 feet on the east end. These portions appeared rich at the time of construction and the soil and drainage were not as satisfactory as on the other portions of the section. The soft places were scarified and remixed during 1931. In 1932 a seal treatment, similar to that used on a portion of section 5, was applied to 265 lineal feet where the surface was beginning to wear. The section was in good condition at the time of the last inspection.

Section 8.—A slow-curing oil was mixed with an open-graded crushed stone. The mix was composed of crushed stone, three-fourths to one-eighth inch in size and a 70–80 oil at the rate of 1.24 gallons per square yard. The aggregate contained from 0.2 to 3.5 percent moisture and mechanical analyses were as follows:

	Sample A	Sample B
Passing—	Percent	Percent
¾-inch screen	100.0	100.0
½-inch screen	84.9	83.9
No. 3 sieve	52.0	48.2
No. 10 sieve	7.0	5.0
No. 200 sieve	1.0	1.0

The material was mixed very quickly and was allowed to remain in the windrows for several days before it was spread. Compaction took place slowly and there was appreciable displacement of stone under traffic for several days during the early compaction. Rolling was finally resorted to and aided considerably in compressing and smoothing the loose surface material. The surface obtained was more open than was desired but, in accordance with the original plan, it was not given a seal. The early behavior of this section and the difficulty in compaction was similar to that experienced on section 2 where a 110–120 penetration asphalt cut back with kerosene was used. The cost of the surface was 59.55 cents per square yard, or $6,987 per mile.

In the spring following construction this section failed by rutting extensively under the truck traffic incident to the construction of sections in 1930. Although the west half of the section, which was in a cut where the subgrade soil and drainage were bad, failed first and most extensively, it was evident, even on the good subgrade, that the mix lacked sufficient stability. The section was considered unsatisfactory and it was discontinued as an experiment during the fall of 1930.

Section 9.—A close-graded crushed stone was mixed with a kerosene cut-back. The mix was composed of crushed stone, three-fourth inch to dust, with muck-sand filler added, and 94+ asphaltic oil cut back with kerosene and applied at the rate of 1.86 gallons per square yard. The aggregate contained from 1 to 2 percent moisture and mechanical analyses were as follows:

	Sample A	Sample B
Passing—	Percent	Percent
¾-inch screen	98.0	96.5
½-inch screen	82.0	83.5
No. 3 sieve	67.5	70.0
No. 10 sieve	41.0	48.5
No. 200 sieve	9.0	11.0

On account of a delay in shipment of a portion of the cut-back material for this section, several days intervened between the mixing of the two windrows. The south windrow was mixed and left to cure for 4 days before being combined with the north windrow. Such slight hardening as occurred in the mix did not seem to add difficulty to the final processing or compaction and seemed to aid in obtaining early compaction with much less raveling under traffic. The section was rolled during the early compaction. The cost of the surface was 50.81 cents per square yard, or $5,962 per mile.

This section had remained in excellent condition. Practically no maintenance had been required although it appeared that a light seal coat would probably be beneficial. The surface was nonskid, uniform in color, and free from soft spots.

Section 10.—A kerosene cut-back and was mixed with close-graded gravel. The mix was composed of a close-graded gravel, such as was used on section 3, containing sufficient fines without the addition of filler and a 94+ asphaltic oil cut back with kerosene. A small amount of cut-back asphalt of 110–120 penetration was also used. The aggregate, containing 0.5 to 0.6 percent moisture, was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	93.0	99.0
¾-inch screen	81.0	85.5
½-inch screen	63.2	77.5
No. 3 sieve	56.4	63.0
No. 10 sieve	36.7	37.5
No. 200 sieve	7.5	6.8

The asphaltic material used in the mix consisted of 1.58 gallons of 94+ cut back and 0.14 gallon of 110–120 cut back, the latter being added to make up for the shortage of the former.

The material for the left half of the road was processed and windrowed 5 days before processing the other half. Four days after mixing the second windrow the two were mixed together and spread. The surface was rolled on the following day. Here, as on section 9, the short period of curing seemed to have been of considerable benefit as the mixture compacted quickly and a smooth hard surface was obtained.

The total cost of the surface was 71.19 cents per square yard or $8,353 per mile. The high cost of this experiment is due largely to the freight charges on the gravel, which was shipped a long distance by rail.

The surface was in excellent condition except for 200 feet on the west end where bad subgrade and drainage conditions had resulted in some displacement and cracking. The surface appeared much richer than that of section 9 and was less nonskid. Except for some patching on the west end and at a few locations on the edges, no maintenance had been required.

Section 11.—This section was road-mix, composed of asphaltic emulsion and crusher-run stone, three-fourths inch to dust. The aggregate was first mixed with 0.48 gallon of 60–70 oil, after which 1.54 gallons of 110–120 M asphaltic emulsion was applied and mixed. The portion between stations 361+39 and 353+59 was enriched by adding 0.49 gallon of 95+ M asphaltic emulsion.

A seal treatment consisting of 0.30 gallon of a mixture of 95+ M and 95+ L emulsions and about 11 pounds of ¼- to ⅛-inch cover stone was applied to the portions between stations 361+39 and 357+49 and between 349+69 and the west end of the section. The remaining portion of the section was left until the following summer when it also was sealed, using 0.18 gallon of 95+ L2 asphaltic emulsion on the left half of the roadway and 0.17 gallon on the right half, with a cover of 11 pounds per square yard of ½- to ⅛-inch stone chips. All the seal treatments were rolled immediately following the application of the cover stone.

The aggregate contained 1.5 percent of moisture and was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
¾-inch screen	100.0	95.0
½-inch screen	85.5	82.0
No. 3 sieve	75.5	70.0
No. 10 sieve	49.0	37.0
No. 200 sieve	4.5	5.0

The results obtained in the mixing operation were not very satisfactory. The emulsion,[1] which was not a true mixing emulsion, broke and became viscous so quickly that mixing was difficult. Instead of coating all of the particles uniformly, as did the other types of bituminous materials, this relatively quick-breaking emulsion had a decided tendency to form the finer particles in balls, leaving the larger particles practically uncoated. When the materials had been processed as well as possible, the mix was spread and rolled but it did not bond well and displaced considerably under traffic. It was decided to enrich the east half from stations 361+39 to 353+59 by remixing with the addition of 0.49 gallon of the 95+ M emulsion. This portion bonded somewhat more readily than before although considerable displacement of aggregate by traffic occurred for several days. An attempt was made to consolidate the mix by rolling intermittently for several days. Consolidation was finally accomplished to a fair degree, the finer particles being pressed around and interlocking with the larger poorly-coated particles.

Although the manufacturers of the emulsion contended, and it was generally agreed at the time of construction, that the emulsion-mix sections would require a seal treatment for best results, it was decided to seal only a portion of each section immediately. However, in order to prevent extensive deterioration of the unsealed portions, which were on relatively poor subgrade, they were given a seal treatment during the following summer.

The cost of the mix and seal was 64.46 cents per square yard or $7,563 per mile.

Section 12.—A road-mix was placed consisting of an asphaltic emulsion and crusher-run stone. The crusher-run stone ranged from three-fourths inch to dust. The aggregate was first mixed with 60–70 oil at the rate of 0.48 gallon between stations 345+79 and 343+79, and 0.70 gallon on the remainder of the section, following which 1.84 gallons of emulsified asphaltic oil of the 95+ M grade was applied and mixed. The portion between stations 345+79 and 343+79 was enriched by adding 0.23 gallon of 110–120 M asphaltic emulsion.

The portions between stations 345+79 and 340+89 and from station 331+09 to the end of the section were sealed shortly after the compaction of the surface. On the first portion 0.3 gallon of a mixture of 95+ M and 95+ L emulsion was applied, while on the latter portion the same amount of the 95+ L grade emulsion alone was used. About 11 pounds per square yard of ¼- to ⅛-inch stone screenings were used in covering both portions. As in the case of section 11, the portion left unsealed at the time of construction was given a seal treatment during the following summer. In this treatment 0.18 gallon of 95+ L2 emulsion was applied to

[1] The demulsibility of this emulsion, using 50 cubic centimeters 0.10N. calcium chloride, was 100 percent compared with present A. S. T. M. requirement of a maximum of 30 percent.

the left half of the roadway and 0.21 gallon to the right half. Both portions were covered with 11 pounds per square yard of ½- to ⅛-inch stone screenings and rolled.

The aggregate used on this section contained 1 to 1.2 percent moisture and was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	92.0	95.0
½-inch screen	72.5	74.5
No. 3 sieve	49.0	44.0
No. 10 sieve	14.0	26.0
No. 200 sieve	2.0	2.5

As in the case of section 11, difficulty was encountered in mixing and compacting and, during the extended period of compaction, considerable aggregate was displaced by traffic. This condition is illustrated in figure 4, *B*. After the mix had hardened, about half the section was sealed, the remaining portion being left until the following summer when the sealed and unsealed surfaces had about the same appearance as the corresponding parts of section 11, except that the unsealed surface was slightly better bonded than that on the leaner portion of section 11.

The cost of the mix and seal was 64.62 cents per square yard or $7,582 per mile.

Section 13.—On this section an asphaltic emulsion was mixed with crusher-run stone ranging from three-fourths inch to dust. The aggregate was primed and mixed with 2.23 gallons of water. Following this, asphaltic emulsion 95+L was applied at the rate of 2 gallons per square yard and mixed. Figure 4, *C* illustrates the mix.

The easterly portion, stations 326+19 to 311+23 was sealed after compaction of the mix, using 0.3 gallon of 95+L emulsion and covered with about 11 pounds per square yard of ¼- to ⅛-inch screenings. The remaining portion was given a seal treatment during the following summer, consisting of 95+L2 emulsion applied at the rate of 0.18 gallon on the left half and 0.21 gallon on the right half and covered with 13 pounds per square yard of ½- to ⅛-inch screenings on the left half and 11 pounds per square yard on the right. Raveling resulting from the leanness of the mix is illustrated in figure 4, *D*.

The aggregate used on this section contained from 5 to 7.5 percent moisture and was analyzed as follows:

	Sample A	Sample B
Passing—	*Percent*	*Percent*
1-inch screen	100.0	100.0
¾-inch screen	89.0	93.0
½-inch screen	69.0	70.5
No. 3 sieve	52.0	48.0
No. 10 sieve	24.0	21.0
No. 200 sieve	1.0	1.5

The cost of the mix and seal was 67.29 cents per square yard or $7,895 per mile.

Although the subgrade was variable and of inferior quality on portions of the section, certain types of failure occurred in the emulsion mixtures which seemed to be due to the character of the mix rather than to that of the subgrade.

