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D. M. BEACH, *Editor*

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

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CERTIFICATE: By direction of the Commissioner of Public Roads, the matter contained herein is published as administrative information and is required for the proper transaction of the public business.

BITUMINOUS TREATMENT OF SANDY SOIL ROADS IN NEBRASKA

Reported by PAUL F. CRITZ, Highway Engineer, Public Roads Administration and

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In 1928 the State of Nebraska began to study methods whereby the sandy soil roads in the sparsely settled areas of the State might be permanently improved and maintained at a cost reasonably commensurate with the traffic carried.

The bituminous mixed-in-place method of treatment offered possibilities. The first experiments showed promise but also indicated the necessity for obtaining definite information on the details of construction and on the performance of various combinations of bituminous materials and sand.

Slow-curing asphaltic materials of the type then being used with graded aggregate as well as medium-curing materials were tried out experimentally to determine their relative merits as binders for the poorly graded sand. Neither material alone was particularly satisfactory at first.

The slow-curing material did not provide the bond required for stability and it became necessary to increase the mechanical stability of the sand by the addition to fine inert soil which served as a filler. This modification of the original mixture produced adequate stability that was relatively independent of the bituminous material in that it was not greatly affected by changes in temperature.

The medium-curing asphaltic material was relatively slow in developing its ultimate binding property. During the early life of the experimental road, the sections containing this material had stability adequate for moving traffic but not for static loads. The upper portion of the mixture developed a crust as the volatile portion of the asphaltic material decreased but volatile material below the surface was dissipated very slowly. As a result this portion remained somewhat plastic and readily susceptible to deformation under load. This condition resulted in extensive surface cracking that gave the sections an unsightly appearance but did not seriously impair their serviceability. In time, the viscosity of the bituminous material increased as did the stability of the mixture so that surface cracking stopped.

The experiment provided information not only on possible methods of improving the sandy soil roads but also on the manner in which construction should be carried out. Most of this information developed by the experiment has already been incorporated in the State's specifications.

TO PROVIDE all-weather road surfaces in sparsely populated areas where the existing roads were very unsatisfactory and where natural road - building materials, other than sand, were not available, the Nebraska Department of Public Works, in 1928, began to experiment with bituminous mixed - in - place construction, using the sandy soil of the existing road and liquid asphaltic materials.

The area for which a suitable type of construction, was sought is known locally as the "sand-hill region." It lies in the north central portion of the State and occupies nearly one-fourth of the State's area. The mileage of the State highway system within this area and the population per square mile are much less than in other parts of the State. Agriculture is the only industry, with stock-raising and hay-growing the chief occupations. Few railroads traverse this territory and practically all products are carried over considerable distances by highway to reach markets or shipping points.

As may be inferred from the name commonly applied to this region, the sand-hill territory is rolling country. The soil is natural sand overlaid with a very light covering of humus which supports the growth of prairie hay. While most of the sand in this area is of considerable depth, some deposits of silty clay of low plasticity occur not only in the lower areas and along stream beds, but in considerable quantities elsewhere. However, this material, in comparison with the clays generally being used in 1928 as binders for sand and gravel surfaced roads, was not considered to be a satisfactory binder because of its low plasticity. Its successful use as a filler in bituminous mixtures came as a later development.

The sandy roads in this area were very difficult to travel over except in wet weather; and as the territory in which they lie receives very little rainfall, they were highly unsatisfactory most of the time. Prior to the start of bituminous construction in this area, the more heavily traveled roads were surfaced with clay upon which a fairly thin layer of gravel, which also had to be shipped in, was placed as a wearing course. Gravel deposits occur in areas bordering the sand-hill region but most of the surfacing gravel had to be imported.

The resulting surface, as would be expected, was very dusty in dry weather and the rather thin covering of gravel was not always effective in preventing slipperiness in continued wet weather. It was superior to the sandy road it replaced only because it was passable throughout the year. Not only was the cost of this type of construction relatively high, but it added little in the way of permanent improvement. Maintenance costs were likewise high in view of the fact that maintenance served merely to keep the road usable and in no sense could be considered betterment work such as often results from routine maintenance.

The average maintenance cost of a gravel road typical of roads in the sand-hill region and adjoining the experimental road to be described herein was $280 per mile annually for a period of 9 years.[1] In addition to surface maintenance, this sum included the cost of snow control and removal, maintenance of right-of-way, equipment repairs and depreciation, and administration. Of this total cost per mile, approximately 33 percent was required for the replacement of the sand-gravel surfacing material and 33 percent for blading and dragging the surface. In other words, an annual expenditure of $186 per mile was required to maintain the surface as constructed but without permanent improvement.

It was realized that the construction and maintenance of this type of surface was not economical; consequently, treatment of this character was limited to the most heavily traveled roads where a surface passable the year around was imperative. Less heavily traveled

[1] Annual Maintenance Expenditure Reports of the Nebraska Department of Roads and Irrigation, 1932–1940.

roads and those that were not so sandy were left unsurfaced.

Where the roads were composed only of sand and the traffic was light, prairie hay was sometimes spread on the surface. This rather novel method of maintenance made the road passable, but it introduced a fire hazard and at best was only a temporary expedient as the hay quickly ground up under traffic or was blown away by the wind.

It was apparent that a change in procedure was necessary in order to provide a more satisfactory all-weather surface at less cost and to obtain some degree of permanent gain.

EARLY STABILIZATION EXPERIMENTS SHOWED PROMISE

The first attempt to stabilize the sandy soil roads in the sand-hill region was made in September, 1928, and involved the construction of a bituminous mat composed of the sandy soil in the road and a liquid asphaltic material designated at that time as a fuel oil containing 78 percent of asphalt of 100 penetration. This experimental section was approximately ¼ mile in length and was constructed by the road-mix method. The mat was 4 inches thick, contained 3½ gallons of oil per square yard, and cost approximately 60 cents per square yard.

The results of the experiment were quite promising and although the cost appeared relatively high in relation to the volume of traffic, it was thought that the reduction in maintenance costs and the provision of an all-weather surface would make this type of construction adaptable to the sand-hill region.

The following summer, another experimental section was constructed near the first and was similar to it except that the 4-inch mat was constructed in two 2-inch layers instead of full depth in one operation as on the first section. The bituminous materials used on the second section were supplied by two refineries and, although both materials met the same specifications, the resulting bituminous mats were quite different in their characteristics.

One mat crusted on the surface and set up so that it could not be worked with a blade grader, while the other remained soft and could easily be manipulated with the blade. The bituminous material used in the former contained an appreciable amount of volatile material that was soon dissipated so that the mixture eventually contained a fairly viscous binder. The other oil did not have this volatile portion; consequently the mixture did not harden appreciably and remained poorly bonded. It was readily displaced by steel tires and by livestock and after a period of time began to dust under traffic.

Because of the difference in behavior shown by the bituminous materials used on this section, and on other sections being constructed at the same time, it was felt advisable to obtain more information on the advantages and limitations of different liquid asphaltic materials before initiating an extensive program of bituminous construction in the sand-hill region.

To obtain such information, a cooperative experimental road was constructed by the Nebraska Department of Roads and Irrigation and the United States Public Roads Administration (then the Bureau of Public Roads). This experimental road was constructed in Holt County, Nebraska, during 1929 and 1930, is located on U. S. Highway 281, and is 9½ miles in length. It begins at a point approximately 4½ miles south of O'Neill, and extends southward to the south fork of the Elkhorn River.

This experimental road is located near the eastern fringe of the sand-hill region and for the most part passes through territory that is characteristic of that region. The terrain adjacent to the north 4 miles is relatively flat and the soil is sufficiently fertile to produce crops of prairie hay in commercial quantities. The south 5½ miles of the road pass through typical sand-hill country where the terrain is rolling and the soil is very sandy and so light that only vegetation suited to cattle grazing is found. The nature of the country through which the road passes is shown in many of the photographs illustrating the construction of the road.

Prior to beginning the bituminous construction the road had been brought to grade using the soil adjacent to it. This material on the north 3½ miles and on the south 1,600 feet contained some clay and black silty loam, but on the remainder of the road it was practically all sand. Bituminous construction extended from September to November 1929, and from June to October 1930. The experimental road consists of 10 sections, nine of which are 1 mile in length and one is ½ mile in length. They are numbered consecutively from the north end where the stationing starts.

Three asphaltic materials were used in constructing the sections. One, designated as a 94+ road-oil cut-back, was a liquid asphalt containing approximately 95 percent of asphalt of 100 penetration, to which kerosene had been added to lower its viscosity. The second material, designated as 60–70 road oil, was a slow-curing asphaltic oil containing 60 to 70 percent of asphalt of 100 penetration. The third material, designated as a 100–120 cut-back, was an asphalt having a penetration of 100 to 120, cut back with kerosene.

Each section, excepting No. 10, was subdivided into two parts designated A and B. The aggregate in the bituminous mats on the A sections was the soil found in the road, but to all B sections limestone dust was added as a filler.

BITUMINOUS MATS CONSTRUCTED IN TWO 2-INCH LAYERS

The location, description, and cost of constructing the experimental sections are given in table 1. The analysis of the sandy soil in the top 4 inches taken from various locations on the road is given in table 2, and that of the subgrade on the north 3½ miles is given in table 3. The subgrade on the south 6 miles was sand excepting the south 1,600 feet of the road which was built on a fill and contained some silty loam. The analyses of the bituminous materials used in the sections are given in table 4 and the composition of, and results of physical tests on, the resulting mixtures are given in table 5.

The bituminous mats were constructed by the mixed-in-place method. They were built in two 2-inch layers, 21 feet wide and contained approximately 4 gallons of bituminous material per square yard (2 gallons per square yard in each 2-inch layer).

Scarifying was not required as the road soil could be manipulated easily with blades. Prior to applying the bituminous material sufficient soil to form the top 2-inch layer was windrowed to the shoulders. The bituminous material for the bottom 2-inch layer was then applied in ½-gallon increments by means of pressure distributors pulled by crawler-type tractors. Following each application of bitumen the mixture was turned with a disk. After the total amount of bitumen had been applied to a half-mile section, tractor-drawn blade graders mixed the aggregate and soil until a uniform mixture was obtained.

TABLE 1.—*Location, composition, and cost of the experimental sections*

Location			Composition			Cost per square yard			
			Bituminous material						
Section	Stations	Area	Type	Quantity per square yard	Dust per square yard	Bitumen	Dust	Manipulation	Total
		Sq. yd.		*Gallons*	*Pounds*	*Cents*	*Cents*	*Cents*	*Cents*
1A	211 to 237	6,067	94+ road oil, cut back with kerosene	3.98		38.69		7.90	46.59
1B	237 to 264	6,300	do	4.12	9.89	40.05	6.30	7.90	54.25
2A	264 to 290	6,067	do	3.82		37.13		7.90	45.03
2B [1]	290 to 316+65	6,116	do	3.99	10.07	38.78	6.30	7.90	52.98
3A [2]	316+90 to 344	6,148	do	3.86		37.52		7.90	45.42
3B	344 to 370	6,067	do	3.94	9.95	38.30	6.30	7.90	52.50
4A	370 to 397	6,300	100–120 penetration asphalt, cut back with kerosene	3.96		38.49		7.90	46.39
4B	397 to 423	6,067	do	4.06	10.00	38.46	6.30	7.90	52.66
5A	423 to 450	6,300	do	4.05		39.37		7.90	47.27
5B	450 to 476	6,067	do	3.93	9.99	38.20	6.30	7.90	52.40
6A	476 to 503	6,300	do	3.91		35.01		7.90	42.91
6B	503 to 527	5,600	do	4.11	10.36	39.95	6.30	7.90	54.15
7A	527 to 554	6,300	60–70 road oil	3.78		36.74		7.90	44.64
7B	554 to 581	6,300	do	3.86	10.03	37.52	6.30	7.90	51.72
8A	581 to 607	6,067	do	4.36		42.38		7.90	50.28
8B	607 to 634	6,300	100–120 penetration asphalt, cut back with kerosene	3.83	9.97	46.04	6.30	7.90	60.24
9A	634 to 660	6,067	do	4.11		49.40		7.90	57.30
9B [3]	660 to 687+15	6,335	do	4.04	10.01	48.56	6.30	7.90	62.76
10 [4]	700 to 726	6,027	do	4.04		48.56		7.90	56.46

[1] Deduct 44 feet for bridge.
[2] Bridge from station 316+65 to 316+90. Deduct 75 feet for bridge.
[3] Station equation: 687+15=700+00.
[4] Deduct 17 feet for bridge.

TABLE 2.—*Mechanical analysis of sandy soil used in the bituminous mats*

Sieve size	Maximum	Minimum	Average
	Percent	*Percent*	*Percent*
Passing ¼-inch sieve, retained on No. 10	0.4	0	0.2
Passing No. 10 sieve, retained on No. 20	3.6	.7	1.4
Passing No. 20 sieve, retained on No. 30	4.5	1.3	2.5
Passing No. 30 sieve, retained on No. 40	21.2	7.3	10.4
Passing No. 40 sieve, retained on No. 50	24.5	11.8	16.3
Passing No. 50 sieve, retained on No. 80	45.7	32.6	38.2
Passing No. 80 sieve, retained on No. 100	15.7	8.3	13.8
Passing No. 100 sieve, retained on No. 200	19.7	7.0	12.9
Passing No. 200 sieve	9.6	1.0	4.3

TABLE 3.—*Analyses of subgrade soils on the north 3½ miles of the experimental road*

	Sample 5628; section 1A; top 8 inches	Sample 5662; section 1A; top 6 inches	Sample 5660; section 2B; top 4 inches	Sample 5661; section 2B; 4 to 14 inches	Sample 5663; section 3A; top 11 inches	Sample 5664; section 3B; top 2 inches	Sample 5665; section 3B; 2 to 5 inches	Sample 5676; section 4A; top 6 inches
Mechanical analysis:								
Coarse sand, 2.0 to 0.25 mm. percent	23	47	29	46	32	31	35	42
Fine sand, 0.25 to 0.05 mm. percent	53	43	48	44	58	38	44	40
Silt, 0.05 to 0.005 mm. do	16	6	17	6	5	19	9	8
Clay, smaller than 0.005 mm. percent	8	4	6	4	5	12	12	10
Colloids, smaller than 0.001 mm. percent	6	2	4	2	3	5	5	7
Tests of material passing No. 40 sieve:								
Liquid limit	13	17	19	17	16	36	22	23
Plasticity index	0	0	0	0	0	0	0	6
Shrinkage limit								20
Shrinkage ratio								1.7
Centrifuge moisture equivalent	11	6	14	7	6	46	35	21
Field moisture equivalent	14	19	20	19	19	38	22	21
Soil group	A-3	A-3	A-3	A-3	A-3	A-2	A-2	A-2

The amount of manipulation required to produce a uniform, well-mixed mat varied considerably, depending upon the air temperature and the promptness and care

TABLE 4.—*Analyses of bituminous materials used in construction*

Analyses	94+ road oil cut back with kerosene; sections 1, 2, and 3		60–70 road oil; sections 7A, 7B, and 8A		100–120 penetration asphalt cut back with kerosene; sections 4, 5, 6, 8B, 9, and 10	
	Range	Aver.	Range	Aver.	Range	Aver.
Specific gravity at 25° C	0.990–0.995	0.993	0.966–0.982	0.973	0.971–0.985	0.979
Flash point, open cup ° C	77–105	94	133–166	142	76–93	84
Specific viscosity, Engler, at 50° C	74.0–90.3	79.1	45.5–66.2	52.0	45.7–91.7	65.8
Loss, 50 grams, 5 hours, 163° C percent	13.1–14.3	13.7	4.4–6.0	5.2	14.5–17.4	15.9
Residue, float at 50° C. seconds	90–110	100	23–30	26	83–158	111
Loss, 20 grams, 5 hours, 163° C percent	17.7–18.8	18.3	6.2–8.1	7.1	20.7–23.9	22.3
Residue, float at 50° C. seconds			27–37	32		
Residue, penetration at 25° C	136–197	167			76–185	111
Soluble in carbon disulphide percent	99.6–100	99.8	99.8–100	99.9	99.7–99.9	99.8
Bitumen insoluble in 86° B. naphtha percent	16.1–19.5	18.0	11.4–14.1	12.5	13.9–22.2	19.1
Residue of 100 penetration percent	77–79	78	62.8–65.5	64.4	74–78	76

with which the mixing operation was performed. Upon completion of this operation, the mixture was spread and the sand that had been previously windrowed to the sides was bladed in and spread uniformly. Additional bituminous material was applied and mixing carried on in the same manner as in the construction of the bottom 2 inches. A considerable amount of manipulation was required in mixing the top portion to insure thorough coating of all sand particles and to eliminate pockets of uncoated material between the two layers.

