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BUREAU OF PUBLIC ROADS

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MIXING TOPSOIL WITH BITUMINOUS MATERIAL IN SOUTH CAROLINA EXPERIMENTS

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SURFACE TREATMENT OF TOPSOIL ROADS

REPORT ON COOPERATIVE EXPERIMENTS BY THE UNITED STATES BUREAU OF PUBLIC ROADS AND THE STATE HIGHWAY DEPARTMENT OF SOUTH CAROLINA

Reported by J. T. PAULS, Associate Highway Engineer

LOCAL considerations of traffic and of economic necessity make it certain that relatively low-cost road types, constructed of local materials, will long continue to constitute a large proportion of our highway system. In some sections sand-clay and sand-clay-gravel surfaces predominate. Where conditions are favorable to these types they are entirely satisfactory, but there is a considerable mileage which is kept in a satisfactory condition only by constant and painstaking maintenance at considerable cost. Such road surfaces are extremely dusty when dry and frequently repair and reconstruction costs amount to large totals.

Topsoil roads have been built extensively in the South, where, in many sections, suitable surfacing material occurs as the thin upper layer of the soil, particularly on hills and knolls. The material contains a preponderance of small gravel particles from which a considerable portion of the original clay content has been removed by natural processes assisted by cultivation.

Naturally, all native deposits are not equally suitable for road building. The characteristics and amount of the clay as well as the gradation of the coarser particles influence the behavior of the material as a road surface. Highly plastic clay is not desirable in as large a quantity as where it is of a low degree of plasticity. An excessive amount of clay, while bonding well in dry seasons, is likely to cause muddiness and rutting during continued wet weather. A deficiency of clay, if not too marked, may prove satisfactory at the time of rains, but is apt to result in raveling when moisture is lacking. Methods for the determination of the quality of clays are not yet fully developed, but tests are available by means of which their properties may be estimated and compared.

Considerable research is being conducted to develop methods of eliminating dust and materially reduce maintenance costs on sand-clay or topsoil road surfaces. Experiments generally involve the use of bituminous materials for the purpose of reinforcing the existing surface either by impregnation or by the addition of a thin surface layer of greater resistance to the destructive agencies of nature and traffic.

SOUTH CAROLINA STATE HIGHWAY DEPARTMENT EXPERIMENTS [1]

In 1924 the State highway department of South Carolina applied a surface treatment to a 7-mile section of the topsoil road between Spartanburg and Inman. A priming coat of light refined tar was first applied at the rate of one-fourth gallon per square yard followed by one-third gallon per square yard of either tar or asphalt applied hot. Crushed stone, one-fourth to 1¼ inches in size, was spread over the surface at a rate of about 50 pounds per square yard and the operation was completed by rolling.

COOPERATIVE EXPERIMENTS UNDERTAKEN

The State work yielded such promising results that further experiments of this general nature were undertaken during 1925 by the South Carolina State highway department in cooperation with the United States Bureau of Public Roads.

A 7-mile section of Route 15 in Anderson County, beginning west of the city of Anderson, at the end of the bituminous pavement and extending west approximately 7 miles, was selected for a service test of six experimental sections. Details of these sections are shown in Table 1. Five other experimental sections were located in Spartanburg County on Route 19, beginning at the south city limits of Inman and extending north on the Spartanburg-Tryon highway to the State line. These five sections aggregated approximately 8 miles in length and were designed as shown in Table 2.

A DOUBLE SURFACE TREATMENT AFTER TWO YEARS SERVICE

Several methods of construction were adopted and a number of very different bituminous materials specified in order that the maximum amount of information might be derived with respect to their behavior when applied to road surfaces varying in composition and texture. In selecting mineral cover material, it was decided to use natural topsoil in comparison with local river sand on some of the sections.

PROPERTIES OF TOPSOIL STUDIED

Before the construction of these experiments was started, a survey was made of the condition of the topsoil surface of the roads selected. Samples of the material were taken from the surface and subgrade at intervals. The results of laboratory tests on these samples are given in Table 3.

A wide variation in the condition of the different sections was noted in the survey. The surface was smooth and well bonded on a major portion of each, but in some places it was loose and in others rough and potholed.

On experimental section 6, from station 280 + 00 to 320 + 00, scaling and crumbling was prevalent. The material in this location contained a large amount of

[1] See Surface Treatment of Roads—Hot Application Method, by N. S. Anderson, maintenance engineer, South Carolina Highway Department, Proceedings of the Fifth Annual Asphalt Paving Conference.

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TABLE 1.—*Details of construction and re-treatments of experimental sections on Route 15, all sections 20 feet in width*

ORIGINAL TREATMENTS IN MAY AND JUNE, 1925

Section and station	Type and depth	Bituminous material		Covering
		Character	Gallons per square yard	
Sec. 1. 0+00 to 15+84	Mixed, 2 inches	Tar, 8 to 13 specific viscosity at 40° C	1.5	None.
Sec. 2. 15+84 to 34+32	do	Medium quick-drying oil	1.5	None.
Sec. 3. 34+32 to 108+24	Surface-treated	Tar, 8 to 13 specific viscosity at 40° C	.38	Topsoil, 34+32 to 85+00; sand, 85+00 to 108+24.
Sec. 4. 108+24 to 161+04	do	Tar, 18 to 25 specific viscosity at 40° C	.38	Topsoil, 134+00 to 161+04; sand, 108+24 to 134+00.
Sec. 5. 161+04 to 279+84	do	Slow-drying oil	.38	Sand, 161+04 to 255+00; topsoil, 255+00 to 279+84.
Sec. 6. 279+84 to 361+00	Double surface-treated	Primer: Tar, 8 to 13 specific viscosity at 40° C Second coat: Hot asphalt, 150 to 200 pen Station 359+00 to 361+00, no primer	.25 .33 	Stone, ¼ to 1 inch.

RE-TREATMENTS

Section and station	Date	Type and depth	Bituminous material		Covering
			Character	Gallons per square yard	
Sec. 1. 0+00 to 15+84	July, 1925	Surface-treated	Tar, 18 to 25 specific viscosity at 40° C	0.2	Sand.
Do	March, 1927	Mixed, 3½ inches	do	1.1	
Do	do	Surface-treated	do	.2	Do.
Sec. 2. 15+84 to 34+32	November, 1925	Mixed, 2 inches	Slow-drying oil	1.1	
Do	March, 1927	Mixed, 3½ inches	do	1.1	
Do	do	Surface-treated	do	.2	Do.
Sec. 3. 34+32 to 81+50	July, 1925	Scarified			
Do	November, 1925	Surface-treated	Tar, 18 to 25 specific viscosity at 40° C	.35	Do.
81+50 to 108+24	do	Surface-treated	do	.18	Do.
34+32 to 47+00 80+00 to 94+50	March, 1927	Scarified and surface-treated	Tar, 13 to 18 specific viscosity at 40° C	.40	Do.
47+00 to 80+00 94+50 to 108+24	do	Surface-treated	do	.25	Do.
Sec. 4. 134+00 to 161+04	July, 1925	Scarified			
Do	November, 1925	Surface-treated	Tar, 18 to 25 specific viscosity at 40° C	.37	Do.
108+24 to 134+00	do	do	do	.24	Do.
159+00 to 161+04	March, 1927	Scarified and surface-treated	Tar, 13 to 18 specific viscosity at 40° C	.40	Do.
108+24 to 159+00	do	Surface-treated	do	.25	Do.
Sec. 5. 161+04 to 279+84	November, 1925	do	Slow-drying oil	.2	Do.
Do	March, 1927	do	do	.2	Do.
Sec. 6. 279+84 to 353+00	November, 1925	do	do	.2	Do.

mica, which seemed not only to weaken the bond but also, by collecting in layers and pockets, to cause scaling of the surface. The South Carolina highway department has found that those portions of the surface containing high percentages of mica are slippery, unstable, and difficult to maintain during the wet season.

The portions of the surface showing the greatest mica content were located in the deeper cuts and on fills built with the soil from these cuts. In these locations the mica-bearing subsoil had been incorporated with the topsoil by the mixing during construction and maintenance.

The topsoil surface material on the experimental sections in Spartanburg County contained in general much less mica than the surface on portions of the Anderson County road. However, in the former county the surface of experimental section 11 between stations 729+00 and 791+25 scaled and crumbled badly during the progress of the treatment. This may have been the result of spreading a coat of finely crushed granite during the spring which at the time was insufficiently mixed with the clay binder underneath.

Table 3 shows that the clay content in the topsoil material ranged from a minimum of 8 per cent to a maximum of 32 per cent, the average being about 20 per cent. The surface from which the sample containing 8 per cent clay was taken was loose and badly broken. In the area represented by the sample having 32 per cent clay, the surface remained smooth and well bonded during dry weather but rutted somewhat during wet weather. It appears, by comparing the clay content with the condition of the surface, that less than 20 per cent clay in this topsoil did not in general give a stable and well-bonded surface during all seasons of the year. Clay was considered as including all particles of less than about 0.02 millimeter diameter and on the average constituted approximately twice as much material as would have been the case had the limit been taken as 0.005 millimeter diameter. A diameter of 0.005 millimeter is usually considered the upper limit under present soil terminology. The low dye-adsorption numbers obtained may be taken to indicate a clay low in stickiness and plasticity. This probably explains why such a large percentage of clay was needed to get a well-bonded surface.

The low moisture equivalent obtained indicates in general that the material dries out very quickly after a rain. This characteristic property of the topsoil surface was noted during construction.

Other physical tests add but little to this information, probably due to some extent to the fact that the proportion of sand is so large as to render inapplicable tests designed primarily for soils. In general, however, it is seen that for samples from poorly bonded locations the dye adsorption is 5 or less, the moisture equivalent is less than 8, and the lower liquid limit is less than 19.

LOCAL CONDITIONS CONSIDERED IN SELECTING BITUMINOUS MATERIALS

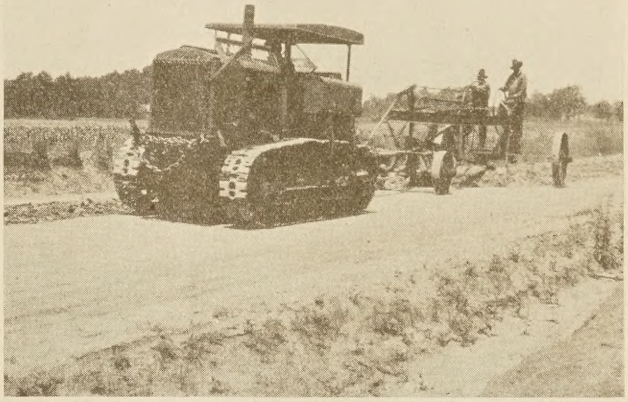
In selecting bituminous materials for the various sections, certain qualities were specified which were thought to be desirable with the methods of construction and maintenance adopted. For sections 1 and 2, materials were desired which would mix readily with the topsoil, permit working and smoothing with road machinery soon after being applied but which would harden with sufficient rapidity to produce a stable surface under traffic.

A thin mat surface, susceptible to further strengthening by subsequent treatments, was desired on sections 3 and 4. For this purpose tars were specified of such nature and consistency that they would penetrate the topsoil, thus minimizing the danger of displacement under traffic. Tars of two consistencies were used to determine their relative efficiencies.

The object on section 5 was the development of a surface somewhat similar to those of sections 3 and 4 except that a rather light grade of slow-curing oil was employed. With such a material it was anticipated that a rather plastic mat would result which could be shaped by dragging and thickened by later treatments.

On the double surface treatments, experiments 6 to 11, inclusive, the purpose was to form a stable mat of stone and bituminous material, firmly bonded with the topsoil surface. A rather fluid product, designed to penetrate the road and to dry with sufficient rapidity to permit early application of the second coat, was used as a primer. Over this a hot refined tar or asphalt was sprayed, the primary function of which was to bind the relatively heavy layer of coarse aggregate.

Table 4 gives the results of tests made on the mineral cover materials and Tables 5 and 6 give the characteristics of the bituminous materials used on the several sections.



Scarifying Topsoil Surface for the Mixing Treatment

CONSTRUCTION METHODS DESCRIBED

Practically the same methods were employed in the construction of experimental sections 1 and 2. The topsoil road surface in each case was scarified to a depth of 2 to 3 inches, after which this loosened material was pulverized by disk harrowing. About one-half of the loose material was then bladed to the sides of the road

Table 2.—*Details of construction and re-treatments of experimental sections on Route 19; from station 0+00 to 38+00 the surface was 25 feet wide and on the remainder 19 feet wide*

ORIGINAL TREATMENTS, JUNE, 1925

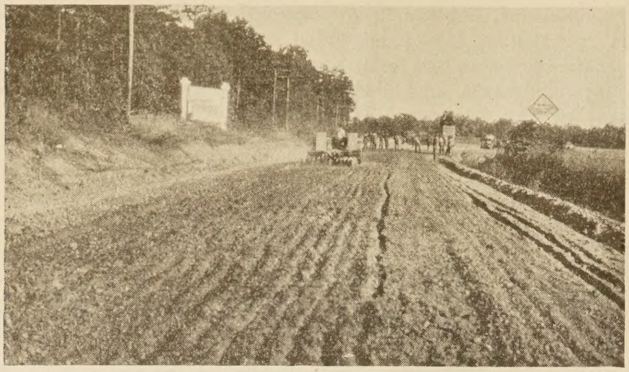
Section and station	Type	Bituminous material		Covering
		Character	Gallons per square yard	
Sec. 7. 0+00 to 82+50	Double surface-treated	Primer: Tar, 8 to 13, specific viscosity at 40° C. Second coat: Hot tar	¼ ⅓	¼ to 1 inch stone.
82+50 to 436+00[1]				
Sec. 8. 436+00 to 512+00	Double surface-treated	Primer: Cut-back oil Second coat: Hot asphalt, 150 to 200 pen	¼ ⅓	Do.
Sec. 9. 512+00 to 536+00	do	Primer: Cut-back oil Second coat: Hot tar	¼ ⅓	512 to 517, ¼ to 1 inch stone, 517 to 533, ¼-inch chats, 533 to 536, ¼ to 1 inch slag.
Sec. 10. 536+00 to 622+50	do	Primer: Tar, 8 to 13, specific viscosity at 40° C. Second coat: Hot tar	¼ ⅓	536 to 553, ¼ to 1 inch slag. 553 to 622+50, ¼ to 1 inch stone.
Sec. 11. 622+50 to 791+25	do	Primer: Tar, 8 to 13, specific viscosity at 40° C. Second coat: Hot asphalt, 150 to 200 pen	¼ ⅓	¼ to 1 inch stone.

[1] This section was double surface-treated by the State highway department in 1925.

RE-TREATMENTS

Section and station	Date	Type	Bituminous material		Covering
			Character	Gallons per square yard	
Sec. 7. 38+00 to 82+50	November, 1925	Surface-treated	Tar, 18 to 25, specific viscosity at 40° C.	⅕	Sand.
0+00 to 38+00	March, 1926	do	Tar, 8 to 13, specific viscosity at 40° C.	⅕	Do.
82+50 to 436+00[1]					
Sec. 8. 436+00 to 512+00	March, 1926	Surface-treated	Medium quick-drying oil	⅕	Do.
Sec. 9. 512+00 to 536+00	do	do	Tar, 8 to 13, specific viscosity at 40° C.	⅕	Do.
Sec. 10. 574+50 to 622+50	November, 1925	do	Tar, 13 to 18, specific viscosity at 40° C.	⅕	Do.
536 to 574+50	March, 1926	do	Tar, 8 to 13, specific viscosity at 40° C.	⅕	Sand, 553 to 574+50; 536 to 553, stone.
Sec. 11. 622+50 to 791+25	November, 1925	do	Slow-drying oil	⅕	Sand, 622+50 to 720, 735 to 750, 780 to 791+25; remainder ¼-¾ inch stone.

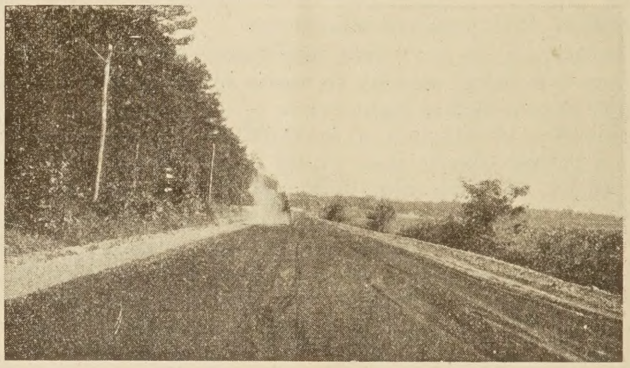
[1] This section was double surface-treated by the State highway department in 1925.