Where the worst subgrade conditions existed, it was necessary to remove the defective subgrade to a depth varying from a few inches to 18 inches or more and to do extensive patching during the early summer of 1931. This work put the surfaces in fairly good condition and

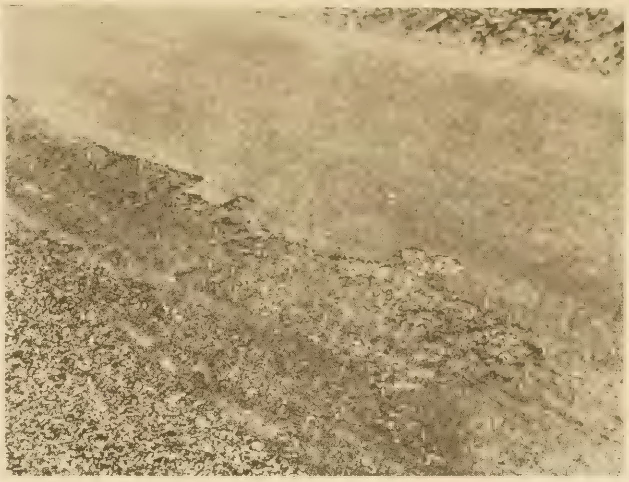

FIGURE 5.—TYPICAL CRACKING AND PEELING WHICH OCCURRED DURING THE SPRING ON PORTIONS OF SECTIONS 11 AND 12, DUE TO THE BAD SUBGRADE AND POOR DRAINAGE IN THE DITCHES.

it was thought that the sections would go through the next winter satisfactorily. However, further failure of the subgrade occurred and additional extensive repairs were again necessary during the spring of 1932.

MORE IMPORTANT FACTORS AFFECTING THE BEHAVIOR OF THE ROAD-MIX SECTIONS DISCUSSED

Of the factors affecting the service behavior of the oil-mix type of surfacing as built in the Western States, moisture is probably the most important. Moisture in the aggregate at the time of mixing, moisture seeping into the surface from the top and, perhaps most important of all, moisture entering the surface from the subgrade, must all be considered as potential causes of failure.

In these experiments the most noticeable result of the effect of moisture was the development of areas having the appearance of excessive richness in bitumen. On these areas the mat became so soft and unstable as to require scarifying and remixing. The time intervening before this unsatisfactory condition developed varied from a short time after construction to a period of 2 years. Subgrade water which entered the mixture from below was responsible for most of the failures of this type.

Examination of the mat from areas affected by moisture in otherwise good sections indicated that water, in rising through the mix toward the surface, had apparently carried with it an appreciable amount of oil.

The richer mixes seemed to lose stability earlier and to a greater extent than did the leaner ones. Section 7 furnishes a good example of the comparative effect of subgrade moisture on rich and lean mixes. On this section drainage and subgrade conditions were fairly uniform but the west half of the section, which was comparatively rich, softened, became unstable and had to be scarified and remixed in 1931, while the east portion, except for a small area at the beginning of the section, has remained in excellent condition. Analyses of mat samples taken from the east and west portions show the former to contain approximately 25 percent more bituminous material than the latter.

Softening of the mat occurred most generally in cuts where drainage conditions were least satisfactory. Section 4 remained in good condition except for a short portion at the east end which was in a cut with poor drainage and subgrade. The mat on this portion of the section softened and was scarified and remixed in 1931.

Section 3, on which gravel was used, softened more extensively than did section 4, on which crushed stone was used. Due to the smooth, round character of the gravel particles, the stability of the gravel is apparently reduced more quickly than that of the rough, angular crushed material when an excess amount of water is present in the mix.

The mix on section 5, which appeared somewhat lean and was lightly sealed with the same oil used in the mix, was affected by water to a much less degree than either section 3 or 4. Only a few small areas of its surface had softened. The seal coat provided an excellent, wear-resistant surface on this section which, due to its leanness, would otherwise undoubtedly have failed by raveling. It is believed, however, that its resistance to loss of stability has been due largely to the leanness of the mix rather than to the seal treatment.

On section 6 the mix was very lean, appearing to be much more so than that on section 5, and the surface was sealed with a soft grade of asphalt. This combination of a lean mix with an asphalt seal coat provided an excellent surface and there were no indications that the mix had softened because of subgrade moisture. The behavior of sections 5 and 6 in contrast to that of the richer unsealed sections, particularly in their resistance to the action of moisture, suggest the possible advantage of using a lean mix with a wear resistant surface treatment, particularly where moisture conditions are unfavorable.

The belief that bituminous materials of high viscosity offer more resistance to the effect of moisture on this type of construction than materials of lower viscosity has led to the use of more viscous materials. The effect of the viscosity of the slow-curing oils on their resistance to moisture was not studied in this investigation, but the exceptionally good condition of section 7 on which the more viscous 70–80 oil was used tends to substantiate the opinion regarding the advantage of the heavier oils. The water-resistant properties of the asphaltic cut-back materials are also well illustrated by the behavior of the road-mix sections in which these materials were used. These surfaces continued in good condition, uniform in color, and free from any indication of softening or lack of stability.

GRADING OF AGGREGATE IMPORTANT IN DESIGNING MIXTURES

The grading of the aggregate is important in designing all types of bituminous mixes and is particularly so in designing those types of road-mix in which the bituminous materials used may not compensate for a possible lack of stability in the aggregate. Obviously, if the aggregate does not possess inherent stability it must be supplied by the bituminous material. Conversely, if the aggregate has this property it need not necessarily be characteristic of the bituminous material. Satisfactory stability was obtained on all the road-oil-mix sections where the aggregate was close-graded (from 5.8 to 11.5 percent of dust), although the bituminous material used with it had relatively little cementing value.

Sections 2 and 8 were built with open-graded crushed-stone aggregate ranging from three-fourths to one-eighth inch. A medium-curing kerosene cut back was used on section 2 and a 70–80 slow-curing oil on section 8. On the former section the mix remained plastic for a long time after construction, during this time it seemed on the verge of failure. However, it gradually hardened and in time its condition materially improved. The behavior of this section conforms with experience on other projects where similar medium-curing cut-back materials were used, in that satisfactory stability of the mix developed only after a considerable period of time during which an appreciable amount of volatile material evaporated resulting in greater viscosity in the remaining bituminous material which enabled it to furnish the stability lacking in the aggregate.

Section 8, on which the 70–80 slow-curing oil was used with open-graded aggregate, lacked stability and failed early since the oil was not of a type which hardened so as to provide the stability lacking in the aggregate.

It is apparent that aggregate should be closely graded, contain an appreciable amount of fine material, and have high inherent stability if it is to be used with slow-curing or medium-curing asphaltic materials. The fine particles, particularly that portion of the aggregate passing the no. 200 sieve, seem to stiffen the bituminous material and provide the necessary early stability. The mix on section 2, which contained no fines, displaced under traffic for a long time after construction. Although it finally developed a well-bonded and stable surface the early behavior was not satisfactory, due to the slow development of cohesive properties in the binder.

The exact amounts of fines which should be present when slow-curing, medium-curing, or rapid-curing materials are used cannot be stated definitely. Experience indicates that in constructing road mixes with average aggregates of open grading, rapid-curing materials should be used and that, in general, slow-curing or medium-curing materials should not be used when the dust content of the aggregate is less than approximately 5 percent.

Sections 2 and 8 are typical examples of surfaces containing open aggregates where better results would have been obtained had a more rapid-curing binder been used.

AMOUNT OF SLOW-CURING OIL REQUIRED MAY BE DETERMINED SATISFACTORILY WITH FORMULAS

The subgrade soils on sections 1 to 13, as shown in table 2, include the A–2 (mostly plastic), the A–4, and A–7 types. The A–2 plastic type predominates except on sections 11, 12, and 13. The more unfavorable A–4 and A–7 types comprise the soil on these three sections and were also found in the deep cuts and on other short portions of some of the other sections.

Failures of the surface due to the subgrade were confined almost entirely to those portions overlying A–4 and A–7 soils. The characteristic tendency of the A–4 soils to flow under load was reflected in the behavior of the surface, which failed by settlement and cracking (fig. 5). This type of surface failure was extensive on section 11.

The A–7 soils, which are elastic when loaded, caused cracking without appreciable displacement of the surface. Failures of this type occurred extensively on section 12.

The data on laboratory curing and stability tests made on the material from the various mixtures passing no. 10 sieve, and presented in table 3, give some indication of the degree of curing which might occur in mixed surfaces containing oils and cut backs. It also illustrates the gain in the stability of the fine portion of the mixtures which accompanies the loss of volatile constituents. The tests reported show high stability values indicating that the inherent stability of the fine portion of these road-mixes was high. Gains in stability corresponding to a given loss of volatile matter were substantially greater for the cut-back mixtures than for the slow-curing oils.

The comparatively low total oven losses of volatile matter for the cut-back mixes from sections 9 and 10 indicates that considerable more volatile matter had gone off during the construction operation than on sections 1 and 2. This explains the better early behavior of sections 9 and 10 as compared with sections 1 and 2 and shows the necessity of obtaining an appreciable loss of the solvent (in cut-back materials) before final compaction of the mix.

A comparison of the amount of bituminous materials used with that shown to be required by several formulas, together with comments as to the sufficiency of the amounts used as indicated by service behavior, are given in table 6. In general, the behavior of the sections indicates that the amounts of slow-curing oil required for close-graded aggregates may be determined satisfactorily by means of one of several formulas now in use. The results of these experiments, however, as well as observations on other projects, indicate that where very heavy slow-curing oils and cut backs which produce heavy residues in the road surface are used it may be advantageous to apply greater quantities than called for by the formulas.

Sections 11, 12, and 13, on which asphaltic emulsions were used, were of a more highly experimental character at the time of construction than the remainder of the sections. Little experience had been had with this type of material and little information was available relative to its behavior during construction or as to the proper amount of the material to use under given conditions. Practically all details therefore were experimental and with the complication of inferior subgrade conditions, the results were not very satisfactory.

Considerable difficulty was encountered in mixing sections 11 and 12. The emulsions broke during the mixing operation, balled with the fine particles of aggregate and produced an apparently lean, nonuniform mix which was harsh and very open and in which the coarse particles were very poorly coated with bitumen. On the unsealed portions, the open and poorly bonded surface cracked extensively, especially during the spring season when the subgrade was least stable.

The emulsion on section 13 had a slower break than that used on sections 11 and 12 as indicated during the mixing operation. The fines did not segregate and ball, the coarser particles were well coated and the mixture obtained was uniform and of a close texture. The appearance of the mix on section 13, as compared to that of sections 11 and 12 at the time of construction, is shown by figure 4, *B*, and 4, *C*.

