PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

VOL. 11, NO. 11 ▽ JANUARY, 1931

TEST SECTION ON TENNESSEE CONCRETE-CURING PROJECT

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

PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

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

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

VOL. 11, NO. 11 JANUARY, 1931 G. P. St. CLAIR, Editor

TABLE OF CONTENTS

THE BUREAU OF PUBLIC ROADS

Willard Building, Washington, D. C.

REGIONAL HEADQUARTERS

Mark Sheldon Building, San Francisco, Calif.

DISTRICT OFFICES

DISTRICT No. 1. Oregon, Washington, and Montana.
Box 3900, Portland, Oreg.

DISTRICT No. 2. California, Arizona, and Nevada.
Mark Sheldon Building, San Francisco, Calif.

DISTRICT No. 3. Colorado, New Mexico, and Wyoming.
301 Customhouse Building, Denver, Colo.

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

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

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

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

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

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

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

DISTRICT No. 11. Alaska.
Goldstein Building, Juneau, Alaska.

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

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

A STUDY OF METHODS OF CURING CONCRETE PAVEMENTS

REPORT OF A FIELD INVESTIGATION IN TENNESSEE CONDUCTED JOINTLY BY THE TENNESSEE DEPARTMENT OF HIGHWAYS AND THE U. S. BUREAU OF PUBLIC ROADS

By F. H. Jackson Senior Engineer of Tests, United States Bureau of Public Roads, and E. W. Bauman, Engineer of Materials, Tennessee Department of Highways

THE field study of methods of curing concrete pavements reported herein was initiated by the Tennessee Department of Highways and Public Works for the purpose of determining the relative efficiency under service conditions of the various special curing methods which have been proposed from time to time as substitutes for the standard earth and water method. The department recognized the possibility of merit in these special methods, from the standpoint of effectiveness as well as that of cost. It possessed, however, no data as to the efficiency of any of them under Tennessee climatic conditions. A field investigation was therefore proposed to include all of the methods of cure to which the attention of the department had been called prior to July 1, 1928, as well as certain additional methods involving the application of burlap kept saturated for various periods up to 96 hour with no other curing.

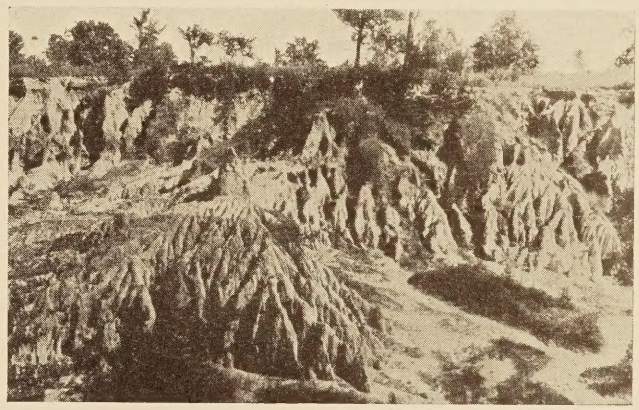
The United States Bureau of Public Roads also being interested in the development of additional information relative to the various methods of curing concrete pavements, an agreement was entered into by the Tennessee department and the bureau for the cooperative conduct of the investigation reported herein.

It was decided to conduct the experiment on a concrete pavement approximately 15 miles in length, to be constructed on State Route No. 15, in Fayette County, Tenn., 20 miles east of Memphis. The location chosen seemed desirable because of the very uniform subgrade condition (a fine silty loam) along the entire length of the highway. Weather Bureau records likewise indicated the probability of hot, dry weather during most of the construction season. An announcement of the cooperative project, including a description of the plans for conducting it, was carried in the November, 1928, issue of Public Roads.

A supplemental agreement was entered into between the State of Tennessee and the contractor, the J. B. McCrary Engineering Corporation, of Atlanta, Ga., providing for a change in the cross-section of the slab from the standard 8–6–8 double parabolic section to an 8–7–8 section with the dowel bars across the center joint eliminated. Expansion joint spacing was increased from 50 to 200 feet and the joint width increased from ¾ to 1½ inches. It was further specified that the center strip stakes should be pulled after finishing operations so that each half of the pavement might be free to move without hindrance from the adjacent section. The contractor was relieved of the duty of curing that portion of the pavement on the south side of the longitudinal joint but was required to cure the other side (the north side) in accordance with the standard specifications which were in force at that time and which provided for the application of burlap kept wet for 24 hours followed by a 2-inch layer of earth kept wet for 10 days. The burlap was dry at the time it was applied to the pavement and was made wet by subsequent sprinkling. The specifications further provided that the earth cover remain in place for at least 18 days.

CURING METHODS LISTED

The south side of the pavement was cured by the various special methods listed in Table 1. These were applied successively to sections approximately 1,000 feet in length, usually one day's run. This procedure permitted the repetition of most of the curing methods a number of times and therefore made it possible to observe their behavoir at various seasons of the year from July to December.



Soil Conditions Encountered on this Project. Note Erosion Characteristics

Table 1.—*List of curing methods employed*

Method of curing	Number of cycles [1]	Total length, feet
Wet burlap applied for 12 hours	2	2, 053
Wet burlap applied for 24 hours	6	5, 007
Wet burlap applied for 48 hours	5	4, 359
Wet burlap applied for 72 hours	4	4, 139
Wet burlap applied for 96 hours	4	3, 252
No cure	9	7, 524
Sisalkraft paper applied for 24 hours [2]	3	2, 963
Sodium silicate:		
Earth subgrade	3	2, 215
Tar paper on subgrade	2	1, 897
Calcium chloride, surface application:		
Earth subgrade	8	5, 265
Tar paper on subgrade	5	4, 481
Hunt Process:		
Earth subgrade	4	3, 668
Tar paper on subgrade	3	2, 824
Barber asphalt emulsion (Curcrete):		
Earth subgrade	4	4, 137
Tar paper on subgrade	3	2, 760
Headley asphalt emulsion:		
Earth subgrade	4	3, 483
Tar paper on subgrade	3	2, 354
Tarvia K. P.:		
Earth subgrade	2	1, 810
Tar paper on subgrade	1	816
Tarvia B:		
Earth subgrade	3	1, 081
Tar paper on subgrade	1	719
Poor earth cure	4	3, 318
Ponding	3	2, 205
Calcium chloride admixture:		
Earth subgrade	3	1, 053
Tar paper on subgrade	3	765
Total		74, 148

[1] In this column is given the number of test sections to which each type of curing was applied.
[2] On one section (cycle No. 2) the Sisalcraft paper was applied for 48 hours.

This program, it will be noted, provided a series of experimental sections on which it was possible to compare the concrete cured by the experimental method with a section across the longitudinal joint similar to it in every respect except that it was cured by the standard method.

Each special curing treatment was applied strictly in accordance with specifications recommended by the manufacturers or sponsors of the materials employed. In practically all cases representatives of the several companies interested were present at least once during the application of their particular material.

QUALITY OF CONCRETE CAREFULLY CONTROLLED

All materials used in the concrete pavement met the requirements of the State specifications. One brand of Portland cement was used throughout the job. Fine and coarse aggregates were obtained from a single source. The results of typical tests of cement, fine aggregates and coarse aggregates are given in Table 2.