All equipment, except the crawler-type tractors, cut deeply into the sand. It was found advisable to insert a drag between the rear wheels and the spray bars of the distributor to eliminate the ruts formed by the wheels and to provide a smooth surface for applying the bitumen. The wheels of the steel-tired blade graders cut into the sand and frequently, when the mixing operation was practically completed, uncoated

Table 5.—*Analyses and tests of bituminous mixtures sampled at intervals subsequent to construction*

Section	Identification: Date sampled	Identification: Location, station	Composition by weight: Bitumen [1]	Passing ¾ inch retained on 10	Passing 10 retained on 20	Passing 20 retained on 30	Passing 30 retained on 40	Passing 40 retained on 50	Passing 50 retained on 80	Passing 80 retained on 100	Passing 100 retained on 200	Passing 200	Approximate percentages of original volatile material remaining in mixtures [2]: Top inch	2nd inch	3rd inch	4th inch	5th inch	Hubbard-Field stability[3] at 77° F.: Top inch	2nd inch	3rd inch	4th inch	5th inch	Composite
			Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
1-A	Sept. 1930	214+25	6.9	0	2.7	2.7	8.8	13.1	31.2	12.7	14.7	7.2	----	----	----	----	----	(4)	(4)	(5)	(5)	(5)	----
	Aug. 1933	214+25	6.9	.1	2.7	4.1	7.5	12.7	31.9	11.7	16.0	6.4	56	82	64	60	----	1,890	575	375	----	----	----
	Oct. 1935	214+25	7.0	0	2.5	3.4	6.6	12.6	29.4	10.5	16.0	12.0	33	62	63	61	----	2,776	800	947	1,182	----	----
1-B	Sept. 1930	251+75	6.5	0	3.5	3.9	9.7	14.0	29.3	11.1	12.5	9.5	----	----	----	----	----	----	----	----	----	----	670
	Aug. 1933	251+75	7.7	.2	4.0	5.1	8.0	13.1	29.8	10.5	13.5	8.1	70	64	82	85	----	1,917	825	767	667	----	----
	Oct. 1935	251+75	7.3	.1	4.4	4.5	7.5	13.4	27.6	9.3	13.4	12.5	40	48	54	----	----	2,727	1,160	1,110	----	----	----
2-A	Sept. 1930	271+60	5.5	0	2.2	2.8	9.3	14.7	32.8	12.3	12.7	7.7	----	----	----	----	----	----	----	----	----	----	1,280
	Aug. 1933	272	6.8	.4	2.7	4.3	7.9	14.1	32.4	10.7	14.0	6.7	45	65	68	82	----	2,492	1,150	715	446	----	----
	Oct. 1935	272	6.7	0	2.7	3.6	7.3	14.2	32.1	8.9	13.8	10.7	34	44	25	20	----	3,757	1,938	1,798	2,398	----	----
2-B	Sept. 1930	304+50	6.4	0	1.1	1.5	6.8	11.6	31.0	12.6	15.3	13.7	----	----	----	----	----	----	----	----	----	----	860-930
	Oct. 1935		6.7	0	1.5	2.0	5.1	11.9	31.1	10.1	15.9	15.7	43	46	60	70	62	3,046	2,330	1,512	1,092	827	----
3-A	Sept. 1930	326	6.6	0	1.0	1.2	4.3	8.3	30.2	17.0	20.9	10.5	----	----	----	----	----	----	----	----	----	----	390
	Oct. 1935		7.3	0	.7	1.3	3.3	7.8	29.5	14.3	22.8	13.0	32	43	54	----	----	3,826	1,350	1,233	----	----	----
3-B	Sept. 1930	352	7.1	0	2.1	2.0	5.8	9.7	27.6	12.9	17.0	15.8	----	----	----	----	----	----	----	----	----	----	1,640
	Aug. 1933	365	7.7	.2	.6	1.4	4.1	9.4	32.3	13.7	19.0	11.6	37	63	62	----	----	1,926	1,317	1,313	1,692	----	----
	Oct. 1935		9.3	0	1.3	1.8	4.4	10.2	30.6	11.6	15.1	15.7	18	39	67	63	----	3,022	2,414	1,750	812	945	----
4-A	Oct. 1930	380	7.2	0	1.1	2.1	7.5	12.2	30.0	12.9	15.1	11.9	----	----	----	----	----	----	----	----	----	----	1,120
	Oct. 1935	380	8.4	0	.9	2.0	5.1	11.1	30.4	11.0	15.6	15.5	32	30	----	----	----	3,336	3,008	----	----	----	----
4-B	Oct. 1930	409	5.8	0	1.1	1.8	7.3	12.6	32.9	15.0	15.3	8.2	----	----	----	----	----	----	----	----	----	----	530
	Oct. 1935		7.2	0	1.9	3.1	6.4	12.9	30.2	11.4	17.2	9.7	34	48	----	----	----	3,308	1,562	----	----	----	----
5-A	Oct. 1930	431	5.9	0	1.1	1.8	7.5	12.3	32.2	14.5	16.7	8.0	----	----	----	----	----	----	----	----	----	----	740
	Oct. 1935	436	6.9	0	1.4	3.5	7.2	13.6	32.2	10.8	16.4	8.0	26	38	39	----	----	4,254	1,918	1,084	----	----	----
5-B	Oct. 1930	464	4.7	0	.5	1.2	7.3	14.2	36.4	15.0	16.1	4.6	----	----	----	----	----	----	----	----	----	----	320
	Oct. 1935		4.9	0	.9	2.0	5.0	10.9	32.2	13.2	21.1	9.8	20	31	48	43	37	3,462	1,940	1,288	1,248	1,343	----
6-A	Oct. 1930	489	4.6	0	.8	1.9	8.3	14.0	37.4	15.3	14.6	3.1	----	----	----	----	----	----	----	----	----	----	320
	Oct. 1935	492	4.8	0	1.1	2.8	6.5	13.9	37.8	11.8	16.3	5.0	23	39	42	48	----	3,044	1,658	803	525	----	----
6-B	Oct. 1930	513	4.5	0	1.3	1.9	8.0	13.4	36.5	15.4	15.3	3.7	----	----	----	----	----	----	----	----	----	----	310
	Aug. 1933	515	4.5	0	2.0	4.6	7.7	13.5	37.7	12.3	15.0	2.7	39	67	69	86	67	1,231	656	381	338	269	----
	Oct. 1935	515	4.8	0	2.3	3.8	7.0	13.7	34.2	11.7	16.1	6.4	19	43	47	----	----	3,292	1,684	945	----	----	----
7-A	Sept. 1930	Average of section	4.9	0	1.7	2.3	8.4	14.1	36.8	14.8	14.8	2.2	----	----	----	----	----	(6)	(6)	(6)	(6)	(6)	----
	Oct. 1935	543	4.7	0	1.4	2.7	5.5	11.9	34.8	12.1	16.2	10.7	----	----	----	----	----	1,288	1,080	1,013	780	----	----
7-B	Sept. 1930	Average of section	4.7	0	1.2	1.9	8.3	14.4	37.9	14.9	13.9	2.8	----	----	----	----	----	(6)	(6)	(6)	(6)	(6)	----
	Aug. 1933	567	4.3	.1	1.1	3.0	6.4	12.9	37.4	11.6	14.7	8.5	----	----	----	----	----	375	494	381	367	292	----
	Oct. 1935	573	4.8	0	1.1	2.7	6.3	13.6	35.7	10.9	14.2	10.7	----	----	----	----	----	1,224	1,220	1,228	1,016	855	----
8-A	Sept. 1930	Average of section	5.4	0	1.1	1.6	7.5	14.3	39.2	15.1	13.7	2.1	----	----	----	----	----	(6)	(6)	(6)	(6)	(6)	----
	Oct. 1935	594	5.7	0	1.0	2.0	5.3	12.9	37.6	10.9	14.3	10.3	----	----	----	----	----	1,108	850	882	787	----	----
8-B	Oct. 1930	Average of section	3.9	0	1.2	1.9	7.9	14.1	39.4	15.4	13.9	2.3	----	----	----	----	----	----	----	----	----	----	140
	Oct. 1935	623	4.8	0	1.1	2.5	5.8	13.1	38.3	13.0	16.6	4.8	26	41	48	56	----	2,238	1,516	706	535	----	----
9-A	Oct. 1930	Average of section	5.7	0	1.2	1.6	6.6	11.5	34.5	15.6	18.7	4.6	----	----	----	----	----	----	----	----	----	----	140
	Oct. 1935	647	6.3	0	.9	1.9	4.7	10.8	34.4	12.6	19.9	8.5	31	57	----	----	----	2,774	1,278	----	----	----	----
9-B	Oct. 1930	Average of section	4.7	0	1.4	1.9	7.5	12.2	34.8	15.4	18.2	3.9	----	----	----	----	----	----	----	----	----	----	230
	Aug. 1933	673	4.9	0	1.7	3.8	7.0	12.5	37.5	12.2	17.7	2.7	49	75	81	80	71	1,800	769	456	394	331	----
	Oct. 1935	673	4.8	0	2.1	3.7	7.2	13.9	33.8	11.4	16.9	6.2	29	46	53	53	51	2,768	1,618	772	658	633	----
10	Oct. 1930	Average of section	6.0	0	1.3	1.1	4.2	8.5	29.4	15.1	22.3	12.1	----	----	----	----	----	----	----	----	----	----	860
	Oct. 1935	713	7.0	0	.7	1.3	3.5	8.5	30.3	11.5	21.4	15.8	45	59	52	58	----	3,288	2,062	1,654	1,283	----	----

1 Water-free.
2 Calculated from the average losses at 163° C. of 20-gram samples of the original bituminous materials and the loss in weight of loose mixtures cured to approximately constant weight at 163° C. All calculations made on a water-free basis.
3 Tests on mixtures sampled in 1930 were made on specimens molded in the laboratory from the loose mixtures. Tests on mixtures sampled in 1933 and 1935 were made on 2-inch specimens cored from the sections and cut into 1-inch layers for the Hubbard-Field test.
4 Stability of sample of top 2 inches=1,000 pounds.
5 Stability of sample of bottom 3 inches=400 pounds.
6 Too soft to form specimens for testing.

sand was brought up by the wheels, necessitating additional manipulation. On one section 250 passes of the blade were required to complete the mixing operation.

Laboratory experiments had indicated the advisability of adding a filler to increase the stability of the poorly graded sand and it was decided to try commercial limestone filler for this purpose. Approximately 10 pounds per square yard of this filler were added to the south ½ mile of each section, designated as section B. Filler was applied with drill-type spreaders of the type commonly used in applying agricultural limestone. When the 5 pounds per square yard of filler to be used in a 2-inch layer had been spread, it was disked with the sand until the mixture appeared to be uniform. The bituminous material was then applied and construction carried out in the same manner as on the sections to which the filler had not been added. No additional mixing was required on account of the filler.

After the top layer had been mixed, it was spread and allowed to compact under traffic. Some light blading was done during the compacting period but the surface was not rolled.

Construction began at the north end nearest O'Neill where the filler and oil were received by rail. Equipment, trucks, distributors, and a small volume of other traffic passed over the sections as they were completed. Such traffic was encouraged to use the entire road width so that compaction, while relatively light, was fairly uniform except at the edges.