Pulverizing the Topsoil After Scarifying

Final Application of Bituminous Material Preparatory to Mixing

First Application of Bituminous Material to a Portion of the Soil. Second Application to Follow After Spreading the Soil Shown in Windrows



Shaping and Compacting

Table 3.—*Analysis and tests of samples of topsoil surfacing from experimental sections*

Soil No.	Section No.	Station of sampling	Mechanical analysis of granular material: Over ¼-inch	¼-inch-No. 10	No. 10-No. 20	No. 20-No. 60	No. 60-No. 100	No. 100-No. 200	Total	Silt 0.02 to 0.07 mm.[1]	Clay under 0.02 mm. diameter[1]	Dye adsorption No.	Moisture equivalent	Lower liquid limit	Plastic index	Shrinkage: Limit	Shrinkage: Ratio	Depth of topsoil surface at center line	Condition of the topsoil surface
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*							*Inches*	
1528	1	2	3	3	7	31	9	7	60	13	27	13	12	25	7	16	1.8	6	Smooth and well bonded.
1529	2	22	6	7	9	33	10	10	75	9	17	3	6	16	0	13	1.9	6	Badly broken, poorly bonded.
1530	3	38	3	4	4	27	13	10	61	13	26	6	10	19	3	14	1.9	7	Smooth and well bonded.
1531	3	74	1	3	7	33	9	6	59	9	32	11	12	27	10	17	1.8	8	Do.
1532	3	106	1	4	7	37	11	10	70	8	22	7	7	19	0	15	1.9	9	Good; some loose material on the surface.
1533	4	125	4	6	7	33	12	11	73	9	18	5	7	18	0	15	1.8	7	Considerable loose material, poorly bonded.
1534	4	145	8	5	5	26	12	10	66	14	20	5	8	19	0	15	1.9	6	Good, except poorly bonded at the edges.
1535	5	170	8	7	5	28	12	12	72	12	16	5	6	17	0	14	1.9	8	Very loose, poorly bonded.
1536	5	213	2	6	10	35	11	8	72	10	18	5	7	19	0	16	1.8	6	Do.
1537	5	244	7	8	9	29	8	8	69	10	22	5	8	19	4	15	1.8	4	Good; some loose material at sides.
1538	5	269	2	8	9	30	11	8	68	12	21	6	9	21	0	16	1.8	5	Do.
1568	6	290	2	6	11	41	13	12	85	8	8	3	4	------	------	------	------	------	Very poor, loose and scaling badly in places.
1539	6	300	3	4	8	33	10	10	68	12	21	6	8	25	0	20	1.7	8	Good, some loose material at sides.
1540	6	340	3	5	8	32	11	11	70	10	21	5	8	19	3	15	1.8	8	Smooth, well bonded.
1562	7	5	4	7	8	26	9	12	66	13	21	7	8	------	------	------	------	7	Do.
1563	7	28	14	9	8	22	8	10	71	13	17	6	8	------	------	------	------	6	Loose and poorly bonded.
1545	8	446	8	3	5	34	12	9	71	10	20	5	8	17	0	15	1.8	5	Rough, well bonded.
1546	8	472	5	3	6	37	13	11	75	9	16	3	6	17	0	15	1.7	6	Loose and poorly bonded.
1547	8	497	8	4	4	29	9	10	64	9	27	7	13	31	6	21	1.7	6	Good, well bonded.
1549	9	525	11	5	5	38	14	11	84	8	10	2	4	15	0	------	------	6	Loose, poorly bonded.
1551	10	552	3	4	6	33	10	11	67	10	22	9	10	23	0	19	1.7	5	Good, well bonded.
1553	10	585	3	2	4	37	13	10	69	9	23	5	8	19	0	15	1.8	4	Good, fairly well bonded.
1554	10	620	1	4	6	36	11	11	69	9	22	5	9	18	0	15	1.8	6	Do.
1555	11	661	4	5	7	34	11	8	69	9	20	8	8	9	0	16	1.7	8	Good, well bonded.
1556	11	693	8	10	7	30	11	9	75	10	16	4	7	18	0	14	1.7	------	Smooth, poorly bonded.
1558	11	726	2	7	7	26	10	12	64	12	26	7	12	23	0	19	1.6	5	Fairly smooth; fairly well bonded.
1559	11	757	8	9	6	25	12	11	71	13	15	5	7	17	0	17	1.7	5	Loose, very poorly bonded.
1560	11	785	2	5	6	30	16	13	72	11	17	5	8	20	0	18	1.7	------	Do.
SAMPLES TAKEN FROM THE SUBGRADE																			
1565	7	49	0	1	1	26	9	8	45	11	44	10	21	44	22	27	1.5	------	
1548	8	497	0	2	4	26	8	9	49	9	42	11	21	37	12	26	1.6	------	
1552	10	552	5	4	6	29	10	12	66	12	22	7	13	30	0	23	1.6	------	
1557	11	693	1	5	5	23	7	8	49	13	38	8	14	33	15	21	1.7	------	

[1] Limiting sizes of silt and clay are as defined for use in testing semigravel, topsoil, and sand-clay aggregate for road surfacing, U. S. Dept. Agr. Bul. 1216, p. 16. Percentages of silt and clay are based on the total samples, calculated from the results obtained on the material passing the 10-mesh sieve.

TABLE 4.—*Characteristics of material used for covering on surface treatments*

Material No.	Where used, stations	Mechanical analysis of granular material: ¼-inch	No. 10	No. 10–No. 20	No. 20–No. 60	No. 60–No. 100	No. 100–No. 200	Silt	Clay
		Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
TOPSOIL ON SECTION 3									
1530	34+32 to 85+00	3	4	4	27	13	10	13	26
1531	34+32 to 85+00	1	3	7	33	9	6	9	32
1541	34+32 to 85+00	12	3	5	24	10	9	10	27
TOPSOIL ON SECTION 4									
1534	134+00 to 161+04	8	5	5	26	12	10	14	20
TOPSOIL ON SECTION 5									
1538	255+00 to 279+84	2	8	9	29	11	8	12	21
SAND ON SECTIONS 3, 4, AND 5									
1542	85+00 to 134+00 161+04 to 255+00	1	9	25	54	4	2	2	3

Material No.	Where used	Character of material	Mechanical analysis, amount retained: 1-inch	¾-inch	½-inch	¼-inch	No. 10	No. 20
			Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
27300	Section 6	Biotite gneiss	11	39	81	98	------	------
26953	Sections 7, 8, 10 and on 9 from station 512 to 517.	Gneissoid granite.	19	33	85	98	------	------
26951	Section 9 from station 517 to 533.	Dolomite	------	------	11	57	93	99
26952	Section 11	Gneissoid granite.	2	17	49	85	------	------

with a grader, and bituminous material was applied to the surface at the rate of one-half gallon per square yard. This was followed by disk harrowing several times, after which the topsoil at the sides of the road was spread over the treatment with the grader. Second and third applications of bituminous material were made, both similar in amount to the first, and followed in each case by disk harrowing, mixing, and shaping with a grader. In mixing, the procedure was to blade all the material from one side of the road to the other, finally shaping the surface to receive the next application.

After the surface had been thoroughly mixed and shaped it was gone over with a steel drag. This method worked very well for both sections, the surface being completely compacted after a few days of occasional dragging.

Although disking did not prove effective in mixing, it is believed that a small amount of such work is beneficial in bringing about a better bond between the mixture and the base and also in preventing the formation of a rich bituminous mat on the surface. It was found that such a mat, if permitted to form, might later peel off and lead to the formation of potholes.

Experimental sections 3 and 4 were both constructed in the same manner. The topsoil road surface was swept clean, using a revolving broom, followed by hand brooming. The bituminous material was then added in two applications, the first being made at the rate of one-fifth gallon per square yard. The first application was covered with pulverized topsoil from the shoulders on a portion of these sections, while on the remaining portions a fairly coarse local river sand was used.

The first application was left to penetrate and consolidate for a day or two, after which such portions of the surface as had excess covering were swept. The second application was then made at the rate of 0.18 gallon per square yard and covered with the same material as had been used after the first application. The depth of the surface treatment several days after completion was about one-half inch.

APPLYING PRIMING COAT TO THE TOPSOIL SURFACE

STONE COVERING APPLIED IMMEDIATELY AFTER THE APPLICATION OF THE HOT TOP COAT

A marked difference in the appearance of the surface treatment was apparent between the sections where sand covering and topsoil covering were used, the sanded surface appearing richer and less fragile.

The method used on section 5 was similar to that on sections 3 and 4, except that less sweeping was done on the topsoil surface before the first application of oil. Local river sand was used in covering a portion of this section, and on the remaining portion topsoil from the surface of the shoulders was employed.

A small amount of dragging was done shortly after the completion of the treatment to develop a smooth finished surface, but continuous machine maintenance was not feasible with the thin surface mat formed by the single treatment.

DOUBLE TREATMENT USED ON SIX SECTIONS

The remaining experimental sections, Nos. 6 to 11, inclusive, were all of the double surface-treatment type. The general procedure in making these treatments was to sweep the topsoil surface clean of all loose material and follow with a priming coat of a light tar or oil at the rate of one-fourth gallon per square yard. Where holes and breaks occurred in the topsoil surface, repairs were made after the priming coat had been applied. These repairs usually consisted of filling the depression with loose stone, but in the case of very bad breaks a bituminous cold-patch mixture was used. Portions of sections 6 and 11 required a large amount of such repair work.

The priming coat was permitted to penetrate and partially set up for a day or two, after which a heavy tar or asphalt was applied hot at the rate of one-third gallon per square yard and covered immediately with crushed stone, spread by hand at the rate of 45 pounds to the square yard. After the crushed stone had been spread the surface was rolled with a 5-ton roller and opened to traffic. For a period of two or three weeks while compaction of the surface was taking place, stone thrown to the sides by traffic was collected and respread in places where bleeding and picking up indicated a deficiency of covering.

The priming material used on sections 8 and 9 was a cut-back asphaltic oil. It was found that this oil was not homogeneous, and great difficulty was experienced in applying it, as the distributor nozzles continually clogged. Only the thinner oil, which appeared to be largely the original cut-back naphtha, penetrated the topsoil, while the heavier material formed a mat on the surface.

TABLE 5.—*Tests of tars used on experimental sections*

	Original treatment							Re-treatment				
Laboratory number	27157	27159	27153	27154	27198	27199	27201	27683	27706	27769	29071	29072
Section	3 and 6	1 and 4	7 and 11	7	9 and 10	10 and 11	11	3 and 4	7 and 10	7, 9, and 10	3 and 4	1
Location of use, stations	34+32 to 108+24, 279+84 to 361	0+00 to 15+84, 108+24 to 161+04	0+00 to 82+50	0+00 to 82+50	512 to 536, 536 to 622+50	536 to 630, 729 to 791+25	630 to 729	34+32 to 161+04	38+00 to 82+50, 574+00 to 622+00	0+00 to 38+00, 512 to 574	34+32 to 161+04	0+00 to 15+84
Specific gravity, 25° at 25° C	1.177	1.184	1.186	1.23	1.231	1.169	1.158	1.186	1.176	1.145	1.144	1.133
Specific viscosity, Engler, 25° C						48.7	36.7			53.8	67.0	69.9
Specific viscosity, Engler, 40° C	8.6	20.4	12.4			12.0	11.3	23.7	18.9	11.4	21.7	25.3
Float test, 32° C. (seconds)				167	182							
Float test, 50° C. (seconds)				69								
Bitumen soluble in CS_2 per cent	91.9	91.4	92.2	88.5	81.8	88.0	89.6	89.7		94.75	94.2	91.1
Free carbon do	8.1	8.6	7.7	11.4	18.1	11.8	10.3	10.2	8.8	5.19	5.2	4.7
Inorganic matter insoluble do	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1		0.1	0.0
Distillation:												
Water do	1.6	1.4	1.2	0.0	0.0	2.0	2.4	1.34	1.36	2.57	0.5	4.1
Distilled to 170° C do	2.22	2.20	2.29	0.0	0.0	2.79	4.21				0.61	2.54
170 to 235° C do	5.06	6.23	7.07	2.25	2.47	9.36	6.26	9.12	4.83	8.80	8.13	5.48
235 to 270° C do	13.91	12.55	10.83	7.10	6.54	10.90	9.98	11.50	12.51	12.76	13.05	15.60
270 to 300° C do	5.87	6.52	6.49	3.66	4.73	5.10	5.83	5.03	6.24	6.76	9.26	7.41
Residue do	73.21	72.62	73.28	87.15	86.60	71.84	73.79	72.94	75.33	69.04	68.80	68.70
Softening point, residue °C do	30	45	34	42	49	40	38	38	30	38	50	48

TABLE 6.—*Tests of oil products used on experimental sections*

	Original treatment							Re-treatment					
Laboratory number	27158 [1]	27160	27161	27197	27200	27202	27203	27684	27685	27705	27760	29073	29074
Section	6	5	2	8 and 9	8	11	11	2	5 and 6	11	8	5	2
Location of use, stations	279+84 to 361+00	161+04 to 279+84	15+84 to 34+32	436to 512, 512 to 536	429+50 to 512	700 to 791+25	622+50 to 700	15+84 to 34+32	161+04 to 353+00	622+50 to 791+25	436+00 to 512+00	161+04 to 279+84	15+84 to 34+32
Specific gravity 25° at 25° C	1.011	0.938	0.929	0.950	1.031	1.032	1.031	0.9496	0.9496	0.9473	0.9439	0.955	0.953
Flash point, °C	195	105	20	28	235	235	235	100	99	90	30	130	140
Burning point, °C		140	31	31				160	160	150	55		
Specific viscosity, Engler, 25° C		73.7	127.5	329				228.3	164.7	169.3	84.7	127.2	121.7
Specific viscosity, Engler, 40° C		30.5	57.5	117				55.7	48.3	44.19	31.8	42.3	40.5
Specific viscosity, Engler, 50° C			48.6										
Specific viscosity, Engler, 100° C	82.8				336	327	332						
Float test, 32° C., seconds	517												
Float test, 50° C., seconds													
Penetration, 25° C., 100 grams, 5 seconds					165	161	164						
Softening point, ° C					40	40	40						
Loss, 163° C., 5 hours, 20 grams per cent	1.23	13.4	24.7	23.0				9.0	9.5	9.6	32.2	7.1	7.0
Residue, float test, 32° C. seconds		Fluid.	1671	4122									
Residue, float test, 50° C. do	174		200	360								8.0	8.0
Loss, 163° C., 5 hours, 50 grams per cent	.64	10.4	22.8	21.3	.17	.14	.16	5.7	6.1	6.1	7.4	4.7	4.1
Residue, float test, 32° C. seconds		Fluid.	516	852									
Residue, float test, 50° C. do	153		131	237								6.0	6.0
Residue, penetration 25° C., 100 grams, 5 seconds					139	147	146						
Bitumen soluble CS_2 per cent	99.9	99.9	100.0	99.8	99.8	99.8	99.8	100.0	100.0	99.9	100.0	99.9	99.9
Organic matter insoluble do	.1	.1	.0	.2	.2	.2	.2			.1		.1	.1
Inorganic matter insoluble do	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
Per cent bitumen insoluble in 86° B. naphtha	21.5	12.7	19.3	20.0	23.6	24.2	23.5	13.3	12.3	13.3	17.6	7.6	.06

[1] Sample No. 27158 contained about 5 per cent adventitious water. Tests made after dehydration at 105° C.

COST DATA KEPT ON VARIOUS SECTIONS

Cost data on the several experimental sections are given in Tables 7 and 8. The costs shown do not include charges for overhead or rental of equipment. The unit cost of constructing experimental sections 1 and 2 is high, but would probably be less on larger sections.

Unit costs of materials and labor used on these sections were as follows:

Oil for cold and hot application at refinery, per gallon	$0.05
Tar for cold and hot application, delivered, do	.1281
Stone, 1¼ inches to one-fourth inch, delivered, per ton	2.05
Common labor, per day of 10 hours	1.75–1.90

TABLE 7.—*Cost per square yard of various items on sections 1 to 6*

Section No.	1	2	3		4		5		6
Covering material	Topsoil	Topsoil	Topsoil	Sand	Topsoil	Sand	Topsoil	Sand	1¼-inch stone
Area (square yards)	3,516	4,103	11,262	5,148	5,998	5,724	5,520	20,854	17,582
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Labor preparing roadway	0.64	0.58	1.23	1.23	0.35	0.35	0.26	0.26	0.88
Heating bituminous material									.28
Applying bituminous material	.46	.58	.32	.32	.13	.13	.13	.13	.56
Hauling covering material				.90		.49		.41	1.10
Applying covering material	1.44	.81	.40	.40	.13	.13	.19	.19	.39
Tar, delivered	18.93		4.54	4.54	5.19	5.19			3.15
Oil, cold application		7.61					1.86	1.86	
Freight on above		2.60					.73	.73	
Oil, hot application									1.60
Freight on above									.58
Cover material									5.18
Fuel, oil, etc	1.23	1.76	.73	.73	.23	.23	.54	.54	.83
Miscellaneous	.55	.68	.15	.15	.30	.30	.42	.42	.72
Total cost per square yard (cents)	23.30	14.62	7.37	8.27	6.33	6.82	4.13	4.54	15.27
Cost per mile, 20 feet wide (dollars)	2,735	1,715	860	970	745	800	485	535	1,790

TABLE 8.—*Cost per square yard of various items on sections 7 to 11*

Section No.	7	8	9			10		11
Covering material	Stone	Stone	Stone	Chats	Slag	Slag	Stone	Stone
Area (square yards)	19,950	16,044	1,056	3,378	633	3,589	14,672	35,625
	Cents	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Cents*
Labor	2.74	2.74	2.74	2.74	2.74	2.74	2.74	2.74
Tar for cold application	2.823					2.823	2.823	2.823
Freight on above	.059					.059	.059	.059
Tar for hot application	5.76		5.76	5.76	5.76	5.76	5.76	
Freight on above	.121		.121	.121	.121	.121	.121	
Oil for cold application		1.833	1.833	1.833	1.833			
Freight on above		.686	.686	.686	.686			
Oil for hot application		2.028						2.028
Freight on above		.760						.760
1 to ¼-inch stone	2.982	2.982	2.982				2.982	2.982
Freight on above	2.491	2.491	2.491				2.491	2.491
Limestone chats				4.07				
Freight on above				4.56				
1 to ¼-inch slag					1.933	1.933		
Freight on above					4.00	4.00		
Fuel and steam	.3445	.3445	.3445	.3445	.3445	.3445	.3445	.3445
Miscellaneous	.5655	.5655	.5655	.5655	.5655	.5655	.5655	.5655
Total cost per square yard (cents)	17.89	14.43	17.52	20.68	17.98	18.45	17.89	14.79
Cost per mile, 20 feet wide (dollars)	2,100	1,695	2,055	2,425	2,110	2,165	2,100	1,735

SERVICE HISTORY OF THE EXPERIMENTAL SECTIONS DESCRIBED

Since the original treatment of these sections in July, 1925, some retreatment has been necessary and all sections have been under patrol maintenance. The patrol maintenance has consisted largely of repairing breaks in the surface, using the same materials as were used in the original treatment. In patching the double surface-treated sections, good results were obtained with the original hot application materials and also with commercial cold patching products.