TABLE 2.—*Tests of materials*

1. Portland cement:	
Fineness, per cent retained on No. 200 sieve	14. 0
Time of set—	
Initial	5 hours, 15 minutes.
Final	7 hours, 25 minutes.
Soundness	Satisfactory.
Tensile strength, pounds per square inch—	
At 7 days	305
At 28 days	400
Chemical analysis—	
Loss on ignition, per cent	0. 80
Insoluble residue, per cent	0. 53
Sulphuric anhydride, per cent	1. 45
Magnesia, per cent	3. 10
2. Fine aggregate:	
Specific gravity	2. 62
Color plate	Lignite.
Loss by washing, per cent	0. 1
Strength ratio, per cent—	
At 7 days	110
At 28 days	125
Sieve analysis—	

Sieve No.—	Per cent retained
4	2. 4
8	9. 6
14	27. 4
28	66. 1
48	96. 9
100	99. 6

Fineness modulus	3. 020
3. Coarse aggregate:	
Specific gravity	2. 58
Per cent of wear	8. 0
Soundness	Satisfactory.
Absorption, per cent	1. 5
Sieve analysis—	

Sieve	Per cent retained
1½-inch	6
1-inch	42
¾-inch	60
⅜-inch	91
No. 4	99

Fineness modulus	7. 56

The concrete was proportioned so as to give an expected average crushing strength of 3,500 pounds per square inch at 28 days and, as the result of tests, a water-cement ratio of 0.75 was established as the correct value for this particular combination of materials. Table 3 gives the results of 28-day tests on field cylinders cast in connection with the routine control of the job with no reference to the special curing methods studied. Each value reported in this table represents the average of tests on three cylinders

TABLE 3.—*Crushing strength of concrete. Routine control tests on 6 by 12 inch cylinders*

Date laid	Crushing strength	Date laid	Crushing strength	Date laid	Crushing strength
	Pounds per square inch		*Pounds per square inch*		*Pounds per square inch*
July 6	3, 310	Aug. 22	4, 053	Oct. 13	3, 190
July 7	3, 104	Aug. 23	4, 371	Oct. 15	3, 685
July 9	3, 417	Aug. 24	4, 648	Oct. 16	2, 826
July 10	3, 886	Aug. 25	3, 997	Oct. 18	2, 575
July 11	3, 783	Aug. 27	3, 634	Oct. 19	4, 491
July 12	3, 879	Aug. 28	2, 969	Oct. 20	3, 514
July 13	3, 909	Aug. 29	3, 762	Oct. 22	3, 602
July 14	3, 867	Aug. 30	3, 971	Oct. 24	3, 256
July 16	4, 152	Sept. 4	3, 946	Oct. 25	4, 698
July 18	3, 005	Sept. 5	4, 598	Oct. 26	3, 816
July 19	3, 667	Sept. 6	3, 985	Oct. 29	3, 998
July 20	4, 151	Sept. 7	4, 022	Oct. 30	2, 841
July 23	3, 827	Sept. 10	3, 714	Oct. 31	2, 854
July 24	3, 675	Sept. 11	3, 714	Nov. 1	3, 023
July 25	3, 504	Sept. 12	3, 457	Nov. 3	3, 301
July 26	3, 271	Sept. 13	3, 298	Nov. 5	3, 609
July 27	3, 805	Sept. 14	4, 023	Nov. 6	2, 162
July 30	3, 815	Sept. 17	3, 705	Nov. 7	4, 153
July 31	4, 119	Sept. 18	3, 905	Nov. 9	4, 311
Aug. 1	3, 218	Sept. 19	4, 426	Nov. 10	3, 696
Aug. 2	3, 799	Sept. 21	4, 000	Nov. 12	3, 311
Aug. 3	3, 260	Sept. 22	4, 409	Nov. 13	3, 978
Aug. 4	3, 419	Sept. 24	4, 057	Nov. 14	3, 317
Aug. 6	3, 840	Sept. 25	4, 865	Nov. 15	2, 827
Aug. 7	3, 564	Sept. 26	4, 202	Nov. 16	3, 545
Aug. 8	3, 501	Sept. 27	4, 215	Nov. 17	2, 575
Aug. 10	3, 871	Sept. 28	4, 263	Nov. 20	2, 772
Aug. 11	3, 180	Sept. 29	4, 073	Nov. 21	3, 217
Aug. 13	3, 551	Oct. 1	3, 752	Nov. 22	2, 960
Aug. 14	3, 693	Oct. 3	4, 005	Nov. 23	3, 358
Aug. 15	4, 049	Oct. 5	3, 426	Nov. 24	3, 367
Aug. 16	3, 700	Oct. 6	3, 467	Nov. 27	3, 539
Aug. 17	3, 496	Oct. 10	4, 011	Dec. 1	3, 613
Aug. 18	3, 690	Oct. 11	3, 638	Dec. 2	4, 077
Aug. 20	3, 892	Oct. 12	4, 094	Dec. 3	3, 449

It will be observed that, although the proportions, including water, were kept reasonably constant on this job, considerable variation in crushing strength resulted, probably because of variations in curing conditions to which the field specimens were subjected. These variable results emphasize the difficulty of attempting to control uniformity of strength by means of tests on specimens cured under job conditions.

CONTROL TESTS CONDUCTED THROUGHOUT

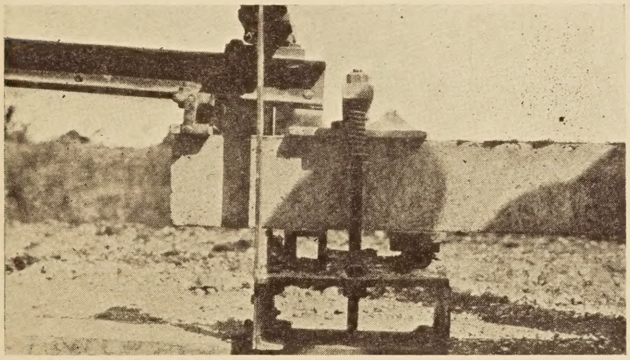
Control test specimens were constructed in the form of beams 6 by 6 by 42 inches in size, permitting four breaks with a cantilever-type transverse testing machine. Beams were cast in gangs of four, according to the procedure recommended in the report of Committee D–4, A. S. T. M., Proc. 1928, vol. 28, part 1, page 538. Twenty-eight beams were cast for each section, 12 cured as nearly as possible in the same manner as the standard earth and water cured section, 12 as nearly as possible in accordance with the special cure being used and 4 without any curing at all. The four so-called "no-cure" beams were tested in order to give some idea of the efficiency of both the standard earth and water cure and the special cures by comparison of cured specimens with specimens which had received no artificial curing at all. In all tests of beams the practice was followed of making one break from a given beam at each of four different ages; that is, 3, 7, 14, and 28 days. This practice provided an opportunity to study age-strength relations on individual specimens. The results of transverse tests of concrete, for each test condition and for a given age, represent, therefore, an average of one break from each of the 12 beams cast during that day's run.

The mass of transverse strength data resulting from these tests, some 10,000 individual beam breaks, was analyzed in the laboratory of the Tennessee Department of Highways by the method of least squares, and, as the result of this analysis, a value for modulus of rupture of concrete for each test condition was obtained which is designated the "most probable average" for the section. This appeared to be the most accurate method of eliminating wild or freak individual results.