Figures 1, 2, and 3, illustrate various conditions and steps in the construction. Figure 1–A is a view of section 3A, near the north end and shows the condition of the soil and surface before bituminous construction began. Figure 1–B shows the sand that was to be used in the top 2 inches windrowed at the sides and the exposed surface of the bottom 2 inches ready to receive the bitumen. Figure 1–C shows the bitumen being applied to half the width of the road. Between the rear wheels and spray bars is a drag held by chains fastened to the front axle. The distributor wheels cut into the sand, especially on the lower 2 inches but the drag filled the ruts just ahead of the spray of bitumen. Immediately following an application of bitumen, a disk such as is shown in figure 1–D made a

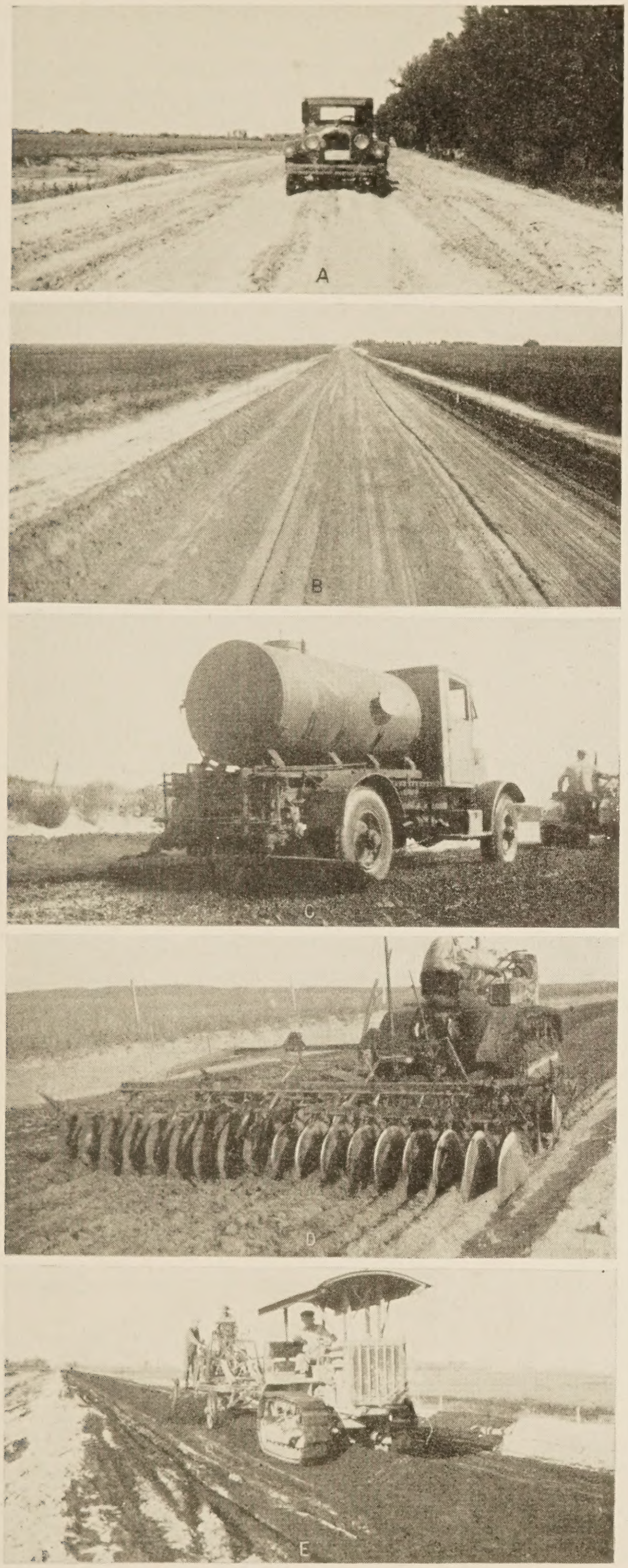

FIGURE 1.—APPEARANCE OF THE ROAD BEFORE AND DURING CONSTRUCTION OF THE BITUMINOUS SURFACE. A, PORTION OF SECTION 3A BEFORE BITUMINOUS TREATMENT. B, SAND FOR THE TOP 2 INCHES WINDROWED AT THE SIDES. C, BITUMINOUS MATERIAL BEING APPLIED AT THE RATE OF ½ GALLON PER SQUARE YARD. D, PRE-MIXING OF SAND AND BITUMEN WITH A DISK HARROW. E, UNIFORM MIXING WAS DIFFICULT WITH THE OLD EQUIPMENT AVAILABLE.

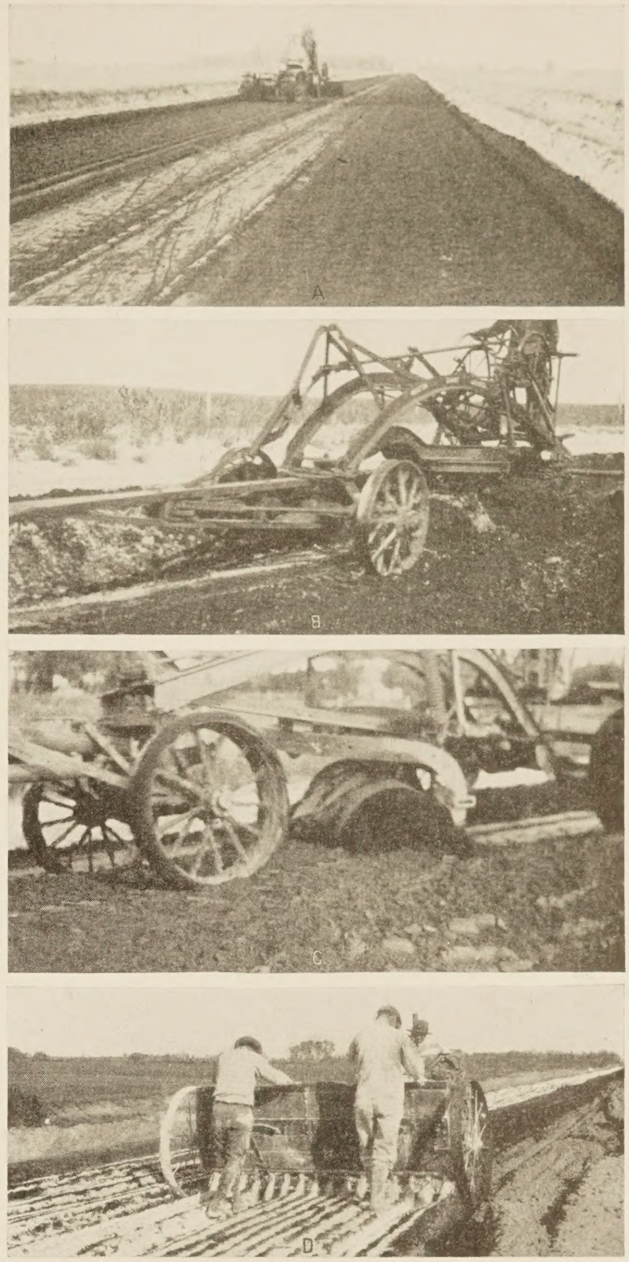

FIGURE 2.—APPEARANCE OF THE SURFACE DURING CONSTRUCTION. A, Blade GRADER SPREADING THE TOP 2 INCHES OF THE SURFACE; THE REMAINING WINDROWS CONTAIN MATERIAL FOR THE SHOULDERS. B, THE EQUIPMENT USED WAS ILL-SUITED TO PERFORM THE WORK REQUIRED OF IT. C, IN COLD OR COOL WEATHER THE MIXTURE WAS TOO ROPY TO MIX WELL AND WAS PICKED UP BY THE WHEELS. D, SPREADING LIMESTONE DUST WITH A DRILL-TYPE SPREADER.

round trip over the area just covered. Figure 1–E shows the bottom 2 inches being mixed. The light areas within the side limits of the mixture are uncoated sand brought to the surface by the grader wheels. This might occur at any stage of the mixing process; and if it occurred when the mixing operation was nearly completed, a considerable amount of additional manipulation became necessary.

Figure 2–A shows the top 2 inches being spread for compaction by traffic. Figures 2–B and 2–C are other views of the mixing operation and show the type of

FIGURE 3.—A PORTION OF SECTION 6B BEFORE, AFTER, AND DURING CONSTRUCTION. A, THIS PORTION OF THE ROAD HAD TO BE RESTORED TO GRADE TWICE BEFORE THE SURFACE WAS MIXED. B, SAME AREA SHOWN IN A AFTER THE MAT WAS COMPLETED AND THE SHOULDERS AND SLOPES HAD BEEN SEEDED AND COVERED WITH HAY TO PREVENT WATER AND WIND EROSION. C, CONSTRUCTING THE MAT THROUGH TYPICAL SAND-HILL COUNTRY.

equipment used. The cup-shaped rims of the steel wheels shown in figure 2–B were presumed to prevent side slip but were not effective in this respect. The difficulty in attempting to road-mix in cold weather is illustrated in figure 2–C. The mixture was very ropy and could not be mixed. The sticky mixture adhered to the wheels, making the blade difficult to handle and hard to pull.

WIND-SHIFTED SAND INTERFERED WITH CONSTRUCTION OPERATIONS

The limestone dust used on the B sections was spread with the spreader illustrated in figure 2–D. When applying dust to the bottom 2 inches, a tractor was needed to pull the spreader, but on the top 2 inches a truck was satisfactory most of the time. Figures 3–A, 3–B, and 3–C are photographs taken at stations 506 and 507. Figures 3–A and 3–B show the same area before and after bituminous construction. The cut shown in figure 3–A had to be brought back to grade twice before the bituminous mat was built. Wind-borne sand built up some portions and the wind removed sand from other portions so that no advantage was gained by bringing the surface to grade very far ahead of construction. Figure 3–B shows the same area after the bituminous surface was constructed. The shoulders and slopes have been covered with prairie hay to reduce wind and water erosion.

Figure 3–C is a view looking south from station 506 and shows typical sand-hill country. The trails paralleling the new road on both sides were used in preference to the old sand road. Figure 4, shows the most prevalent type of traffic, other than automobiles, that used the road. The gross load of this wagon was 8,430 pounds and was carried on wheels with 4-inch steel rims. The front wheels carried 410 pounds per inch width of tire and the rear wheels carried 644 pounds. Although the day on which the photograph was taken was warm and the cut-back section on which the vehicle traveled was not well compacted, the wheels while moving did not cut into the surface. They did mark the surface definitely but the marks were later ironed out by other traffic. Traffic such as that illustrated is fairly heavy during marketing season and, as the shipping point is O'Neill, all loaded vehicles traveled in the same direction and used the same side of the road. This concentration of relatively heavy traffic had no noticeable effect on the road surface.

FIGURE 4.—LOADS OF THIS CHARACTER MADE UP THE BULK OF THE TRAFFIC, OTHER THAN MOTOR VEHICLES, THAT USED THE ROAD.

Construction of bituminous mats by the mixed-in-place method is common practice at the present time and is not considered especially difficult where a reasonably substantial base is available and equipment adapted to the purpose is used. However, for the conditions existing on this road, as shown by the foregoing photographs, construction was not as simple as might be inferred. Two factors, especially, added considerably to construction difficulties. One that was present constantly was the problem of mixing the extremely loose sand to a given depth when the material that had to serve as a base was an indefinite depth of the same loose material.

The other factor was wind-drifted sand. So extensive was this movement at times that considerable work was required to restore the road grade immediately ahead of bituminous construction. During the mixing operation, especially when a section was only partially mixed, work had to be stopped when drifting became especially bad. Application of the limestone filler also was delayed at times because of the wind. When the bituminous mixture was being spread, drifting sand was sometimes deposited on it in sufficient amounts as to make some remixing necessary.

After a cut-back section had been laid down and had received even a small amount of compaction, drifting sand did not remain on the surface but was carried across it. Figure 5–A shows sand drifting across a cut-back section. It will be noted that where the surface has been made smooth by pneumatic tires, the sand is not intercepted but is filling the depressions made by the tractor cleats and also has covered the edges. On the road-oil sections the moving sand was more troublesome as it remained on the surface in considerable amounts and at one time, as illustrated in figure 5–B, nearly filled the side ditch and completely covered a 2-foot strip of the oiled-sand mat. It has become common practice more recently to use ordinary snow fence to control the drifting of sand in bad areas, not only as an aid during construction operations but also as a protective measure for the finished road.

FIGURE 5.—A, SAND DRIFTING ACROSS A CUT-BACK SECTION. THE WIND WAS BLOWING TOWARD THE CAMERA AND AT A SLIGHT ANGLE TO THE CENTERLINE OF THE ROAD. B, DRIFTED SAND ON A LOOSE, ROAD-OIL SECTION. THE SPADE MARKS THE RIGHT EDGE OF THE BITUMINOUS MAT.

The experimental road was constructed by contract except that the limestone dust was handled on a force-account basis. The unit costs of the various items contained in the contract were as follows:

	Cents per gallon
94+ road oil cut-back, applied	9.72
60–70 road oil, applied	9.72
100–120 penetration asphalt cut-back, applied [1]	9.72
100–120 penetration asphalt cut-back, applied [2]	12.02

	Cents per sq. yd.
Manipulating bitumen and aggregate	7.90
Limestone dust in place (average cost) [3]	6.30

[1] Used on sections 4, 5, and 6.
[2] Used on sections 8B, 9, and 10.
[3] Actual cost to contractor plus 15 percent profit.

SECTIONS VARIED IN APPEARANCE AND PROPERTIES

The costs of the different sections, based on the above unit costs, are given in table 1. These are merely the costs to the State and give no indication of the actual total cost of the experimental road.

As might be expected, the mats in which the cut-backs and slow-curing materials were used differed considerably in appearance and properties. The cut-back sections compacted under traffic and, except at the edges, very quickly acquired the color and appearance of a sheet asphalt pavement. The surface was dense and fairly smooth although the transverse profile of some of the sections was not especially uniform. The road-oil sections, on the other hand, remained in a loose condition and, while their surfaces compacted some under traffic, they did not attain any bond or acquire a smooth transverse profile. The mixture was readily displaced by traffic until the advent of cool weather when, because of the increased viscosity of the bitumen, temporary stability and bond were obtained.

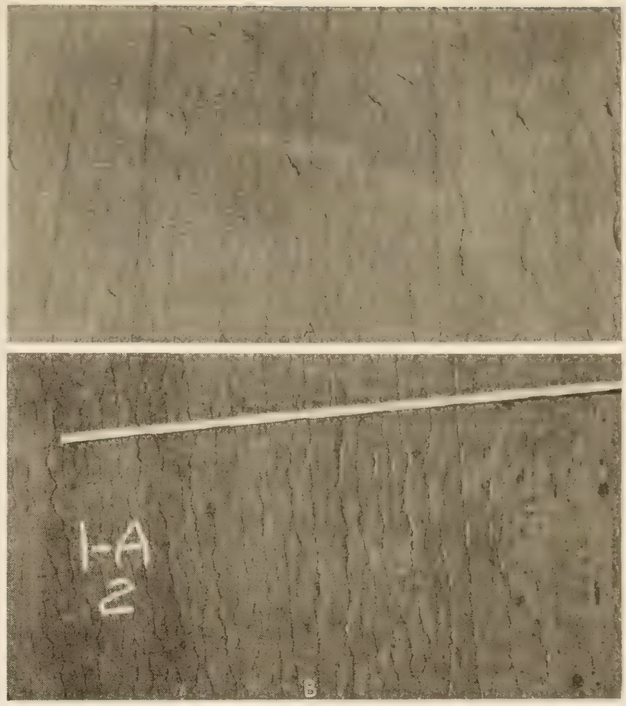

FIGURE 6.—THE SURFACES OF CUT-BACK SECTIONS CRACKED LONGITUDINALLY; A, DURING COMPACTION, AND B, AS THE SURFACE AGED.

Surface cracking was not observed on the road-oil sections but was very pronounced on the cut-back sections. Here fine longitudinal cracks appeared almost as soon as a section was subjected to traffic and became more extensive as the surface gradually developed a thin crust. Marks of steel-tired traffic, made while the surface was still soft, became cracks as the crust formed. Most of these cracks were extremely narrow and of no considerable depth. They did not affect the riding quality of the surface but did give it an unsightly appearance. For some time, as the sections increased in age, the cracks increased in number, but not greatly in size or depth, and they did not heal under traffic in spite of extended warm weather.

Loss of volatile material in the cut-back asphalt resulted in the formation of a surface crust that prevented the escape of the volatile material remaining in the mixture below it. Consequently, the mixture retained its original plasticity and moved under traffic, causing the thin surface crust to crack.

Figure 6–A illustrates the character of surface cracking that developed during the compacting period and immediately thereafter. Figure 6–B shows the extent to which cracking developed after a time in service. It should be noted, however, that while the cracking

FIGURE 7.—THE ROAD-OIL SECTIONS REMAINED IN A LOOSE CONDITION EXCEPT IN COLD WEATHER. AFTER FINE SOIL FILLER WAS ADDED THE MIXTURE COMPACTED AND BECAME STABLE.

may be considered excessive, raveling was practically negligible. The pieces of surface crust, although detached from the adjoining surface, adhered to the more plastic mixture immediately below the surface and consequently were but rarely displaced by traffic.