TAR MIXED SECTION WITHOUT SEAL COAT SHORTLY AFTER CONSTRUCTION

Most of the retreatments were as had been originally planned. In most cases they were for the purpose of sealing the surface or of thickening and strengthening the original treatment. On several sections, however, the work amounted to reconstruction. Table 9 summarizes the nature and cost of the work done on the experimental sections to June, 1927. A description of this work up to August, 1927, and a survey of the condition of the sections at that time is given below in some detail.

The experiments in Anderson County (secs. 1 to 6) have carried much less traffic than those in Spartanburg County. Counts made on the Anderson County experiments during the months from January to September of 1927 showed an average of 456 vehicles and a maximum of 935 for the 12-hour period from 7 a. m. to 7 p. m.

The traffic on the Spartanburg sections has greatly increased since the experiments were completed. Traffic counts made by the State on week days during five summer months of 1924 before these treatments were made, showed an average of 636 and a maximum of 800 vehicles for the 12-hour period from 7 a. m. to 7 p. m., while a similar count during the same period of 1926 gave an average of 834 and maximum of 1,082 vehicles.

SECTION 1

A few months after this section was subjected to traffic, evidence of nonuniform mixing developed. Corrugations denoting excessive richness appeared in some places and in others leanness was indicated by raveling. A light seal-coat treatment consisting of tar of a specific viscosity at 40° C. of 18 to 25 was applied at the rate of one-fifth gallon per square yard and covered with sand. This treatment prevented further raveling but the mixture continued to be highly unstable in certain areas.

This section was maintained through the year 1926 by patching and cutting down corrugations, but in March, 1927, it was apparent that further maintenance of this character would not be justified. The surface was scarified to a depth sufficient to produce a surface

TABLE 9.—*Cost per square yard of maintenance of experimental sections, from June, 1925, to June, 1927* [1]

Section No.	Original treatments (May and June, 1925): Type	Bituminous material	Covering	Cost per square yard	Re-treatments: Date	Type	Bituminous material and rate of application	Covering	Cost per square yard	Maintenance cost per square yard: July–December, 1925	January–June, 1926	July–December, 1926	January–June, 1927	Total cost per mile of surface to June, 1927 (20 feet wide)	Average yearly cost of re-treatments and maintenance per mile (20 feet wide)	Cost of retreatments and maintenance during year July, 1926, to July, 1927, per mile (20 feet wide)
				Cents					*Cents*	*Cents*	*Cents*	*Cents*	*Cents*	*Dollars*	*Dollars*	*Dollars*
1	Mixed	1.5 gallons tar No. 27159.		23.30	July, 1925	Surface-treated	½ gallon tar No. 27159	Sand	5.50	2.04	4.20	2.00	1.50	7,010	2,140	2,900
					March, 1927	Mixed, surface-treated.	1.1 gallons tar No. 29072 ½ gallon tar No. 29072	do	21.20							
2	do	1.5 gallons oil No. 27161		14.62	November, 1925.	Mixed	1.1 gallons oil No. 27684		11.40	.63	.18	1.29	2.04	5,195	1,740	2,045
					March, 1927	Mixed, surface-treated.	1.1 gallons oil No. 29074 ½ gallon oil No. 29074	Sand	14.10							
3	Surface-treated	0.38 gallon tar No. 27157	Topsoil	7.37	November, 1925.	Surface-treated	0.38 gallon tar No. 27683	do	6.27	2.76	3.61	1.96	3.30	3,670	1,415	1,290
			Sand	8.27	do	do	0.18 gallon tar No. 27683	do	3.29							
					March, 1927	do	0.40 gallon tar No. 29071	do	5.31							
					do	do	0.25 gallon tar No. 29071	do								
4	do	0.38 gallon tar No. 27159	do	6.82	November, 1925.	do	½ gallon tar No. 27683	do	3.92	4.63	5.03	2.76				
			Topsoil	6.33	do	do	0.37 gallon tar No. 27683	do	6.22							
					March, 1927	do	¼ gallon tar No. 29071	do	5.31							
					do	do	0.40 gallon tar No. 29071	do								
5	do	0.38 gallon oil No. 27160	do	4.13	November, 1925.	do	½ gallon oil No. 27685	do	2.94	2.63	2.35	2.33	2.59	2,390	935	935
			Sand	4.54	March, 1927	do	½ gallon oil No. 29073	do	3.06							
6	Double surface-treated.	Primer: ¼ gallon tar No. 27157. Top coat: ⅓ gallon asphalt No. 27158.	1 to ¼-inch stone	15.27	November, 1925.	do	½ gallon oil No. 27684-5	do	3.22	2.66	1.48	.78	.87	2,850	530	195
7	do	Primer: ¼ gallon tar No. 27153. Top coat: ⅓ gallon tar No. 27154.	do	17.89	do	do	Stations 38 to 82+50, ½ gallon tar No. 27706.	do	3.49	1.73	1.35	.70	1.41	3,120	520	245
					March, 1926	do	Stations 0 to 38, ½ gallon tar No. 27769.	do	3.51							
8	do	Primer: ¼ gallon oil No. 27197. Top coat: ⅓ gallon asphalt No. 27200.	do	14.43	do	do	½ gallon oil No. 27760	do	3.24	1.50	1.13	.70	1.29	2,615	460	235
9	do	Primer: ¼ gallon oil No. 27197. Top coat: ⅓ gallon tar No. 27198.	512 to 517, 1 to ¼ inch stone.	17.52	do	do	½ gallon tar No. 27769	do	4.75	1.70	.67	.47	.31	3,240	465	90
			517 to 533, ¼-inch chats.	20.68												
			533 to 536, 1 to ¼ inch slag.	17.98												
10	do	Primer: ¼ gallon tar No. 27199.	536 to 553, 1 to ¼ inch slag.	18.45	November, 1925.	do	Stations 574+50 to 622+50, ½ gallon tar No. 27706.	Sand	3.41	1.88	2.12	.89	1.18	3,385	635	245
		Top coat: ⅓ gallon tar No. 27198.	553 to 622+50, 1 to ¼ inch stone.	17.89	March, 1926	do	Stations 536 to 574+50, ½ gallon tar No. 27769.	Stations 536 to 553, ¼ to ¾ inch stone.	8.91							
								Stations 553 to 574+50, sand.	4.80							
11	do	Primer: ¼ gallon tar No. 27153. Top coat: ⅓ gallon asphalt No. 27202.	1 to ¼ inch stone	14.79	November, 1925.	do	½ gallon oil No. 27705	Stations 622+50 to 720, 735 to 750, and 780 to 791+25, sand.	2.38	3.64	1.89	1.49	1.71	3,090	680	375
								Remainder, ¼ to ¾ inch stone.	4.07							

[1] Above costs do not include rental or depreciation.

layer 3½ inches in thickness. An application of tar at the rate of 1.1 gallons per square yard was required on account of the greater depth of the new surface layer and extreme care was taken to secure a homogeneous and uniform mixture. After the surface had been exposed to traffic for a few days a seal-coat application of one-fifth gallon of tar per square yard was applied and covered with sand.

The reconstructed section appears to have been very successful. Neither raveling nor evidences of instability have developed. The seal coat exhibited a tendency to peel off, due probably to the blotting action of the fine sand cover which, with the tar, formed a lean mat which did not adhere closely to the mixture beneath.

SECTION 2

The quick-curing oil used on this section produced a more brittle mixture than was desired. It was intended that the surface should possess sufficient plasticity to be self-sealing. However, the mixture proved to be lean except in spots where, due to the nonuniformity of composition, the surface corrugated. Late in the fall of 1925 the entire section was scarified and remixed, the mixture being enriched by the addition of 1.1 gallons per square yard of the slow-curing oil used in the construction of section 5.

Throughout the winter this section remained smooth and well bonded, but with the advent of warm weather, instability developed and the surface rutted and corrugated badly. It was evident that, although satisfactory under winter conditions, this mixture was too rich to withstand traffic during the summer months.

The section was reconstructed in March, 1927, by scarifying and adding 1.1 gallons per square yard of slow-curing oil. Mixing was carried to a depth of about 3½ inches, thus producing a much leaner mixture despite the addition of more oil. As a protection to the surface from the abrasive action of traffic, one-fifth gallon per square yard of the same oil was applied and covered with fine sand.

This surface application acted much the same as that on section 1, peeling off badly within a few weeks and it appeared that resealing would be required in the near future.

SECTIONS 3 AND 4

The portions of these experiments upon which topsoil cover was used originally, broke up badly shortly after construction and were scarified and refinished as topsoil surfaces and left to consolidate for four months and then retreated. The sand-covered portions remained in fair condition.

In pursuance of the original plan to develop a mat of appreciable thickness by subsequent treatments, the entire surface of both experiments was treated with tar of 18 to 25 specific viscosity at 40° C. during the following fall. The areas which had been scarified were given about one-third gallon per square yard and about one-fourth gallon per square yard was applied to the remainder. Sand was used as the mineral cover throughout.

The bituminous mats on these experiments were thin and rather brittle and suffered severely from the steel-tire traffic to which they were subjected. This condition was more prevalent on areas of the road where the topsoil was not well bonded.

In March, 1927, those portions which had given particular trouble, aggregating about one-half mile, were re-treated with 0.4 gallon of tar per square yard. At the same time the remainder of the sections were more lightly treated with one-fourth gallon per square yard. The tar was of 13 to 18 specific viscosity at 40° C. and sand was used as the cover.

In general, these sections were in good condition. The mat proved stable and as weak spots were gradually corrected the amount of maintenance required to keep them in repair decreased.

Tar Penetration Treatment on Sections 3 and 4. The Thin Brittle Surface Broke and Scaled Badly During the First Year but Was Materially Strengthened by Later Re-treatments

SECTION 5

This section was in good condition in November, 1925, although a few breaks had occurred in the oil mat. Following the original plan of thickening this mat by repeated treatments, an application of one-fifth gallon of the original slow-curing oil per square yard was made and covered with sand. The surface remained generally in good condition during the summer and winter of 1926. Minor breaks developed early in 1927 and during March of that year the section was again re-treated as before. At the time of inspection the section was in excellent condition. It appeared likely that little maintenance would be required for some time.

SECTION 6

A large portion of the topsoil surface on this section was poorly bonded. In such places the surface treatment failed in many instances and made a large amount of patching necessary during the first few months.

For the purpose of strengthening and resealing the mat, a treatment of one-fifth gallon per square yard of slow-drying oil and sand was applied in November, 1925, to the whole section with the exception of 800 feet at the west end. The untreated portion was in relatively good condition and it was desired to observe its behavior during the winter.

Numerous breaks developed in the surface mat along the edges during the summer of 1926, and were undoubtedly due to poor support by the topsoil. The repair of these defects and subsequent ordinary maintenance has kept the experiment in good condition and when last inspected no further general re-treatment was thought to be necessary in the near future.

SECTION 7

The first 3,800 feet of this section was in excellent condition late in the fall of 1925 and was permitted to go through the winter without re-treatment. The remaining portion of the surface had developed numerous breaks and was therefore given an application of tar of 18 to 25 specific viscosity at 40° C. at the rate of one-fifth gallon per square yard. This material was applied cold and was covered with sand.

The latter portion remained in excellent condition during the winter but considerable patching was required on the part upon which the fall re-treatment had been omitted. In March of 1926 this area was given an application of tar at the rate of one-fifth gallon per square yard and covered with sand.

The condition of this experiment has since continued entirely satisfactory.

SECTION 8

This section was not given a re-treatment in the fall of 1925 with the result that a large amount of patching was required during the winter and early spring.

A re-treatment consisting of one-fifth gallon of a medium quick-curing oil per square yard with a covering of sand, was applied during March, 1926. The surface has since continued in excellent condition and, when last inspected, was not regarded as likely to require early re-treatment.

SECTION 9

The surface of this section was smooth and showed no defects in the fall of 1925. The portion covered with dolomite chats had an appearance resembling a Topeka pavement, while that on which coarse slag was used possessed a rough and granular texture.

Although some patching was required during the first winter after construction on the portion covered with chats, its condition was, in general, much better than that on which coarse slag was used.

The entire section was given a re-treatment of tar of 8 to 13 specific viscosity at 40° C. and a sand cover during March, 1926. The re-treatment resulted in marked improvement of the surface, and its subsequent behavior has been entirely normal and satisfactory.

SECTION 10

The surface between stations 574+50 and 622+50 was treated during the late fall after construction with one-fifth gallon of tar of 13 to 18 specific viscosity at 40° C. and covered with sand. All of this section was not treated as it was desired to retain the rough, granular surface of the slag portion over the winter and at the same time secure information as to the need for the early re-treatment.

The portion of the surface which had not been treated in the fall developed many breaks during the winter. These breaks were repaired during March, 1926, and the surface sealed with an application similar to that applied to the other portion during the fall. The entire section was in good condition at the time of inspection.

SECTION 11

The surface of the north half of this section broke up badly during the first year after construction. On the remaining portion where the underlying topsoil was relatively well bonded the surface was in much better condition.

A surface treatment was applied during November, 1925, using a slow-drying road oil. The oil was covered with sand except for two short sections upon which stone chips were used.

The surface of this experiment has continued in good condition except for a stretch of about 1 mile on which the topsoil was loosely bonded and unsuitable for this type of construction.

EXPERIENCE INDICATES IMPROVEMENTS IN METHODS OF DOUBLE-SURFACE TREATMENT

Observation of the behavior of the different sections since the time of construction has suggested several changes in the character of the bituminous materials and methods of construction, which it is believed would improve the surface. In a few cases such changes have been carried out in reconstruction. The following discussion touches on such factors as appear from the results of these experiments to have an important effect on the results secured with the different treatments.

A Well Bonded Topsoil Surface Suitable for Double Surface Treatment

A well-bonded surface with good support is essential for the double-surface treatment of the kind used on sections 6 to 11, inclusive. Local surface failures which have occurred in these experiments, developed where the topsoil surface was poorly bonded. Such areas may, of course, be anticipated in any topsoil road, but a period of constant and patient maintenance will generally result in a satisfactory bituminous surface.

A priming coat seems to be desirable for this type of construction in order to secure a good bond between the surface bituminous mat and the topsoil, although on a short portion of section 6 where the priming coat was omitted, the surface is still in perfect condition. On this area, however, the application of hot material was heavier than the rest and a thicker mat was originally formed. Tar of 8 to 13 specific viscosity at 40° C. was used as primer. On well-bonded topsoil surfaces the penetration obtained ranged from one-quarter to three-eighths-inch. Greater penetration seemed to be obtained when the topsoil surface was slightly moist than when it was dry and somewhat dusty. Both tar and asphaltic oil were used for binder, and one-third gallon per square yard seemed to be about the correct amount. In one case shoving developed where 0.45 gallon per square yard was used. Both tar and asphaltic oil seem to be equally satisfactory in producing a well-bonded topsoil surface.

A fragile granite ranging from 1/4 to 1 1/4 inches in size was used for covering on most of the double surface-treatment experiments. This stone crumbled to a much smaller size under rolling and early traffic. Where a hard, tough slag of the same size was used the surface remained open and rough. Evidently the size used was too large for this type of surface treatment except in the case of the stone which broke up readily. For a stone of fairly tough character, 1/4 to 3/4 inch in size should prove more suitable.

A supplementary treatment which will seal any small breaks or areas not sufficiently covered by the first application of heavy material has been shown to be desirable before the original treatment goes through the first winter. On several areas where this treatment was omitted, increased maintenance was needed.

Further experimental work will be required to determine the types of materials most suited for supplementary treatments. Two grades of road oil, slow-drying and quick-drying, respectively, and refined tar of 8 to 13 and 18 to 25 specific viscosity at 40° C. were used for this purpose. In some cases the sections re-treated with a cold application of oil showed somewhat uneven covering, due probably to the shearing action of traffic on the thin soft mat before it had bonded firmly. In the case of the slow-curing oil, brooming the sand covering occasionally for a few days following the treatment seems to aid in securing a more uniform surface mat. Of the two tars, the heavier seems to have given a better seal. It is possible that too much covering material was used for these light bituminous materials.

The purpose of the original seal coat is primarily to seal the surface, while later treatments may be required for this purpose and also to increase the plasticity of the bituminous mat and to add to its thickness. It seems that such results might best be obtained with an occasional light application of a heavier grade of tar or a cut-back oil prepared from an adhesive asphalt base.