The raveling which occurred on the unsealed portions of section 13 appears to have been caused by insufficient bitumen rather than by the character of the emulsion. As shown in table 3, there was only 1.4 percent bitumen in the mix, and the total amount, including the seal, was 2.7 percent. Figure 4, *D*, illustrates the tendency of the surface to ravel before being surface-treated. A further comparison of the quantity of bitumen, including the admixed oil used in the mix on sections 11, 12, and 13, is obtained by deducting the water content of the emulsions as given in table 5 from the total amounts used. This shows that approximately 1.2 to 1.5 gallons of bitumen per square yard were used in the mix on section 11, 1.8 gallons on section 12, and only 1.2 gallons on section 13.

Since these sections were built, considerable progress has been made in the development of methods of manufacture and handling of this type of material and, without doubt, most of the construction difficulties encountered on these experimental sections can, to a large extent, now be avoided.

VARIOUS TYPES OF SURFACE TREATMENT APPLIED TO CRUSHED-ROCK BASE

A 3-inch compacted base course for the surface treatments, sections 14 to 21, inclusive, was built in the fall of 1929. This consisted of crusher-run stone, three-fourths inch to dust, to which 10 to 15 percent of local clay and silt binder was added. Early snow and freezing weather made it impossible to thoroughly shape and consolidate the base course so that it was necessary to continue this work during the following spring.

Due to the unusually dry weather during the early summer, much of the base material was whipped off by traffic, the final thickness of the base course being thus reduced to between 2 and 2½ inches instead of 3 inches as planned.

Immediately prior to application of the surface treatments, the base was lightly scarified, watered, and bladed. This work was often done during the night preceding application of the prime coat to avoid, so far as possible, damage from traffic between the final shaping of the base and the application of the prime treatment. The base was swept and this was followed immediately by the prime coat. Figure 6, *A*, shows the sweeping operation.

A typical grading of the aggregate used in the base course was as follows:

Passing—	Percent
1-inch screen	99.6
¾-inch screen	95.9
½-inch screen	80.6
No. 3 sieve	68.9
No. 10 sieve	38.7
No. 200 sieve	10.2

Details concerning the various sections are given in table 7. A prime treatment was applied to all of the sections. On the right half of sections 14 to 17, inclusive, a 110–120 penetration asphalt cut-back with kerosene was used, while on the left half of these four and on the remaining sections a 50–60 penetration slow-curing oil was used.

The prime coat was applied to one-half the road width and the material allowed to penetrate and dry for about 2 days, after which it was opened to traffic while the other side was similarly treated. Wet areas remaining at the end of the 2-day drying period were blotted with stone chips, one-eighth inch to dust. The cut-back asphalt penetrated to an average depth of three-eighths inch and the slow-curing oil to about one-half inch. The former material produced a tougher, better bonded and more wear-resistant surface than did the oil. Failures did not develop in the cut-back-primed surface, but considerable breaking and scaling occurred where the light oil was used. This tendency of the oil-primed surface to break and ravel is illustrated in figure 6, *B*.

Where raveling occurred in the primed base, the holes were swept clean of dust, sprayed lightly with a slow-curing oil and then filled with crushed rock, three-fourths inch to dust in size.

FIGURE 6.—A, SWEEPING BASE BEFORE PRIMING; B, SURFACES PRIMED WITH SLOW-CURING OIL BROKE IN MANY PLACES AND REQUIRED CONSIDERABLE REPAIRING BEFORE APPLYING THE SURFACE TREATMENT; C, SPREADING STONE WITH BOXES ATTACHED TO TRUCKS; D, EQUIPMENT USED TO LIGHTLY MANIPULATE AND SPREAD THE COVER STONE.

Both light and heavy types of surface treatments involving several types and grades of bituminous materials were used. To facilitate their application, all the bituminous materials, including the emulsion, were warmed.

The crushed stone was loaded from cars or stock piles with a truck crane fitted with a ½-cubic-yard clamshell bucket. Three- and four-cubic-yard dump trucks were used for hauling and spreader boxes were used for spreading. Figures 6 and 7 illustrate the spreading, leveling, and finishing operations.

Typical gradings of the crushed stone used as cover material are given below:

	¾ to ½ inch	½ to ⅛ inch
Passing—	*Percent*	*Percent*
1¼-inch screen	100.0	
1-inch screen	98.2	
¾-inch screen	64.3	100.0
½-inch screen	7.5	93.4
No. 3 sieve	2.5	65.9
No. 10 sieve	1.5	8.3
No. 200 sieve		2.1

All of the surface treatments were applied in the summer of 1930 and their behavior up to the final inspection in October 1932 is described.

SURFACE TREATED SECTIONS DESCRIBED IN DETAIL

Section 14.—A heavy treatment of hot asphalt was applied.

The cut-back priming on the right half of the section had been down 5 days and the 50–60 slow-curing oil priming on the left side 3 days when the surface treatment was applied.

On this section an attempt was made to further smooth the surface by honing the seal coat cover. This procedure was abandoned, however, since it proved impossible to hone the surface without disturbing the larger underlying stone. It was therefore decided to use a broom drag on all cover courses and to limit the light honing operation to the heavy stone cover.

The application of the bituminous material on this section was unsatisfactory due to poor operation of the distributor. Many small areas were missed and considerable patching was necessary before applying the seal. The seal treatment was applied after the surface had been under traffic for about 3 weeks.

The cost of the base course was 31.98 cents per square yard, or $3,752 per mile. The cost of the surface treatment was 42.12 cents per square yard, or $4,942 per mile.

TABLE 7.—*Details of surface treatments applied to 3-inch compacted stone base, three-fourths inch to dust and bound with approximately one-fiftieth cubic yard per square yard of selected soil*

SECT	21		20		19		18	
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
	PRIME, 50-60 SLOW-CURING OIL, 32 GAL. ASPHALTIC EMULSION (STANDARD)[1]		PRIME, 50-60 SLOW-CURING OIL, 32 GAL.	.31 GAL. ASPHALTIC EMULSION (STANDARD)[1]	PRIME, 50-60 SLOW-CURING OIL, .32 GAL. ASPHALTIC EMULSION[1] 94+L2		PRIME, 50-60 SLOW-CURING OIL, .32 GAL. ASPHALTIC EMULSION[1] 90-95 L3	94+L2
BITUMINOUS MATERIAL, GALLONS PER SQ. YD.	.19, .39, .20	.19, .38, .18	.26, .35	.25, .37	.16, .28, .25	.26, .29	.15, .27, .35[2]	.17, .27, .29
CRUSHED STONE FOR COVER: POUNDS PER SQ. YD.	45, 8, 26, 11	44, 7, 24, 11	44, 11, 21	44, 10, 25	47, 8, 17	48, 30	47, 16, 16	58, 13, 13
CRUSHED STONE FOR COVER: SIZE IN INCHES	¾-½, ½-⅛, ½-⅛, ¼-⅛ (GRAVEL)	¾-½, ½-⅛, ½-⅛, ¼-⅛ (GRAVEL)	¾-½, ½-⅛, ¼-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛
STATIONS	94+66 to 121+06		121+06 to 147+80		147+80 to 174+20		174+20 to 200+60	

SECT	17		16		15		14	
	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT
	PRIME, 50-60 SLOW-CURING OIL, .29 GAL. 110-120 ASPHALT CUT BACK WITH NAPHTHA[1]	PRIME, 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL.	PRIME, 50-60 SLOW-CURING OIL, .29 GAL. 94+ ASPHALTIC OIL, APPLIED HOT[1]	PRIME, 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL.	PRIME, 50-60 SLOW-CURING OIL, .29 GAL. 94+ ASPHALTIC OIL, APPLIED HOT[1]	PRIME, 110-120 ASPHALT CUT BACK WITH KEROSENE, [illegible] GAL.	PRIME, 50-60 SLOW-CURING OIL, .29 GAL. 150-200 ASPHALT APPLIED HOT[1]	PRIME, 110-120 ASPHALT CUT BACK WITH KEROSENE, .29 GAL.
BITUMINOUS MATERIAL, GALLONS PER SQ. YD.	.29, .15, .22	.28, .2[illegible], .17	.18, .31, .20	.11, .28, .20	.29	.29	.26, .26, .20	.26, .26, .20
CRUSHED STONE FOR COVER: POUNDS PER SQ. YD.	50, 19, 11	37, 15, 13	32, 18, 13	32, 34, 12	27	27	47, 31, 15	49, 31, 21
CRUSHED STONE FOR COVER: SIZE IN INCHES	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛	½-⅛	½-⅛	¾-½, ½-⅛, ½-⅛	¾-½, ½-⅛, ½-⅛
STATIONS	200+60 to 227+07		227+07 to 253+47		253+47 to 279+87		279+87 to 306+2[illegible]	

[1] Quantities used in successive applications and corresponding applications of cover material are shown below.
[2] The final application consisted of 0.58 gallon of 90–95 L3 emulsion from stations 185+00 to 174+20 and 0.35 gallon of the 94+22 emulsion of the remainder of the section

	Left half	Right half
	(*a*) Base swept and holes repaired before priming	
Prime	0.29 gallon, 50–60 slow-curing oil of 17.6 specific viscosity (Engler) at 50° C.	0.29 gallon, 110–120 penetration asphalt cut back with kerosene to a specific viscosity (Engler) of 17.2 at 50° C.
	(*b*) Hand broomed and holes repaired as necessary	
Tack coat	0.26 gallon of 150–200 penetration asphalt applied hot.	0.26 gallon of 150–200 penetration asphalt applied hot.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	49 pounds, ¾- to ½-inch crushed stone.
	(*c*) Stone spread with spreader boxes, lightly honed with a blading machine, spotted, drag broomed and rolled	
Penetration application.	0.26 gallon of the same asphalt as that used in the tack coat application.	0.26 gallon of the same asphalt as that used in the tack coat application.
Keystone	31 pounds of ½- to ⅛-inch crushed stone.	31 pounds of ½- to ⅛-inch crushed stone.
	(*d*) Stone spread with spreader boxes, spotted, drag broomed and rolled	
Seal application	0.20 gallon of the same asphalt.	0.20 gallon of the same asphalt
Cover	15 pounds, ½- to ⅛-inch crushed stone.	21 pounds, ½- to ⅛-inch crushed stone.
	(*e*) Drag broomed, spotted, and rolled	

The total cost was 74.10 cents per square yard, or $8,694 per mile.

Section 15.—A light surface treatment of a heavy asphaltic oil was applied hot.

	Left half	Right half
Prime	0.29 gallon, 50–60 slow-curing oil.	0.29 gallon, kerosene cut-back.
Hot application	0.29 gallon of 94+ asphaltic oil.	0.29 gallon of 94+ asphaltic oil.
Cover stone	27 pounds, ½- to ⅛-inch crushed stone.	27 pounds, ½- to ⅛-inch crushed stone.

Because of the light cover used in this treatment, smoothing by blading, as in the other sections, was not attempted. The equipment and methods used were otherwise the same.