Since the bituminous material in the road-oil sections 7A, 7B and 8A contained practically no volatile material that would be lost at normal temperatures, little permanent change in viscosity occurred except that caused by weathering. Consequently, with the return of warm weather in the spring following construction, the sections containing the road oil gradually softened and lost the bond they had during cooler weather. They were soon in the same loose, uncompacted state in which they had been immediately after construction. When in this condition, illustrated in figure 7, travel was difficult and traffic followed a single lane until the ruts that were formed extended below the bottom of the mat and travel became almost impossible. It was realized that some modification of the road-oil sections was necessary in order to increase their stability sufficiently to carry traffic in warm weather.

The first attempt to stabilize these sections was made in 1931 by adding sand to a 500-foot portion of section 8A. This did decrease the richness of the mixture but as the only sand available was similar to that already in the mixture, practically no increase in stability was obtained. Consequently, it was decided to experiment by changing the grading of the aggregate to obtain more frictional resistance by the addition of finely graded material. Commercial filler was deemed too expensive so it was decided to try soil as a filler.

Tests were made on clays from several pits whose soils had low plasticity indexes. The material selected was taken from a pit near the south end of the experimental road. It was not processed in the pit and considerable difficulty was experienced in breaking down the soil lumps during the mixing operation. Approximately 20 percent of filler by weight was added to the oiled sand of section 8A. This experiment gave quite satisfactory results in that sufficient stability was obtained to carry the traffic. The remainder of the road-oil sections rutted badly during the summer of 1931 and had to be bladed and dragged repeatedly.

With the return of warm weather in 1932, a repetition of this unsatisfactory condition was apparent so it was decided to add soil filler to all sections of the experimental road that contained road oil. From the experience gained in 1931, a different filler was selected. This material was a silty clay soil found in the bottom of an old clay surfacing pit about 8 miles south of the south end of the experimental road. This filler had the following characteristics:

	Percent
Mechanical analysis:	
Fine sand, 0.25 to 0.05 mm	20
Silt, 0.05 to 0.005 mm	66
Clay, smaller than 0.005 mm	14
Colloids, smaller than 0.001 mm	6
Tests of material passing No. 40 sieve:	
Liquid limit	25
Plasticity index	2
Shrinkage limit	20
Shrinkage ratio	1. 7
Centrifuge moisture equivalent	20
Field moisture equivalent	30

This material was disked, pulverized, and windrowed in the pit. It was placed on the road in two applications. The first application was mixed with the lower half of the oiled sand which was exposed by windrowing the top half of the mat. The second application of filler was mixed with the top half of the oiled sand. A total of 42 pounds of filler per square yard was used.

FILLER MATERIAL CONSIDERABLY INCREASED STABILITY

The results obtained were quite satisfactory. The surface did not crust as much as that of the cut-back sections did, and traffic marked it somewhat. Sufficient stability was developed, however, to meet the demands of traffic. In table 5 are given the Hubbard-Field stability test results on cores taken in 1933 and 1935. It will be noted that considerable stability, as measured by this method, had resulted from the addition of the filler, since the mixtures sampled immediately after construction had practically no stability. Moreover the stability thus obtained not only was apparently adequate in warm weather but also, as shown by the curves in figure 8, was much less affected by temperature changes than was the stability of the original mixture.

After the soil filler was added, the road-oil sections remained in good condition for 5 years and required practically no surface maintenance. Figure 9–A, a view taken in October 1935, shows the typical condition of these three sections during this period, which is in marked contrast to their early appearance, as shown in figure 7.

Some dusting of the surface and pot-holing began to appear in 1937. Cracking also appeared in the outer wheel lanes, caused primarily by lack of shoulder support. This condition is shown in figure 9–B. The sections were surface-treated in May 1938 with 0.3 gallon of RC–2 cut-back [2] and 35 pounds of pit-run gravel per square yard. This treatment was beneficial in eliminating the previous defects. Maintenance through the spring of 1940 was practically negligible. The cost of maintaining, reconstructing, and surface-treating these sections is given in table 6.

In passing, it is interesting to note that the plan of adding mineral filler to increase the stability of road-oil sections was later used by the State on other road-oil-sand roads when it became necessary to increase their stability. Fillers were also used on all oiled sand roads

[2] Cut-back materials containing kerosene and naphthas had been used prior to the construction of this road but they varied considerably in composition and in their curing properties. About 1932, however, such materials were standardized on the basis of composition and rate of curing into medium-curing (MC) and rapid-curing (RC) materials having definite properties. Each class was further divided into several grades on the basis of viscosity. Thus, an RC–2 material is a rapid-curing, cut-back material having a Furol viscosity of 200 to 400 at 122° F. The MC–2, for example, is a medium-curing cut-back of the kerosene type having a Furol viscosity of 150 to 250 at 140° F.

The use of specific designations such as MC–2 or RC–2, therefore, is taken to refer to materials meeting the standard specifications for such definite materials, whereas the use of such general terms as cut-backs refers to the general type of materials such as were used in the construction of this road.

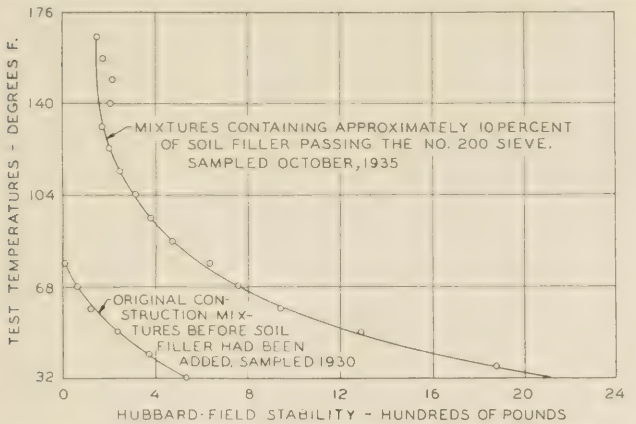

Figure 8.—Effect of Temperature on the Stability of Laboratory Molded Specimens of Road-oil Sections 7A, 7B, and 8A.

constructed in 1932 and later, when stability tests indicated that filler was necessary.

Table 6.—*Cost of maintaining the bituminous surfaces from Nov. 1, 1931, to Jan. 1, 1940, exclusive of equipment, depreciation and administration costs*

Section		Type of maintenance			Total cost		Average annual cost	
No.	Type	Routine	Reconstruction	Surface treatment	Per section	Per sq. yd.	Per sq. yd.	Per mile
		Dollars	*Dollars*	*Dollars*	*Dollars*	*Cents*	*Cents*	*Dollars*
1A	Cut-back	162		180	342	5.63	0.69	85
1B	do	60		180	240	3.81	.47	58
2A	do	94		180	274	4.52	.55	68
2B	do	230		199	429	7.01	.86	106
3A	do	92		219	311	5.06	.62	76
3B	do	153	213	248	614	10.12	1.24	153
4A	do	70	294	237	601	9.54	1.17	144
4B	do	35		180	215	3.54	.43	53
5A	do	37		180	217	3.44	.42	52
5B	do	33		180	213	3.52	.43	53
6A	do	45		180	225	3.57	.44	54
6B	do	49		180	229	4.09	.50	62
7A	Road oil	[1] 154	370	180	704	11.17	1.37	169
7B	do	[1] 133	370	180	683	10.84	1.33	164
8A	do	[1] 210	370	180	760	12.53	1.53	188
8B	Cut-back	40		220	260	4.13	.51	63
9A	do	27		210	237	3.91	.48	59
9B	do	58		220	278	4.39	.54	67
10	do	67		210	277	4.60	.56	69

[1] Includes cost of blading during the first 2 years before these sections were stabilized.

Cut-back sections 1A, 1B, and 2A were completed in 1929. Section 2B was partially constructed in 1929 and was completed in 1930, as were the remaining cut-back sections. There was no apparent difference in appearance or early service behavior between the sections with limestone dust and those without, or between those containing the cut-back made with 94+ road oil and the ones containing the 100–120 penetration asphalt cut-back.

Very shortly after construction, however, there appeared a condition on section 1A that was strictly local and that was not duplicated elsewhere on the experimental road. On approximately the south 100 feet of section 1A, the surface cracked extensively. The cracks opened to a considerable width and small areas bounded by such cracks displaced under traffic. What appeared to be pure viscous bitumen emerged through some of the cracks and spread over the surface in small pools. During the 1930 construction period, sections 1A,

Figure 9.—Road-oil Section after Addition of Fine Soil Filler. A, Note Vegetation Covering the Shoulders and Slopes; B, Cracking Appeared in the Outer Wheel Lane, and Roughness, Dusting, and Pot-holing Developed.

1B, 2A, and 2B were plowed, remixed, and relaid to obtain a more satisfactory cross-section. This work was done in September, and very shortly thereafter movement of bitumen to the surface again began on the south end of section 1A. As an experiment, a small portion of the area thus affected was torn up and remixed by hand. No materials were added and the mixture was relaid and hand tamped. This method of repair was successful, as the area reworked remained free from cracking and no bleeding or exuding of bitumen occurred. Figure 10–A, a view of this area 3 years after reworking, shows the stable area and also the adjacent areas through which bitumen continued to exude.

The subgrade under the south end of section 1A has high capillary and moisture retentive properties. Prior to construction of the bituminous mat traffic mired down in this area, which was a virtual swamp bog despite the fact that the soil contained considerable sand. A supply of moisture was continuously available and apparently was pumped to the surface of the base by a vibrating effect produced by traffic. Apparently, the hydrostatic pressure and the moisture vapor pressure during warm weather were sufficient to force the bitumen to flow out through the cracks in the mat.

CUT-BACK SECTIONS SUFFICIENTLY STABLE FOR MOVING VEHICLES

The cut-back sections remained in a satisfactory condition during the first winter but, with the advent of warm weather the following year, they softened some since the viscosity of the bituminous material naturally decreased as the air temperature increased. However, some permanent increase in viscosity had been obtained through the loss of some of the volatile material and consequently these sections increased in stability

FIGURE 10.—PLACES WHERE SURFACE FAILURE OCCURRED. A, THE RECTANGULAR PORTION IN THE CENTER WAS REMIXED AND TAMPED BY HAND; SHINY AREAS ARE POOLS OF BITUMEN. B, BREAK-UP CAUSED BY UNTREATED SAND LYING BETWEEN UPPER AND LOWER PORTIONS OF THE MAT.

independently of atmospheric conditions. At all temperatures they were sufficiently stable to carry moving traffic without detriment, but vehicles standing on the surface for any length of time in warm weather sank into the mat. The surface crust increased in thickness very slowly, due to the relatively slow rate at which the volatile material was dissipated.

By September 1932, section 3B had become unsatisfactory. The north end was very rough and the south end, apparently becoming rich and unstable, had shoved and cracked. The north end lies on a fill composed of mucky, silty loam which rests on soil of the same type. The south end of the section lies on a low sand fill. The entire section was scarified and remixed in September 1932. No bituminous material was added to either portion, but filler such as had been used in stabilizing sections 7A, 7B and 8A, was added to the south portion in the amount of 10 to 15 pounds per square yard. Remixing and aeration of the cut-back was beneficial but, on the north portion where the unsatisfactory condition was due primarily to the base material, this benefit was temporary.

The addition of filler to the south end of the section, together with the aeration of the cut-back, increased the stability of the mat considerably. The surface cracks present before remixing did not reappear and 1 year later this part of the section was in good condition, whereas the north portion, in the spring of 1933, had settled and was again rough and badly cracked.

At the time section 3B was reworked, the north two-thirds of section 4A was scarified and remixed to eliminate the badly cracked, checked, and rough condition of the surface. Four-tenths gallon of road oil per square yard was added in the remixing process. One year later this area was in good condition. The number of cracks in evidence was considerably less than before remixing and the mat showed no tendency to ravel. The south one-third of this section, which was not remixed, was badly surface cracked at this time.

In the spring of 1933, a part of section 3A near the north end again began to fail. On a 165-foot portion about 700 feet from the north end the mat began to break and settle into the mucky soil of the fill. As the cause of the failure lay in the base and subgrade rather than in the bituminous mat, an attempt was made to develop stability by constructing a drainage system in the fill. A French drain 2 feet wide by 2 feet deep was installed under the center of the road with two laterals to each side. Coarse material ranging in size from 1 to 5 inches was placed in the trenches. The fill was then restored to grade and cross section, after which the bituminous mat was remixed with 2.4 gallons of road oil per square yard and relaid. This drain was an effective remedy and after 7 years is still operating. Some displacement of the mat has occurred for about 200 feet from each end of the drained portion, indicating that an extension of the drains would have been beneficial.

With the exception of the work done on sections 3B and 4A in 1932 and 1933, the cut-back sections required little attention up to the fall of 1935. Little change in appearance occurred except that the number of cracks increased, adding to the unsightliness of the surface. The amount of raveling that occurred was practically negligible and there was a gradual increase in the stability of the mixture. As shown by the results of tests on cores taken in October 1935, the mixture below the surface had acquired considerable stability (table 5).

Maintenance of the surface prior to 1935, excepting the work described, consisted mainly of routine patching to fill depressions caused by standing vehicles, repair of raveled areas, and small replacements where the mat broke. In practically all of these small break-ups it was observed that the part of the mat that broke was very thin and that untreated sand lay between it and the mat below it. Figure 10–B shows several areas that failed from this cause, which was a construction defect.

Maintenance of other portions of the right-of-way consisted of seeding the slopes and shoulders and spreading hay on them to induce the growth of vegetation and prevent wind and water erosion. During the fall of 1934 the shoulders and slopes were rebuilt and surfaced with clay in the sandy sections, 5B to 9B inclusive, and a part of section 10. Work of this character ordinarily constitutes a greater part of the total maintenance required in the sand-hill area than does the actual maintenance of the road surface.

SEVERAL CUT-BACK SECTIONS GIVEN SURFACE TREATMENTS

In an attempt to seal the surface cracks, smooth the surface, and at the same time reduce the likelihood of raveling, several of the cut-back sections were given a seal treatment early in October 1935. The treatment was applied for a width of 18 feet and consisted of approximately 0.25 gallon of medium-curing cut-back asphalt (MC–2), and 30 pounds of unscreened sand-gravel cover per square yard. The bitumen and aggregate were not mixed but the completed surface was rolled with a pulled roller. The treatment was applied on the west half of the south 100 feet of section 3A (9-foot width) and to all of sections 3B, 4A, 8B, 9A, 9B and 10, all of which are cut-back sections. It was also applied to the south 100 feet of section 8A, which is a road-oil section.

When inspected later in October, the treatment was still relatively soft and it had not bonded with the surface crust of the old mat. Cool weather had apparently prevented the cut-back from softening the old mat and producing a bond and had also prevented sufficient loss of the volatile portion of the cut-back to develop stability. The treatment was easily marked by horses' hoofs and it had picked up somewhat under traffic.