When the curing method involved the spraying or painting of the material on the surface of the pavement, the method of curing the beams presented some difficulties. In this investigation it was the practice to spray or paint the surface of the beams in the specified manner. The forms were then stripped at the end of 24 hours, and the four beams constituting the set were placed on the subgrade with tar paper between the beams and earth banked around the outside edges. This method was criticised by certain of the manufacturers and as a result a special set of tests was run during the third cycle in which the sides of the beams were protected immediately after stripping the forms by means of an application of the curing material.

CONCRETE CORES FROM EACH SECTION TESTED

Four concrete cores were drilled from each test section throughout the project. Unusual difficulties encountered in drilling this concrete, due possibly to the presence of very hard flint in the coarse aggregate, prevented the testing of the cores at 90 days as originally contemplated. Cores were therefore drilled at various ages and shipped to the central laboratory at Nashville, where they were cured in moist air until the age of one year.



Beam in Testing Machine, Ready to be Broken

CRACK SURVEYS AND WEAR TESTS MADE

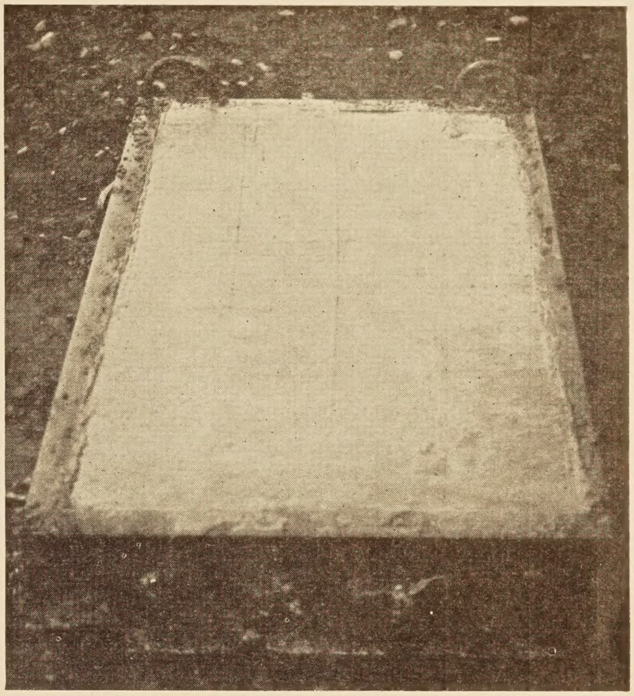
For the first two rounds of tests crack surveys were made on each section at frequent intervals during the first 60 days. In addition, two complete crack surveys were made at later periods, one on December 3, 1929, and one on May 26, 1930. These crack surveys show the average length of uncracked slab for each section for both the standard cure and the special cure.

A series of surface wear tests on selected sections was also conducted in an effort to determine how the curing method affected this characteristic of the concrete. These tests were made with apparatus developed by the Bureau of Public Roads and first described in Public Roads, July, 1929.

DATA PRESENTED IN BOTH TABULAR AND GRAPHIC FORMS

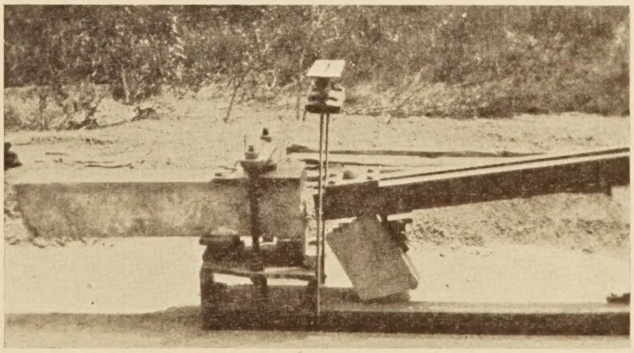
The data obtained from the various tests are presented in Tables 4, 5, and 6 and Figures 1 and 2. In Table 4 are given the results of the strength tests of beams and cores. In the case of the beam tests values of the "most probable average" modulus of rupture at each age of test (3, 7, 14, and 28 days) are tabulated under the heading "Beam strength," for the specimens cured by experimental methods and the corresponding standard-cure and no-cure specimens. These values are given for each test section or cycle included in the investigation. Similarly, in the case of the core tests, values of core strength at one year are tabulated for both research and standard cured specimens.

In this and in subsequent tables values of the so-called test ratings are tabulated for both beam and core data. The test rating is defined as the comparative value or rating of a test result (strength, average slab length, etc.), expressed as the percentage which



Moulded Beams, Ready for Application of Curing Material

the value reported for the experimental cure bears to the corresponding value for the standard cure. In Table 4 an analogous rating is also given for comparison of the experimental with the "no-cure" beams. For purposes of reference the date of laying each test cycle, the length of cycle, the total rainfall during the



First Break on Beam Specimen, Obtained 3 Days After Construction

10-day period following laying of the concrete, and the average daily temperature range during that period are also included in Table 4. The temperatures given cover the working day rather than the whole 24 hours.

TABLE 4.—*Results of strength tests on control test beams and on cores drilled from test sections*