The cost of the base was 32.1 cents per square yard, or $3,769 per mile. The cost of the surface treatment was 14.5 cents per square yard, or $1,707 per mile. The total cost was 46.68 cents per square yard, or $5,477 per mile.

Section 16.—A heavy surface treatment of a heavy asphaltic oil was applied hot.

The method of construction was similar to that used on the other heavy surface treatments. The subgrade conditions were about the same as on the other sections.

The cost of the base was 32.1 cents per square yard or $3,766 per mile. The cost of the surface treatment was 29.8 cents per square yard or $3,493 per

FIGURE 7.—TOUCHING UP SURFACE BY HAND AND DRAGGING WITH A BROOM.

	Left half	Right half
Prime	0.29 gallon, 50–60 slow-curing oil.	0.29 gallon, kerosene cut-back.
Tack coat	0.18 gallon of 94+ asphaltic oil.	0.11 gallon of 94+ asphaltic oil.
Cover stone	32 pounds of ¾- to ½-inch crushed stone.	32 pounds of ¾- to ½-inch crushed stone.
Penetration application.	0.31 gallon of 94+ asphaltic oil.	0.28 gallon of 94+ asphaltic oil.
Keystone	18 pounds, ½- to ⅛-inch crushed stone.	34 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.20 gallon of the same asphaltic oil.	0.20 gallon of the same asphaltic oil.
Seal cover	13 pounds, ½- to ⅛-inch crushed stone.	12 pounds, ½- to ⅛-inch crushed stone.

mile. The total cost was 61.87 cents per square yard or $7,259 per mile.

Section 17.—A heavy surface treatment of rapid-curing cut-back asphalt was applied.

	Left half	Right half
Prime	0.29 gallon of 50–60 slow-curing oil.	0.29 gallon of kerosene cut-back.
Tack coat application.	0.29 gallon of 110–120 asphalt cut back with about 25 per-cent naphtha.	0.28 gallon of 110–120 asphalt cut back with about 25 per-cent naphtha.
Cover stone	50 pounds, ¾- to ½-inch crushed stone.	37 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.15 gallon of naphtha cut-back.	0.22 gallon of naphtha cut-back.
Keystone	19 pounds, ½- to ⅛-inch crushed stone.	15 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.22 gallon of naphtha cut-back.	0.17 gallon of naphtha cut-back.
Seal cover	11 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.

The same methods were used in the construction of this section as on sections 14 and 16. The prime had been applied on the left side 18 days and on the right 20 days at the time the surface treatment was applied. The right half of the base which was primed with the cut-back asphalt was in perfect condition and free from holes or raveling, while the left side on which the 50–60 slow-curing oil was used had developed a few pot holes and some raveling.

The amount of cover stone used, particularly on the left half, was far too great for the quantity of asphalt used. An excessive amount of raveling occurred on this half before the seal coat was applied. The difficulty was corrected to some extent in applying the seal treatment by increasing the amount of asphalt and reducing the amount of stone cover.

The cost of the base was 32.6 cents per square yard or $3,825 per mile. The cost of the surface treatment was 38.7 cents per square yard or $4,544 per mile. The total cost was 71.33 cents per square yard or $8,369 per mile.

The high cost of this section was largely due to the cost of transporting the cut-back asphalt in steel drums, which was necessary because of the small quantity used.

Section 18.—A heavy surface treatment of asphalt emulsion was applied.

This section, as well as sections 19, 20, and 21, received surface treatments of essentially the same type as did sections 14, 16, and 17, except that asphaltic emulsions from two producers were used. The designs of the sections were furnished by the producers and the work was carried out under their supervision.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat application.	0.15 gallon of 90–95 L3 asphaltic emulsion.	0.17 gallon of 94+ L2 asphaltic emulsion.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	58 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.27 gallon of 90–95 L3 asphaltic emulsion.	0.27 gallon of 94+ L2 asphaltic emulsion.
Keystone	16 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.58 gallon of 90–95 L3 asphaltic emulsion from stations 185+00 to 174+20 and 0.35 gallon of the L2 grade on the remainder.	0.29 gallon of 94+ L2 asphaltic emulsion.
Seal cover	16 pounds, ½- to ⅛-inch crushed stone.	13 pounds, ½- to ⅛-inch crushed stone.

The prime coat had been down on the left side 8 days and on the right side 9 days before the surface treatment was applied. Holes and raveling which had developed during this time were repaired before applying the surface treatment.

The change in the grade of emulsion for the seal on the left side was made because of a shortage of L3 material. The emulsion was heated at the plant to about 140° F. in order to facilitate handling and spreading. The penetration application did not penetrate through the cover stone to meet the tack coat and, as a result, the stone was only partly coated. Failure from insufficient bituminous material was indicated by the large amount of raveling which occurred before the application of the seal treatment. Although the surface was considerably strengthened by the seal coat, failures by raveling continued to develop on many areas.

The cost of the base was 32.2 cents per square yard or $3,781 per mile. The cost of the surface treatment was 34.5 cents per square yard or $4,050 per mile. The total cost was 66.74 cents per square yard or $7,831 per mile.

Section 19.—A heavy surface treatment of asphaltic emulsion was applied.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat application.	0.16 gallon of 94+ L2 asphaltic emulsion.	0.26 gallon of 94+ L2 asphaltic emulsion.
Cover stone	47 pounds, ¾- to ½-inch crushed stone.	48 pounds, ¾- to ½-inch crushed stone.
Penetration application.	0.28 gallon of the same emulsion.	0.29 gallon of the same emulsion.
Keystone	8 pounds, ½- to ⅛-inch crushed stone.	30 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.25 gallon of the same emulsion.	None.
Seal cover	17 pounds, ½- to ⅛-inch crushed stone.	None.

The treatment on this section was essentially the same as that on section 18, except that the seal coat was applied only to the left half.

The priming coat had been down 8 days on the left half and 9 days on the right half when the surface treatment was applied. As on section 18, an insufficient amount of emulsion was used on this section. The cover stone was poorly coated, and the application did not penetrate through to the tack coat. Early loosening and raveling of the stone occurred under traffic.

The cost of the base was 32.7 cents per square yard or $3,834 per mile. The cost of the surface treatment was 26.9 cents per square yard or $3,160 per mile. The total cost was 59.61 cents per square yard or $6,994 per mile.

Section 20.—A heavy surface treatment of asphaltic emulsion was applied.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.31 gallon of 50–60 slow-curing oil.
Tack coat application.	0.26 gallon of asphaltic emulsion (standard).	0.25 gallon of asphaltic emulsion (standard).
Cover stone	44 pounds, ¾- to ½-inch crushed stone.	44 pounds, ¾-to ½-inch crushed stone.
Choke stone	11 pounds, ½- to ⅛-inch crushed stone.	10 pounds, ½- to ⅛-inch crushed stone.
Penetration application.	0.35 gallon of the same emulsion.	0.37 gallon of the same emulsion.
Keystone	21 pounds, ½- to ⅛-inch crushed stone.	25 pounds, ½- to ⅛-inch crushed stone.

The section differs from sections 18 and 19 in that a different asphaltic emulsion was used and also that a choke stone cover was added before the penetration application. No seal treatment was used.

It was apparent during the construction that the amount of emulsion used was insufficient to fully penetrate and coat the heavy stone cover. The use of a choke stone further increased the deficiency of asphalt. A similar deficiency had been apparent on sections 18 and 19 but additional stone cover was not used on those sections. Excessive raveling occurred in the surface shortly after construction and it was soon apparent that this section would not prove entirely satisfactory.

The cost of the base was 31.3 cents per square yard and $3,674 per mile. The cost of the surface treatment, including the cost of the emulsion, was 27.2 cents per square yard or $3,196 per mile. The total cost was 58.55 cents per square yard or $6,870 per mile.

Section 21.—A heavy surface treatment of asphaltic emulsion was applied.

The method of construction was similar to that on section 20, except that a seal treatment was applied. As was the case in all the experiments with emulsions the stone was poorly coated due to the use of an insufficient amount of bituminous material. The surface showed early indications of weakness and failure from this cause.

	Left half	Right half
Prime	0.32 gallon of 50–60 slow-curing oil.	0.32 gallon of 50–60 slow-curing oil.
Tack coat	0.19 gallon of asphaltic emulsion (standard).	0.19 gallon of asphaltic emulsion (standard).
Cover stone	45 pounds, ¾- to ½-inch crushed stone.	44 pounds, ¾- to ½-inch crushed stone.
Choke stone	8 pounds, ½- to ⅛-inch crushed stone.	7 pounds, ½- to ⅛-inch crushed stone.
Penetration application.	0.39 gallon of the same emulsion.	0.38 gallon of the same emulsion.
Keystone	26 pounds, ½- to ⅛- inch crushed stone.	24 pounds, ½- to ⅛-inch crushed stone.
Seal application	0.20 gallon of the same emulsion.	0.18 gallon of the same emulsion.
Seal cover	11 pounds, ¼- to ⅛-inch gravel.	11 pounds, ¼- to ⅛-inch gravel.

The cost of the base was 35.4 cents per square yard or $4,158 per mile. The cost of the surface treatment was 33 cents per square yard or $3,876 per mile. The total cost was 68.47 cents per square yard or $8,034 per mile.

PERFORMANCE OF SURFACE-TREATED SECTIONS NOT SATISFACTORY

The behavior of the surface-treated sections was, in general, unsatisfactory. In the spring following construction, extensive failures had occurred.

Except on section 21 which was discontinued as an experiment and rebuilt, these failures were repaired during the early summer. In the fall a light surface treatment was added to sections 18, 19, and 20. This treatment consisted of applying one-quarter gallon of emulsion, of the type and grade used on the original construction, covering with screenings at the rate of about 25 pounds per square yard and rolling.

Following this maintenance work in the fall of 1931 all the sections appeared in good condition. However, failures occurred again during the winter of 1931–32 to such an extent that it was decided to discontinue all the surface-treatment experiments.

Although other factors, particularly the subgrade conditions and the operation of heavy equipment for snow removal, seriously affected the behavior of the sections, an important cause of early failure was insufficient bituminous material.

As shown in table 8, all of the surface-treatment experiments except section 15 and the left half of section 16 were greatly deficient in bituminous material. Because of the low specific gravity of the cover stone, which weighed only 1,970 pounds per cubic yard, this deficiency was actually greater than the quantities used might indicate. Table 8 gives the percentages by weight of bitumen which would have resulted had the same volume of asphaltic material been used with the same weight of aggregate but weighing 2,700 pounds per cubic yard.

Experience has shown that surface-treated wearing surfaces require approximately 0.1 gallon of bitumen for each 10 pounds of cover, particularly where the subgrade is poor. It is believed that had these sections been built with quantities conforming more closely to this rule the surfaces would have been better bonded and more plastic and would therefore have been more satisfactory, particularly for the conditions which prevailed on this project.