The MC material was used in an unsuccessful attempt to obtain some surface penetration. The earlier behavior of the treatment would probably have been more satisfactory had a rapid-curing material been used, such as was used later on other sections. However, the seal containing the MC material gradually stiffened and eventually assumed the same appearance as that of the sections on which an RC material was used in constructing a seal treatment later.

The unscreened sand-gravel used as the cover material contained some relatively large pebbles that were embedded by rolling, as was some of the finer aggregate. Aggregate not held by the bitumen was whipped to the sides by traffic. Figures 11–A and 11–B are typical views of the surface treatment taken late in October.

In July 1937 a surface treatment was applied to the south 800 feet of section 2B and to all of section 3A. This treatment consisted of an application of 0.32 gallon of RC–2 asphalt and a cover of 35 pounds of pit-run gravel per square yard. A similar treatment was applied in May 1938 to all the sections of the experimental road that had not been previously treated.

As might be expected from the method of applying the treatments without manipulating the bitumen and cover, the resulting surfaces were not uniform in appearance generally. More bitumen and cover were held in the depressed areas, obviously, than on the higher areas. The cracks were sealed but they were covered only in the depressed areas where the surface treatment mat was of appreciable thickness. Figure 11–C is a view of the surface of section 9A 3 years after it was surface treated and is typical of the surface texture obtained by the treatments.

Aside from these treatments, surface maintenance requirements have been very light and have consisted almost entirely of patching to eliminate small depressions. The cost of constructing, maintaining, and re-treating the various cut-back sections is given in table 6.

As stated earlier, the main purpose of this experiment was to develop information on the use of various types of liquid asphaltic materials with poorly graded sand. It was expected that additional information on construction methods would be obtained that would be of value in formulating a program of bituminous construction suitable for the sand-hill region. The experimental road not only yielded direct information of considerable value but also indicated a number of phases of design and construction that required solution before a detailed plan of construction could be developed that would utilize local materials to the fullest extent and most economically.

Such information as was developed by the experiment was put to practical use in later construction work and in initiating research studies which the experiment indicated were necessary. Obviously most of the

Figure 11.—A, Cut-back Section after Re-Treatment. The Grass Line Marks the Edge of the Original Bituminous Mat and the Arrow Marks the Edge of the Re-treatment. Loose Material near the Edges Has Been Whipped to the Sides by Traffic. B, Appearance of the Surface Immediately after Re-Treatment. C, Appearance of Section 9A 3 Years after Surface Treatment. The Dark Strip is the Area Between Wheel Tracks and is Slightly Raised.

information developed by an experiment of this character can be used long before a report covering its history for any extended period can be published. However, since current specifications are based largely upon experience gained in previous construction and on closely observed experiments such as herein described, a discussion of the information obtained on this experiment and its part in the development of present-day methods of construction should prove of interest.

SEVERAL IMPORTANT FACTS REVEALED BY EXPERIMENT

In addition to emphasizing the necessity for using efficient equipment and for providing adequate supervision and control that are so essential in the low-cost types of construction, the experiment brought out a number of facts relative to design and construction, the more important of which were as follows:

1. The stability obtained with the cut-back asphalt was considerably greater than that obtained with the slow-curing road oil but neither material provided satisfactory stability with the natural blow-sand.

2. Lack of stability resulted in excessive surface cracking of the cut-back sections and caused the road-oil sections to remain in a loose, uncompacted state.

3. Loss of volatile material in the cut-back mixture

at the immediate surface caused the formation of a thin, hard surface crust but the mixture below the surface, retaining such volatile material, remained plastic and moved under traffic, thereby causing the surface crust to crack.

4. Extended manipulation did not remove sufficient volatile material from the cut-back sections to make them stable. The addition of filler material was much more effective than continued or extended manipulation.

5. The lack of mechanical stability of the blow-sand was not compensated for by the cut-back asphalt while it retained the volatile diluent or by the slow-curing oil which had little cementing value.

6. The presence of the relatively small percentage of commercial filler added to alternate sections could not be detected by visual inspection, on the basis of service behavior, or by analysis of the finished mixture. The filler naturally contained in the blow-sand varied considerably and, in many instances, was greater than the amount of commercial filler added.

7. The addition of a considerable amount of soil filler was effective in imparting satisfactory stability to the road-oil sections as well as to the cut-back asphalt section to which it was added.

8. The addition of soil filler to one of the cut-back sections was of apparently greater benefit than was remixing to increase stability and eliminate surface cracking.

9. Failure to eliminate the volatile portion of the cut-back asphalt prevented the formation of the expected cementitious residue. Had a more rapid-curing material been used, it would have lost a greater amount of volatile matter during the manipulation and would therefore have provided greater stability.

10. The desirability of mechanical compaction for greater immediate stability was indicated, although self-propelled rollers of the type then available did not appear suited to the conditions existing on the road.

11. Inefficient equipment added to the difficulty of construction. The narrow, steel-tired equipment, non-flexible in operation, prevented rapid and successful prosecution of the work. The need for equipment designed for the various operations required was very evident.

During construction as well as in the early life of the experimental road it was quite apparent that definite information was highly desirable on a number of factors, the most important of which were as follows:

1. The stability required for satisfactory service behavior.
2. The relation between the grading of the aggregate and the amount of bitumen required.
3. The relation between the character and grading of the aggregate and the type and character of the bitumen.
4. The character and amount of filler required.
5. Effect of compaction and amount required.
6. Essentials of construction procedure.

It will be observed that all of these factors, except possibly the last enumerated, directly affect that property of pavements referred to as stability which, for the purpose of this discussion, will be taken to mean the resistance of the bituminous mat to displacement under static and moving loads as measured by the Hubbard-Field stability test method.

That there was need to determine what stability is required for static and moving loads is very definitely indicated by the service behavior of the different experimental sections and by reference to the stability test results on mixtures (table 5).

It has been noted that, in their early life, the road-oil sections were unable to carry any load without displacement and that they had little or no stability as measured by the Hubbard-Field method of test. The cut-back sections, on the other hand, had considerable stability as measured by the laboratory test method and in service they carried moving traffic, although with some resulting deformation. Standing vehicles, as mentioned before, sank into the mat in warm weather. In 1932, however, soil filler was mixed with the road-oil sections and the resulting mats became entirely stable, so far as concerned their ability to carry traffic, and have so remained. The cut-back sections during this period did increase somewhat in stability as their plasticity decreased, but such increase was slow, whereas the road-oil sections attained a high resistance to displacement almost immediately after the soil filler was added.

The data in table 5 show that the stability, as measured by the Hubbard-Field test, is decidedly lower for the road-oil than for the cut-back sections. Apparently the mechanical stability afforded by the soil filler, although it failed to produce a mixture having a high Hubbard-Field stability, was of greater benefit than that developed by the cut-back asphalt binder. The former, having practically no plasticity, was not affected by temperature changes or by the amount or rate of application of load. The cut-back mixtures, however, could be expected to retain some degree of plasticity for an indefinite period and consequently would be more susceptible to deformation under load. The amount of such deformation would, moreover, be affected by the temperature and the amount and rate at which the load was applied. It is apparent, therefore, that a laboratory stability test alone cannot serve as a probable service indicator for the comparison of mixtures having such fundamentally different characteristics.

AMOUNT OF BITUMEN LESS IMPORTANT THAN AMOUNT OF VOLATILE MATERIAL RETAINED

In this experiment no attempt was made to determine the effect of the percentage of bitumen used. Approximately 4 gallons of bituminous material per square yard were applied on each section. The variations in bitumen content shown by extraction tests are due somewhat to unavoidable variations in applying the bitumen but primarily to variations in depth of the mixture. The resulting variation in bitumen content was not apparent in the behavior of the various sections nor does there seem to be any relation between the bitumen content and corresponding stability. This might be attributed to the fact that all of the sand mixtures, strictly speaking, were rather open and that small variations in bitumen content were therefore not important. Although the amount passing the No. 200 sieve varied from about 2 to 16 percent, the higher amount was only approximately half of that which would be contained in a densely graded material having the maximum size of this sand. Had the mineral aggregate been more densely graded, it is probable that the variation in bitumen content would have been reflected in the behavior of the section. So far as concerns this road, it is apparent that the amount of bituminous material the mixtures contained was of less importance than was the percentage of volatile material it retained.

The most important characteristic of the blow-sand comprising the aggregate portion of the bituminous mixture was its lack of inherent stability because of poor grading. It was known that had the grading of the aggregate been improved increased stability would have been obtained and less dependence upon the bituminous material would have been required. Materials deemed satisfactory at that time for blending to obtain an improvement in grading were not available; consequently, the bituminous materials were tried out experimentally to determine to what extent they would furnish the required stability.

As was shown by the service behavior of both the cut-back asphalt and the road-oil sections, neither material provided sufficient stability with the natural blow-sand for two reasons. One was the retention of a large percentage of volatile material, and the other was the unsatisfactory grading of the aggregate.

It will be recalled that sections 1A, 1B, and 2A, which are cut-back sections, were completed in the fall of 1929 and that they were torn up and remixed in September 1930 when the remaining sections were being built. Remixing of these three sections did not greatly increase their stability nor did it prevent surface cracking later. It might be assumed that a certain amount of the volatile portion of the bitumen was dissipated in the mixing operation, although reference to table 5 indicates that the percentage retained was relatively high. In contrast to this behavior was the behavior of section 3B, also a cut-back section, after it was remixed in September 1932 and filler was added to a portion of it. As before mentioned, the portion that contained the added soil filler developed considerable stability and the surface cracking that had previously been so pronounced did not reappear so extensively. The other portion of this section, which was remixed but to which soil filler was not added, was not permanently benefited by the remixing operation. Evidently sufficient volatile material was not eliminated in the latter case, whereas the addition of the filler in the first case compensated for the presence of the volatile material by providing a mechanical stability of the aggregate or by causing an increase in the apparent viscosity of the bitumen.

ADEQUACY OF FILLER DEPENDS UPON MANY FACTORS

Although the cut-back material was of the character now designated as medium-curing, it is apparent that the diluent, which was of the kerosene type, contained a certain percentage of heavy ends that were nonvolatile at ordinary atmospheric temperatures. This nonvolatile fraction was evidently present in sufficient quantities to prevent the formation of a binder of sufficient cementitiousness. Had the diluent been more highly and completely volatile, it would have been dissipated by the manipulation and a more viscous residue would have been obtained. The more volatile type of material was not used since it was believed that too rapid a loss of diluent would make such material unsuitable for the road-mix method of construction. Moreover, from lack of experience, it was expected that in the mixing operation most of the diluent in the kerosene cut-back would be eliminated and that the desired viscous residue would be obtained. Consequently the specifications did not provide for additional manipulation to eliminate the volatile material or designate what percentage of it should be eliminated before the mixture was spread for compaction.

The original plan of the experiment was to attempt to develop a stable mat by providing the stability required solely by means of bituminous materials irrespective of the grading of the blow-sand. It was recognized that the grading was poor and that it would be improved by the addition of coarser material or filler, both of which would be expensive. Coarse material was not to be found in the vicinity and filler material, at that time considered synonymous with commercial ground limestone, would be very expensive. However, as a result of preliminary laboratory experiments with mixtures of blow-sand, cut-back asphalt, and limestone filler, it was felt that the addition of some filler was justified. It has already been shown that the small amount of filler thus used was not effective but that the addition of considerable amounts of soil filler produced satisfactory results where it was used in 1932.

Because of these satisfactory results, the plan of adding soil filler was used not only on other sections where the oil-sand mat was lacking in stability but on new construction later. The material used as a filler in 1932 on the experimental road was a silty clay whose analysis has been given. It was selected primarily because it contained a high percentage of very fine material, could be pulverized fairly easily, and because it was the only such material near at hand. It was not selected because of its characteristics as determined by routine laboratory tests for soils, since the importance of such characteristics was not recognized at that time. On other road construction where the addition of filler seemed advisable, the material was selected on approximately the same basis, that is, upon its fineness and low cementing value. It was soon noted, however, that variable results were being obtained that were not indicated by a cursory examination of the apparently acceptable materials.

No great amount of any one material was available at any one location and it was realized that a method would have to be developed for evaluating the merits of a considerable variety of materials as fillers if uniformly satisfactory results were to be obtained without greatly increasing the cost of construction. This led to a laboratory study of a variety of finely divided materials that might serve as fillers and included soils of low plasticity, limestone dust, silica dust, volcanic ash, loess, and waste lime from sugar refineries.

Since the filler was probably the most important constituent of the mixture, effort was made not only to develop methods of comparing one material with another, but also for determining the amount of various fillers required to provide stability for given conditions and the corresponding percentages of bituminous materials to use with such fillers.

Formulas for proportioning in use in other States were tried out in Nebraska after modifying them to suit Nebraska conditions. In all of these formulas the percentage of material passing the No. 200 sieve has the greatest effect on the bitumen content required. Where a plentiful supply of crushed rock and stone dust is available at reasonable cost, as is the case in many States, a simple formula whose application is practically State-wide is adequate. In Nebraska, however, where no great supply of any one kind of material that might serve as a filler is available, the problem was more complicated in that it became necessary to develop by laboratory research certain tests by which suitable filler coefficients could be established for use in the formula.

In determining the suitability or the comparative value of a material as a filler, its void-filling capacity as well as its properties as measured by the tests ordinarily employed in soil analyses was determined. The amount of bitumen required for any given filler was termed the *S* factor and was determined by consideration of a number of properties of the material. It was found that the characteristics that most greatly affected the percentage of oil required were (a), the fineness of the portion of aggregate passing the No. 200 sieve, (b) the absorptive capacity and surface condition of the particles and (c), the specific gravity of the material.

The method of determining the suitability of materials as fillers and of determining the *S* factors of materials considered as suitable is given elsewhere [3] in detail.

Essentially the method is as follows: Routine soil tests are used to measure such properties as particle size, bulk specific gravity, volume change, plasticity, and cohesion or cementation. The latter test indicates the ease with which a material can be pulverized. The stabilizing action of the filler or fillers is then determined by observing the effect of the filler in changing the viscosity of the oil. By laboratory experimenting it was found that the consistency of the filler-bitumen mixture measured by the Furol viscosity and float test methods brought out very definitely the differences between fillers and indicated their relative stabilizing effect. The combination of filler and bitumen necessary to produce a mixture having a float of 1,000 seconds at 100° F., determined by the A. S. T. M. method (slightly modified) was arbitrarily termed the filler-bitumen ratio and from this ratio the *S* factor was then calculated.

RESULTS OF LABORATORY RESEARCH USED TO OBTAIN BETTER MIXTURES

Information obtained by laboratory research, and applied to field construction, resulted in the gradual accumulation of data and information that made it possible to establish definitely the proper proportioning for bituminous mixtures. Obviously the greatest consideration was given to the filler material and its effect upon the quantity of bitumen required and conversely the amount of filler required with a given type of bitumen for satisfactory service behavior.