The character of the mineral cover is as important as the bituminous material. A clean, coarse sand or stone or slag chips not exceeding one-half inch in maximum size is probably best suited for the purpose.

An Example of Excessive Scaling Due to the Improper Selection of Surface Treatment Materials

Sparing use of coarse sand is preferable if the object is to reseal or enrich the surface. Coarser material applied more heavily should be used in thickening or correcting inequalities in the earlier treatments. The above illustration of similar work on a neighboring project shows an extreme case where materials selected for re-treatments were not suitable for use on the hard smooth surface of the original treatment.

MAINTENANCE AN IMPORTANT FACTOR

The double-treated sections have received only one re-treatment which was applied primarily to seal the surface. On a few of the experiments this was applied before the first winter, while on others re-treatment was not made until a year after the original construction. The question of how often such treatments will be required for the purpose of sealing and adding life and thickness to the bituminous mat has not been answered. South Carolina has several miles of this type of surface which have been in service for three years and have received only the first re-treatment. It is possible that a re-treatment as often as every other year may prove economical by keeping the patrol maintenance cost at a minimum.

Appearance of Double Surface Treatment Shortly After Construction. Patrol Maintenance Needed at this Stage to Respread Loose Covering and Repair Broken Places

The degree of success to be obtained by this method depends almost as much upon correct maintenance as upon the original treatments. The careful attention devoted to details of construction must not be relaxed in maintenance if the greatest benefits are to be derived.

Patrol maintenance was found to be necessary immediately after the treated surfaces were opened to traffic. It is very important to repair early breaks and respread such stone as may be displaced under traffic. The cost of such maintenance is high during the first six months but thereafter decreases greatly.

A large portion of the patrol maintenance consisted of repairing breaks occurring along the edges. Such breaks developed frequently at places where the top-soil had not been well bonded previous to applying the surface treatment. A substantial reduction in the maintenance cost on surface treatments of this type will result if some method can be devised for strengthening this portion of the surface. The South Carolina highway department is at present experimenting with various methods of edge thickening. However, until a more adequate method is developed, good results can be expected from widening the surface and treating to a greater width.

Maintenance costs on the 3-year-old double surface-treatment experiments of the State highway department indicate the decided economy of such treatments in comparison with untreated surfaces, which for the same traffic conditions cost on the average from $500 to $600 per mile per year. The present work was, of course, relatively expensive during the year immediately following construction, but during the last six months the costs have been low, substantiating the conclusion that with proper attention to maintenance ultimate economy may be confidently expected.

Based on the successful results obtained with this type of treatment, South Carolina has recently treated a considerable mileage of well-bonded topsoil roads with double surface treatment.

ENCOURAGING RESULTS SECURED WITH MIXING METHOD ON POORLY BONDED SURFACES

A large mileage of the topsoil roads has poorly bonded surfaces. It was hoped to develop a mixing treatment suited to this condition. At first it was thought that the mixture should be sufficiently rich in bitumen to seal itself under traffic. However, experiments based upon this theory proved unsatisfactory because of the shoving that developed. In the reconstruction of such sections a lean mixture was used and a seal coat added. The indications are that his latter construction gives a more stable mixture protected by a richer and better sealed surface.

A Topsoil Surface Loosely Bonded and Not Suitable for Double Surface Treatment. A Slow-Drying Oil Penetration or Mixed Treatment Would Be Better for This Condition

Tests made on the original mixture taken from the surface showed from 5 to 7 per cent of bituminous binder. Shoving had taken place where the binder occurred in excess of 6 per cent. With the type of soil which constituted the surfacing of the mixed sections, about 1.5 gallons per square yard of nonvolatile binder is required to produce a stable mixture of 2-inch thickness. This quantity of bitumen was insufficient to thoroughly coat the grains of the clay-bearing aggregate used on the mixed sections and the bond was derived in part from the clay. Other experiments have shown that in the absence of clay a sufficient amount of bituminous binder must be provided to entirely coat the particles. Relatively clean, very fine sandy soils may require as high as 10 or 11 per cent by weight of bitumen.

These amounts are, of course, exclusive of the bituminous material required for surface enrichment or seal coating. The body of the base mixture is fragile and easily abraded and must be protected against the action of traffic and weather. In case a highly volatile cut-back bituminous product is used in the mixture, an excess must be provided to compensate for the loss of fluxing material through volatilization.

Refined tar of 18 to 25 specific viscosity at 40° C. was used on section 1. On section 2 a quick-drying road oil was used in the original treatment and a slow-drying oil in the later re-treatment. The tar and quick-drying oil behaved similarly, both producing mixtures which soon became brittle. The slow-drying oil was substituted in the re-treatment of section 2 in order to adapt it to machine maintenance.

Although no particular difficulties were experienced in the construction of these sections, care is needed in mixing and compacting to prevent the formation of rich and lean layers, which tend to occur when compaction of the full depth is attempted in one operation. This tendency was largely overcome by progressively building up the surface layer. After spreading the mixture to the full depth, all except a thin layer was bladed off. Again the material was spread over the road and again it was removed, leaving an added thickness above that which first remained. This process was repeated until the full depth was attained.

The results obtained to date on these two sections do not conclusively establish the value of this type of treatment but the indications are encouraging where the lean mixture and surface enrichment method has been used.

COLD SURFACE TREATMENT WITH SLOW-DRYING OIL SUITED FOR SPECIAL CONDITIONS

Sections 3 and 4 were treated originally with tar of 8 to 13 and 18 to 25 specific viscosity at 40° C., respectively. In the later treatment both experiments were combined, using the heavier tar. These sections have required a large amount of maintenance. The thin mat is brittle and breaks very often, particularly under steel-tire traffic. Both sections are in fairly good condition at present and will probably require much less attention in the future. However, future possibilities of this type of treatment can not be considered entirely satisfactory in view of the accumulated maintenance costs.

Section 5 is similar to sections 3 and 4, except that in this section a slow-drying oil was used. It was hoped that by using this material machine maintenance could be used. This was found to be impossible without breaking the thin surface mat. The present condition of the section is very good. The built-up mat is plastic and does not break as readily as that containing tar. Considering the present condition, together with the cost to date, this treatment can be regarded as satisfactory for use on roads carrying light traffic or as a temporary expedient on heavy-traffic routes.

TESTS WARRANT CERTAIN CONCLUSIONS

Results obtained with the different experimental treatments up to this time seem to warrant the following general conclusions:

A double surface treatment composed of a prime coat followed with a binder coat of heavy bituminous material and mineral covering is a successful and economical treatment for soil-type roads, provided the surface is well supported and bonded.

Surface treatments of well bonded topsoil roads with light tar are not likely to be successful, as a thin fragile mat is formed which breaks excessively under traffic.

. Surface treatments of well-bonded topsoil roads with light slow-drying oil, which forms a plastic mat, are likely to prove successful under light traffic or, for a limited period, under heavier traffic.

Results on mixed treatment experiments are inconclusive, but indicate the probable success of lean mixtures supplemented by surface enrichment.

A light supplementary application of bituminous material which will enrich the surface and at the same time seal any small breaks or areas not sufficiently covered has been found to be necessary shortly after the original treatment.

THE ACTION OF SULPHATE WATER ON CONCRETE[1]

FURTHER TESTS OF SPECIMENS IMMERSED IN MEDICINE LAKE, S. DAK.

Reported by DALTON G. MILLER, Drainage Engineer, U. S. Bureau of Public Roads

Tests on concrete cylinders immersed in the sulphate waters of Medicine Lake, S. Dak., for periods up to three and one-half years have yielded considerable additional data to that contained in the report on the tests made at the end of one year's immersion.[2] As pointed out in the earlier report, these experiments were designed principally to aid in the general improvement of farm draintile and particularly to develop tile that will endure under the wide range of soil conditions peculiar to Minnesota. The results are applicable, however, to many other sections of the United States and to concrete culvert pipe subjected to the action of sulphate waters under conditions similar to those to which draintile are subjected.

In carrying out the field tests, several hundred concrete cylinders of various materials and treatments were immersed in Medicine Lake, S. Dak. The laboratory routine of making the cylinders and the conditions of exposure were discussed in the first report so that only such general details will be reviewed as are necessary to make possible a clear understanding of the data presented.

TEST CYLINDERS DESCRIBED

Each series of test cylinders consisted of five batches made on different days, and nine cylinders were made from each batch. All cylinders were 2 by 4 inches in size. The concrete cylinders were mixed in the proportion 1:3 by volume with a relative consistency of 1.00 and water ratio of about 0.62. The aggregate passed all standard physical tests and was separated into screen sizes and recombined for each batch to produce a fineness modulus of 4.67. The mortar cylinders were made of standard Ottawa sand as representing fairly well a poorly graded aggregate such as is too often used in smaller size tile.

Extreme care was exercised to make the cylinders of a series as nearly uniform as possible and variables were introduced singly in the different series so that the influence of any variable on the life of cylinders of a series might definitely be determined.

Thirteen different materials were used as admixtures in cylinders. These materials were as follows: Akagel "A," barium chloride, blast-furnace slag, Cal, calcium chloride, Celite, Colloy, Ironite, powdered fuel ash, Trass, Truscon, sulphur, and volcanic ash. The amounts of these materials used expressed as a percentage of the weight of cement used are shown in Tables 2 and 3. Specimens were also surface treated with Inertol, linseed oil, and sulphur.

Special curing conditions included curing in water vapor and steam ranging in temperature from 70° to 285° F. and covered a wide range of variables as to the time of application and duration of the special curing period.

All of the cylinders for exposure in the lake were numbered and placed in copper-nailed wooden crates with a capacity of 50 cylinders each. In all of the crates the cylinders in any vertical row represent the same series. The crates were installed in the lake in about 5 feet of water and were not subjected to freezing and thawing.

MEDICINE LAKE DESCRIBED

Medicine lake is a natural alkali lake located 18 miles northwest of Watertown, S. Dak. It has stretches of gravel beach, so the conditions for installing field specimens are almost ideal. Analyses of water samples taken at different seasons of the year have shown a total salt content ranging between 2.34 and 4.72 per cent, consisting almost entirely of a combination of magnesium and sodium sulphates in which the magnesium salt greatly predominates. (See Table 1.) These are the salts that have caused trouble in Minnesota. The larger of these two figures represents a total salt content somewhat in excess of any soil water so far found in contact with tile in Minnesota, and much more severe than is ordinarily encountered in agricultural lands anywhere.

TABLE 1.—*Analyses of water from Medicine Lake, S. Dak.*

[Analyses by the water and beverage laboratory, Bureau of Chemistry, U. S. Department of Agriculture]

No.	Date taken	Radicals								
		Na (Calc.)	Ca	Mg	NO_3	Cl	SO_4	CO_3	HCO_3	Total
		MILLIGRAMS PER LITER (PARTS PER 1,000,000)								
778.2	Dec. 10, 1923	3,755	1,006	5,012	1	580	28,898	84	282	39,618
781.2	Feb. 14, 1924	4,344	1,082	6,116	Trace.	596	34,533	54	490	47,215
803.2	Apr. 29, 1924	395	344	4,276	Trace.	396	17,585	98	323	23,417
808.2	July 1, 1925	3,649	436	4,910	Trace.	464	27,067	114	158	36,828
		PERCENTAGE REACTING VALUES								
778.2		13.05	4.01	32.94	0.00	1.31	48.10	0.22	0.37	100.00
781.2		12.67	3.62	33.71	.00	1.13	48.22	.12	.53	100.00
803.2		2.23	2.22	45.55	1.00	.45	47.44	.42	.69	100.00
808.2		13.58	1.86	34.56	.00	1.12	48.25	.41	.22	100.00

For comparative purposes, specimens similar to those immersed in the lake were stored in a tank of ordinary tap water at the laboratory.

Tests have been made on cylinders at periods ranging from one to three and one-half years. Figures 1 to 8 show the condition of the various test groups on removal from the lake. Tables 2 and 3 give data on the character, curing, and results of compression tests on the cylinders for both the concrete and mortar specimens.

CONCLUSIONS

The time of exposure of the cylinders has been too short to justify drawing definite conclusions for those that as yet show little evidence of deterioration. However, study of the data brings out several facts, the more important of which are stated below.

[1] This report is the result of experiments at the Draintile Laboratory at University Farm, St. Paul, Minn., conducted by the department of agriculture of the University of Minnesota, the Department of Drainage and Waters of the State of Minnesota, and the U. S. Department of Agriculture. This report has been published under the title "Tests of Concrete Exposed to the Sulfate Waters of Medicine Lake, South Dakota" as University of Minnesota Paper No. 726, Journal Series.

[2] THE ACTION OF SULPHATE WATER ON CONCRETE, Public Roads, vol. 6, No. 8, Oct., 1925.

Cylinders cured in steam at 212° F. after three and one-half years in lake

Cylinders variously cured after three and one-half years in lake. Series 96 was the only one in which the curing temperature reached 212° F.

Cylinders made with high alumina cement A and variously cured after three years in lake

Fig. 1.—Cylinders of Various Series After Three and Three and One-Half Years in Medicine Lake. All the Cylinders in any Vertical Row Are of the Same Series and the Series Number Is Shown At the Top

(1) Standard Portland cements from different manufacturing plants vary greatly in resistance. This is evidenced by tests of more than 30 different cements after exposure for one year, and in the case of the 4 cements used in series 257 to 260 it will be noted that after two years exposure the cylinders of series 260 still had an average compressive strength of 4,390 pounds per square inch as compared with strengths of 690, 0, and 0 pounds per square inch for series 257, 258, and 259, respectively. (See Table 2 and fig 4.)

(2) All cylinders of high alumina cements made very satisfactory showings, up to and including three years' exposure, with the exception of the mortar cylinders of high alumina cement B and Ottawa sand mixed in the proportion of 1:5. These cylinders, designated as series 280, had almost completely failed at one year. (Fig. 4.) On the other hand the 1:5 high alumina cement B concrete cylinders of series 290 had a strength of 122 per cent of normal at one year and showed no visible disintegration. (Fig. 5.) The natural inference is that high alumina cements, while more resistant than standard Portland cements, are not of such high resistance as will permit of the use of extremely lean mixes for concrete subject to the action of sulphate waters.

(3) Specimens cured in steam at a temperature of 212° F. continue to make excellent showings in all series, and, without exception, cylinders so cured in series 77, 78, 79, 80, 81, 105, and 106 averaged stronger after three years in the lake than they did at one year. (See Table 2 and fig. 1.)

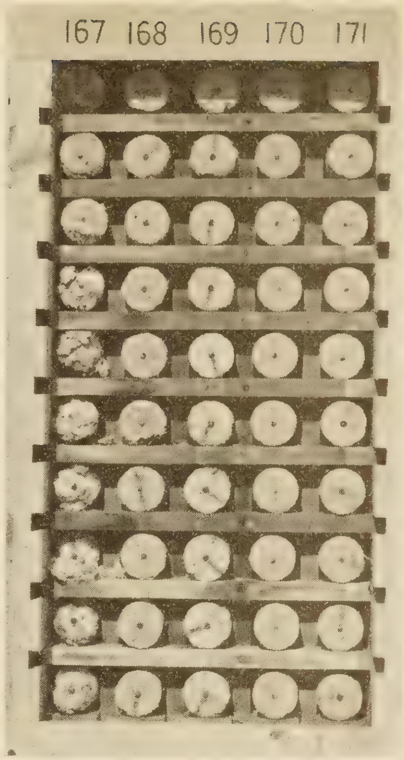
(4) Cylinders cured in steam at a temperature of 212° F. made equally favorable showings irrespective of brand of cement used in the mix.

(5) There is slight difference between the specimens cured in steam at a temperature of 212° F. and those cured at higher temperatures up to 285°. The left photograph of Figure 6 shows cylinders of series 351 to 355, which taken in numerical order, were cured in temperatures of 190°, 212°, 235°, 260°, and 285°. The fifth cylinder from the top of series 352 shows slight deterioration, while no deterioration is evident in series 353 to 355.

(6) The results secured with admixtures were somewhat indefinite as they were at the end of the first year, but they apparently indicate that certain admixtures, if properly handled, may have sufficient value in developing resistance to justify their use under special conditions. In this connection the cylinders in series 161, 166, 170, 176, and 180 were of greater average strength after two years in the lake than those in the lake or in the laboratory tank at one year. Figures 2 and 3 show the generally excellent appearance of cylinders containing admixtures.