Research cure	Cycle No.	Date laid	Location		Length of cycle	Precipitation during first 10 days after laying	Temperature first 10 days after laying		Beam strength in pounds per square inch (most probable average) [1]												Beam strength rating,[2] per cent								Core strength at one year		
									Research cure				Standard cure				No cure				Research cure to standard cure				Research cure to no cure						
			From station	To station			Average maximum	Average minimum	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	Average, research cure	Average, standard cure	Core strength rating [2]
					Feet	*Inches*	° *F.*	° *F.*																					*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per cent.*
Burlap, 12 hours	1	July 5, 6, 7	267+58	281+50	1,392	⅜	93	76	408	452	541	482	424	462	535	543					96	98	101	89					3,352	3,066	109
	2	Nov. 20	658+54	665+15	661	2½	55	35	178	398	545	628	213	505	620	599	201	373	549	613	84	79	88	105	89	107	99	102	2,970	3,551	84
Average									293	425	543	550	319	484	578	571	201	373	549	613	90	88	95	97	89	107	99	102	3,161	3,308	96
Burlap, 24 hours	1	Aug. 24	113+38	123+60	1,022	2½	85	78	432	529	505	508	517	561	655	576	322	408	420	366	84	94	77	88	134	130	120	139	3,838	3,746	102
	2	July 9, 10	254+24	267+58	1,334	1½	94	74	394	470	530	530	429	489	517	572	282	407	389	492	92	96	102	93	140	115	136	108	3,787	3,094	122
	3	Oct. 29	564+90	567+75	285	1⅞	60	44	186	397	508	652	161	367	518	647	145	423	450	459	115	108	98	101	128	94	113	142	3,767	4,409	85
	4	Sept. 24	298+32	305+03	671	1½	81	59	392	466	488	570	427	560	582	692	224	265	243		92	83	84	82	175	176	201		3,880	3,880	100
	5	Nov. 1, 3	584+70	592+48	778	¾	60	41	168	415	516	618	149	410	514	629					113	101	100	98					4,022	3,563	113
	6	Nov. 24	623+38	632+55	917	2½	53	36	87	391	506	675	82	385	529	679	93	437	559	581	106	102	96	100	94	89	91	116	4,361	3,805	115
Average									277	445	509	592	294	462	553	632	213	388	412	475	100	97	93	94	134	121	132	126	3,942	3,750	106
Burlap, 48 hours	1	Aug. 25	123+60	133+65	1,005	2½	83	79	528	534	515	487	492	616	634	662	396	472	440	343	107	87	81	74	133	113	117	142	3,063	3,246	94
	2	July 11, 12	246+20	254+24	804	2	94	73	432	502	558	468	441	523	551	524	334	377	447	434	98	96	101	89	129	133	125	108	3,228	3,160	102
	3	Sept. 25	305+03	315+11	1,008	2¼	82	61	355	520	517	555	340	574	562	672	264	341	446		104	91	92	83	134	152	116		3,640	3,863	94
	4	Nov. 5	592+48	600+72	824	¾	62	45	283	482	574	629	303	552	609	693	257	425	563	426	93	87	94	91	110	113	102	148	3,796	3,762	101
	5	Nov. 27	613+54	620+72	718	2	61	46																					4,252	3,863	110
Average									400	510	541	535	394	566	589	638	313	404	474	401	100	90	92	84	127	128	115	133	3,596	3,579	100
Burlap, 72 hours	1	Aug. 27	133+65	144+36	1,071	2½	81	70	506	539	468	458	495	540	522	600	476	487	393	410	102	100	90	76	106	111	119	112	3,630	3,662	99
	2	July 13	235+80	246+20	1,040	1⅞	93	73	504	489	574	521	431	441	531	501	423	425	528	465	117	111	108	104	119	115	109	112	3,799	3,796	100
	3	Sept. 26	315+11	323+78	867	2¼	82	63	391	508	495	634	357	506	530	601	416	508	481		110	100	93	105	94	100	103		3,953	4,120	96
	4	Nov. 6, 7, 8	728+87	740+42	1,161	1½	65	48	159	428	544	611	176	416	542	559	125	368	440	588	90	103	100	109	127	116	124	104	4,067	2,712	150
Average									390	491	520	556	365	476	531	565	360	447	461	488	105	104	98	98	112	110	114	110	3,862	3,573	111
Burlap, 96 hours	1	Aug. 30	165+84	174+51	867	2½	81	61	490	576	515	548	471	567	617	617	403	386	397		104	102	84	89	122	149	130		3,777	4,122	92
	2	July 14, 16	227+92	235+80	788	2	92	74	437	531	644	532	399	516	573	572	412	646	547	488	110	103	112	93	106	82	118	109	3,305	3,176	104
	3	Sept. 29	343+57	349+64	607	2¼	83	65	341	438	427	513	306	436	477	534					111	100	90	96					3,255	3,902	83
	4	Nov. 10	712+48	722+38	990	1½	64	48	190	425	569	699	207	487	603	708	179	310	380	538	92	87	94	99	106	137	150	130	3,184	3,763	85
Average									365	493	539	573	346	502	568	608	331	447	441	513.	104	98	95	94	111	123	133	120	3,380	3,741	91
No cure	1	Aug. 15	55+55	62+50	695	2⅞	90	75	559	569	530	580	561	623	618	673	436	533	387	579	100	91	86	86	128	107	137	100	3,420	4,392	78
	2	Aug. 28	144+36	155+53	1,117	2½	81	66	398	429	485	460	444	507	510	499	394	406	502	476	90	85	95	92	101	106	97	97	3,433	3,167	108
	3	July 17, 18, 19	217+05	227+92	1,087	⅞	90	75	447	524	525	507	507	582	634	550					88	90	83	92					2,975	3,359	89
	4	Sept. 27	323+78	334+33	1,055	2¼	82	64	332	462	470	544	343	421	465	570	356	492	524	482	97	110	101	95	93	94	90	113	4,113	3,441	120
	5	Oct. 5, 6	369+21	381+80	1,259	2	86	67	405	451	538	552	444	579	675	718	432	333	450	527	91	78	80	77	94	135	120	105	3,090	3,717	83
	6	Sept. 13	425+00	428+22	322	0	82	62	404	430	426	498	481	595	671	637	426	460	410	518	84	72	64	78	95	93	104	96			
	7	Oct. 24	543+15	549+13	598	2⅞	64	47	361	571	557	640	365	616	649	736	379		571	652	99	93	86	87	95		98	98	4,825	3,986	121
	8	Nov. 23	632+55	639+97	742	2½	55	38	330	387	572	642	162	430	618	684	342	387	529	594	204	90	93	94	96	100	108	108	4,130	3,451	120
	9	Nov. 9	722+38	728+87	649	1½	64	48	204	402	515	588	180	464	623	670	296	405	470	604	113	87	83	88	69	99	110	97	3,624	3,978	91
Average									382	469	513	557	387	535	607	637	383	431	480	554	107	88	86	88	96	105	108	102	3,701	3,686	101
Sisalkraft, 24 hours	1	Aug. 29	155+53	165+84	1,031	2½	80	61	491	482	510	503	522	573	591	574	549	595	527	391	94	84	86	88	89	81	97	129	3,573	4,073	88
Sisalkraft, 48 hours	2	July 24	190+86	200+94	1,008	½	89	76	454	522	420	598	464	563	580	604	426		366	409	98	93	72	99	107		115	146	3,271	3,368	97
Sisalkraft, 24 hours	3	Sept. 28	334+33	343+57	924	2¼	83	65	449	538	492	564	460	517	501	626	381	476	425	612	98	104	98	90	118	113	116	92	4,551	4,131	110
Average									465	514	474	555	482	551	557	601	452	536	439	471	97	94	85	92	105	97	109	122	3,798	3,857	98