In contrast to the sketchy preliminary work and outlined plan of the experimental road, the method of procedure now used in sand-oil construction includes a survey of the materials available, a laboratory study of those materials, and a detailed method of construction. A survey is made of the material on the road and of deposits of fine material that may prove satisfactory as a filler. In the laboratory such materials are tested in experimental mixtures. The *S* factor, previously mentioned, is then determined for the filler or fillers.

The amount of a given filler required with a given bituminous material is determined in the laboratory by a modified Hubbard-Field stability test. Trial mixtures containing different amounts of filler are prepared and aerated until 50 percent of the volatile portion of the bituminous material is removed. Briquets 2 inches by 4 inches are formed with this partially cured mixture and then tested for stability. A stability of 1,200 pounds at 77° F. formerly appeared adequate but it has more recently become necessary to raise this requirement to 1,800 pounds. Concentration of traffic in definite lanes after the center stripe was painted on the surface resulted in a gradual deformation of the bituminous mat and the sandy subgrade in many locations. In addition, the gradual loss of moisture in the sand subgrade during the drought years has lessened its supporting strength. For these reasons, it became necessary to increase the strength of the bituminous mat and consequently the stability requirement was raised from 1,200 to 1,800 pounds.

[3] The Selection and Use of Mineral Fillers for Low-Cost Roads, by R. E. Bollen, Proceedings of the January 1937 meeting, Association of Asphalt Paving Technologists.

Since the designated stability can be obtained by a number of combinations of different fillers and a given bituminous material, the actual selection of the material can be made on the basis of economy.

In actual practice, the amounts of bituminous material and of filler are stated as master ranges in the specifications with the added requirement that the exact percentages for a given project shall be designated by the engineer. These exact percentages are determined in the laboratory, as previously discussed, and the information thus developed is supplied to the field engineer for his guidance during construction. To illustrate the application of this procedure, the specifications require that 3.3 to 3.9 gallons of bituminous material shall be used per square yard for a bituminous sand mix 5 inches thick. The percentages of filler required with different types of bituminous materials are as follows:

Type of bitumen:	Percent passing No. 200 sieve
Slow-curing liquid asphalt	10 to 30
Medium-curing liquid asphalt	5 to 25
Rapid-curing liquid asphalt	5 to 20
Emulsified asphalt	2 to 15

The actual amount of a given filler or fillers and the bitumen coefficients or *S* factors for each are determined on the basis of laboratory stability and float tests as previously described. Having determined this, the total bitumen requirement is based upon the following formula developed through laboratory study and field experience:

$$P=AG\ (0.02a)+0.04b+0.06c+Sd$$

when P=percent by weight of bitumen in the mix;
a=percent by weight of aggregate retained on the No. 50 sieve;
b=percent by weight of aggregate passing the No. 50 and retained on the No. 100 sieve;
c=percent by weight of aggregate passing the No. 100 and retained on the No. 200 sieve;
d=percent by weight of material passing the No. 200 sieve, which amount has been established in the laboratory;
A=an absorption factor for the aggregate as determined in the laboratory;
G=a specific gravity factor based on the relation of the gravity of the aggregate to 2.62; and
S=filler factor determined in the laboratory as previously described.

COMPACTION DURING CONSTRUCTION DEEMED ADVISABLE

On the experimental sections the bituminous mixtures were spread for compaction by traffic without mechanical rolling. It was felt that the types of rollers then available would not be satisfactory for the conditions existing and that satisfactory consolidation would eventually be obtained by traffic. Pulled rollers of the type now available, especially the multiple-wheeled, pneumatic-tired type, could probably have been used advantageously for obtaining greater initial density and correspondingly increased stability. However, the volatile material in the cut-back would have been trapped by the rolling and the actual viscosity of the bituminous material would have been unchanged. Consequently it cannot be definitely stated that rolling would have entirely prevented the movement and surface cracking that occurred.

For the purpose of obtaining information on the relation between density and stability, as well as other information, 2-inch cores were taken from each section in 1935. A sample consisted of 4 to 6 cores taken for the full depth of the pavement. The composition and the stability of the mixtures as taken from the road are given in table 5, while tests to determine density and stability obtained by other methods of compaction are given in table 7. The data given in table 7 were obtained in all cases from tests on mixtures obtained by coring the pavement.

The field cores were cut into specimens 1 inch high and the stability of each specimen was determined. Laboratory remolded specimens were afterwards made in standard Hubbard-Field molds in two ways, that is (a), by the routine method of applying a load of 3,000 pounds per square inch and (b), by applying a load sufficient to form a specimen having the same density that the material had in the road. All specimens were tested by the standard Hubbard-Field method of test.

The data obtained in this study of the mixtures show that, with few exceptions, the density and stability obtained by the standard Hubbard-Field method of test are considerably lower than those of the specimens compacted in service by traffic, and that the Hubbard-Field stability obtained on laboratory-prepared specimens molded by direct compression to the density of the field specimens is likewise considerably lower than that of the field specimens. The average stability obtained by the routine method of forming laboratory specimens was only 52 percent of that actually obtained in service while laboratory-made specimens having the same density as the field specimens had, on the average, only 65 percent of their stability. To obtain laboratory specimens having the same density as the field specimens, a series of specimens was molded to densities above and below the densities of the field specimens and, although these data are not included in table 7, it was observed that the stability increased as the density increased for a given mixture, that is, for any single 1-inch layer of material. It will be observed, however, by reference to table 7 that no relationship exists between density and stability of different 1-inch layers of the same core or of one sample as compared with another.

Apparently the stability depends less upon the actual density than upon the manner in which the density is obtained. The compaction obtained in service by traffic was therefore more beneficial than that which resulted from direct compression even though the density obtained by both methods was the same, which would indicate that the method of compaction was more important than the amount.

These test results seem to indicate that compaction with a device similar to the multiple-wheel, pneumatic-tired roller, which compacts with a kneading action similar to that of traffic, would probably have been beneficial in producing greater initial stability.

TABLE 7.—*Stabilities and densities of mixtures sampled in 1935*

Section No.	Field No.	1-inch layer	Cored field specimens		Standard laboratory molded specimens		Specimens molded to field density	
			Density	Stability	Density	Stability	Density	Stability
94+ CUT-BACK SECTIONS								
				Pounds		*Pounds*		*Pounds*
1A	7	Top inch	2.122	2,776	2.020	1,184	2.122	2,150
		2d inch	2.089	800	1.992	324	2.089	890
		3d inch	2.087	947	1.964	363	2.088	1,210
		4th inch	2.074	1,182	1.968	587	2.074	1,310
1B	4	Top inch	2.175	2,727	2.079	1,265	2.175	2,100
		2d inch	2.110	1,160	2.051	562	2.110	960
		3d inch	2.080	1,110	2.025	670	2.080	940
2A	8	Top inch	2.067	3,757	1.960	1,686	2.067	2,470
		2d inch	2.047	1,938	1.990	1,064	2.047	1,350
		3d inch	2.043	1,798	1.976	1,052	2.043	1,530
		4th inch	1.983	2,398	1.935	1,960	1.983	2,200
2B	9	Top inch	2.225	3,046	2.107	1,670	2.225	2,840
		2d inch	2.050	2,330	2.005	1,300	2.050	1,830
		3d inch	1.986	1,512	2.010	1,248	1.986	970
		4th inch	2.000	1,092	2.035	1,010	2.000	800
		5th inch	1.976	827	2.014	960	1.977	630
3A	10	Top inch	2.021	3,826	1.956	1,658	2.021	2,230
		2d inch	1.978	1,350	1.952	815	1.978	780
		3d inch	2.001	1,233	1.949	758	2.001	930
3B	11	Top inch	1.911	3,022	2.010	2,940	1.911	2,120
		2d inch	1.916	2,414	2.001	2,445	1.916	1,700
		3d inch	1.938	1,750	2.043	1,850	1.938	1,190
		4th inch	1.936	812	2.014	1,173	1.936	660
		5th inch	1.905	945				
100–120 CUT-BACK SECTIONS								
4A	18	Top inch	2.005	3,336	2.023	2,270	2.005	2,000
		2d inch	1.938	3,008	1.997	2,514	1.938	1,840
4B	12	Top inch	2.069	3,308	1.965	1,352	2.069	2,370
		2d inch	2.038	1,562	1.960	850	2.038	1,400
5A	19	Top inch	2.013	4,254	1.923	1,510	2.013	2,420
		2d inch	1.979	1,918	1.928	808	1.979	1,140
		3d inch	1.950	1,084	1.922	694	1.950	725
5B	13	Top inch	1.946	3,462	1.882	1,244	1.946	1,700
		2d inch	1.922	1,940	1.887	808	1.922	1,060
		3d inch	1.904	1,288	1.888	682	1.904	730
		4th inch	1.908	1,248	1.885	715	1.908	740
		5th inch	1.861	1,343	1.877	882	1.861	680
6A	20	Top inch	1.926	3,044	1.840	874	1.926	1,670
		2d inch	1.893	1,658	1.837	545	1.893	830
		3d inch	1.875	803	1.824	360	1.875	570
6B	14	Top inch	1.995	3,292	1.861	802	1.995	2,175
		2d inch	1.946	1,684	1.862	535	1.946	1,090
		3d inch	1.942	945	1.858	420	1.942	840
60–70 ROAD OIL SECTIONS								
7A	5	Top inch	2.001	1,288	1.926	421	2.001	970
		2d inch	1.976	1,080	1.927	405	1.976	650
		3d inch	1.967	1,013	1.921	368	1.967	570
		4th inch	1.939	780	1.931	447	1.939	460
7B	6	Top inch	1.992	1,224	1.929	422	1.992	710
		2d inch	1.996	1,220	1.922	356	1.996	640
		3d inch	1.977	1,228	1.931	398	1.977	580
		4th inch	1.947	1,016	1.928	366	1.947	410
		5th inch	1.951	855	1.920	259	1.951	320
8A	21	Top inch	1.915	1,108	1.895	426	1.915	500
		2d inch	1.902	850	1.884	362	1.902	370
		3d inch	1.896	882	1.884	362	1.896	380
		4th inch	1.870	787	1.910	470	1.870	340
100–120 CUT-BACK SECTIONS								
8B	15	Top inch	1.934	2,238	1.842	670	1.934	1,350
		2d inch	1.887	1,516	1.833	472	1.887	780
		3d inch	1.869	706	1.824	349	1.869	470
		4th inch	1.875	535	1.824	267	1.875	425
9A	22	Top inch	1.949	2,774	1.887	898	1.949	1,330
		2d inch	1.934	1,278	1.882	512	1.934	670
9B	16	Top inch	1.980	2,768	1.891	790	1.980	1,625
		2d inch	1.920	1,618	1.866	518	1.920	825
		3d inch	1.906	772	1.861	356	1.906	570
		4th inch	1.892	658	1.859	317	1.892	480
		5th inch	1.865	633	1.849	292	1.865	370
		6th inch	1.892	673	1.864	339	1.892	500
10	17	Top inch	1.987	3,288	1.977	1,578	1.987	1,740
		2d inch	1.997	2,062	1.983	1,134	1.997	1,170
		3d inch	1.959	1,654	1.948	978	1.959	1,000
		4th inch	1.862	1,283	1.915	977	1.862	660

The specifications governing the construction of the experimental sections, due to a lack of experience, were necessarily very indefinite. Practically no restrictions were placed upon the equipment to be used nor was the procedure to be followed definitely prescribed. The descriptions already given, as well as some of the photographs, best illustrate the procedure permitted under the specifications.

IMPROVED EQUIPMENT AND DESIGN MAKE DEFINITE CONSTRUCTION PROCEDURE POSSIBLE

Concurrently with the increase in knowledge of the properties of bituminous mixtures came the realization that old-fashioned, makeshift equipment not only was inefficient, but its use prevented the practical application of information gained by research in the laboratory. Obviously the ability to design satisfactory mixtures with a variety of materials served no useful purpose unless such design could be accurately produced by the construction operations.

Fortunately, with the increase in volume of low-cost road building, improvements have been made in the types of equipment in use and in the development of new equipment. Large-size pneumatic tires have replaced the narrow steel tires on blade machines; mechanical shifting has replaced hand shifting; and units having greatly increased power have made possible almost absolute control over the mixing operation. On the experimental sections it was practically impossible to control the depth of mixing, as the steel-tired wheels sank through the mix. With the blade machines available at the present time, mixing to a given depth is no longer such a difficult task even on loosely bonded bases such as existed on the experimental road. Mixing at the present time, moreover, is not confined to blade machines or to stationary mixing plants, but can be done on the road with traveling mixers. These machines pick up the untreated material from the roadway, pass it through the mixing chamber where it is accurately proportioned and mixed with the bitumen, and then deposit the mixture on the road for spreading by blade machines or it may be delivered directly to mechanical spreaders and finishers.

Self-propelled smooth rollers, formerly the only type available, were not considered suitable for use on work such as herein described, but the need for some initial compaction was felt. As a substitute for self-propelled rollers, pulled types of rollers were tried. Although such rollers had smooth continuous surfaces, they were a decided improvement over the old type. Perhaps, however, the greatest improvement was the development of the pneumatic-tired, multiple-wheel roller. Such rollers appear to simulate the action of traffic and provide the kneading movement that is so beneficial but which is not readily obtained with smooth rollers, except to a limited extent on hot mixtures.

With the foregoing equipment available for use, it becomes possible not only to construct a road having the properties designed for it but to permit the use of different methods of construction to accomplish a given purpose. On the experimental road a 4-inch mat was to be constructed. With the equipment then available this almost automatically implied the two-course construction that was specified. The difficulties encountered in construction with the equipment used and for the conditions existing on the road have already been indicated. With present-day equipment a similar procedure would have been no great problem. Blade mixing could be accomplished to the complete depth in one operation or, if desired, two-course mixing could readily be done. The use of traveling mixers now available would insure a uniform mixture both as to depth and composition.

During the course of construction it appeared that less difficulty in mixing would be encountered if the bitumen content in the lower 2 inches were held somewhat lower than that of the upper portion. This would have resulted in the formation of a leaner course that would have been less plastic, thereby affording somewhat greater support for the equipment while mixing the top 2 inches. The small amount of bitumen withheld from the lower 2 inches could have been placed in the top half to enrich it and delay weathering. In addition to improving the method of construction this procedure would have limited probable movement to the upper 2 inches and might have decreased the cracking caused by such movement. The specifications, however, did not provide for the alternate use of such procedure.

In contrast to the necessarily incomplete specifications that governed the construction of the experimental road, present-day construction of bituminous-sand surface courses is more definitely described by current specifications.

The equipment that is to be used must meet the approval of the engineer and be satisfactory for the purpose to be served. The composition of the mixture is specified definitely and the exact bitumen content to be used within those limits is set by the laboratory and based upon a study of the materials to be used.

Alternate methods of mixing are permitted, including blade mixing and travel-plant mixing.

The condition of the mixture immediately prior to spreading for compaction is also controlled by limiting the moisture content and by requiring that it shall have a specified stability.