Considering the character of the subgrade, the unfavorable drainage during the early spring months and the use of very heavy snow-removal equipment, it is evident that the conditions were unfavorable for any type of thin surface treatment, and were particularly so for the lean surface treatments used on this project.

CONSTRUCTION COST DETAILS GIVEN

Due to the experimental nature of the project and to the short sections built, the actual costs of the different surfaces are excessively high and would no doubt be considerably reduced in the construction of an appreciable mileage of any one type. Table 9 gives details of costs by sections and the following tabulation gives

TABLE 8.—*Quantity of bitumen and stone cover used on each of the surface treatments and conclusions as to the sufficiency of bitumen based on construction and early service behavior*

Section and lane	Bituminous material: Types	Bituminous material: Gallons per square yard	Stone cover	Seal	Cover stone used for each 0.1 gallon of bitumen: Stone as used weighing 1,970 pounds per cubic yard	Cover stone used for each 0.1 gallon of bitumen: Based on equal volume of stone weighing 2,700 pounds per cubic yard	Calculated bitumen: With the stone used weighing 1,970 pounds per cubic yard	Calculated bitumen: Based on equal volume of stone weighing 2,700 pounds per cubic yard	Adequacy of amount of bitumen used based on behavior of the surfaces
			Pounds per square yard		*Pounds*	*Pounds*	*Percentage by weight*	*Percentage by weight*	
14, Left	150–200 asphalt, hot	0.72	93	Applied	13	18	6.1	4.5	Deficient.
Right		.72	101	do	14	19	5.6	4.1	Do.
15, Left	94+ asphaltic oil, hot	.29	27	None	9	12	8.2	6.0	Satisfactory.
Right		.29	27	do	9	12	8.2	6.0	Do.
16, Left	do	.69	63	Applied	9	12	8.4	6.1	Do.
Right		.59	78	do	13	18	5.9	4.3	Slightly deficient.
17, Left	Asphalt cut back with naphtha [1]	.66	80	do	15	21	5.2	3.8	Deficient.
Right		.67	65	do	12	16	6.4	4.7	Slightly deficient.
18, Left [1]	Emulsion [3]	.77	79	do	19	26	4.4	3.2	Greatly deficient.
Left [2]		1.00	79	do	14	19	5.6	4.1	Deficient.
Right		.73	84	do	21	29	3.9	2.8	Greatly deficient.
19, Left	do [3]	.69	72	do	19	26	4.3	3.1	Do.
Right		.55	78	None	25	34	3.2	2.3	Do.
20, Left	do [3]	.61	76	do	22	30	3.6	2.6	Do.
Right		.62	79	do	23	32	3.5	2.5	Do.
21, Left	do [3]	.78	90	Applied	21	29	3.9	2.8	Do.
Right		.75	86	do	21	29	3.9	2.8	Do.

[1] In the calculation, emulsion was assumed to contain 56 percent of bitumen and the naphtha cut-back 80-percent residual bitumen.
[2] Stations 185 to 200+60.
[3] Stations 174+20 to 185.

TABLE 9.—*Cost of construction and maintenance of the experimental sections*

Sections	Date constructed	Cost of construction		Cost per square yard of maintaining bituminous surfaces										Annual cost per mile of maintenance
		Per square yard	Per mile	Total to October 1930	October 1930 to January 1931	January 1931 to April 1931	April 1931 to July 1931	July 1931 to October 1931	October 1931 to January 1932	January 1932 to April 1932	April 1932 to July 1932	July 1932 to October 1932	October 1932 to July 1933	
		Cents	*Dollars*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Dollars*
1, A	September 1929	46.94	5,507											
1, B	do	51.18	6,005					0.72	0.22	0.19	0.36	[1] 3.41	None	153
1, C	do	58.57	6,872											
2	do	66.50	7,802				0.07	.43	.22		.29	.61	None	51
3	do	69.68	8,175	0.28			.30	.15			.37	[1] 5.42	None	204
4	do	44.57	5,229	.31			.35	1.13	.31		.71	[1] 1.82	None	145
5	do	52.03	6,105				.44	.54			.32	[1] 2.45	None	117
6	do	47.17	5,534				.11	.11		.04	.57	.50	None	42
7	do	47.82	5,611				.22	.68				1.43	None	73
8	do	59.55	6,987	13.29	(2)									
9	do	50.81	5,962				.07		.28					11
10	do	71.19	8,353				.05	.14	.81		.21			38
11	do	64.46	[3] 7,563	1.51		0.06	7.82	.36			(4)	(4)	(4)	
12	do	64.62	[3] 7,582	1.33			.85	.03			(4)	(4)	(4)	
13	do	67.29	[3] 7,895	1.19			3.30	.20	.55		(4)	(4)	(4)	
14	July 1930	74.10	8,694			.32	1.00	.63	.22	(2)				
15	do	46.68	5,477			.11	1.19	.38	.31	(2)				
16	do	61.87	7,259		0.05	.67	1.13	.18	.11	(2)				
17	do	71.33	8,369			.08	.29	.05	.13	(2)				
18	do	66.74	7,831		.32	.45	1.92	[1] 9.75		(2)				
19	do	59.61	6,994	.10	.03	.22	6.00	[1] 9.90		(2)				
20	do	58.55	6,870	.03		.24	1.19	[1] 11.28		(2)				
21	do	68.47	8,034		1.10	1.45	2.01	(2)						

[1] Experiment retreated in part only; cost prorated over entire experiment.
[2] Surface failed and experiment discontinued.
[3] Includes seal applied in 1930 to complete construction.
[4] Maintenance cost not reported.

the average unit cost of some of the more important items entering into the construction of the experimental sections:

	Per cubic yard
Local stone at crushing plant:	
¾ inch to dust	$1.19
¾ to ⅛ inch	2.46
¾ to ½ inch	1.44
½ to ⅛ inch	.99
Other aggregates, f. o. b. destination:	
Crushed gravel, ¾ inch to dust, per cubic yard	$2.78
Fine sand filler (muck sand), per ton	2.25

Up to the time of the inspection in 1932 the eight surface-treated sections had required complete reconstruction. The three road-mix sections on which emulsions were used had received extensive repairs where subgrade failures had occurred. The road-mix section with 70–80 oil and open-graded aggregate had been reconstructed by extensive foundation repairs and by reworking the surface with the addition of fines. The remaining nine sections, all of the road-mix type, had required some repairs due primarily to base failures but were generally in good condition.

Later inspection of the experimental sections in 1934, 5 years after construction, showed that all of the road-mix sections were in serviceable condition. No extensive maintenance or reconstruction had been required except over certain areas where poor subgrade and drainage existed. A seal coat of hot oil had been applied to portions of sections 1, 3, 4, 5, and 7 and to all of sections 11, 12, and 13.

RESULTS OF INVESTIGATION SUMMARIZED

A summary of the more important results follows:

1. Portions of the oil-mix sections were affected by capillary moisture which resulted in the surface becoming soft and unstable.

2. The effect of moisture on the road-mix sections with slow-curing oils was greatest with the rich mixes and on areas where the drainage was not satisfactory, as well as on subgrades having high capillarity.

3. The road-mix surfaces containing emulsion and cut-back asphalt did not lose stability or develop soft areas from the action of moisture as did several of the oil-mix sections.

4. The action of moisture seemed to be more severe on the oil and gravel mixes than on the oil and crushed stone mixes.

5. The excellent behavior of a lean oil mix with a light surface treatment of heavy asphaltic oil and stone chips suggests possible advantages of this type over the richer and unsealed oil mixes, particularly where moisture conditions are unfavorable.

6. Satisfactory repair of those portions of the oil-mix surfaces which softened was obtained by scarifying and remixing.

7. Slow-curing or medium-curing bituminous materials should be used for road-mix construction with aggregates of the dense-graded type, while the more rapid-curing materials are best adapted to aggregates of the more open type (those containing less than 5 percent of material passing the no. 200 sieve).

8. The results of these experiments indicate that several of the formulas now in use are satisfactory for determining the amount of bituminous material required as binder in road-mix construction with the lighter slow-curing oils and close-graded aggregates.

9. For the very heavy slow-curing oils and the cut-backs and emulsions which develop heavy asphaltic residues in the road surface, somewhat greater quantities than those indicated by the formulas may be used to advantage.

10. Early failure of the road-mix sections occurred generally where unsatisfactory subgrade conditions existed. In the case of the unsealed portions of the road-mixes containing emulsions, failure was hastened by the open and porous condition of the mix.

11. Early failure of the treated surfaces was due to the unsatisfactory subgrade and the use of an insufficient amount of bituminous material which resulted in surfaces which were highly friable and poorly bonded. Because of the dust content and low specific gravity of the stone cover, the deficiency in bitumionus material was greater than the quantities indicate when expressed by weight.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