Sodium silicate, earth subgrade.	1	July 20	208+82	217+05	823	⅞	88	76	566	598	564	560	560	621	662	629	506	525	452	542	101	96	85	89	112	114	125	103	3,352	3,243	103
	2	Sept. 6	470+16	481+03	1,087	0	89	68	475	448	501	655	511	532	618	658	416	399	430	539	93	84	81	100	114	112	117	122	3,796	4,435	86
	3	Oct. 10	498+00	501+05	305	3½	80	62	408	521	550	553	400	493	581	583	470	488	604	493	102	106	95	95	87	107	91	112	2,612	4,902	53
Average									483	522	538	589	490	549	620	623	464	471	495	525	99	95	87	95	104	111	111	112	3,253	4,193	81
Sodium silicate, tar paper on subgrade.	1	July 23	200+94	208+82	788	½	89	76	422	520	557	538	436	565	598	593	487	568	599	567	97	92	93	91	87	92	93	95	3,006	3,102	97
	2	Sept. 5	481+03	492+12	1,109	0	88	67	484	426	489	656	448	563	602	654	444	424	464	480	108	76	81	100	109	100	105	137	3,263	4,379	75
Average									453	473	523	597	442	564	600	624	466	496	532	424	103	84	87	96	98	96	99	116	3,135	3,741	86
Calcium chloride, surface application, earth subgrade.	1	Aug. 16	62+50	65+80	330	2⅞	90	75	464	457	372	346	599	616	643	707	529	512	500	493	77	74	58	49	88	89	74	70	3,609	3,386	107
	2	July 25, 26	174+51	190+86	1,635	⅜	90	76	490	531	509	588	487	531	548	613	485	387	486	548	101	100	93	96	101	137	105	107	3,618	2,845	127
	3	Oct. 1	349+64	357+43	779	2¼	84	68	442	466	551	657	443	529	568	672	436	482	502	626	100	88	97	98	101	97	110	105	3,708	3,163	117
	4	Sept. 4	492+12	498+00	588	0	87	66	442	438	488	577	483	590	560	596	405	339	423	462	92	74	87	97	109	129	115	125	4,109	4,263	96
	5	Oct. 31	572+82	574+80	198	1⅞	59	44	131	353	419	534	89	356	401	510	209	407	467		147	99	104	105	63	87	90		2,481	3,889	64
	6	Nov. 21	649+63	658+54	891	2½	54	36	260	458	551	635	227	484	581	638	210	366	547	628	114	95	95	100	124	125	101	101	3,235	3,148	103
	7	Nov. 14	680+21	682+40	219	1½	62	45																					2,599	3,250	80
	8	Nov. 13	695+50	701+75	625	1½	63	45	391	565	504	582	385	572	611	604	363	482	424	468	102	99	82	96	108	117	119	124	3,380	2,835	119
Average									374	467	485	560	388	525	559	620	377	425	478	538	105	90	88	92	99	112	102	105	3,342	3,347	102
Calcium chloride, surface application, tar paper on subgrade.	1	July 30, 31	563+98	575+37	1,139	¼	93	79	458	533	522	530	500	613	653	688	518	609	555	579	92	87	80	77	88	88	94	92	4,032	4,371	92
	2	Oct. 3, 4	357+43	369+21	1,178	¾	86	66	432	593	608	666	476	590	605	698	434	454	534	644	91	100	100	96	100	131	114	103	3,891	4,124	94
	3	Oct. 31	577+07	582+00	493	1⅞	59	44	214	478	560	608	150	414	509	609					143	115	110	100					3,030	3,797	80
	4	Nov. 22	639+97	649+63	966	2½	54	35	207	423	571	634	189	488	574	636	138	284	729	640	109	87	100	100	150	149	78	99	3,139	3,937	80
	5	Nov. 14	684+40	691+45	705	1½	62	45	298	480	535	549	289	525	621	481	362	542	438		103	91	86	114	82	89	122		3,225	3,018	107
Average									322	501	559	597	321	526	592	622	363	472	564	621	108	96	94	96	105	114	102	98	3,463	3,849	91
Hunt process, earth subgrade.	1	Aug. 1, 2	575+37	589+96	1,459	0	92	78	433	476	557	481	445	566	586	620	392	515	429	449	97	84	95	78	110	92	130	107	3,444	4,692	73
	2	Sept. 7	462+16	470+16	800	0	89	69	464	542	492	558	484	551	593	621	480	468	493	530	96	98	83	90	97	116	100	105	3,916	4,564	86
	3	Oct. 19	534+97	538+33	336	3¼	70	50	483	585	612	593	415	617	625	650	374	513	625	544	116	95	98	91	129	114	98	109	4,163	4,746	88
	4	Nov. 12	701+75	712+48	1,073	1½	63	46	380	547	633	646	323	565	699	717	205	347	410	505	118	97	91	90	185	158	154	128	3,377	3,602	94
Average									440	538	574	570	417	575	626	652	363	461	489	507	107	94	92	87	130	120	121	112	3,725	4,401	85
Hunt process, tar paper on subgrade.	1	Aug. 3, 4	589+96	9+05	1,367	0	92	77	418	516	517	490	487	553	582	371	439	439	441	419	86	93	89	132	95	118	117	117	3,504	4,093	86
	2	Sept. 10	452+41	462+16	975	0	86	65	493	498	500	501	468	553	605	504	410	425	378	361	105	90	83	99	120	117	132	139	3,711	3,757	99
	3	Oct. 20	538+33	543+15	482	3¼	68	49	422	622	668	652	393	605	650	656	296	432	474	507	107	103	103	99	143	144	141	129	3,858	4,500	86
Average									444	545	562	548	449	570	612	510	382	432	431	429	99	95	92	110	119	126	130	128	3,691	4,117	90
Barber asphalt emulsion, earth subgrade.	1	Aug. 18	71+84	82+00	1,016	2⅛	89	76	451	449	467	506	391	445	520	534	475	410	439	466	115	101	90	95	95	110	106	109	3,508	3,566	98
	2	Sept. 11	441+44	452+41	1,097	0	86	64	478	478	491	576	520	578	602	585	385	451	249	374	92	83	82	98	124	106	197	154	4,177	3,501	119
	3	Oct. 11	501+05	511+08	1,003	3½	79	61	495	538	636	592	461	544	670	647	503	465	491	502	107	99	95	92	98	116	130	118	3,770	4,361	86
									463	543	650	597	461	544	670	647	503	465	491	562	100	100	97	92	92	117	132	119			
	4	Nov. 15, 16	670+00	680+21	1,021	1½	56	38	329	325	577	575	356	558	596	514	436	475	586	575	92	58	97	112	75	68	98	100	3,595	3,485	103
Average									438	448	543	562	432	531	597	570	450	450	441	479	101	85	91	99	98	100	133	120	3,762	3,728	101
Barber asphalt emulsion, tar paper on subgrade.	1	Aug. 20	82+00	92+03	1,003	2⅛	89	76	508	451	481	491	474	520	547	592	448	382	541		107	87	88	83	113	118	89		3,138	3,550	88
	2	Sept. 12	430+81	441+44	1,063	0	84	63	470	503	518	556	466	543	586	580	466	386	382	407	97	93	88	96	101	130	136	137	3,640	4,454	82
	3	Oct. 12	511+08	518+02	694	5	78	60	454	531	583	614	428	608	662	667	403	504	591	576	106	87	88	92	113	105	99	107	3,645	4,135	88
									430	574	656	615	428	608	662	667	403	504	591	576	100	94	88	92	107	114	111	107			
Average									477	495	527	554	462	557	598	613	439	424	505	492	103	89	88	90	109	118	108	122	3,474	4,046	86
Headley asphalt emulsion, earth subgrade.	1	Aug. 21, 22	92+03	102+88	1,085	2⅝	87	78	400	497	529	514	557	533	588	627	397	414	540	404	72	93	90	82	101	120	98	127	3,140	3,459	91
	2	Sept. 21	281+50	290+59	909	0	79	52	495	558	542	565	510	611	582	696	265	327	406	431	97	91	93	81	187	171	134	131	3,346	3,395	99
	3	Oct. 25	549+13	559+17	1,004	2⅞	62	46	397	541	620	671	392	630	694	750	286	437	535	476	101	86	89	89	139	124	116	141	4,213	4,328	97
									344	592	530	588	392	630	694	750	286	437	535	476	88	94	76	78	120	135	99	124			
	4	Nov. 17	665+15	670+00	485	1½	53	35	264	458	518	555	237	421	594	573					111	109	87	97					3,348	3,534	95
Average									389	514	552	576	424	549	615	662	316	393	493	437	95	95	90	87	142	138	116	133	3,512	3,679	95
Headley asphalt emulsion, tar paper on subgrade.	1	Aug. 23	102+88	113+38	1,050	2⅝	87	78	466	504	517	573	496	517	604	611	447	431	525	674	94	98	86	94	104	117	98	85	3,248	4,001	81
	2	Sept. 22	290+59	298+32	773	½	79	54	478	557	549	643	412	502	619	575	506	585	566	700	116	111	89	112	94	95	97	92	3,416	3,543	96
	3	Oct. 26	559+17	564+48	531	2⅞	61	45	297	572	676	745	251	567	717	753	293	564	642	781	118	101	94	99	101	101	105	95	4,025	4,673	86
									351	530	683	782	251	567	717	753	293	564	642	781	140	94	95	104	120	94	106	100			
Average									414	544	581	654	386	529	647	646	415	527	578	718	109	103	90	102	100	104	100	91	3,563	4,772	88
Tarvia K. P., earth subgrade.	1	Aug. 11, 13	31+32.5	46+84	1,551.5	3¾	90	74	482	536	531	523	435	521	513	562	476	579	557	461	111	103	104	93	101	93	95	113	3,993	4,515	88
	2	Sept. 13	428+22	430+81	259	0	82	62																					3,334	4,638	72
Average									482	536	531	523	435	521	513	562	476	579	557	461	111	103	104	93	101	93	95	113	3,664	4,577	80

[1] Where two sets of results are shown for a given section the results shown on the upper line represent tests of beams coated on top only, while those on the lower line represent tests of beams coated on sides as well as on top. The latter tests (3 sides coated) are not included in the average.