The results being obtained by the procedure followed in Nebraska are very satisfactory and illustrate what can be accomplished by laboratory research and field application of the results of such research. Neither field studies nor laboratory research alone would have made possible the definite results being obtained at the present time. And in this respect the experimental road herein described was of considerable value not only because of the direct information it developed but also because it definitely exposed many of the problems that required a solution before a successful and economical plan could be developed for bituminous construction with sandy soils.

It is of additional interest to note that the information developed by this experiment was gained at a net saving in maintenance rather than at a somewhat increased cost which may frequently result and which is normally justified in experimental construction. The data given in table 6 show that the surface maintenance of the experimental road cost $92 per mile annually, which is in marked contrast to the $186 per mile annual cost of the sand-gravel surfaced road adjacent to it. This is a definite saving in addition to such intangible benefits as conserving material and providing a superior day-to-day riding surface.

EFFECT OF CARBON BLACK ON THE STRENGTH OF MORTAR

BY THE DIVISION OF TESTS, PUBLIC ROADS ADMINISTRATION

Reported by D. O. WOOLF, Materials Engineer

A small amount of black colloidal pigment may be added to portland cement concrete to improve its appearance and to reduce glare. Carbon black is the pigment generally used.

To determine the effect of carbon black on the strength of concrete at ages up to 1 year, a series of tests including both tension briquets and 2-inch cubes for compressive strength tests was made.

The results of these tests indicated that to an age of 1 year, none of the samples of emulsified carbon black tested caused any important reduction in the strength of the mortar. The tensile strength test appears to be preferable for use in determining the quality of samples of carbon black, and a strength ratio of 90 percent appears to be a suitable minimum value in such tests.

TO IMPROVE the appearance of concrete pavement and to reduce the glare from the road due to bright sunshine, a small amount of black colloidal pigment may be added to the concrete. In suitable amounts this pigment gives a deep black color to the concrete.

On different paving projects, amounts of pigment varying from 1 to 3 pounds per sack of cement have been used, with the larger amount the more common. In a recent specification for concrete pavement the following requirements for carbon black appear:

> Emulsified carbon black shall be a uniform colloidal dispersion of standard carbon gas black in a liquid medium. At least 25 percent by weight of the commercial product shall be carbon black. The product shall be free from lampblack, mineral black, silicas, asbestine, talc, bone black, or other fillers. Emulsified carbon black shall contain no substance which can adversely affect the strength, durability, or appearance of concretes or mortars when used in the concentration specified.
>
> Emulsified carbon black shall be so finely processed and dispersed that when one part of the product is stirred into 10 parts of tap water, the resulting liquid shall, upon standing without agitation for 72 hours, remain uniformly colored from top to bottom.

Carbon black is described [1] as a fluffy, black pigment produced by burning natural gas in a supply of air insufficient for complete combustion and collecting the liberated carbon on a metal surface by actual contact of the flame on the surface. Carbon black, also called channel black or gas black, is entirely different in physical characteristics from lampblack. The latter is gray in contrast to the deep black of carbon black. Lampblack usually is prepared by burning byproducts from the distillation of coal, petroleum, tar, and vegetable oils and, as it is somewhat soluble in ether, its presence in pigment can be determined. Mineral black is prepared by grinding and heating slate, shale, coal, or similar materials. Bone black is produced by calcining animal bones. Both mineral black and bone black contain mineral impurities that may be detected by the ash left after ignition.

Acceptance tests of carbon black usually include a mortar strength test to determine if the material has any deleterious effect on the strength. In this test the strength of mortar containing carbon black in the amount specified for the project is compared with the strength of an uncolored mortar made with the same cement and sand, and mixed with the same amount of water. Carbon black is added to the mixture in the form of an emulsion. The water in the carbon black emulsion is usually considered to be 75 percent by weight of the emulsion and the mixing water used is corrected accordingly. Tests are usually made at ages of 7 and 28 days.

To determine the effect of carbon black on the strength at greater ages, a series of tests including both tension briquets and 2-inch cubes for compressive strength tests was made. Four samples of carbon black representing the product of three manufacturers were obtained for these tests. The colored mortars contained 3 pounds of carbon black per sack of cement, and correction was made in the amount of mixing water for the water contained in the emulsion. The tensile strength specimens were made using a 1 : 3 mix with standard Ottawa sand and the usual stiff consistency employed in cement testing.[2] The compressive strength specimens were made using a 1 : 3.2 mix with Ottawa sand having a fineness modulus of 2.40; and a water-cement ratio of 0.6 by weight was used. This produced a mortar with a plastic to slightly wet consistency. Both types of test specimens were prepared on each of 3 days for testing at ages of 28, 60, 90, and 365 days. After removal from the molds at an age of 24 hours, all specimens were cured in running water until tested.

The results of these tests are given in table 1. Each value for the three rounds is the average for at least three specimens. Average values for the three rounds are plotted in figure 1.

In the compression tests the strength showed a marked increase from 28 to 60 days, followed by a steady decrease. The strengths at an age of 1 year were greater, however, than those at the initial test of 28 days. Some of the tension specimens showed a slight increase in strength from an age of 28 days to ages of 60 or 90 days but, in general, there was little change in strength during that period. At an age of 1 year the tensile strength was slightly less than that at 28 days. Some of the reduction in strength noted for all specimens at an age of 1 year was probably due to solution of a portion of the cement by the running storage water.

TENSION TEST GAVE BEST INDICATION OF EFFECT OF CARBON BLACK ON STRENGTH

At ages to and including 90 days the mortar containing carbon black sample No. 1 had higher strengths, both tensile and compressive, than any of the other samples. At an age of 1 year the mortars containing samples 2 and 3 had tensile and compressive strengths equal to or higher than that for sample No. 1. Samples 2 and 3, which were produced by the same manufacturer, showed about the same strength with the exception of the compressive strength at 28 days. Sample

[1] The Condensed Chemical Dictionary, Second Edition, 1930. The Chemical Catalog Co. Inc., New York, N. Y.

[2] A. S. T. M. Standard Method C 77-39, section 13.

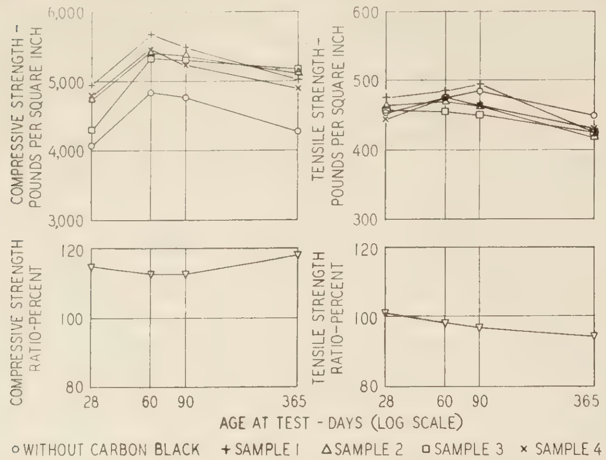

FIGURE 1.—STRENGTH OF MORTAR CONTAINING 3 PERCENT CARBON BLACK AND RATIO OF AVERAGE STRENGTH OF COLORED MORTARS TO STRENGTH OF PLAIN MORTAR.

No. 4 gave the lowest strengths at some ages, and strengths about the average for the remainder of the testing periods. In general there is little choice with respect to tensile or compressive strengths between mortars containing the four samples of carbon black.

The ratio between the average compressive strength of the mortars containing carbon black and that of the plain mortar showed little change with increase in age. That for tensile strength showed a slight decrease with increase in age. The values of the ratio for compression and tension are given in table 2. Of the two methods of test it is believed that the tension test is the more critical, and that it may furnish a more nearly correct indication of the effect of carbon black on strength.

No method has yet been established to use in interpreting the requirement quoted above (that the emulsified carbon black shall contain no substance which can adversely affect the strength of the mortar or concrete). The word "adversely" might be taken to mean that there must be no reduction in strength. However, it is customary to recognize some tolerance due to unavoidable errors in laboratory technique as a result of which presumably identical sets of specimens may show somewhat different test results. Reference to the literature shows that sand tested under A. A. S. H. O. Standard Method T71–38 is usually required to have a strength ratio of at least 90 percent. A strength ratio of 90 percent is also required for water proposed for use in concrete when tested under A. A. S. H. O. Standard Method T35–35. With these two specifications as examples, the use of the same strength ratio with the tensile strength test might be considered suitable for the acceptance of samples of carbon black proposed for use in concrete. All of the samples tested in this investigation meet this suggested requirement at all ages.

The results of these tests indicate that to an age of 1 year, none of the samples of emulsified carbon black included in this investigation caused any important reduction in the strength of mortar. The tensile strength test appears to be preferable for use in determining the quality of samples of carbon black, and a strength ratio of 90 percent appears to be a suitable minimum value in such tests.

TABLE 2.—*Compressive and tensile strength of mortars containing carbon black expressed as a percentage of the strength of plain mortars, at various ages*

Age, days	Strength ratio	
	Compression	Tension
	Percent	*Percent*
28	115	101
60	113	99
90	113	97
365	118	94

TABLE 1.—*Effect of carbon black on strength of mortar*

Carbon black sample number	Round	Compressive strength				Tensile strength			
		28 days	60 days	90 days	1 year	28 days	60 days	90 days	1 year
		Lb. per sq. in.	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*	*Lb. per sq. in.*
None	1	4,050	4,675	4,650	(1)	460	485	480	435
	2	3,960	4,760	4,395	3,830	435	500	480	455
	3	4,245	5,090	5,135	4,740	470	440	490	460
	Average	4,085	4,840	4,730	4,285	455	475	485	450
1	1	4,900	5,390	5,280	(1)	465	455	510	420
	2	5,060	5,925	5,475	4,845	490	500	500	415
	3	4,910	5,720	5,730	5,190	465	495	470	445
	Average	4,955	5,680	5,495	5,020	475	485	495	425
2	1	4,520	5,380	5,470	(1)	485	470	460	435
	2	4,680	5,250	5,270	4,805	455	470	475	430
	3	5,060	5,635	5,290	5,435	460	465	465	400
	Average	4,755	5,420	5,345	5,120	465	470	465	420
3	1	4,105	5,155	5,440	(1)	455	465	450	430
	2	4,660	5,460	5,210	5,175	470	465	475	430
	3	4,140	5,360	5,260	5,270	455	435	420	410
	Average	4,300	5,325	5,305	5,220	460	455	450	425
4	1	4,525	5,220	5,255	(1)	425	445	455	435
	2	4,980	5,395	5,165	4,855	460	475	480	435
	3	4,835	5,720	5,450	4,945	445	505	465	415
	Average	4,780	5,445	5,290	4,900	445	475	465	430
All blacks	Average	4,700	5,470	5,360	5,065	460	470	470	425

1 Specimens broken at 90 days.

TWENTIETH ANNIVERSARY OF FEDERAL HIGHWAY ACT

November 9, 1941, marked the twentieth anniversary of passage of the Federal Highway Act. During these 20 years the Federal-aid highway system created by the act has been steadily improved to serve a rapidly increasing volume of motor-vehicle traffic.

Pictures on the cover page vividly illustrate the evolution of a Federal-aid highway in Rhode Island. The top picture shows Nooseneck Hill Road in 1912, 4 years before Federal highway aid was initiated. (In 1912 there were 9 thousand registered motor vehicles in Rhode Island, 1 million in the entire country.)

The middle picture shows the same section of road in 1923, after it had been improved as a Federal-aid project by the construction of two 9-foot lanes of concrete. (In 1923 there were 76 thousand registered motor vehicles in Rhode Island, 15 million in the entire country.)

The bottom picture shows Nooseneck Hill Road in 1941, after it had been widened to four lanes and resurfaced as a Federal-aid project. The new surface consists of 25 feet of bituminous macadam flanked by 11-foot lanes of concrete and 10-foot bituminous shoulders. (In 1940 there were 190 thousand registered motor-vehicles in Rhode Island, 32 million in the entire country.)