Cylinders with 10 per cent and 40 per cent admixtures of blast-furnace slag, variously cured

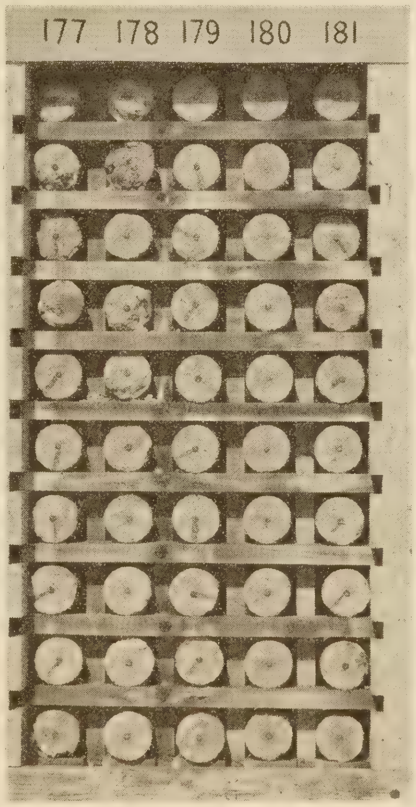
Cylinders with 4 per cent and 8 per cent admixtures of calcium chloride, variously cured



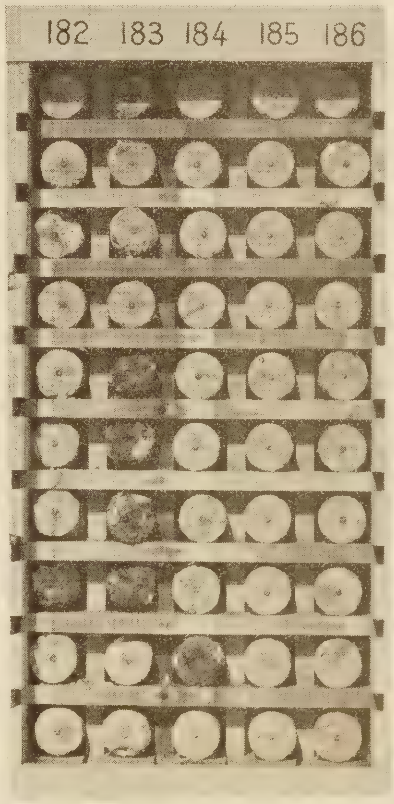
Cylinders with 4 per cent and 8 per cent admixtures of Cal, variously cured

FIG. 2.—CYLINDERS CONTAINING ADMIXTURES AFTER THREE YEARS IN LAKE

Cylinders without admixture and with 20 per cent Ironite admixed and variously cured

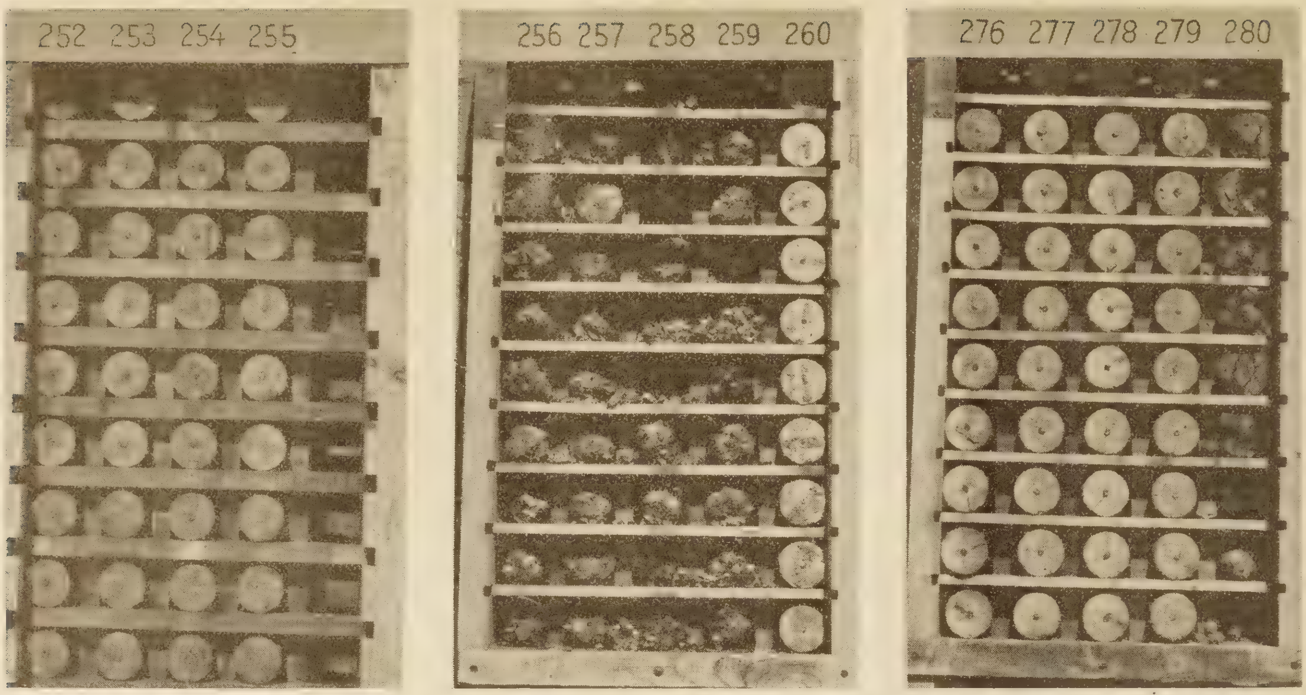


Cylinders without admixture and with 20 per cent volcanic ash admixed and variously cured



Cylinders without admixture and with 3 per cent Alkagel "A" admixed and variously cured

FIG. 3.—COMPARISON OF CYLINDERS WITH AND WITHOUT ADMIXTURES AFTER THREE YEARS IN LAKE

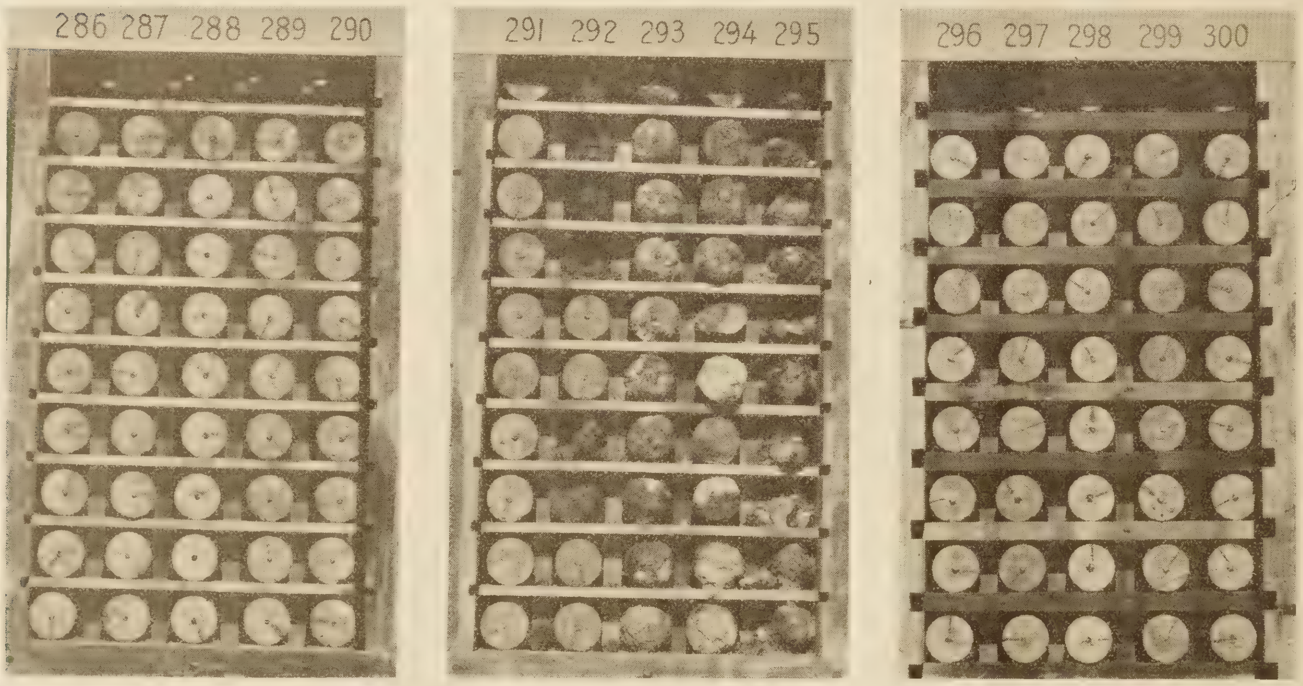


Cylinders of high alumina cement C

Cylinders of different brands of standard Portland cement

Ottawa sand mortar cylinders of various mixes of high alumina cement B

Fig. 4.—Comparison of Cylinders of Various Cements After Two Years in Lake

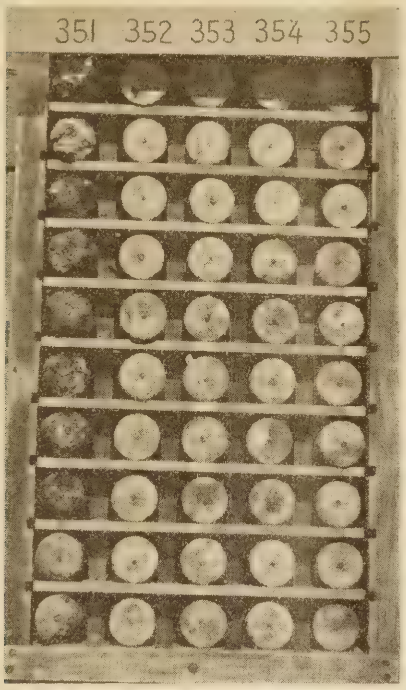


Cylinders of various mixes of high alumina cement B.

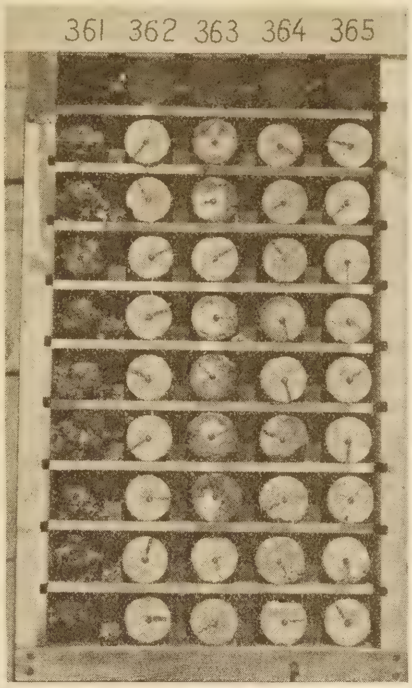
Series 291.—High alumina, cement C, 1:5 mix concrete.
Series 292.—High alumina, cement C, 1:5 mix mortar.
Series 293.—Portland cement mortar.
Series 294.—Portland cement mortar, sulphur impregnated.
Series 295.—Portland cement mortar, sulphur admixed.

Cylinders cured in water at 212° F. for 48 hours.

Fig. 5.—Cylinders of Various Types After Two Years in Lake



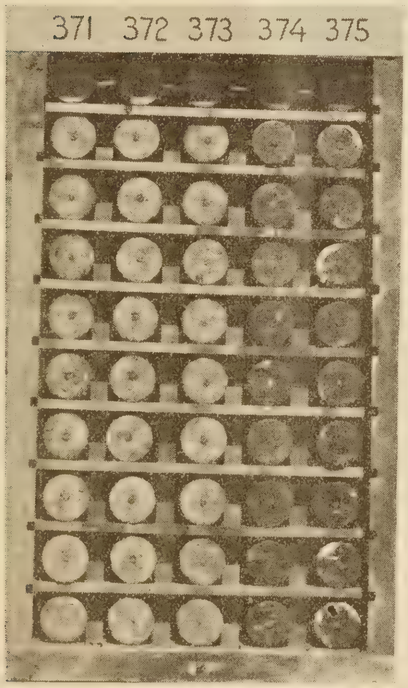
Cylinders cured in water vapor for 12 hours at the following temperatures:
Series 351.—190° F.
Series 352.—212° F.
Series 353.—235° F.
Series 354.—260° F.
Series 355.—285° F.



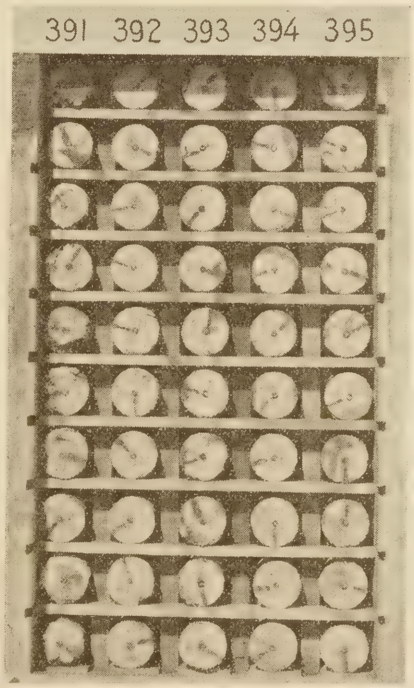
Cylinders made with different brands of standard Portland cement.

Cylinders made with different brands of standard Portland cement.

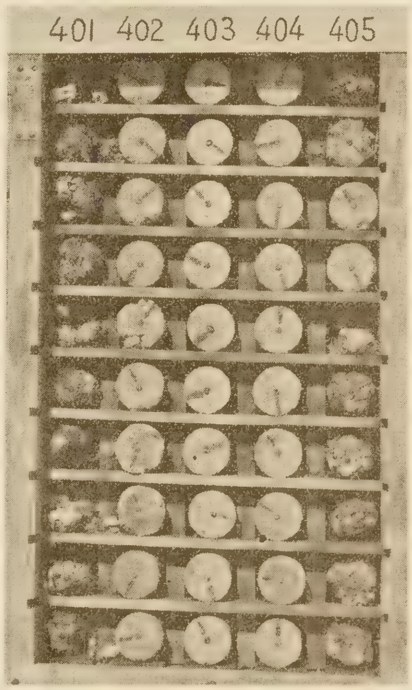
Fig. 6.—Cylinders of Various Types After One and One-half Years in Lake



Cylinders of series 371 to 373 are of standard Portland cement. Those of 374 and 375 are concrete and mortar cylinders, respectively, treated with Inertol.



Cylinders containing admixtures of Trass ranging from zero on the left to 66 per cent on the right.



Cylinders made with different brands of standard Portland cement.

Fig. 7.—Cylinders of Various Types After One Year in Lake

TABLE 2.—*Description and tests of all laboratory standard concrete cylinders immersed in Medicine Lake, S. Dak., and parallel tests on specimens stored in laboratory tanks*

[Unless otherwise noted the fineness modulus of aggregate is 4.67 and the mix is 1 : 3. Each test result, with a few exceptions, is an average of five cylinders made on different days]

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture, impregnation or surface treatment	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water, vapor or steam	Curing method: Temperature of water, vapor or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at one year	Lake specimens: 2 years [1]	Lake specimens: 3 years [1]
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*		*Lbs. per sq. in.*	*Lbs. per sq. in.*
77	11	One-half Portland A, one-half Portland B.	0.59		3		69	212	25	7.9	1,110	1,250	1,250	1,210	97		1,340
78	11	do	.59		6		66	212	25	7.2	2,260	3,040	3,130	2,840	91		2,930
79	11	do	.59		12		60	212	25	6.9	3,400	4,120	4,550	4,410	97		4,940
80	11	do	.59		24		48	212	25	6.9	3,060	4,020	4,600	4,330	94		4,860
81	11	do	.59		48		24	212	25	6.7	2,910	3,850	4,630	4,410	95		5,340
82	11	do	.59		3		69	155	25	6.9	3,360	4,210	5,380	500	9	0	0
83	11	do	.59		6		66	155	25	6.9	3,840	4,720	5,700	490	9	0	0
84	11	do	.59		12		60	155	25	6.7	4,440	4,960	5,250	1,030	20	0	0
85	11	do	.59		24		48	155	25	6.6	4,350	4,550	6,460	1,220	19	0	0
86	11	do	.59		48		24	155	25	6.7	3,540	4,210	6,250	1,660	27	0	0
87	11	do	.59		3		69	100	25	6.6	3,730	4,120	5,110	1,430	28	0	0
88	11	do	.59		6		66	100	25	6.7	3,590	4,320	4,960	1,370	28	0	0
89	11	do	.59		12		60	100	25	6.7	4,050	4,680	5,270	1,290	25	0	0
90	11	do	.59		24		48	100	25	6.7	4,080	4,220	5,240	1,630	31	0	0
91	11	do	.59		48		24	100	25	6.8	3,510	4,060	5,010	1,920	38	0	0
92	11	do	.59		24	27			28	6.7	2,620	4,540	5,690	3,780	66	2,270	
93	11	do	.59		72				25	7.0	3,380	3,560	5,120	3,150	62	1,200	
94	11	do	.59		24		48	100	25	6.8	3,810	4,000	5,640	2,020	36	560	0
95	11	do	.59		24		48	155	25	6.4	4,240	4,370	5,510	1,660	30	690	0
96	11	do	.59		24		48	212	25	6.5	3,770	4,410	4,560	4,300	94	4,910	
97	11.8	do	.59		24		48	155	25	6.3	3,900	4,770	5,690	1,880	33	890	0
98	11.8	do	.59		24		24 24	155 212	25	6.7	4,180	4,120	5,020	4,340	87	6,030	
99	11.8	do	.59		24		72	155	24	6.4	4,490	4,830	5,410	1,530	28	560	0
100	11.8	do	.59		24		48 24	155 212	24	6.2	4,310	4,960	5,730	5,540	97	5,770	
101	11.8	do	.59		24		24 48	155 212	24	6.3	4,110	4,710	4,890	4,640	95	5,970	
102	17	do	.59		24		48	155	25	6.2	4,550	4,730	5,580	980	18	0	0
103	17	do	.59		24		24 24	155 212	25	6.0	4,600	5,510	5,290	4,980	94		5,510
104	17	do	.59		24		72	155	24	6.1	4,910	5,180	5,180	1,270	25	0	0
105	17	do	.59		24		48 24	155 212	24	6.0	4,820	5,070	4,910	5,220	106		6,000
106	17	do	.59		24		24 48	155 212	24	5.7	5,110	5,900	5,320	5,250	99		5,830
137	14	High alumina A	.64		24		48	155	25	6.2	3,250	3,550	2,830	3,400	120		4,510
138	14	do	.64		24		24 24	155 212	25	6.2	3,150	3,670	2,860	3,320	116		
139	14	do	.64		24		72	155	24	6.1	3,160	3,840	2,640	3,790	144		
140	14	do	.64		24		48 24	155 212	24	6.1	3,190	3,890	2,730	3,790	139		
141	14	do	.64		24		24 48	155 212	24	6.1	3,360	3,800	3,020	3,670	121		
147	14	do	.62		24	27				6.3	4,560	4,890	4,560	5,220	114	6,410	
148	14	do	.62		72				25	7.0	5,020	4,810	5,310	5,960	112	6,300	
149	14	do	.62		24		48	100	25	6.5	5,370	5,510	5,240	5,450	104	5,300	
150	14	do	.62		24		48	155	25	6.2	3,360	3,870		3,400		4060(120)	
151	14	do	.62		24		48	212	25	6.1	3,300	3,750	2,840	3,650	129	4,110	
152	14	do	.62		24	20			344	6.3	4,570	5,040	5,100	5,040	99		
153	14	do	.62		24	20			56	6.5	4,830	4,910	5,120	6,280	123		
154	14	do	.62		24	20			28	6.5	4,760	4,850	5,450	5,620	103		
155	14	do	.62		24	20			14	6.5	4,250	4,960	4,570	5,770	126		
156	14	do	.62		24	20				6.3	4,710	4,860	4,380	4,960	113		
157	14	One-half Portland A, one-half Portland B.	.74	40 per cent blast-furnace slag admixed.	24	20				6.5	2,420	3,960	6,030	4,230	70	2,340	
158	18	do	.63	10 per cent blast-furnace slag admixed.	24	20			35	6.0	2,880	4,180	5,440	5,170	95	3,930	
159	18	do	.74	40 per cent blast-furnace slag admixed.	24	20			35	6.7	2,410	4,190	5,670	5,560	98	5,220	
160	18	do	.63	10 per cent blast-furnace slag admixed.	24		48	155	35	6.4	3,850	4,010	5,300	4,800	91	3,540	
161	18	do	.74	40 per cent blast-furnace slag admixed.	24		48	155	35	6.9	3,800	4,020	5,450	4,830	89	5,640	
162	18	do	.63	4 per cent calcium chloride admixed.	24	20				5.7	2,870	4,330	5,530	3,910	71	1,710	
163	18	do	.79	8 per cent calcium chloride admixed.	24	20			35	7.1	2,200	3,010	4,280	3,550	83	3,130	
164	18	do	.63	4 per cent calcium chloride admixed.	24	20			35	5.9	2,940	4,000	5,450	5,050	93	5,240	
165	18	do	.79	8 per cent calcium chloride admixed.	24		48	155	35	7.1	3,800	3,640	4,600	3,300	72	3,860	