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

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

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 3,947,753	$ 2,129,921	$ 4,617,753	$ 2,514,859	$ 35,890	252.8	$ 2,532,250	$ 1,231,350	$ 261,873	160.3	$ 129,086	$ 882,957	51.4	$ 72,458	$ 949,202
Arizona	3,878,555	1,338,712	4,348,078	3,713,426	41,269	290.8	790,917	157,724	618,953	47.6	4,655	205,880	20.6	2,750	472,610
Arkansas	3,334,167	1,714,000	2,444,464	1,886,556	138,919	134.0	1,464,499	1,293,409		43.9	72,616	779,146	36.4	81,587	795,935
California	7,912,928	3,713,643	7,224,499	5,391,792		241.8	5,007,793	2,514,683	881,600	87.0		690,800	23.9	6,453	2,141,243
Colorado	3,437,265	2,424,504	3,508,159	3,376,400	49,399	155.0	1,684,085	16,425	1,608,755	84.5	10,047	341,238	26.0	34,393	425,113
Connecticut	1,404,213	607,500	618,204	618,204		10.7	1,489,477	786,009	520,000	25.4		12,499			75,001
Delaware	892,544	461,697	876,080	873,987		33.4	465,318		450,140	10.7				18,557	11,557
Florida	2,519,011	1,330,672	2,808,803	2,068,798		103.3	778,633	372,460	273,046	27.4	6,136	477,283	18.8	71,617	580,343
Georgia	5,045,592	2,556,745	3,254,753	3,227,544		238.4	1,474,891	1,190,244	140,502	66.0	588,902	609,105	50.8	38,903	1,807,138
Idaho	2,166,858	1,131,910	2,068,561	1,985,815	14,243	177.9	605,246	171,151	421,900	32.8		101,297	14.7	9,892	594,470
Illinois	4,468,247	3,060,041	1,796,692	1,792,514		32.2	2,757,430	2,479,132	278,298	33.2	170,911	502,879	6.5	25,690	2,278,863
Indiana	5,018,921	2,843,478	3,033,316	3,025,496		100.7	1,705,868	1,705,128		38.5	288,297	601,151	76.6		2,242,327
Iowa	5,027,830	2,217,361	4,846,999	4,618,969		253.3	1,748,392	380,600	1,274,197	137.4		545,325	31.0	28,261	397,839
Kansas	5,044,802	2,558,837	5,211,591	4,888,918	84,944	453.7	1,260,995	75,293	1,185,701	197.7		1,279,231	102.6	80,590	8,962
Kentucky	3,751,605	1,527,324	3,440,744	3,264,209		238.3	734,208	359,844	268,733	46.0	109,476	210,452	33.9	18,076	1,048,139
Louisiana	2,711,152	1,380,419	1,524,551	1,520,772		61.5	1,872,012	1,139,887	225,474	23.9	45,845	823,944	11.8	4,648	331,001
Maine	1,617,560	793,644	1,309,462	1,284,365		43.1	815,140	241,620	563,051	13.7	28,442	197,402	7.3	63,134	33,191
Maryland	1,782,263	289,609	787,781	778,132		14.6	771,952	665,366	106,586	16.1	204,764	137,014	6.0	134,000	46,009
Massachusetts	1,101,716	1,632,874	1,159,396	870,145		32.5	701,966	157,399	389,045	14.1		257,343	1.1	74,172	986,485
Michigan	6,113,389	3,226,284	4,670,420	4,600,283		216.6	2,391,675	1,451,250	925,625	96.3		749,475	21.1	61,856	1,551,184
Minnesota	4,561,011	2,642,244	5,576,835	4,327,180	1,170,809	842.2	774,333	183,627	525,305	114.1		494,274	81.2	50,203	451,855
Mississippi	3,489,337	2,301,148	3,152,453	1,701,224		162.6	3,296,163	1,609,029	414,197	175.2	30,117	296,003	16.7	148,966	1,590,947
Missouri	5,237,532	2,778,183	4,630,609	4,096,746		187.4	2,354,158	756,989	1,343,156	69.1	293,639	169,716	5.5	90,158	1,265,311
Montana	4,463,849	2,714,208	5,168,105	4,417,657	109,308	386.4	1,720,383	36,653	1,614,773	193.2		154,417	16.7	9,539	835,711
Nebraska	3,914,481	1,982,182	4,538,382	3,449,750	27,348	324.9	1,843,153	464,731	941,321	99.1		936,113	52.3		77,400
Nevada	2,909,387	1,350,356	2,724,343	2,674,841		259.3	919,397	151,423	767,974	110.4	17,735	14,755	2.6	65,388	567,627
New Hampshire	725,739	484,731	642,877	623,374		10.8	425,572	79,730	324,780	11.2		118,599	1.3	22,635	41,352
New Jersey	3,173,019	951,379	1,713,050	1,693,518		31.9	1,435,567	1,296,101		15.3	97,912	105,868	2.7	85,489	845,510
New Mexico	2,846,648	1,676,769	2,922,244	2,760,948	17,366	277.6	1,113,756	18,762	1,094,994	106.4	66,938	116,186	10.2		448,223
New York	10,465,672	2,872,521	9,793,718	8,352,868	53,000	207.0	7,842,928	2,109,693	2,161,600	137.9		205,950	8.3	3,111	451,971
North Carolina	4,761,147	2,040,068	4,352,701	3,615,766	57,146	568.5	1,156,761	513,353	248,597	109.8	253,058	216,298	41.1	378,970	1,518,027
North Dakota	2,902,224	1,469,484	3,090,149	2,652,776	31,434	990.2	369,554	72,297	219,180	134.7	46,049	383,341	230.4	131,102	835,529
Ohio	7,277,758	3,539,256	7,370,525	7,037,866		188.4	1,003,710	70,898	647,290	19.8		1,812,206	38.0	168,994	1,079,759
Oklahoma	4,608,399	2,342,590	3,646,829	3,584,048		272.9	1,170,417	739,622	412,496	53.9	278,381	1,344,180	66.3	6,348	585,913
Oregon	3,053,448	1,452,741	3,329,545	2,996,112		182.8	1,126,918	24,519	1,027,499	47.9		80,857	8.0	32,817	344,386
Pennsylvania	6,691,194	4,554,082	5,042,718	4,868,286	17,389	117.6	4,033,104	1,732,286	2,103,471	62.8	17,361	2,049,106	39.8	73,261	384,116
Rhode Island	979,367	464,572	984,804	921,936		20.5	298,876	46,205	210,273	8.1		245,737	3.4	11,226	8,562
South Carolina	2,729,583	1,385,477	1,927,023	1,923,409		162.5	1,048,651	746,353	285,865	93.7	14,500	174,101	11.2	45,321	925,512
South Dakota	3,005,739	1,523,821	2,810,564	2,385,615		428.5	673,573	547,825	93,171	174.7	72,299	745,511	127.9		685,140
Tennessee	4,246,309	2,105,453	3,660,867	3,059,845		149.6	1,584,579	998,204	489,974	49.6	155,447	503,096	25.1	32,813	1,112,383
Texas	11,588,643	6,145,627	10,822,912	10,371,890		949.9	2,325,145	1,130,915	1,135,078	183.5	81,349	1,793,250	125.9	4,488	3,217,299
Utah	2,374,205	1,066,345	2,756,918	2,279,806	365,500	237.8	697,493	47,632	429,451	57.1	40,000	1,000	1.0	6,766	270,394
Vermont	928,184	466,042	975,782	913,366	29,890	47.9	277,219	10,670	249,114	13.9				4,148	187,038
Virginia	3,708,379	1,882,693	3,569,159	3,359,113		143.6	510,484	57,508	411,093	22.9	26,980	934,735	41.9	264,778	536,865
Washington	3,057,934	1,553,206	2,567,807	2,551,840		94.8	1,060,184	436,929	623,255	25.9	30,664	416,262	7.5	38,502	513,689
West Virginia	2,013,405	1,140,167	1,764,248	1,753,641		61.8	730,703	239,456	474,356	29.4		208,412	7.4	20,308	457,399
Wisconsin	4,697,518	1,865,947	4,458,518	4,342,445	549	213.1	661,175	239,442	322,490	35.9	50,000	724,898	31.2	65,632	818,010
Wyoming	2,250,663	1,692,907	2,320,263	2,038,160	67,583	469.8	1,093,538	195,228	872,144	131.8	16,766	531,702	100.4	509	221,478
District of Columbia															
Hawaii	1,683,956	598,778	254,428	178,070		10.9	1,766,159	1,437,846		28.1	66,000		.7	2,040	598,778
TOTALS	185,521,101	93,982,152	166,118,682	147,233,280	2,311,986	11,085.8	74,366,400	32,382,900	29,836,376	3,517.9	3,314,372	24,180,994	1,645.2	2,590,549	37,652,796

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

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

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

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,389,928	$ 1,064,961	$ 980,045	$ 980,045		25.8	$ 1,251,292	$ 1,234,924	$ 16,368	37.4	$ 21,289	$ 98,661	4.0	$ 153,670	$ 949,931
Arizona	807,982	305,191	626,513	618,491	$ 6,592	12.3	20,819	500	15,124	.7	149,322	2,709	.9	39,670	280,766
Arkansas	1,964,534	857,025	1,198,104	1,101,038		32.0	686,211	667,122		11.7	146,732	17,953	1.9	49,643	839,072
California	4,213,986	2,219,360	3,896,733	3,402,117		46.7	1,054,196	789,009	43,200	6.5		403,500	6.2	22,859	1,772,660
Colorado	1,718,633	190,000	1,755,371	1,705,334		35.2	19,122		19,122	1.8		170,878	2.0	13,299	
Connecticut	802,407	426,500	806,490	802,407		10.2	6,892		6,892			155,920	1.2		263,687
Delaware	477,680	230,849	474,326	466,045		7.4	54,180		54,180	.7	4,323		.7	7,313	176,669
Florida	1,410,008	665,336	911,221	670,710		10.4	796,390	725,501	70,889	10.2	7,721	24,263	.6	6,075	570,184
Georgia	2,724,620	1,278,373	1,118,295	1,117,289		49.5	747,558	747,558		18.7	596,332	67,440	8.2	263,440	1,210,933
Idaho	1,197,829	321,126	837,839	799,532	2,643	19.2	390,046	367,764	22,282	1.6		2,156	.2	30,533	294,045
Illinois	7,692,483	2,515,835	5,606,631	5,556,567		61.4	1,888,283	1,862,346	25,937	10.6	57,163	439,067	3.7	216,408	2,050,831
Indiana	4,287,050	2,035,585	2,614,514	2,604,092		58.1	1,458,175	1,458,026		13.2	166,973	159,463	5.4	57,959	1,876,122
Iowa	2,614,472	1,311,000	1,774,151	1,678,664	3,680	51.3	867,626	789,808	36,963	9.1	146,000	177,354	8.3		1,093,003
Kansas	2,522,401	1,279,419	2,030,425	2,010,283	1,285	36.8	891,244	453,792	292,599	7.1	32,129	985,535	10.0	26,198	
Kentucky	1,927,828	954,578	1,290,289	1,273,301		29.1	606,461	558,334	43,798	4.9	94,506	247,387	5.7	1,687	663,393
Louisiana	1,718,577	744,560	610,276	610,274		14.1	927,581	879,754	21,233	13.5	143,577	106,356	5.8	84,972	616,971
Maine	909,878	490,045	808,427	802,833		16.4	38,606	38,606		.4		111,539	.8	68,440	378,506
Maryland	891,132	452,515	388,284	384,134		4.1	911,650	98,129		.4				408,869	452,515
Massachusetts	5,007,199	847,600	1,315,478	1,273,933		10.7	3,692,649	3,615,424	52,248	6.8		141,429	.7	117,841	653,923
Michigan	3,438,781	1,613,142	2,362,064	2,346,755		35.9	2,207,865	1,085,565	1,109,800	11.2	6,461	211,400	7.1		291,942
Minnesota	3,719,143	1,421,494	3,243,704	3,019,572	193,497	106.7	362,446	155,856	198,390	9.7		40,724	6.4	543,715	988,883
Mississippi	1,744,669	885,056	554,462	542,002		19.5	728,456	665,432	63,024	24.0	281,960	54,974	7.1	255,275	767,059
Missouri	4,019,501	1,543,435	2,126,474	1,975,278		48.7	1,670,615	1,501,987	144,128	12.7	46,509	395,411	2.4	495,727	1,003,896
Montana	1,115,962	113,092	1,064,837	1,062,457		32.4	65,264	34,716	5,994	4.5	8,796	33,230	3.2	9,992	73,868
Nebraska	1,957,240	991,091	1,163,906	1,071,939	79,637	30.7	1,121,477	881,804	239,673	7.9		502,172	9.7	3,497	169,608
Nevada	500,051	100,000	501,943	483,944		8.8					16,107	50,332	1.5		49,668
New Hampshire	706,640	242,366	681,187	678,670		15.6	176,185		175,975	3.4				27,970	66,391
New Jersey	3,117,921	1,809,500	2,383,144	2,284,751		20.0	843,545	813,545		2.8		399,314	4.2	19,625	1,410,186
New Mexico	1,674,158	529,506	1,352,595	1,352,595		30.6	400,136	220,039	180,097	9.6		60,330	1.7	101,524	289,079
New York	8,255,661	4,203,000	5,511,788	5,164,770		51.7	4,473,856	3,057,756	1,246,200	24.3		1,282,300	7.1	33,135	1,674,500
North Carolina	2,380,573	1,210,236	1,842,389	1,813,467	26,797	72.6	412,006	337,602	30,837	9.2	127,497	37,135	3.5	102,007	1,115,467
North Dakota	1,451,112	734,742	1,007,990	1,005,717		42.4	217,558	142,308	75,250	8.3	277,222	55,501	14.2	25,864	603,991
Ohio	4,335,686	2,359,503	4,451,179	3,971,268		56.0	521,580	323,138	167,700	6.5		804,400	11.7	41,280	1,387,404
Oklahoma	2,304,200	1,171,295	1,752,643	1,731,058		38.3	527,828	506,493		8.1	65,270	389,880	5.3	1,379	781,415
Oregon	1,526,724	867,977	1,361,445	1,343,930		25.7	127,593	127,593		2.1	30,841	265,959	6.7	24,360	602,018
Pennsylvania	4,854,988	2,397,703	3,227,172	3,116,628	19,191	53.1	1,787,936	1,503,424	274,030	16.4	193,049	1,534,932	15.9	41,887	569,550
Rhode Island	579,625	255,000	527,914	527,015		7.4						40,627	.6	52,609	214,373
South Carolina	1,364,791	692,738	806,757	805,679		27.5	388,252	384,108	4,144	15.0	100,311		1.6	74,693	688,594
South Dakota	1,502,870	761,911	1,083,540	1,083,540		36.1	73,967	73,799	168	4.5	72,640	29,169	4.9	272,891	732,574
Tennessee	2,123,155	1,121,790	1,546,795	1,540,995		22.7	519,035	457,328	61,707	4.8	118,647	221,727	3.6	6,185	838,356
Texas	6,642,863	3,072,813	3,688,185	3,579,204		101.1	2,868,207	2,703,917		19.8	254,107	53,952	6.6	105,635	3,018,861
Utah	771,826	533,173	749,910	652,514	65,900	20.2	76,221		71,000	1.9	115,000	245,000	6.7	4,312	151,273
Vermont	500,509	240,611	465,187	441,585		12.9	78,014	58,924	18,000	1.8		48,000	1.1		174,611
Virginia	2,008,458	941,347	1,270,817	1,243,195		24.6	803,985	457,115	150,144	4.3	32,212	154,448	4.9	275,936	636,755
Washington	1,977,260	776,603	1,950,946	1,933,290		32.4	134,257		134,257	4.1	36,458	292,329	8.1	7,512	350,017
West Virginia	1,342,270	570,085	804,536	804,536		15.5	559,095	506,641	28,109	5.9				31,094	541,976
Wisconsin	2,596,143	1,293,455	2,534,030	2,473,556	15,575	52.4	327,925	116,488	211,437	6.3		128,516	2.8	6,099	937,927
Wyoming	1,125,332	22,877	1,031,616	1,028,227		22.3	104,315	97,105	6,629	2.6		6,249	.7		9,999
District of Columbia	968,235	243,460	861,028	704,305	156,723	5.9	322,521	250,164	72,357	.7				13,766	14,381
Hawaii															
TOTALS	115,884,974	50,908,859	80,953,595	77,639,531	571,520	1,600.4	38,209,121	30,749,444	5,389,885	387.7	3,349,154	10,649,621	215.6	4,146,845	34,297,833