[2] Beam and core strength ratings are expressed as the percentages which the strengths of the research-cured specimens bear to the strengths of the corresponding standard-cured sections. Average strength ratings for a given type of cure were obtained by averaging the strength ratings for the individual cycles.

TABLE 4.—*Results of strength tests on control test beams and on cores drilled from test sections*—Continued

Research cure	Cycle No.	Date laid	Location		Length of cycle	Precipitation during first 10 days after laying	Temperature first 10 days after laying		Beam strength in pounds per square inch (most probable average)												Beam Strength rating, per cent								Core strength at one year		
			From station	To station			Average maximum	Average minimum	Research cure				Standard cure				No cure				Research cure to standard cure				Research cure to no cure				Average, research cure	Average, standard cure	Core strength rating
									3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day	3-day	7-day	14-day	28-day			
					Feet	*Inches*	*° F.*	*° F.*																					*Lbs. per sq. in.*	*Lbs. per sq. in.*	*Per cent.*
Tarvia K. P., tar paper on subgrade.	1	Aug. 14	46+84	55+00	816	3⅞	90	74	489	541	573	427	444	513	586	574					110	106	98	74					3,116	3,952	79
Average									489	541	573	427	444	513	586	574					110	106	98	74					3,116	3,952	79
Tarvia B, earth subgrade	1	Sept. 17	413+50	417+90	440	0	77	52	391	429	467	490	413	535	584	544	234	297	297	355	95	80	80	90	167	144	157	138	4,106	4,278	96
	2	Sept. 14	417+90	421+61	371	0	80	57	384	438	492	521	408	559	574	523					94	78	86	100					4,131	3,848	107
	3	Nov. 1	582+00	584+70	270	1⅝	58	44	249	428	469	686	301	474	529	649	328	463	448	600	83	90	89	106	76	92	105	114	3,490	3,678	95
									283	475	458	634	301	474	529	649	328	463	448	600	94	100	87	98	86	103	102	106			
Average									341	432	476	566	374	523	562	572	281	380	373	478	91	83	85	99	122	118	131	126	3,909	3,935	99
Tarvia B, tar paper on subgrade.	1	Sept. 17	406+31	413+50	719	0	77	52	457	545	527	525	412	548	629	600	289	309	216	418	111	99	84	88	158	176	244	126	3,480	4,610	75
Average									457	545	527	525	412	548	629	600	289	309	216	418	111	99	84	88	158	176	244	126	3,480	4,610	75
Poor earth cure	1	Aug. 6, 7, 8	9+05	21+85	1,280	1¾	92	75	499	534	577	546	551	587	592	649	401	325	489	486	91	91	97	84	124	164	118	112	3,890	4,678	83
	2	Sept. 18	395+10	406+31	1,121	0	78	52	393	432	565	575	370	500	590	605	442	397	540	605	106	86	96	95	89	109	105	95	3,918	3,880	101
	3	Oct. 13	518+02	521+48	346	5	76	59	363	539	609	608	331	491	579	552					110	110	105	110					4,420	4,128	107
	4	Oct. 18	529+26	534+97	571	2½	71	50	459	588	649	631	445	536	648	608	401	456	535	513	103	110	100	104	114	129	121	123	4,067	3,870	105
Average									429	523	600	590	424	529	602	604	415	393	521	535	102	99	100	98	109	134	115	110	4,074	4,139	99
Ponding	1	Aug. 9, 10	23+95	29+65	570	1¾	91	74	414	466	467	486	420	492	516	548	429	393	486	498	99	95	90	89	97	119	96	98	4,020	4,147	97
	2	Sept. 19	381+80	395+10	1,330	0	79	53	457	517	617	602	486	622	643	629	423	416	492	505	94	83	96	96	108	124	125	119	4,267	3,940	108
	3	Oct. 15, 16	521+48	524+53	305	3	73	52	433	579	611	651	365	578	614	664	472	626	588	656	119	100	100	98	92	92	104	99	3,859	3,928	98
Average									435	521	565	580	424	564	591	614	441	478	522	553	104	93	95	94	99	112	108	105	4,049	4,005	101
Calcium chloride admixture, earth subgrade.	1	Aug. 16	65+80	68+46	266	2⅞	90	75	491	470	378	399	599	616	643	707	529	512	500	493	82	76	59	56	93	92	76	81	3,372	3,693	91
	2	Oct. 30	567+75	572+82	507	1⅞	60	44	309	381	467	512	161	367	518	647	145	423	450	459	192	104	90	79	213	90	104	112	3,454	3,207	108
	3	Nov. 13	692+70	695+50	280	1½	62	45	373	533	471	548	385	572	611	604	363	482	424	468	97	93	77	91	103	111	111	117	3,745	2,714	138
Average									391	461	439	486	382	518	591	653	346	472	458	473	124	91	75	75	136	98	97	103	3,524	3,205	112
Calcium chloride admixture, tar paper on subgrade.	1	Aug. 17	68+46	71+84	338	2⅛	89	76	441	438	402	403	391	445	520	534	475	410	439	466	113	98	77	75	93	107	92	86	3,030	3,169	96
	2	Oct. 31	574+80	577+07	227	1⅞	59	44	304	461	558	543	89	356	401	510	209	407	467		342	129	139	106	145	113	119		3,438	4,163	83
	3	Nov. 14	682+40	684+40	200	1½	62	45	471	550	590		289	525	621	481	362	542	438		163	105	95		130	101	135		3,218	3,427	94
Average									405	483	517	473	256	442	514	508	349	453	448	466	206	111	104	90	123	107	115	86	3,229	3,586	91