[1] Figures in parentheses show percentage of normal strength as indicated by parallel tests on cylinders from same batches stored in tap water in the laboratory.

TABLE 2.—*Description and tests of all laboratory standard concrete cylinders immersed in Medicine Lake, S. Dak., and parallel tests on specimens stored in laboratory tanks*—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture, impregnation or surface treatment	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water, vapor or steam	Curing method: Temperature of water or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at one year	Lake specimens: 2 years	Lake specimens: 3 years
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
166	18	One-half Portland A, one-half Portland B.	0.63	4 per cent calcium chloride admixed.	24		48	155	35	5.8	4,840	4,920	4,990	4,460	89	5,840	
167	18	do	.59	4 per cent Cal admixed.	24	20				5.7	3,200	4,150	4,860	3,910	80	1,380	
168	18	do	.60	8 per cent Cal admixed.	24	20			35	5.8	3,180	4,290	5,570	4,620	83	3,690	
169	18	do	.59	4 per cent Cal admixed.	24	20			35	5.8	3,250	4,280	4,550	4,800	105	3,620	
170	18	do	.60	8 per cent Cal admixed.	24		48	155	35	6.0	4,990	4,670	5,030	5,010	100	6,200	
171	18	do	.59	4 per cent Cal admixed.	24		48	155	35	6.0	4,550	4,690	5,140	4,980	97	5,560	
172	18	do	.59		24	20			35	5.6	2,870	4,190	5,300	4,370	82	2,050	
173	18	do	.61	20 per cent ironite admixed.	24	20			35	5.9	2,950	3,980	4,890	5,020	102	4,000	
174	18	do	.59		24		48	155	35	6.1	4,020	4,390	4,330	3,910	90	2,670	
175	18	do	.61	20 per cent Ironite admixed.	24		48	155	35	6.1	3,880	4,440	5,510	4,630	84	4,830	
176	18	do	.61	do	24		48	100	35	6.1	3,680	4,220	5,250	5,190	99	5,210	
177	18	do	.59		24	20			35	5.9	2,520	4,200	4,930	3,670	74	1,910	
178	18	do	.74	20 per cent volcanic ash admixed.	24	20			35	6.8	1,900	3,210	5,450	2,960	54	1,970	
179	18	do	.59		24		48	155	35	5.8	4,110	4,510	5,210	3,820	73	2,380	
180	18	do	.74	20 per cent volcanic ash admixed.	24		48	155	35	7.6	3,240	3,340	4,440	3,600	81	4,510	
181	18	do	.74	do	24		48	100	35	7.3	2,710	2,820	5,130	4,290	84	3,590	
182	18	do	.59		24	20			35	6.0	2,800	4,010	5,780	4,450	77	2,100	
183	18	do	.63	3 per cent Alkagel "A" admixed.	24	20			35	5.3	2,260	3,560	4,570	3,520	77	2,140	
184	18	do	.59		24		48	155	35	6.0	4,070	4,530	5,100	4,240	83	4,700	
185	18	do	.63	3 per cent Alkagel "A" admixed	24		48	155	35	5.0	3,280	3,940	4,570	3,300	72	3,900	
186	18	do	.63	do	24		48	100	35	5.4	3,120	3,730	3,820	3,550	93	3,060	
208-212	25	High alumina B	.51		24	20			35	4.9	6,700	6,780	6,260	7,420	118	7,690(95)	7,240(91)
243-247	28	Special A 1	.60		24	20			35	6.2	2,910	3,770	5,370	4,030	75	780(12)	0
252-253	58	High alumina C	.53		24	20			35	5.4	7,730	7,230	7,480	7,010	94	7,430	
256	61	One-half Portland A, one-half Portland B.	.59		24	20			35	5.8	2,780	3,950	5,200	1,480	28	120	
257	63	Portland A	.59		24	20			35	5.8	2,720	4,290	5,490	3,190	58	690	
258	62	Portland B1	.59		24	20			35	5.8	2,960	3,790	4,580	800	17	0	
259	33	Portland D	.59		24	20			35	5.4	3,340	4,780	5,900	1,590	27	0	
260	34	Portland C	.66		24	20			35	6.1	3,340	4,540	5,980	5,090	85	4,390	
286 [2]	27	High alumina B	.44		24	20			35	5.1	7,490	6,820	8,080	8,460	106		
287-288	27	do	.53		24	20			35	4.9	7,080	6,620	8,160	8,210	101	7,400	
289 [3]	27	do	.67		24	20			35	5.3	6,560	5,680	6,290	6,160	98		
290 [4]	27	do	.81		24	20			35	5.8	4,640	4,840	4,150	5,080	122		
291 [4]	58	High alumina C	.79		24	20			35	6.5	4,360	4,630	2,910	4,370	150		
296	61	One-half Portland A, one-half Portland B.	.62		24		48	212	53	6.5	3,330	3,660	5,020	4,390	88		
297	63	Portland A	.60		24		48	212	53	6.4	3,650	3,660	4,680	4,600	98		
298	62	Portland B1	.62		24		48	212	53	6.9	3,700	3,830	4,580	4,480	98		
299	33	Portland D	.60		24		48	212	53	6.4	3,690	3,770	4,620	4,270	92		
300	34	Portland C	.67		24		48	212	53	6.6	3,880	4,540	4,940	4,890	99		
301	61	One-half Portland A, one-half Portland B.	.62		24		48	212	53	6.5	3,690	3,610	4,500	4,480	100		
302	35	Portland E	.60		24		48	212	53	6.2	3,540	3,530	4,550	4,450	98		
303	37	Portland F	.60		24		48	212	53	6.0	3,550	3,900	5,060	4,920	97		
304	39	Portland G1	.60		24		48	212	53	6.2	3,740	3,920	4,990	4,680	94		
305	41	Portland H	.60		24		48	212	53	6.1	3,730	3,840	4,860	4,410	91		
306	61	One-half Portland A, one-half Portland B.	.62		24		48	212	53	6.2	3,280	3,920	4,480	4,410	98		
307	40	Portland I	.60		24		48	212	53	5.9	3,420	4,150	5,090	4,190	82		
308	42	Portland J	.62		24		48	212	53	6.4	2,650	3,240	4,680	3,480	74		
309	55	Portland K1	.62		24		48	212	53	6.5	3,260	4,200	4,950	4,910	99		
310	60	Portland L1	.60		24		48	212	53	6.2	3,260	3,870	5,060	4,460	88		
311	65	Portland M	.60		24		48	212	53	5.5	4,660	5,580	5,810	5,570	96		
313	65	do	.60		24	20			35	5.9	3,150	3,950	6,050	2,250	37		
314	65	do	.60		24		48	155	53	6.0	4,460	4,010	6,170	5,430	88		
315	65	do	.60		24		48	100	53	6.2	3,740	3,800	5,970	4,230	71		
351	74	One-half Portland A, one-half Portland B.	.62		24		12	190	54	6.6	2,650	2,940	5,320	1,730	33		
352	74	do	.62		24		12	212	54	6.9	2,450	2,910	5,230	4,240	81		
353	74	do	.62		24		12	235	54	7.3	1,900	2,750	4,780	3,800	79		
354	74	do	.62		24		12	260	54	7.1	2,270	2,490	4,880	3,760	77		
355	74	do	.62		24		12	285	54	7.2	2,260	2,870	4,340	3,870	89		

[2] Mix 1:2. [3] Mix 1:4. [4] Mix 1:5.

TABLE 2.—*Description and tests of all laboratory standard concrete cylinders immersed in Medicine Lake, S. Dak., and parallel tests on specimens stored in laboratory tanks*—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture, impregnation or surface treatment	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water, vapor or steam	Curing method: Temperature of water or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at one year	Lake specimens: 2 years	Lake specimens: 3 years
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
361	80	Portland F	0.62		24	20			35	6.3	2,870	4,320	6,350	0	0		
362	79	Portland N1	.62		24	20			35	6.1	3,220	4,600	6,970	4,000	57		
363	89	Portland O1	.62		24	20			35	5.9	4,010	5,220	6,730	670	10		
364	81	Portland E	.62		24	20			35	5.8	3,340	4,770	7,320	2,910	40		
365	83	Portland H	.62		24	20			35	6.1	3,940	4,770	6,280	3,680	59		
366	77, 96	Portland G2	.64		24	20			35	6.0	4,050	4,820	5,900	1,930	33		
367	82, 95	Portland C	.67		24	20			35	6.8	3,220	4,320	6,270	4,790	76		
368	85, 94	Portland D	.64		24	20			35	6.4	3,390	4,130	5,730	2,980	52		
369	86, 99	Portland I	.64		24	20			35	6.1	3,590	4,370	6,110	4,470	73		
370	87, 88	Portland P	.64		24	20			35	6.1	3,730	5,040	6,540	810	12		
371	84	Portland L2	.64		24	20			35	5.8	3,690	5,000	5,770	3,170	55		
372	97	Portland K2	.64		24	20			35	5.4	3,120	4,440	5,720	4,600	80		
373	98	Portland K1	.64		24	20			35	6.1	4,220	4,970	7,050	3,400	48		
374	74	One-half Portland A, one-half Portland B.	.62	Two coats Inertol	24	20			35	6.7	2,930	4,870	5,570	5,390	97		
391	74	One-half Portland A, one-half Portland B.	.62		24	20			35	6.3	3,130	4,890	6,060	2,480	41		
392	74	do	.76	33 per cent Trass admixed.	24	20			35	7.3	2,710	3,830	5,790	5,040	87		
392a [3]	74	do	.85	do	24	20			35	7.1	2,430	3,450	5,260	4,170	79		
393	74	do	.93	66 per cent Trass admixed.	24	20			35	9.1	1,930	3,350	4,600	4,400	96		
393a [4]	74	do	1.09	do	24	20			35	8.4	1,440	2,670	4,270	3,660	86		
394	86	Portland I	.78	33 per cent Trass admixed.	24	20			35	6.8	3,330	4,690	6,620	5,300	80		
394a [3]	86	do	.87	do	24	20			35	6.7	3,000	3,850	6,170	4,140	67		
395	86	do	.95	66 per cent Trass admixed.	24	20			35	7.6	2,710	3,770	6,060	4,300	71		
395a [4]	86	do	1.09	do	24	20			35	7.3	2,280	3,380	4,090	3,810	93		
396	70, 71	High alumina B	.44		24	20			35	5.6	5,300	5,760	6,110	5,780	95		
397	70, 71	do	.53		24	20			35	4.9	6,660	7,120	8,100	7,580	94		
398	70, 71	do	.59		24	20			35	5.3	6,890	7,210	8,630	7,390	86		
399	70, 71	do	.73		24	20			35	6.3	5,950	5,710	6,440	5,400	84		
400	70, 71	do	.88		24	20			35	7.6	5,140	4,230	3,480	3,790	109		
401	100	Portland Q1	.62		24	20			35	6.4	2,900	4,310	5,110	0	0		
402	101	Portland R	.62		24	20			35	6.3	3,680	4,940	6,290	2,440	39		
403	102	Portland N2	.62		24	20			35	5.9	3,860	5,640	6,630	4,410	67		
404	103	Portland S	.62		24	20			35	6.0	3,010	4,380	5,470	3,160	58		
405	104	Portland T	.62		24	20			35	6.4	2,940	4,380	5,530	280	5		
412	105	Portland Q2	.66	2½ per cent Celite admixed.	24	20			35	6.4	3,530	5,050	6,670	3,760	56		
413	105	do	.62		24	20			35	5.7	3,520	5,390	6,500	4,300	66		
414	106	Portland U	.62		24	20			35	6.1	3,030	4,410	6,430	2,490	39		
415	107	Portland V	.62		24	20			35	6.5	2,830	4,540	5,920	2,940	50		
416	108	Portland W	.62		24	20			35	5.8	3,670	5,010	6,510	1,490	23		
421 [5]	74	One-half Portland A, one-half Portland B.	.37		24	20			35	15.8	6,330	7,630	8,600	8,990	105		
422 [5]	97, 98	Portland K1 and K2.	.35		24	20			35	10.5	6,890	9,880	9,560	10,230	107		
423 [5]	86, 99	Portland I	.38		24	20			35	12.1	8,020	9,330	9,720	9,380	97		
424 [5]	82, 95	Portland C	.42		24	20			35	14.8	7,080	8,560	10,120	8,920	88		
425 [5]	83	Portland H	.36		24	20			35	13.6	6,140	7,290	10,480	9,910	95		
429 [5]	70, 71	High alumina B	.35		24	20			35	9.7	9,460	8,420	10,440	9,330	89		
430	97, 98	Portland K1 and K2.	.64		24		12	285	54	6.6	2,960	3,470	3,950	3,680	93		
431	86, 99	Portland I	.64		24		12	285	54	6.1	3,650	4,150	4,470	4,290	96		
432	82, 95	Portland C	.67		24		12	285	54	6.9	3,330	3,820	5,530	4,930	89		
433	83	Portland H	.64		24		12	285	54	6.5	3,460	3,950	5,110	4,840	95		
434	74	One-half Portland A, one-half Portland B.	.66		24	20			35	6.4	2,590	4,030	5,050	4,870	96		
435	70, 71, 74	5 per cent high alumina B, 47.5 per cent Portland A, and 47.5 per cent Portland B.	.66		24	20			35	6.3	2,630	3,880	5,490	4,100	75		
436	70, 71, 74	10 per cent high alumina B, 45 per cent Portland A and 45 per cent Portland B.	.66		24	20			35	6.2	2,260	3,760	4,820	2,720	56		
437	70, 71, 74	20 per cent high alumina B, 40 per cent Portland A and 40 per cent Portland B.	.66		24	20			35	7.0	1,360	2,830	3,640	3,320	91		

[3] Mix 1:4. [4] Mix 1:5. [5] Neat cement.