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

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

CLASS 3.—PROJECTS ON SECONDARY OR FEEDER ROADS

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$ 2,032,452	$ 1,064,960	$ 328,712	$ 328,712		16.0	$ 1,602,627	$ 1,545,599	$ 57,028	122.7	$ 123,547	$ 344,795	32.8	$ 34,594	$ 663,138
Arizona	525,423	998,032	530,237	517,610		42.3	155,442		139,878	14.5	7,813	112,459	3.9		745,695
Arkansas	1,449,634	857,024	765,223	764,238		123.4	562,188	557,188		37.2	59,132	127,302	27.3	69,076	729,722
California	3,480,440	1,999,203	2,851,174	2,370,743		130.6	1,430,072	1,109,697	126,600	53.8		456,556	14.3		1,416,047
Colorado	1,718,632	871,502	1,717,340	1,608,632	$ 11,000	174.2	864,466	110,000	341,287	158.2		112,695	5.7		406,519
Connecticut	659,120	420,868					887,796	659,120	222,880	19.0					197,988
Delaware	448,864	230,849	210,549	202,680	7,869	11.3	486,455	246,184	183,315	48.4					39,665
Florida	1,302,815	665,335	1,279,636	1,273,590		74.8	258,654		258,654	11.1		134,294	11.2	29,226	272,387
Georgia	2,320,973	1,278,373	1,056,732	1,055,479		80.9	973,308	973,308		65.1	183,491	139,830	15.3	108,695	1,138,543
Idaho	1,121,562	824,450	1,287,068	1,121,498	60,449	156.5	402,152		391,674	42.5		51,700	6.8	64	320,627
Illinois	5,410,040	3,345,525	1,761,827	1,757,460		118.9	4,253,782	3,563,263	690,519	243.1	89,317	1,811,109	85.6		843,898
Indiana	731,872	209,900	345,107	345,107		35.8	270,290	270,290		41.1	116,475	16,356	11.5		193,544
Iowa	2,413,358	1,590,000	1,883,103	1,812,595	15,800	257.6	1,146,993	516,950	473,150	210.7	38,200	690,300	152.5	45,613	410,750
Kansas	2,522,401	1,279,419	1,905,415	1,876,925	24,566	166.4	1,137,785	637,717	500,068	100.3	7,758	754,785	48.8		
Kentucky	1,837,926	1,336,409	1,765,773	1,729,492		205.9	555,671	85,833	453,118	56.8	21,369	214,471	32.0	1,232	668,820
Louisiana	1,398,862	838,953	950,765	949,942		45.1	326,143	323,941		14.3		155,403	9.0	124,978	683,550
Maine	842,479	427,897	1,042,171	828,393	137,550	90.4	283,371	5,000	258,312	23.1		16,994	.7	9,085	15,041
Maryland	891,132	1,067,934	622,914	613,642		47.5	479,375	252,997	212,451	27.1	20,419	291,894	11.0	4,074	563,589
Massachusetts	488,185	870,000	469,741	469,741		15.2								18,444	870,000
Michigan	3,184,057	1,613,142	2,830,230	2,813,830	16,400	201.7	976,027	370,227	590,900	40.1		359,700	17.4		646,142
Minnesota	2,376,415	1,361,813	2,282,932	2,204,016	58,916	233.1	764,074	155,444	450,830	98.5		237,567	33.7	16,956	614,500
Mississippi	1,744,669	354,023	444,928	444,928		55.6	1,016,355	1,016,355		92.3	216,589		15.7	66,797	354,023
Missouri	2,923,273	1,852,122	2,841,364	2,690,423	79,917	554.5	565,393	78,632	486,761	174.1	29,933	683,992	113.9	124,286	601,452
Montana	1,859,937	942,434	1,830,540	1,829,829		226.1	173,754		173,754	8.3		149,021	19.6	30,108	619,659
Nebraska	1,957,240	991,091	1,519,246	1,398,089	118,655	300.4	896,838	557,763	338,825	103.1		437,935	85.1	1,389	95,676
Nevada	1,136,479	852,000	1,133,078	1,037,806	75,272	133.3	251,481	98,673	128,402	22.3		169,404	20.0		478,921
New Hampshire	477,460	242,365	521,129	476,963		25.6	84,746		82,590	4.8		70,658	3.4	497	89,117
New Jersey	55,099	460,000	56,528	55,099		.5									460,000
New Mexico	1,272,129	735,425	1,226,434	1,226,434		207.4	122,479	35,000	87,479	30.9	10,695	427,908	37.1		220,038
New York	3,608,768	4,252,400	3,292,248	2,961,095	10,500	83.6	3,647,420	625,700	2,207,500	156.4		1,295,040	119.1	21,973	739,360
North Carolina	2,380,573	1,590,637	1,913,496	1,912,718		201.4	780,702	394,215	386,487	80.8		417,653	40.2	73,639	786,497
North Dakota	1,451,112	734,741	897,063	897,063		283.1	270,426	270,426		70.3	180,638	109,053	97.3	102,985	625,689
Ohio	3,871,148	1,966,253	4,064,393	3,768,518		297.8	418,610	73,810	344,800	73.8		317,600	30.3	28,820	1,303,853
Oklahoma	2,304,199	1,171,295	1,335,611	1,307,347		191.1	1,026,630	967,443		84.5	28,270	729,076	31.3	1,139	442,220
Oregon	1,526,724	777,096	1,710,635	1,496,761	23,904	112.0	426,789	19,526	364,143	32.3		116,801	18.0	10,437	272,248
Pennsylvania	7,344,822	2,639,003	5,864,869	5,726,999		493.3	2,893,406	1,613,823	1,274,488	244.9	4,000	1,122,863	27.7		241,652
Rhode Island	439,716	295,000	413,706	408,636		33.2						49,894	1.0	31,080	245,106
South Carolina	1,364,791	692,739	964,879	964,879		104.4	438,892	331,442	107,450	53.7		410,827	61.7	68,470	174,462
South Dakota	1,502,870	761,911	1,091,582	1,091,570		312.1	408,669	360,518	48,151	115.1	34,544		28.3	16,238	713,760
Tennessee	2,123,155	1,075,748	1,217,051	1,195,481		102.4	1,092,889	851,020	241,869	60.3	4,503	179,693	10.8	72,151	654,186
Texas	6,012,518	3,072,813	5,878,781	5,452,453		750.6	755,092	500,417	252,955	32.3	18,556	872,798	57.6	41,093	1,947,060
Utah	1,048,677	533,173	1,176,414	955,732	105,800	185.6	253,259	92,945	117,000	40.5		95,613	19.3		214,760
Vermont	438,880	241,354	405,920	386,990	7,391	33.1	170,794	50,328	108,023	11.2		80,990	6.5	1,563	44,950
Virginia	1,699,920	941,347	1,458,922	1,400,781		202.2	321,468	236,139	74,146	16.7	11,450	192,172	8.4	51,550	675,029
Washington	1,080,673	776,603	992,047	974,789		62.6	227,029	103,666	123,363	11.5		441,725	34.7	2,218	211,515
West Virginia	1,118,559	570,083	535,468	528,390		28.2	532,021	506,887		28.9	48,468	49,971	.1	34,813	520,112
Wisconsin	2,431,220	1,782,435	2,325,089	2,160,766	48,583	170.4	449,760	183,711	189,867	14.5	50,000	248,142	13.0	36,743	1,295,842
Wyoming	1,125,332	571,928	1,076,107	1,057,813		148.4	90,037		90,035	12.2	30,935	224,994	37.5	36,584	256,899
District of Columbia	950,234	730,382	1,046,829	931,582	115,247	8.5	99,768		99,768	1.8		312,510	1.8	18,651	202,856
Hawaii	187,106	351,000	177,718	177,718		4.9								9,388	351,000
TOTALS	92,593,925	55,108,989	73,298,724	69,561,977	917,819	7539.9	35,231,378	20,351,197	12,678,520	3,005.1	1,336,102	15,234,543	1,458.9	1,344,649	26,278,107

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

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

SUMMARY OF CLASSES 1, 2, AND 3.