TABLE 5.—*Results of crack surveys*

Type of research cure	Cycle No.	Date laid	Length of section	Survey of Dec. 3, 1929: Average length of section: Research cure	Survey of Dec. 3, 1929: Average length of section: Standard cure	Survey of Dec. 3, 1929: Slab length rating [1]	Survey of May 26, 1930: Average length of section: Research cure	Survey of May 26, 1930: Average length of section: Standard cure	Survey of May 26, 1930: Slab length rating [1]
			Feet	Feet	Feet	Per cent	Feet	Feet	Per cent
Burlap, 12 hours	1	July 5, 6, 7	1,392	53.6	55.7	96.2	51.6	53.6	96.3
	2	Nov. 20	661	50.8	60.1	84.6	44.1	55.1	80.0
Average				52.7	57.0	92.3	48.9	54.0	90.5
Burlap, 24 hours	1	Aug. 24	1,022	63.9	53.8	118.8	63.9	53.8	118.8
	2	July 9, 10	1,334	58.0	60.6	95.6	58.0	58.0	100.0
	3	Oct. 29	285	71.2	71.2	100.0	71.3	71.3	100.0
	4	Sept. 24	671	95.9	95.9	100.0	83.9	83.9	100.0
	5	Nov. 1, 3	778	77.8	77.8	100.0	70.7	77.8	90.9
	6	Nov. 24	917	45.8	61.2	75.0	43.7	50.9	85.7
Average				62.6	65.0	96.2	60.4	61.1	98.8
Burlap, 48 hours	1	Aug. 25	1,005	47.9	41.9	114.3	47.9	40.2	119.0
	2	July 11, 12	804	57.4	50.2	114.3	50.2	47.3	106.2
	3	Sept. 25	1,008	77.5	84.0	92.3	72.0	77.6	92.8
	4	Nov. 5	824	82.4	82.4	100.0	82.4	74.9	110.0
	5	Nov. 27	718	35.9	37.8	95.0	32.6	32.6	100.0
Average				55.9	53.8	103.9	52.5	49.5	106.0
Burlap, 72 hours	1	Aug. 27	1,071	53.6	44.6	120.0	46.6	41.2	113.0
	2	July 13	1,040	69.3	57.8	120.0	65.0	57.8	112.5
	3	Sept. 26	867	61.9	57.8	107.1	57.8	54.2	106.6
	4	Nov. 6, 7, 8	1,161	68.3	64.5	105.9	68.3	64.5	105.9
Average				62.7	55.2	113.7	58.3	53.1	109.8
Burlap, 96 hours	1	Aug. 30	867	54.2	57.7	93.7	54.2	54.2	100.0
	2	July 14, 16	788	52.5	60.6	86.7	52.5	60.6	86.7
	3	Sept. 29	607	60.7	55.2	110.0	60.7	46.7	130.0
	4	Nov. 10	990	52.1	58.2	89.4	52.1	55.0	94.8
Average				54.2	58.1	93.4	54.2	54.2	100.0
No cure	1	Aug. 15	695	49.6	53.4	92.8	43.4	53.4	81.3
	2	Aug. 28	1,117	48.6	48.6	100.0	48.6	48.6	100.0
	3	July 17, 18, 19	1,087	64.0	49.4	129.4	63.9	49.4	129.4
	4	Sept. 27	1,055	48.0	50.2	95.4	48.0	50.2	95.4
	5	Oct. 5, 6	1,259	74.0	74.0	100.0	74.0	70.0	105.8
	6	Sept. 13	322	46.0	29.3	157.1	46.0	29.3	157.1
	7	Oct. 24	598	85.4	74.8	114.3	85.4	74.8	114.3
	8	Nov. 23	742	30.9	43.7	70.8	28.5	41.2	69.2
	9	Nov. 9	649	81.1	81.1	100.0	64.9	81.1	80.0
Average				54.1	53.8	100.7	51.9	53.0	97.9
Sisalkraft, 24 hours	1	Aug. 29	1,031	41.3	44.8	92.0	36.8	43.0	85.7
Sisalkraft, 48 hours	2	July 24	1,008	56.0	56.0	100.0	56.0	56.0	100.0
Sisalkraft, 24 hours	3	Sept. 28, 29	924	57.8	61.6	93.7	54.4	54.4	100.0
Average				50.2	52.9	94.9	47.0	50.2	93.7
Sodium silicate, earth subgrade	1	July 20	823	63.3	54.9	115.4	54.9	54.9	100.0
	2	Sept. 6	1,087	40.3	47.3	85.2	40.2	47.3	85.2
	3	Oct. 10	305	43.6	43.6	100.0	38.1	33.9	112.5
Average				47.1	49.2	95.8	44.3	47.1	94.0
Sodium silicate, tar paper on subgrade	1	July 23	788	49.2	56.3	87.2	43.8	49.2	88.9
	2	Sept. 5	1,109	44.4	55.4	80.0	42.6	48.2	88.5
Average				46.3	55.8	82.9	43.1	48.7	88.7
Calcium chloride surface application, earth subgrade	1	Aug. 16	330	30.0	33.0	90.9	27.5	30.0	91.6
	2	July 25, 26	1,635	56.4	58.4	96.6	51.1	54.5	93.7
	3	Oct. 1	779	86.6	97.4	88.9	86.5	97.4	88.9
	4	Sept. 4	588	42.0	45.2	92.8	39.2	39.2	100.0
	5	Oct. 31	198	66.0	66.0	100.0	66.0	66.0	100.0
	6	Nov. 21	891	40.5	46.9	86.4	37.1	42.4	87.5
	7	Nov. 14	219	73.0	73.0	100.0	54.8	73.0	75.0
	8	Nov. 13	625	78.1	78.1	100.0	69.4	78.1	88.9
Average				53.2	57.2	93.0	48.8	53.3	91.6
Calcium chloride surface application, tar paper on subgrade	1	July 30, 31	1,139	34.5	38.0	90.9	31.6	36.7	86.2
	2	Oct. 3-4	1,178	69.3	65.4	105.9	69.3	65.4	105.9
	3	Oct. 31	493	70.4	70.4	100.0	54.8	44.8	122.2
	4	Nov. 22	966	48.3	46.0	105.0	38.6	43.9	88.0
	5	Nov. 14	705	88.1	88.1	100.0	88.2	88.2	100.0
Average				52.7	53.4	98.8	47.2	49.8	94.8
Hunt process, earth subgrade	1	Aug. 1, 2	1,459	31.0	34.7	89.4	28.6	33.2	86.4
	2	Sept. 7	800	26.7	38.1	70.0	23.5	38.1	61.8
	3	Oct. 19	336	22.4	37.3	60.0	22.4	37.3	60.0
	4	Nov. 12	1,073	21.5	46.7	46.0	19.5	43.0	45.5
Average				25.8	38.6	66.9	23.7	37.1	63.8

[1] The slab length rating is expressed as the percentage which the average length of research-cured section bears to the corresponding average length of standard-cured section.