TABLE 2.—*Description and tests of all laboratory standard concrete cylinders immersed in Medicine Lake, S. Dak., and parallel tests on specimens stored in laboratory tanks*—Continued

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture, impregnation or surface treatment	Curing method: Time in moist closet	Curing method: Time in water	Curing method: Time in water, vapor or steam	Curing method: Temperature of water or steam	Curing method: Time in air	Absorption at 21 days	Average of compression tests: Tank specimens: 7 days	Tank specimens: 28 days	Tank specimens: 1 year	Lake specimens: 1 year	Lake specimens: Percentage of normal strength as indicated by tank specimens at one year	Lake specimens: 2 years	Lake specimens: 3 years
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
438	70, 71	High alumina B	0.66		24	20			35	5.8	7,080	7,790	7,820	7,220	92		
464	109	Portland B2	.64		24	20			35	5.8	3,740	5,010	7,070	5,950	84		
465	110	Portland B2	.64		24	20			35	5.5	3,660	4,920	6,910	4,850	70		
466	111	Portland B3	.64		24	20			35	5.7	3,810	5,020	5,860	3,960	68		
467 [2]	112	Portland X	.54		24	20			35		2,830	4,390	4,820	4,830	100		
468	113	Portland O3	.64		24	20			35	6.3	2,140	3,940	6,000	5,590	93		
549	129	One-half Portland A, one-half Portland B.	.62		24	20	Water at 212°-½ min.		3 32	5.8	3,790	4,770					
550	129	do	.62	One coat boiled linseed oil at 70° F.	24	20			35	5.8	3,540	4,960					
551	129	do	.62	Two coats boiled linseed oil at 70° F.	24	20			35	5.8	3,730	5,260					
552	129	do	.62	One coat boiled linseed oil at 225° F.	24	20			35	5.8	3,430	4,680					
553	129	do	.62	Two coats boiled linseed oil at 225° F.	24	20			35	5.8	3,750	4,960					
554	129	do	.64		24	20			35	6.3	3,570	4,760					
555	128	Portland Y	.64		24	20			35	6.0	3,780	4,670					
556	127	Special A2	.64		24	20			35	6.0	3,200	4,720					
557	128	Portland Y	.73		24	20			35	6.4	2,760	4,250					
558	127	Special A2	.73		24	20			35	6.6	2,280	4,480					
559 [6]	129	One-half Portland A, one-half Portland B.	.62		24	20 days in damp sand.			35	8.3	3,340	4,530					
560 [6]	128	Portland Y	.62		24	20 days in damp sand.			35	8.2	3,550	5,160					
561 [6]	127	Special A2	.62		24	20 days in damp sand.			35	7.9	3,260	4,720					
562 [6]	128	Portland Y	.71		24	20 days in damp sand			35	9.2	2,720	4,290					
563 [6]	127	Special A2	.71		24	20 days in damp sand			35	9.1	2,290	4,520					
564–565	129	One-half Portland A, one-half Portland B.	.62	2½ per cent powdered fuel ash admixed.	24	20			35	6.3	3,580	5,100					
566	129	do	.64	5 per cent powdered fuel ash admixed.	24	20			35	6.4	3,300	4,700					
567–568	129	do	.67	10 per cent powdered fuel ash admixed.	24	20			35	6.3	3,390	5,080					
573	130	Special B	.62		24	20			35	6.3	4,140	4,800					
574	131	Special C	.62		24	20			35	6.6	3,490	4,580					
575	132	Portland Z	.62		24	20			35	6.0	4,760	5,160					
576	133	Portland AA	.62		24	20			35	6.0	3,460	4,820					
577	134	Portland G1	.62		24	20			35	6.3	3,910	5,610					
578	129	One-half Portland A, one-half Portland B.	.62	1 per cent Truscon admixed.	24	20			35		3,370	4,700					
579	129	do	.62	2 per cent Truscon admixed.	24	20			35		3,370	4,580					
580	129	do	.62	4 per cent Truscon admixed.	24	20			35		3,020	3,980					
581	129	do	.62	6 per cent barium chloride admixed.	24	20			35	6.5	3,530	4,570					
582	129	do	.62	12 per cent barium chloride admixed.	24	20			35	6.7	3,240	4,460					
583	139	do	.62		24	20			35	6.3	3,810	4,950					
584	139	do	.62		24	20	1 min.	212	35	6.3	3,740	5,150					
585	139	do	.62		24		1 min.	212	55	6.4	2,770	2,860					
586–587	139	do	.62		24		------ 1 min.		1 54	6.6	2,970	2,920					
634	139	do	.64	2 per cent Celite admixed.	24	20			35	6.1	3,260	5,340					
635–636	139	do	.64		24		48	212	53	6.3	3,960	4,330					
637–638	139	do	.64	2 per cent Celite admixed.	24		48	212	53	6.2	4,160	4,730					
639	139	do	.64	2 per cent Colloy admixed.	24	20			35	6.5	3,630	4,610					
640	139	do	.64		24	20			35	6.5	3,320	4,470					
641	139	do	.64		24		48	212	53	6.9	3,590	3,760					
642–643	139	do	.64	2 per cent Colloy admixed.	24		48	212	53	6.8	3,870	4,100					

[2] Mix 1 : 2. [5] Neat cement. [6] Mix 1 : 2.25 and fineness modulus 3.10.

TABLE 3.—*Description and tests of standard Ottawa sand cylinders immersed in Medicine Lake, N. Dak., and parallel tests on specimens stored in laboratory tanks*

(Unless otherwise noted the mix is 1:3. Each test result, with a few exceptions, is an average of five cylinders made on different days.)

Series No.	Cement laboratory No.	Cement	Water ratio	Admixture, impregnation or surface treatment	Curing method					Absorption at 21 days	Average of compression tests						
											Tank specimens			Lake specimens			
					Time in moist closet	Time in water	Time in water, vapor or steam	Temperature of water, vapor, or steam	Time in air		7 days	28 days	1 year	1 year	Percentage of normal strength as indicated by tank specimens at one year	2 years [1]	3 years [1]
					Hours	*Days*	*Hours*	*°F.*	*Days*	*Per cent.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*
107	17	One-half Portland A, one-half Portland B.	0.64		24		48	155	25	9.8	2,660	3,080	3,580	770	23	0	0
108	17	do	.64		24		24 24	155 212	25	9.8	2,590	2,910	2,930	2,540	87		3,390
109	17	do	.64		24		72	155	24	9.6	2,670	3,220	3,490	930	27	0	0
110	17	do	.64		24		48 24	155 212	24	9.5	2,600	3,160	2,940	2,720	93		3,160
111	17	do	.64		24		24 48	155 212	24	9.7	2,510	31,30	2,630	2,450	93		2,820
112	17	do	.64		24	27				10.0	1,650	2,630	3,540	1,790	51	0	0
113	17	do	.64		72				25	10.7	2,000	2,000	2,980	840	28	0	0
114	17	do	.64		24		48	100	25	10.1	2,270	2,790	3,040	630	21	0	0
115	17	do	.64		24		48	155	25	10.1	2,730	2,900	3,400	860	25	0	0
116	17	do	.64		24		48	212	25	10.3	2,220	2,470	2,500	2,430	97	2,580	
127	17	do	.64		24		48	155	53	9.1	2,530	2,710	3,460	2,280	66		
128	17	do	.64		24		24 24	155 212	53	9.1	2,350	2,480	2,830	3,180	112		
129	17	do	.64		24		72	155	52	9.0	2,700	3,120	3,320	1,970	59		
130	17	do	.64		24		48 24	155 212	52	9.1	2,750	2,720	2,830	3,080	109		
131	17	do	.64		24		24 48	155 212	52	9.2	2,630	2,470	2,600	2,560	98		
132	14	High alumina A	.65		24		48	155	25	8.1	2,250	2,910	2,760	2,790	101	2,930	
133	14	do	.65		24		24 24	155 212	25	8.0	2,280	2,680	2,080	2,900	139	3,140	
134	14	do	.65		24		72	155	24	8.0	2,470	2,850	2,440	2,840	116	3,120	
135	14	do	.65		24		48 24	155 212	24	7.8	2,620	2,960	2,650	2,590	98	2,930	
136	14	do	.65		24		24 48	155 212	24	7.8	2,550	2,930	2,630	2,580	98	3,170	
142	14	do	.63		24	27				8.7	2,910	3,600	3,590	4,060	113		
143	14	do	.63		72				25	9.3	4,220	4,430	4,220	4,310	102		
144	14	do	.63		24		48	100	25	9.1	4,320	4,640	3,750	4,490	120		
145	14	do	.63		24		48	155	25	8.1	2,200	2,760	2,780	2,620	94		
146	14	do	.63		24		48	212	25	7.8	2,500	2,870	2,500	3,010	120		
248–250	10	Special A3	.63		24	20			35	9.5	1,430	2,730	3,750	3,280	87	1,930(45)	800(20)
254–255	58	High alumina C	.60		24	20			35	9.3	5,010	4,850	2,920	4,340	149	4,380	
276 [2]	27	High alumina B	.44		24	20			35	6.3	6,210	7,680	6,490	8,000	123		
277–278	27	do	.59		24	20			35	8.3	5,060	4,830	5,110	5,560	109	5,060	
279 [3]	27	do	.73		24	20			35	10.2	3,380	3,090	3,250	3,730	115		
280 [4]	27	do	.99		24	20			35	11.8	2,160	1,920	1,680	700	42	0	
292 [4]	58	High alumina C	.90		24	20			35	12.3	2,130	1,820	1,130	920	81	0	
293	19	One-half Portland A, one-half Portland B.	.64		24	20			35	9.9	1,420	2,240	3,850	2,140	56	1,340	
294	19	do	.64	Sulphur impregnated.	24	20			35	9.9	1,350	2,210	3,130	1,500	48	970	
295	19	do	.67	10 per cent sulphur admixed.	24	20			35	9.7	1,150	1,250	1,870	0	0	0	
375	74	do	.64	Two coats Inertol at 70° F.	24	20			35	10.5	1,430	2,790	3,640	2,970	82		

[1] Figures in parentheses show percentage of normal strength as indicated by parallel tests on cylinders from same batches stored in tap water in the laboratory.
[2] Mix 1:2.
[3] Mix 1:4.
[4] Mix 1:5.

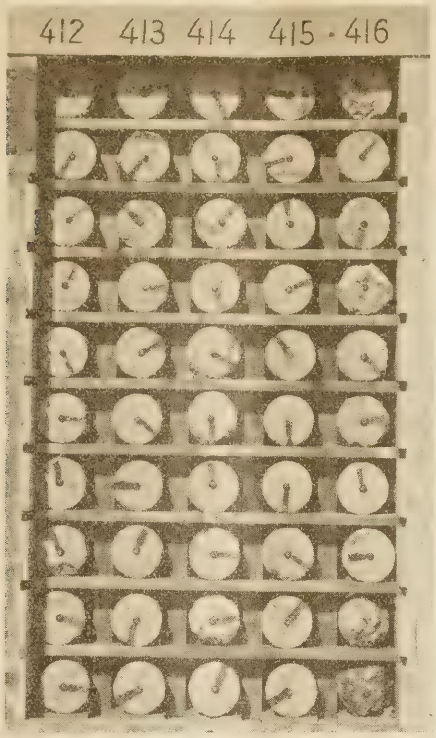


Fig. 8.—Cylinders Made with Different Brands of Standard Portland Cement After One Year in Lake

ANALYSIS OF CONCRETE ARCHES

"Analysis of concrete arches," by W. P. Linton and C. D. Geisler, which appeared in the June and July, 1927, issues of Public Roads, is now available as a separate publication. The authors have developed a method which greatly reduces the tedious and complicated processes usually followed in the calculation of arch stresses. The method makes use of a set of standard forms, based on formulas not greatly different from those found in other texts. Many of the entries on the forms are the same for all arches and can be printed on them; and the authors have presented the various steps in filling out the forms in such a way that the work is largely mechanical and the chances of error greatly reduced.

A copy may be secured by addressing the United States Department of Agriculture, Office of Information, Washington, D. C.

REGIONAL HIGHWAY PLANNING SURVEY FOR CLEVELAND

Field work has been under way since September 3 upon the Cleveland regional highway planning survey, embracing a territory within a radius of approximately 30 miles of Cleveland, Ohio. The survey is being carried on by the United States Bureau of Public Roads and Cuyahoga County as the principal cooperators. Information and assistance is also being rendered by the several administrative organizations responsible for highway development in the Cleveland region.

The preliminary work included a comprehensive study of traffic density—its distribution, origin, and destination—on the various routes in the area. This is being followed by a study of the traffic capacity of the various county highways and the principal entrances into the city of Cleveland and an analysis of the present highway system. Recommendations as to the location of new highways or relocation of present routes will involve consideration of the influence of such factors as topography, waterways, railroad terminals and yards, large industrial plants, suburban developments, and special use areas. With this information there is to be developed a plan of highway improvement adequate for anticipated traffic and designed especially to eliminate highway congestion. An improvement budget for a period sufficient to carry the complete plan into effect will also be prepared.

At the present time collection of field data is practically completed and a detailed analysis of this material is in progress. Traffic records were taken at 263 points in the area and show the daily and hourly volume of passenger cars, motor trucks, and motor busses on all important highways. Information was also taken as to weights of motor trucks. Records as to the origin and destination were taken for approximately 100,000 vehicles.

The "roughometer" described in the issue of Public Roads for September, 1926, was used in making a condition survey of the improved roads in the area. This instrument is attached to a passenger car and gives an accumulated record of the roughness of the surfaces over which the vehicle is driven.

Another new instrument, used for the first time in this survey, gives a record of the speed at which traffic moves at all points along a highway. This instrument is being used in studying traffic congestion and traffic capacity of various widths of highway.

GASOLINE TAXES FOR FIRST SIX MONTHS OF 1927

State	Gross tax assessed prior to deduction of refunds	Exemption refunds (deducted from gross tax)	Total tax earnings on fuel for motor vehicles [2]	Disposition of total gasoline tax earnings [1]: Collection costs (half year)	Disposition: Construction and maintenance of rural roads: State highways	Disposition: Construction and maintenance of rural roads: Local roads	Disposition: State and county road-bond payments	Disposition: Miscellaneous	Tax rates, first six months of 1927: Cents per gallon: Jan. 1	Tax rates: Cents per gallon: June 30	Tax rates: Date of rate change	Net gallons of gasoline taxed and used by motor vehicles	Estimated additional gallons (not taxed) used by motor vehicles
Alabama	$2, 653, 637		$2, 653, 637	$10, 302	$1, 300, 778	$1, 342, 557			2	4	Jan. 25	68, 096, 599	
Arizona	662, 729	$144, 130	518, 599		259, 300	259, 299			3	3		17, 286, 641	
Arkansas	1, 741, 086	180, 527	1, 560, 559	46, 817	358, 929	171, 661	[3] $983, 152		4	5	June 9	39, 013, 981	
California	9, 677, 342	641, 408	9, 035, 934	19, 918	4, 508, 008	4, 508, 008			2	2	([4])	451, 796, 681	
Colorado	1, 237, 359	43, 282	1, 194, 077	([5])	730, 359	463, 718			2	3	May 1	57, 701, 371	
Connecticut	1, 307, 024		1, 307, 024		1, 307, 024				2	2		65, 351, 209	
Delaware	273, 203	6, 112	267, 091		267, 091				2	3	Mar. 24	10, 329, 754	
Florida	5, 355, 219		5, 355, 217	2, 100	4, 014, 838	1, 338, 279			4	4	([6])	133, 880, 422	
Georgia	3, 071, 528		3, 071, 528	2, 100	2, 192, 448	876, 980			3½	3½		87, 757, 935	
Idaho	637, 373	30, 679	606, 694	5, 203	601, 491				3	4	Feb. 28	15, 750, 489	
Illinois									0	[7] 0	No. tax.		286, 900, 000
Indiana	4, 697, 106	132, 395	4, 564, 711	7, 398	3, 038, 209	1, 519, 104			3	3		152, 157, 038	
Iowa	2, 865, 439	88, 256	2, 777, 183	4, 956	924, 076	1, 848, 151			2	2	([8])	138, 859, 170	
Kansas	2, 217, 334	326, 089	1, 891, 245	([9])	1, 640, 500	250, 745			2	2		94, 562, 249	
Kentucky	2, 472, 015		2, 472, 015		2, 472, 015				5	5		49, 348, 018	
Louisiana	1, 411, 554		1, 411, 554	([10])	1, 411, 554				2	2		70, 577, 705	
Maine	761, 073	18, 148	742, 925	5, 341	368, 792	368, 792			3	3		24, 461, 721	
Maryland	1, 831, 699	57, 257	1, 774, 442	1, 250	[11] 1, 418, 554			[12] $354, 638	2	4	Apr. 1	57, 069, 042	
Massachusetts									0	0	No tax.		148, 200, 000
Michigan	5, 414, 065	380, 267	5, 033, 798	14, 718	2, 994, 725	1, 024, 355	[13] 1,000,000		2	2	([14])	251, 689, 874	
Minnesota	2, 367, 545	93, 218	2, 274, 327	([15])	2, 274, 327				2	2		115, 891, 613	
Mississippi	2, 136, 296		2, 136, 296	1, 800	1, 003, 006	1, 068, 244		[16] 63, 246	4	4		51, 826, 257	
Missouri	2, 968, 788	47, 723	2, 921, 065	24, 017	2, 897, 048				2	2		146, 053 264	
Montana	443, 439	15, 076	428, 363	3, 150	425, 213				3	3	Jan. 1	14, 278, 756	
Nebraska	1, 477, 472	7, 408	1, 470, 064	3, 639	1, 466, 425				2	2		73. 503, 208	
Nevada	217, 604	18, 107	199, 497		99, 749	99, 748			4	4		4, 987, 419	
New Hampshire	421, 366	7, 765	413, 581		413, 581				2	3	May 1	18, 310, 415	
New Jersey									0	[17] 0	No tax.		137, 500, 000
New Mexico	[18] 614, 200		[18] 614, 200	11, 590	602, 610				3	5	Mar. 7	14, 081, 758	
New York									0	0	No tax.		375, 100, 000
North Carolina	4, 108, 931	176, 387	3, 932, 544	8, 218	1, 705, 745		[19] 2,218,581		4	4		98, 313, 590	
North Dakota	467, 210	71, 277	395, 933		395, 933				2	2		19, 796, 669	
Ohio	7, 722, 220	182, 394	7, 539, 826		4, 739, 600	1, 272, 830		[20] 1, 527, 396	2	3	May 25	336, 902, 146	
Oklahoma	3, 208, 634	12, 258	3, 196, 376		2, 130, 919	1, 065, 457			3	3		110, 262, 328	
Oregon	1, 690, 893	77, 684	1, 613, 209	4. 149	1, 609, 060				3	3		54, 084, 297	
Pennsylvania	6, 101, 696		6, 101, 696	([21])	4, 067, 797	2, 033, 899			2	2	([22])	305, 084, 825	
Rhode Island	326, 848	25, 877	300, 971	([21])	253, 953		47, 018		1	2	June 1	25, 395, 311	
South Carolina	2, 214, 215	3, 579	2, 210, 636	([21])	1, 360, 794	849, 842			5	5		44, 212, 717	
South Dakota	1, 095, 630	135, 000	960, 630	2, 783	957, 847				3	3	([25])	32, 616, 933	
Tennessee	1, 983, 139		1, 983, 139	19, 831	1, 963, 308				3	3		66, 104, 639	
Texas	5, 975, 553		5, 975, 553		4, 481, 665			[26] 1,493,888	1	3	Mar. 16	271, 417, 466	
Utah	567, 794		567, 794	5, 375	[27] 212, 419		[28] 350, 000		3½	3½		16, 222, 709	
Vermont	-275, 536		275, 536		275, 536				2	3	June 1	12, 130, 292	
Virginia	3, 298, 685	176, 167	3, 122, 518	([29])	2, 081, 679	1, 040, 839			4½	4½		69, 259, 098	
Washington	1, 734, 604	103, 378	1, 631, 226		1, 631, 226				2	2		81, 561, 285	
West Virginia	1, 458, 314	42, 257	1, 416, 057	([30])	1, 416, 057		([30])		3½	3½	([31])	40, 458, 768	
Wisconsin	2, 618, 397	92, 339	2, 526, 058	([32])	1, 085, 000	1, 441, 058			2	2		126, 302, 901	
Wyoming	257, 275	367	256, 908	[33] 8	256, 900				2½	3	Mar. 1	9, 244, 481	
District of Columbia	551, 405	2, 800	548, 605					[34] 548, 605	2	2		27, 430, 267	
Total			101, 250, 841	204, 663	69, 616, 088	22, 843, 566	4, 598, 751	3, 987, 773	Aver. 2.55 cents			3, 971, 423, 311	947, 700, 000