AS OF DECEMBER 31, 1934

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR NEW PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$8,370,133	$4,259,842	$5,926,510	$3,823,616	$35,889	294.6	$5,386,169	$4,011,873	$335,269	320.4	$273,922	$1,326,413	88.2	$260,722	$2,562,271
Arizona	5,211,960	2,641,935	5,504,828	4,849,526	47,862	345.3	967,177	158,224	773,954	62.8	161,790	321,048	25.3	42,420	1,499,071
Arkansas	6,748,335	3,428,049	4,407,791	3,751,831	138,919	289.4	2,712,897	2,517,719		92.8	278,479	924,401	65.6	200,306	2,364,729
California	15,607,354	7,932,206	13,972,406	11,164,653		419.1	7,492,061	4,413,389	1,051,400	147.3		1,550,856	44.3	29,312	5,329,950
Colorado	6,874,530	3,486,006	6,980,869	6,690,366	60,399	364.4	2,567,674	126,425	1,969,164	244.4	10,047	624,811	33.7	47,692	831,632
Connecticut	2,865,740	1,454,868	1,424,694	1,420,611		21.0	2,384,165	1,445,129	749,772	44.5		168,420	1.2		536,676
Delaware	1,819,088	923,395	1,560,955	1,542,711	7,869	52.1	1,005,953	246,184	687,635	59.7	4,322		.7	25,870	227,891
Florida	5,231,834	2,661,343	4,999,661	4,013,099		188.5	1,833,676	1,097,960	602,589	48.7	13,858	635,840	30.6	106,918	1,422,914
Georgia	10,091,185	5,113,491	5,429,780	5,400,312		368.7	3,195,757	2,911,110	140,502	149.9	1,368,725	816,375	74.4	411,038	4,156,614
Idaho	4,486,249	2,277,486	4,193,469	3,906,845	77,335	353.7	1,397,445	538,915	835,856	76.9		155,153	21.7	40,489	1,209,142
Illinois	17,570,770	8,921,401	9,165,150	9,106,541		212.6	8,899,495	7,904,741	994,754	287.0	317,391	2,753,055	95.8	242,098	5,173,592
Indiana	10,037,843	5,088,963	5,992,936	5,974,695		194.6	3,434,334	3,433,444		92.8	571,744	776,970	93.6	57,959	4,311,993
Iowa	10,055,660	5,118,361	8,504,252	8,110,228	19,480	562.1	3,763,011	1,687,358	1,784,310	357.1	184,200	1,412,979	191.9	73,874	1,901,592
Kansas	10,089,604	5,117,675	9,147,431	8,776,126	110,795	656.8	3,290,024	1,166,802	1,978,367	305.2	39,887	3,019,551	161.3	106,788	8,962
Kentucky	7,517,359	3,818,311	6,496,806	6,267,001		473.4	1,896,340	1,004,011	765,649	107.8	225,352	672,310	71.7	20,995	2,380,352
Louisiana	5,828,591	2,963,932	3,085,591	3,080,988		120.8	3,125,736	2,343,583	246,707	51.6	189,422	1,085,703	26.6	214,598	1,631,522
Maine	3,369,917	1,711,586	3,160,060	2,915,591	137,550	149.9	1,137,116	285,225	821,363	37.2	28,442	325,935	8.8	140,659	426,738
Maryland	3,564,527	1,810,058	1,798,979	1,775,909		66.3	2,162,977	1,016,492	319,038	43.6	225,183	428,907	17.0	546,943	1,062,113
Massachusetts	6,597,100	3,350,474	2,944,616	2,613,820		58.5	4,394,615	3,772,823	441,294	20.9		398,772	1.7	210,457	2,510,408
Michigan	12,736,227	6,452,568	9,862,714	9,760,868	16,400	454.1	5,575,567	2,907,042	2,626,325	147.6	6,461	1,320,575	45.6	61,856	2,489,268
Minnesota	10,656,569	5,425,551	11,103,471	9,550,768	1,423,222	1,182.1	1,900,853	494,927	1,174,526	222.3		772,565	121.3	610,874	2,055,238
Mississippi	6,978,675	3,540,227	4,151,843	2,688,155		237.8	5,040,974	3,290,816	477,221	291.5	528,666	350,977	39.5	471,038	2,712,029
Missouri	12,180,306	6,173,740	9,598,447	8,762,446	79,917	790.6	4,590,166	2,337,608	1,974,045	255.9	370,081	1,249,120	121.8	710,171	2,870,659
Montana	7,439,748	3,769,734	8,063,482	7,309,943	109,308	644.8	1,959,401	71,369	1,794,521	205.9	8,796	336,667	39.6	49,639	1,529,238
Nebraska	7,828,961	3,964,364	7,221,535	5,919,778	225,640	656.0	3,861,468	1,904,298	1,519,820	210.1		1,876,220	147.1	4,886	342,684
Nevada	4,545,917	2,302,356	4,359,364	4,196,591	75,272	401.4	1,170,879	250,097	896,376	132.7	33,841	234,491	24.1	65,388	1,096,216
New Hampshire	1,909,839	969,462	1,845,193	1,779,007		52.1	686,503	79,730	583,345	19.3		189,257	4.7	51,102	196,860
New Jersey	6,346,039	3,220,879	4,152,723	4,033,367		52.4	2,279,112	2,109,646		18.1	97,912	505,182	6.9	105,114	2,715,696
New Mexico	5,792,935	2,941,700	5,501,272	5,339,977	17,366	515.6	1,636,371	273,801	1,362,570	146.9	77,633	604,424	49.0	101,524	957,340
New York	22,330,101	11,327,921	18,597,753	16,478,733	63,500	342.2	15,964,204	5,793,149	5,615,300	318.6		2,783,290	134.5	58,219	2,865,831
North Carolina	9,522,293	4,840,941	8,108,586	7,341,952	83,944	842.5	2,349,470	1,245,171	665,920	199.8	380,555	671,086	84.9	554,616	3,419,991
North Dakota	5,804,448	2,938,967	4,995,202	4,555,557	31,433	1,315.7	857,538	485,031	294,430	213.3	503,909	547,895	341.8	259,951	2,065,209
Ohio	15,484,592	7,865,012	15,886,098	14,777,651		542.2	1,943,900	467,846	1,159,790	100.1		2,934,206	80.0	239,094	3,771,016
Oklahoma	9,216,798	4,685,180	6,735,083	6,622,453		502.2	2,724,875	2,213,557	412,496	146.5	371,921	2,463,136	102.9	8,866	1,809,548
Oregon	6,106,896	3,097,814	6,401,625	5,836,803	23,904	320.5	1,681,299	171,638	1,391,641	82.3	30,841	463,617	32.6	67,614	1,218,652
Pennsylvania	18,891,004	9,590,788	14,134,759	13,711,913	36,580	664.1	8,714,446	4,849,533	3,651,989	324.1	214,410	4,706,901	83.4	115,148	1,195,318
Rhode Island	1,998,708	1,014,572	1,926,423	1,857,588		61.1	298,876	46,205	210,273	8.1		336,258	5.1	94,915	468,041
South Carolina	5,459,165	2,770,954	3,698,659	3,693,967		294.4	1,875,795	1,461,902	397,458	162.4	114,811	584,928	74.4	188,484	1,788,568
South Dakota	6,011,479	3,047,643	4,985,687	4,560,724		776.7	1,156,208	982,142	141,490	294.2	179,484	774,680	161.1	289,129	2,131,474
Tennessee	8,492,619	4,302,991	6,424,713	5,796,321		274.7	3,196,503	2,306,551	793,550	114.7	278,597	904,516	39.5	111,149	2,604,925
Texas	24,244,024	12,291,253	20,389,878	19,403,547		1,801.5	5,948,444	4,335,249	1,388,033	235.6	354,012	2,720,000	190.1	151,216	8,183,220
Utah	4,194,708	2,132,691	4,683,242	3,888,052	537,200	443.5	1,026,973	140,578	617,451	99.5	155,000	341,613	27.0	11,078	636,427
Vermont	1,867,573	948,007	1,846,889	1,741,940	37,281	93.9	526,027	119,922	375,137	26.9		128,990	7.6	5,711	406,599
Virginia	7,416,757	3,765,387	6,298,898	6,003,089		370.4	1,635,937	750,762	635,383	43.9	70,643	1,281,355	55.2	592,264	1,848,649
Washington	6,115,867	3,106,412	5,510,800	5,459,919		189.8	1,421,470	540,595	880,875	41.6	67,122	1,150,316	50.3	48,232	1,075,221
West Virginia	4,474,234	2,280,335	3,104,251	3,086,567		105.5	1,821,820	1,252,984	502,465	64.1	48,468	258,383	7.5	86,215	1,519,487
Wisconsin	9,724,881	4,941,837	9,317,637	8,976,767	64,707	435.8	1,438,860	539,641	723,795	56.7	100,000	1,101,556	47.0	108,474	3,051,779
Wyoming	4,501,327	2,287,712	4,427,986	4,124,200	67,583	640.5	1,287,890	292,334	968,808	146.7	47,701	762,945	138.6	37,093	488,376
District of Columbia	1,918,469	973,842	1,907,858	1,635,888	271,970	14.5	422,289	250,164	172,125	2.6		312,510	1.8	32,417	217,237
Hawaii	1,871,062	949,778	432,146	355,788		15.7	1,766,159	1,437,846		28.1	66,000		.7	11,428	949,778
TOTALS	394,000,000	200,000,000	320,371,001	294,434,788	3,801,325	20,226.1	147,806,899	83,483,541	47,904,781	6,910.7	7,999,628	50,065,158	3,319.7	8,082,043	98,228,736