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$3,222,587	$1,602,075	109.7	$6,327,985	$3,141,570	203.1	$1,258,992	$625,800	30.9	$721,276
Arizona	787,431	564,020	36.7	1,578,310	1,057,479	64.3	546,962	373,330	12.2	864,109
Arkansas	2,835,847	1,321,265	50.2	1,199,527	599,183	53.5	95,795	47,320	12.7	395,211
California	5,477,284	2,919,410	101.9	5,878,244	3,111,414	61.6	3,214,879	1,636,208	56.4	1,259,897
Colorado	2,291,427	1,296,089	154.6	2,557,455	1,476,916	139.9	1,621,622	909,448	50.2	910,687
Connecticut	1,216,857	595,915	12.7	1,917,853	922,053	22.7	491,595	216,825	9.4	512,588
Delaware	275,257	132,307	4.9	749,827	371,718	21.2	268,040	134,020	8.4	987,558
Florida	1,167,179	582,930	65.3	1,832,154	919,305	17.7	1,869,084	910,542	28.7	1,927,146
Georgia	2,543,841	1,270,628	84.5	6,343,846	3,151,673	258.0	4,017,506	2,008,753	170.4	4,716,832
Idaho	1,730,436	1,067,443	93.7	995,217	613,588	44.3	398,906	246,643	18.8	949,357
Illinois	3,066,506	1,524,662	77.6	7,916,907	3,957,832	133.6	1,447,517	723,599	6.4	3,193,146
Indiana	3,276,115	1,490,493	49.1	6,378,985	3,090,727	92.7	2,357,298	1,178,649	34.9	463,295
Iowa	2,223,834	1,047,843	94.3	5,788,544	2,594,458	196.0	711,159	97,500	22.9	31,494
Kansas	3,245,863	1,642,099	169.5	5,413,878	2,710,874	286.8	2,791,704	1,076,423	117.9	2,922,958
Kentucky	2,744,644	1,376,135	97.6	6,747,827	3,210,370	151.8	2,510,102	1,255,051	21.1	198,063
Louisiana	800,645	400,301	22.3	2,074,120	1,028,642	39.7	2,568,556	1,259,086	56.3	3,031,749
Maine	843,077	419,641	23.4	1,950,882	1,001,401	23.0	78,610	39,305	.1	369,120
Maryland	2,000,209	999,000	20.7	4,173,153	1,836,178	23.9				784,489
Massachusetts	2,346,521	1,175,891	17.3	2,223,103	1,142,862	14.9	1,175,721	584,274	8.4	2,601,239
Michigan	6,552,505	3,252,827	152.0	3,789,270	1,894,635	55.4	1,928,000	955,700	18.3	774,473
Minnesota	3,663,717	1,827,410	338.2	9,958,631	4,936,205	414.9	813,196	405,823	33.4	723,651
Mississippi	3,524,088	1,759,644	201.9	4,853,024	2,372,112	267.1	718,200	357,350	32.5	527,839
Missouri	4,003,565	1,973,458	142.6	10,272,484	4,668,076	192.7	3,828,486	742,646	51.4	3,021,266
Montana	2,181,671	1,233,971	117.1	3,026,292	1,719,746	142.4	1,335,989	759,643	86.7	2,552,867
Nebraska	1,371,553	682,292	182.3	6,713,713	3,393,274	575.2	706,289	353,144	37.8	2,171,080
Nevada	2,020,298	1,756,854	101.5	974,271	844,579	31.0	274,686	238,701	3.4	98,148
New Hampshire	339,179	167,678	5.9	1,177,545	565,221	13.6	531,352	262,450	6.6	559,566
New Jersey	2,348,574	1,174,287	20.5	3,562,648	1,781,244	22.2	23,910	11,955		1,759,109
New Mexico	943,125	580,478	71.0	1,404,542	899,084	87.2	364,655	235,786	17.9	1,266,286
New York	6,233,056	3,109,833	92.2	10,049,219	5,001,211	108.6	2,507,480	984,185	19.4	1,767,263
North Carolina	2,447,101	1,207,381	109.6	4,148,399	2,077,020	163.5	1,228,430	580,300	37.0	1,377,754
North Dakota	3,147,023	1,735,191	274.1	2,783,460	1,442,888	217.3	2,421,360	1,214,050	205.5	2,728,327
Ohio	6,311,454	3,149,377	58.1	12,998,932	6,258,751	99.5	6,704,900	2,700,918	40.5	1,138,998
Oklahoma	1,736,116	863,894	83.7	2,906,222	1,533,671	64.8	2,123,270	1,111,825	77.1	3,981,176
Oregon	1,770,398	1,070,826	64.6	3,958,496	2,135,468	77.8	394,852	191,270	7.8	170,881
Pennsylvania	4,501,005	2,243,123	54.9	12,904,315	6,344,572	101.9	3,864,226	1,891,708	32.1	747,355
Rhode Island	1,195,971	596,025	10.0	645,746	322,853	4.8	567,583	215,956	2.0	558,324
South Carolina	894,247	415,437	64.7	4,426,770	2,067,957	97.5	1,658,353	646,081	46.0	1,023,248
South Dakota	2,022,523	1,166,709	239.0	4,751,583	3,062,109	515.1	1,081,820	643,090	137.3	1,304,393
Tennessee	2,488,256	1,242,144	71.6	4,480,856	2,240,428	84.9	2,327,086	1,163,543	56.5	2,031,294
Texas	6,946,521	3,405,362	357.3	12,525,815	6,045,545	452.5	5,336,861	2,283,985	184.7	3,268,566
Utah	856,700	643,407	45.6	2,009,427	1,512,730	40.2	181,116	131,610	14.8	173,777
Vermont	565,928	278,466	22.7	1,467,207	729,953	26.9	36,906	18,453	.3	60,424
Virginia	1,725,659	864,287	39.8	4,834,174	2,244,108	86.2	859,610	426,755	6.4	1,083,463
Washington	745,789	390,247	13.1	2,923,116	1,561,904	39.6	551,037	268,500	5.4	731,048
West Virginia	1,789,960	892,433	35.5	3,253,125	1,610,358	41.5	555,662	277,831	6.3	1,088,276
Wisconsin	1,311,232	647,054	60.3	6,306,458	2,968,068	195.2	1,539,216	553,400	48.4	2,394,761
Wyoming	1,411,471	903,980	148.3	1,762,635	1,149,016	123.5	47,665	30,648		287,908
District of Columbia	448,744	224,166	2.5	873,178	413,300	1.9				254,588
Hawaii	140,808	70,395	1.1	744,378	540,561	9.5	471,159	294,217	5.2	1,399,922
Puerto Rico	176,101	87,085	2.6	2,116,647	1,044,620	17.7	251,149	124,950	.6	402,753
TOTALS	117,909,898	61,043,868	4,470.3	220,650,895	111,349,510	6,226.8	72,658,552	33,399,249	1,887.4	68,268,998

U. S. GOVERNMENT PRINTING OFFICE: 1941

STATUS OF FEDERAL-AID SECONDARY OR FEEDER ROAD PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$848,005	$422,368	35.8	$987,352	$506,340	51.9	$255,259	$121,280	6.1	$243,014
Arizona	121,340	88,202	13.2	141,552	105,006	.8	126,721	59,418	6.8	294,577
Arkansas	408,089	202,544	32.6	301,968	150,918	21.3	189,486	94,743	5.1	67,556
California	582,990	350,340	14.0	1,110,504	790,478	11.9				401,296
Colorado	150,002	84,134	20.7	129,755	72,649	2.1	4,602	2,598	1.9	249,368
Connecticut	298,035	136,331	6.1	266,247	115,937	4.8				76,648
Delaware	31,959	15,264		274,043	135,122	12.3	102,873	37,617	3.9	160,439
Florida	450,722	225,361	4.7	714,798	362,849	7.1				232,834
Georgia	342,419	156,209	31.7	1,150,671	667,685	72.6	662,173	331,086	57.7	682,604
Idaho	224,756	135,497	15.6	127,680	78,387	14.1	189,612	90,911	10.1	117,670
Illinois	853,012	422,594	38.2	1,287,660	643,830	68.0	155,700	74,600	17.7	212,513
Indiana	197,450	98,725	9.1	1,542,255	737,971	77.4				599,828
Iowa	508,279	239,292	124.3	384,252	163,258	71.6	436,258	204,836	73.6	154,646
Kansas	348,387	176,679	54.6	2,021,192	1,012,763	141.6	516,394	258,197	37.7	592,838
Kentucky	599,804	155,245	25.0	1,404,741	352,567	85.0	582,618	144,800	19.4	110,785
Louisiana	558,248	227,059	20.6	14,160	7,080		289,362	138,761	21.5	443,106
Maine	35,700	17,850	2.1	277,058	138,529	12.1	16,850	2,714	.4	9,491
Maryland	337,000	168,500	16.9	465,000	232,325	5.6				202,116
Massachusetts	179,789	93,569	4.1	634,608	334,371	10.1				361,339
Michigan	643,168	321,541	50.4	997,860	498,930	37.8	630,770	315,385	23.0	115,130
Minnesota	1,120,968	566,234	159.4	1,353,885	679,750	134.9	418,730	194,457	39.8	123,146
Mississippi	601,094	300,547	28.2	896,867	439,249	42.0	1,020,900	381,800	45.1	88,619
Missouri	310,844	154,337	37.6	821,842	393,037	92.1	377,928	150,075	42.5	556,095
Montana	377,420	214,407	58.5	241,662	137,374	23.7	53,031	30,154	11.8	547,270
Nebraska	237,314	118,222	23.7	552,216	282,999	62.6	95,157	47,578	37.0	330,671
Nevada	156,815	135,496	17.8	160,533	120,012	10.9	98,898	79,290	4.5	3,198
New Hampshire	152,914	75,436	4.7	237,331	95,284	3.6				91,572
New Jersey	303,260	151,550	5.5	568,422	301,670	16.1	82,910	41,455	1.8	353,335
New Mexico	413,309	259,776	42.6	357,018	223,662	20.2				9,247
New York	831,023	419,785	21.9	1,040,396	521,914	21.3	499,660	211,330	1.5	299,900
North Carolina	224,260	112,130	23.2	648,577	354,343	48.0	69,820	20,000	5.0	256,228
North Dakota	49,569	26,558	2.4	3,434	3,434		808,050	793,860	42.7	485,901
Ohio	1,141,972	570,730	46.7	1,412,340	753,260	20.7	106,160	53,080	4.7	805,284
Oklahoma	336,340	177,384	19.2	74,842	39,515	8.4	847,786	447,631	62.4	723,546
Oregon	463,457	243,324	41.8	459,611	217,324	28.5	30,482	18,000	1.3	115,964
Pennsylvania	801,174	400,587	17.7	1,706,486	842,176	30.3	73,588	36,794	1.8	47,688
Rhode Island	220,936	111,505	2.6	11,494	7,497					56,220
South Carolina	461,032	170,066	44.9	539,900	214,224	10.2				165,627
South Dakota	32,130	18,006	15.2	3,622	3,622	.	1,143,430	1,047,600	114.5	490,587
Tennessee	333,741	165,879	10.9	1,430,720	715,360	48.5	190,926	95,463	5.3	404,270
Texas	694,216	337,241	74.1	1,009,341	486,118	92.2	369,000	179,000	33.6	1,146,237
Utah	186,949	123,240	17.0	84,238	49,485	2.9	52,253	25,664	.7	166,950
Vermont	36,231	18,109	1.2	180,204	59,279	7.8	46,514	23,257	1.1	3,059
Virginia	339,398	155,485	11.1	374,996	171,246	9.1	59,050	29,525	4.5	352,850
Washington	201,068	105,105	16.7	518,573	254,814	14.8				147,778
West Virginia	211,250	105,625	9.6	518,883	261,008	16.6				309,250
Wisconsin	793,627	397,321	38.0	1,708,472	756,743	52.7	76,438	37,300	.8	129,885
Wyoming	360,882	155,250	18.8	511,240	220,929	34.3				2,582
District of Columbia	80,772	39,924	.9	2,558	1,279					76,120
Hawaii				2,375	2,375					249,562
Puerto Rico	45,960	22,305	2.5	185,404	90,550	8.1				134,883
TOTALS	19,239,079	9,588,868	1,334.1	31,850,838	15,806,527	1,568.6	10,679,389	5,820,259	747.3	14,001,322

STATUS OF FEDERAL-AID GRADE CROSSING PROJECTS

AS OF NOVEMBER 30, 1941

STATE	COMPLETED DURING CURRENT FISCAL YEAR					UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
			NUMBER					NUMBER					NUMBER			
	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Federal Aid	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$80,836	$80,836		2	2	$346,725	$344,703	6	3	1	$154,235	$154,235	3	1	6	$729,700
Arizona						309,635	300,944	1	2		13,255	13,255			2	104,698
Arkansas	107,311	107,256			1	517,043	515,059	6		1	31,907	31,907			11	309,331
California	601,570	415,854	2		2	1,095,774	1,089,801	8	1		18,098	18,098			6	1,521,783
Colorado	5,685	5,646				590,186	590,186	6			94,118	94,118	1		10	474,949
Connecticut	166,222	165,415	2			61,712	60,676		1		231,374	222,740		1		352,566
Delaware	4,380	4,380			1	94,135	94,135	1			692,694	504,341	3	1		74,168
Florida	92,071	92,071			15	731,773	729,593	8		5	203,082	203,021			19	590,695
Georgia	403,084	403,084	6	1	1	1,061,641	1,061,641	6	7	9	851,183	851,183	2	4	19	1,141,222
Idaho	17,938	17,938			2	325,915	317,244	4	1		6,212	6,212			3	260,406
Illinois	183,389	150,471			74	2,162,122	1,978,887	10	1	13	423,644	404,694	1	1	36	1,543,758
Indiana	173,001	173,001	1		8	763,405	750,918	6	1	12	231,995	226,286	1		44	659,898
Iowa	219,964	210,540	2	1	7	1,510,353	1,254,581	11	2	15	247,894	245,800			64	119,305
Kansas	56,455	56,351	2		3	672,683	672,368	8		1	227,293	183,723	4		13	871,214
Kentucky	690,409	688,863	6		1	541,903	541,903	4	1		328,927	328,927	3			38,902
Louisiana						593,185	593,185	8			477,919	476,752	4		3	600,748
Maine						363,086	363,086	2			8,680	8,680			3	153,576
Maryland	481,550	449,757	2	2	8	686,237	685,759	3		3	234,625	91,305	1		11	205,511
Massachusetts	342,732	332,292	1			774,431	773,559	5	2		767,367	767,367	2	1	1	878,903
Michigan	398,512	398,512		1	7	1,137,505	1,137,505	4	3	7	358,145	327,984	1		21	668,725
Minnesota	382,370	382,055	4	3	1	1,103,537	1,103,537	6	4		162,704	162,704		2	4	684,640
Mississippi	209,275	209,275	2		1	815,109	815,109	9	1	4	92,208	92,208	1		7	322,764
Missouri	120,702	120,702		2		1,922,921	1,467,501	6	2		432,185	298,526	2	2		1,075,899
Montana	138,064	138,064	2		1	95,841	95,841	1			3,485	3,485			1	474,600
Nebraska	157,936	157,932		1	16	1,180,009	1,180,009	23		4	26,458	26,458			7	109,209
Nevada	119,580	119,580	2			56,484	56,484	2			26,644	26,644			9	98,975
New Hampshire	141,603	133,725	3			219,456	219,131	3	2	1	8,463	8,463			4	215,964
New Jersey	473,480	473,480	3			995,743	870,194	4	2	1	361,960	302,535	1	2	1	547,371
New Mexico						68,342	68,342	1			259,103	252,068	3		1	342,146
New York	1,739,083	1,711,427	2	10		2,667,646	2,520,227	3	11		502,645	464,285		1		2,427,803
North Carolina	436,625	436,625	2	4	22	242,986	240,108		3	2	326,223	326,223	3	1	21	712,407
North Dakota	177,392	176,939	4			600,080	587,143	6			223,120	223,120	2			336,428
Ohio	891,022	890,194	3	1	2	2,891,172	2,810,560	13		3	927,977	466,350	3		7	865,956
Oklahoma	148,883	145,088	1		20	843,319	839,909	6		5	402,791	344,749	3		14	1,122,238
Oregon	419,536	355,255	4		3	13,187	13,187	1			192,766	177,018	1		2	214,101
Pennsylvania	890,612	890,284	7	1		3,884,363	3,843,919	20			468,591	464,125	3			1,351,490
Rhode Island	205,241	205,241		1		3,655	3,655									176,421
South Carolina	181,848	178,618	2		12	342,678	330,278	5	3	5	287,940	154,266	1	2	14	693,472
South Dakota	365,743	365,743	10		6	659,642	643,692	12		3	41,200	41,200	2			577,780
Tennessee	228,346	216,452	1	3		1,182,063	1,182,063	8			163,851	163,851	1	1	2	777,953
Texas	717,706	708,673	8			1,853,625	1,837,591	20			105,446	105,348	1		5	1,286,088
Utah	44,855	44,113	2		14	74,424	74,424	1		11	69,025	69,025			26	226,161
Vermont	18,683	18,671			4	322,869	293,090	2								6,266
Virginia	92,292	92,292		2		778,475	758,515	6	3	1	42,541	42,541	1		4	572,245
Washington	55,443	55,443		1	1	337,650	337,650	3	1	1	7,919	7,919			3	472,371
West Virginia	247,260	241,640	3		6	654,982	654,982	6	1		8,730	8,730			3	510,865
Wisconsin	182,330	154,052	1		19	826,861	825,155	4	2	19	49,140	49,140			10	1,180,235
Wyoming	477,151	477,150	5			7,994	7,994			1	5,236	5,236			5	284,675
District of Columbia	2,193	2,193				1,462	1,462				298,213	273,744		1		5,851
Hawaii	192,574	192,566	2			214,170	213,655	2								180,308
Puerto Rico	103,629	102,980	1			639,340	632,516	9			150,994	149,890	2			188,708
TOTALS	13,586,566	13,148,719	98	36	260	39,839,534	38,383,656	289	60	128	11,250,205	9,870,479	56	21	422	29,341,448