[1] Disposition data is estimated in some cases, and approximately allocated according to motor fuel laws.
[2] Actual amount available for disposal excluding refunds.
[3] On State highway bonds, $78,028; remainder on District road bonds.
[4] New 3-cent tax effective July 29, 1927.
[5] Paid from oil-inspection fund.
[6] New 5-cent tax effective July 1, 1927.
[7] New 2-cent tax effective Aug. 1, 1927.
[8] New 3-cent tax effective July 4, 1927.
[9] Paid from State general fund, $4,500.
[10] Collection cost of $3,750 from Legislative appropriation.
[11] Includes $125,742 for elimination of grade crossings.
[12] Assigned to Baltimore City, includes $31,435 for elimination of grade crossings.
[13] State highway bond retirements.
[14] New 3-cent tax effective Sept. 4, 1927.
[15] Collection costs, $2,300 from inspection oil fund.
[16] For sea wall to protect highway; collected by an extra tax of 2 cents in Harrison County and 1 cent in Hancock County.
[17] New 2-cent tax effective July 1, 1927.
[18] Includes $4,402 for license fees for gasoline distributing stations.
[19] Approximated by prorating motor vehicle fees and gasoline taxes for interest on road bonds.
[20] For maintenance of streets in municipalities.
[21] Paid from general fund; approximately $40,000.
[22] New 3-cent tax effective July 1, 1927.
[23] Legislative approxion $5,000 for the year.
[24] State appropriation of $5,000 for the year.
[25] New 4-cent tax effective July 1, 1927.
[26] For free-school fund.
[27] Not available for road use until 1928.
[28] On State road bonds.
[29] Costs of $3,228 paid from appropriation from State revenues.
[30] Collection costs and interest of State road bonds chargeable to this fund but amounts not reported.
[1] New 4-cent tax effective July 1, 1927.
[32] Appropriation by State of $5,000 for half year.
[33] Excludes $600 costs not charged to tax.
[34] Assigned by law for use on Washington streets.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

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

ANNUAL REPORTS

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

DEPARTMENT BULLETINS

No. 105D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1913.
*136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
*463D. Earth, sand-clay and gravel. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*537D. The Results of Physical Tests of Road-Building Rock in 1916, Including all Compression Tests. 5c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917. 5c.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
*1077D. Portland Cement Concrete Roads. 15c.
*1132D. The Results of Physical Tests of Road-Building Rock from 1916 to 1921, Inclusive. 10c.

DEPARTMENT BULLETINS—Continued

No. 1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures, 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

No. 94C. T. N. T. as a Blasting Explosive.
331C. Standard Specifications for Corrugated Metal Pipe Culverts.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal Aid Highway Projects.
93M. Direct Production Costs of Broken Stone.
105M. Federal Legislation Providing for Federal Aid in Highway Construction and the Construction of National Forest Roads and Trails.

FARMERS' BULLETINS

No. *338F. Macadam Roads. 5c.
*505F. Benefits of Improved Roads. 5c.

SEPARATE REPRINTS FROM THE YEARBOOK

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*849Y. Roads. 5c.
914Y. Highways and Highway Transportation.

REPRINTS FROM THE JOURNAL OF AGRICULTURAL RESEARCH

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

* Department supply exhausted.

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

STATUS OF FEDERAL AID HIGHWAY CONSTRUCTION

AS OF

OCTOBER 31, 1927

GOVERNMENT PRINTING OFFICE

STATES	FISCAL YEARS 1917-1927			FISCAL YEAR 1928									BALANCE OF FEDERAL AID FUND AVAILABLE FOR NEW PROJECTS	STATES
	PROJECTS COMPLETED PRIOR TO JULY 1, 1927			PROJECTS COMPLETED SINCE JUNE 30, 1927			*PROJECTS UNDER CONSTRUCTION			PROJECTS APPROVED FOR CONSTRUCTION				
	TOTAL COST	FEDERAL AID	MILES	TOTAL COST	FEDERAL AID	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES	ESTIMATED COST	FEDERAL AID ALLOTTED	MILES		
Alabama	$ 20,061,371.68	$ 9,615,099.94	1,400.2	$ 84,878.41	$ 40,723.98	0.2	$ 8,346,382.61	$ 4,016,659.69	459.4	$	$		$ 2,224,191.39	Alabama
Arizona	11,809,950.70	6,447,169.27	800.8	267,759.35	192,918.61	14.1	1,448,605.72	1,088,686.44	67.7	34,528.88	17,264.44	0.3	2,928,204.24	Arizona
Arkansas	22,337,014.63	9,525,192.75	1,560.6	52,245.29	26,122.64	0.1	3,613,444.42	1,880,893.63	223.9	717,686.26	158,899.73	7.3	1,292,591.25	Arkansas
California	35,128,269.04	16,967,026.82	1,306.3	1,663,742.65	810,515.86	49.3	7,427,892.89	3,390,057.86	148.6	29,144.22	17,486.53	0.1	3,371,164.93	California
Colorado	15,497,121.91	7,934,298.91	829.0	91,935.74	48,486.64	0.9	6,620,930.26	3,245,327.97	284.8	60,171.65	24,498.87	3.2	2,449,719.61	Colorado
Connecticut	6,397,392.29	2,444,000.54	137.3	1,324,934.52	355,348.84	17.7	5,143,625.87	1,460,489.75	61.9	596,818.25	150,731.24	7.8	395,795.63	Connecticut
Delaware	6,237,026.55	2,345,572.42	159.5	263,662.17	120,820.22	14.6	998,398.73	365,371.18	31.1				7,919.18	Delaware
Florida	7,476,856.31	3,627,912.60	245.1	1,517,818.43	734,206.79	32.7	8,325,791.94	3,561,785.95	176.3	777,845.42	269,730.00	18.0	790,769.66	Florida
Georgia	31,951,436.50	15,101,232.40	2,173.6	3,882,173.22	1,834,341.18	163.9	6,487,697.09	3,215,959.71	223.9	60,305.70	30,152.85	0.1	229,475.86	Georgia
Idaho	13,225,515.45	7,075,527.16	835.5	519,938.13	365,549.79	57.4	2,447,435.27	1,465,082.31	154.8	969,517.91	562,232.94	66.9	26,427.80	Idaho
Illinois	48,538,982.16	22,781,516.60	1,530.8				14,706,605.85	7,067,757.86	507.3	3,060,176.60	1,462,638.15	102.4	1,674,714.39	Illinois
Indiana	23,372,717.74	11,238,568.20	732.5	449,555.13	211,986.95	13.3	17,088,350.28	8,184,818.49	518.8	872,490.11	241,195.05	32.2	254,558.31	Indiana
Iowa	34,306,138.86	14,395,603.75	2,484.4	1,014,168.01	496,539.00	114.3	14,947,503.76	6,475,755.95	501.4	235,060.23	91,398.66	5.6	71,264.64	Iowa
Kansas	37,442,061.61	14,730,829.48	1,495.2	686,362.16	306,659.34	36.9	15,242,211.85	6,022,427.83	807.8	534,755.84	190,280.53	47.8	282,745.82	Kansas
Kentucky	23,216,600.53	9,510,694.75	874.9	552,359.25	262,003.09	27.5	10,075,828.40	4,758,672.09	434.7	169,222.22	84,611.10	9.2	14,774.97	Kentucky
Louisiana	15,877,552.20	7,093,892.21	1,178.7	931,554.63	442,316.21	37.9	3,434,613.07	1,530,286.40	95.6	1,922,511.62	961,255.78	78.4	257,965.40	Louisiana
Maine	10,564,800.06	4,858,452.67	357.6	831,523.59	346,621.88	33.2	2,158,416.63	689,118.44	48.0	391,447.59	195,499.27	19.9	1,055,929.74	Maine
Maryland	11,790,203.93	5,524,938.27	477.8				2,265,620.89	1,026,885.64	104.6				8,352.09	Maryland
Massachusetts	20,670,246.02	7,425,928.15	410.4	773,728.83	158,264.74	9.5	6,402,482.70	1,749,024.45	107.7	175,422.28	70,800.00	4.7	1,793,808.66	Massachusetts
Michigan	31,977,248.37	14,328,484.99	1,084.2	380,950.52	181,630.83	31.6	15,102,668.03	6,794,274.75	412.4	1,789,779.10	700,394.50	33.7	552,270.93	Michigan
Minnesota	45,099,648.47	19,046,145.67	3,643.5	560,946.48	193,200.00	25.5	7,662,298.62	2,339,298.90	390.4	981,273.24	21,000.00	46.3	112,876.43	Minnesota
Mississippi	18,331,230.75	9,004,294.62	1,314.1	993,468.54	492,884.75	63.6	6,484,928.72	3,138,235.78	340.2	275,095.87	137,547.93	23.4	662,933.92	Mississippi
Missouri	42,389,290.41	19,681,026.48	1,944.8	2,160,732.60	899,862.79	76.3	8,986,902.95	3,912,657.34	286.4				698,064.39	Missouri
Montana	12,854,995.72	7,287,288.69	1,151.6	206,458.10	152,882.59	25.3	3,439,091.18	2,425,302.78	264.6	1,821,690.41	1,047,180.66	195.4	4,063,729.28	Montana
Nebraska	16,157,040.25	7,739,386.39	2,246.6	2,131,360.33	1,022,276.51	209.1	13,491,924.63	6,645,818.21	1,334.9	793,561.66	396,795.25	73.8	416,096.64	Nebraska
Nevada	10,421,349.31	7,589,168.68	853.6	217,464.75	188,218.20	49.5	1,691,900.15	1,468,560.05	171.6	318,330.87	279,239.82	17.8	218,538.25	Nevada
New Hampshire	5,868,897.76	2,778,928.05	264.8	127,942.33	62,814.27	4.4	1,516,472.17	662,133.15	45.0	70,803.54	28,110.00	1.9	3,131.53	New Hampshire
New Jersey	22,228,240.08	7,495,364.48	316.3	1,584,371.23	362,265.00	24.2	6,812,108.77	1,544,398.56	100.8				2.96	New Jersey
New Mexico	13,336,250.94	7,937,598.06	1,505.2	192,486.89	116,166.12	19.1	3,185,543.90	2,486,129.33	233.7				1,619,255.49	New Mexico
New York	54,183,085.44	21,693,955.65	1,439.3	2,628,439.43	825,701.34	56.2	42,556,336.00	10,452,378.95	646.1	6,878,300.00	1,395,347.50	89.2	3,313,028.56	New York
North Carolina	35,295,849.21	14,518,903.16	1,460.1	972,233.03	454,898.15	38.2	3,658,648.76	1,740,015.52	97.1	248,220.85	121,500.00	21.0	595,245.17	North Carolina
North Dakota	15,881,558.55	7,746,293.68	2,715.6	1,791,457.48	1,090,133.96	166.2	5,516,107.45	2,733,483.61	869.4	452,454.23	215,663.74	67.1	158,035.01	North Dakota
Ohio	52,621,391.49	19,331,376.76	1,515.0	1,259,580.76	542,989.32	41.3	12,520,057.18	4,844,337.74	335.4	3,765,702.00	1,442,245.00	79.2	2,333,076.18	Ohio
Oklahoma	30,381,957.08	14,117,589.21	1,268.1	789,742.25	379,754.99	9.6	4,389,116.17	1,853,189.24	308.4	2,600,590.55	1,308,471.72	131.1	152,672.84	Oklahoma
Oregon	19,583,584.76	10,041,452.94	1,055.0	161,863.43	92,383.50	0.2	2,468,818.01	1,292,493.27	74.1	209,901.12	111,744.98	4.8	523,474.31	Oregon
Pennsylvania	77,726,174.22	26,317,620.32	1,534.3	1,857,836.31	577,970.03	45.1	19,420,748.76	5,927,068.82	372.2	2,406,709.02	765,457.49	39.8	1,086,399.34	Pennsylvania
Rhode Island	5,233,413.38	1,998,479.06	116.0	433,553.96	148,020.00	9.9	1,299,827.33	332,348.74	21.2	427,199.34	128,638.67	7.6	425,707.53	Rhode Island
South Carolina	17,002,039.93	7,526,989.80	1,568.4	1,599,570.97	761,794.70	39.3	8,073,707.02	2,387,480.76	251.2	735,980.03	65,999.94	5.2	114,247.80	South Carolina
South Dakota	19,262,063.24	9,507,525.54	2,502.9	153,619.70	81,737.63	42.1	4,642,060.49	2,448,199.10	734.5	568,355.04	250,058.06	99.2	99,333.67	South Dakota
Tennessee	24,283,035.03	11,551,457.55	868.7	1,449,112.56	632,743.67	24.6	9,484,414.10	3,955,685.21	243.8	554,634.68	276,334.83	25.7	479,135.74	Tennessee
Texas	78,190,246.37	31,566,960.45	5,466.4	5,490,529.30	2,453,957.84	187.6	13,001,376.83	5,868,382.98	433.8	4,508,062.40	1,873,874.85	137.7	3,340,526.88	Texas
Utah	9,154,377.33	5,767,079.95	628.9	393,000.76	298,136.85	35.9	2,692,198.63	2,005,007.34	130.5	727,135.19	397,593.56	37.9	197,867.30	Utah
Vermont	5,037,118.23	2,348,856.01	152.7	702,679.70	268,993.49	11.9	2,736,034.21	1,003,794.57	59.7				12,487.93	Vermont
Virginia	26,844,025.24	12,537,143.25	1,138.9	275,796.37	117,551.38	8.2	5,406,638.94	2,193,151.16	117.3	190,902.52	79,535.23	5.0	16,846.98	Virginia
Washington	18,184,505.97	8,246,551.95	711.1	847,151.85	415,736.32	5.3	2,913,690.33	1,330,600.00	66.5	1,370,649.79	489,000.00	58.6	795,419.73	Washington
West Virginia	10,424,847.32	4,573,748.01	419.4				7,123,946.40	2,929,734.05	238.2	1,500,484.17	617,475.22	48.7	25,189.72	West Virginia
Wisconsin	27,891,502.16	11,847,858.90	1,729.5	2,114,097.29	1,063,613.32	111.7	9,531,954.00	4,279,049.97	331.9	470,000.00	140,000.00	11.5	1,978,747.81	Wisconsin
Wyoming	12,650,712.15	7,139,267.05	1,315.9	213,889.07	143,801.81	24.3	2,910,025.46	1,862,296.04	224.1	203,250.00	127,618.10	35.1	227,660.00	Wyoming
Hawaii	343,664.15	97,440.00	6.5	160,636.91	70,440.00	4.7	1,624,080.08	491,922.64	25.0				805,975.36	Hawaii
TOTALS	1,154,740,601.48	510,007,691.24	60,957.6	46,764,312.91	20,845,965.12	2,014.4	367,531,453.50	152,542,490.20	14,168.7	44,476,180.40	16,945,502.19	1,700.6	44,158,351.25	TOTALS

* Includes projects reported completed (final vouchers not yet paid) totaling: Estimated cost $ 117,679,214.31 Federal aid $ 50,334,503.28 Miles 4,703.1