TABLE 5.—*Results of crack surveys*—Continued

Type of research cure	Cycle No.	Date laid	Length of section	Survey of Dec. 3, 1929: Average length of section: Research cure	Survey of Dec. 3, 1929: Average length of section: Standard cure	Survey of Dec. 3, 1929: Slab length rating	Survey of May 26, 1930: Average length of section: Research cure	Survey of May 26, 1930: Average length of section: Standard cure	Survey of May 26, 1930: Slab length rating
			Feet	*Feet*	*Feet*	*Per cent*	*Feet*	*Feet*	*Per cent*
Hunt process, tar paper on subgrade	1	Aug. 3, 4	1,367	27.3	38.0	72.0	24.4	37.0	66.1
	2	Sept. 10	975	29.5	33.6	87.9	25.6	30.4	84.2
	3	Oct. 20	482	48.2	40.2	120.0	48.2	40.2	120.0
Average				30.4	36.7	82.8	27.2	34.9	77.8
Barber asphalt emulsion, earth subgrade	1	Aug. 18	1,016	21.6	37.6	57.4	19.6	36.3	53.8
	2	Sept. 11	1,097	21.5	30.5	70.6	20.3	28.9	70.4
	3	Oct. 11	1,003	35.8	41.8	85.7	33.4	41.8	80.0
	4	Nov. 15, 16	1,021	46.4	51.0	90.9	44.4	51.1	87.0
Average				28.0	38.7	72.2	26.0	37.6	69.2
Barber asphalt emulsion, tar paper on subgrade	1	Aug. 20	1,003	25.1	40.1	62.5	22.3	37.2	60.0
	2	Sept. 12	1,063	25.9	36.7	70.7	23.6	33.2	71.2
	3	Oct. 12	694	36.5	49.6	73.6	34.7	49.6	70.0
Average				27.6	40.6	68.0	25.1	37.8	66.4
Headley asphalt emulsion, earth subgrade	1	Aug. 21, 22	1,085	20.9	31.0	67.3	20.1	31.0	64.8
	2	Sept. 21	909	35.0	47.8	73.1	34.9	37.8	92.4
	3	Oct. 25	1,004	24.5	47.8	51.2	22.8	40.2	56.8
	4	Nov. 16, 17	485	25.5	48.5	52.6	24.2	48.5	50.0
Average				25.2	41.0	61.6	24.2	37.1	65.2
Headley asphalt emulsion, tar paper on subgrade	1	Aug. 23	1,050	22.8	35.0	65.2	20.6	32.8	62.8
	2	Sept. 22	773	38.6	51.5	75.0	36.8	48.3	76.2
	3	Oct. 26	531	53.1	59.0	90.0	37.9	59.0	64.2
Average				31.0	43.6	71.1	27.4	41.3	66.3
Tarvia K. P., earth subgrade	1	Aug. 11, 13	1,551.5	26.3	40.8	64.4	24.2	39.8	60.9
	2	Sept. 13	259	16.2	23.5	68.7	14.4	19.9	72.2
Average				24.1	37.0	65.4	22.1	34.8	63.5
Tarvia K. P., tar paper on subgrade	1	Aug. 14	816	18.5	40.8	45.4	17.0	37.1	45.8
Average				18.5	40.8	45.4	17.0	37.1	45.8
Tarvia B, earth subgrade	1	Sept. 17	440	22.0	33.8	65.0	21.0	33.8	61.9
	2	Sept. 14	371	17.7	26.5	66.7	15.5	24.7	62.5
	3	Nov. 1	270	67.5	67.5	100.0	67.5	54.0	125.0
Average				24.0	34.9	68.9	22.1	32.8	67.4
Tarvia B, tar paper on subgrade	1	Sept. 17	719	37.8	47.9	78.9	36.0	45.0	80.0
Average				37.8	47.9	78.9	36.0	45.0	80.0
Poor earth cure	1	Aug. 6, 7, 8	1,280	55.6	45.7	121.8	47.4	41.3	114.7
	2	Sept. 18	1,121	70.1	74.8	93.8	70.1	74.8	93.8
	3	Oct. 13	346	86.5	86.5	100.0	86.5	86.5	100.0
	4	Oct. 18	571	81.6	95.2	85.7	63.5	95.2	66.7
Average				66.4	62.6	106.0	59.3	59.3	100.0
Ponding	1	Aug. 9, 10	570	40.7	43.8	92.8	38.0	43.8	86.7
	2	Sept. 19	1,330	63.4	78.2	80.9	55.4	66.5	83.3
	3	Oct. 15, 16	305	61.0	61.0	100.0	61.0	61.0	100.0
Average				55.1	63.0	87.5	50.1	58.0	86.4
Calcium chloride admixture, earth subgrade	1	Aug. 16	266	29.6	38.0	77.8	29.6	38.0	77.8
	2	Oct. 30	507	63.4	50.7	125.0	63.4	50.7	125.0
	3	Nov. 13	280	35.0	46.7	75.0	31.1	46.7	66.7
Average				42.1	45.8	92.0	40.5	45.8	88.5
Calcium chloride admixture, tar paper on subgrade	1	Aug. 17	338	37.6	42.2	88.9	37.6	42.2	88.9
	2	Oct. 31	227	56.7	56.8	100.0	45.4	56.8	80.0
	3	Nov. 14	200	100.0	100.0	100.0	100.0	100.0	100.0
Average				51.0	54.6	93.3	47.8	54.6	87.5

In Table 5 are presented the results of the crack surveys of December 3, 1929, and May 26, 1930. This tabulation includes values of average length of uncracked section for both research and standard cures, and the corresponding test ratings. The results of the tests for surface hardness are tabulated in a similar manner in Table 6, and are discussed in a subsequent part of the report.

The data presented in Tables 4 and 5 is shown in condensed graphic form in Figures 1 and 2. These two diagrams give the date of laying each test section, the daily rainfall and temperature records, and the various test ratings, with the exception of those for surface hardness given in Table 6. The temperature ranges, which cover the working day only, are denoted by vertical lines, the presence of an arrow indicating that no minimum temperature was recorded. The ratings for each section or cycle are also denoted by vertical lines, which appear in the following order, reading from left to right:

1. Modulus of rupture at 3 days.
2. Modulus of rupture at 7 days.
3. Modulus of rupture at 14 days.
4. Modulus of rupture at 28 days.
5. Crushing strength at 1 year.
6. Uncracked slab length on December 3, 1929.
7. Uncracked slab length on May 26, 1930.

SIGNIFICANCE OF TEST DATA DISCUSSED

Before the results are considered in detail, it will be of interest to discuss briefly the significance of the methods of establishing the relative efficiency of the various cures. The beam tests were made for the purpose of determining the effect of the curing method upon early strength; that is, upon strength acquired during periods up to 28 days. The value of a rating based on the strength of molded beams depends, of course, upon the degree to which it can be assumed that the curing effect on the beam is exactly the same as the effect upon the road slab itself. Although every effort was made in this work to make the conditions of curing closely comparable, it must be admitted that certain of the curing methods, especially those which depend upon sealing the moisture within the concrete, probably had an effect upon the small beams somewhat different from their effect upon the pavement because of the greater relative surface area exposed to evaporation. As has been noted above, the practice of spraying only the tops of the beams was criticized by the sponsors of certain of the so-called "black-surface" or bituminous cures. As a result, a number of special sets of beams were cast, which were sprayed on both sides and top, the sides being sprayed immediately after removal of the forms. The results of transverse tests on these beams compared to similar beams sprayed only on the top are given in Table 7. It will be observed that the additional spraying produced no consistent effect in either direction.

TABLE 6.—*Results of tests for surface hardness*

Type of cure	Cycle No.	Depth of wear, thousandths of an inch: Research cure	Depth of wear, thousandths of an inch: Standard cure	Wear test rating,[1] per cent
Wet burlap applied for 12 hours	1	35.3	39.3	90
Wet burlap applied for 24 hours	1	43.7	57.0	77
Wet burlap applied for 48 hours	1	34.3	42.3	81
Wet burlap applied for 72 hours	1	35.7	47.3	75
Wet burlap applied for 96 hours	1	43.7	58.7	74
No cure	1	33.3	37.7	88
Do	4	32.0	37.3	86
Sisalkraft paper applied for 24 hours	1	43.7	54.0	81
Sisalkraft paper applied for 48 hours	2	36.0	36.0	100
Sodium silicate, earth subgrade	1	25.3	27.3	93
Sodium silicate, tar paper on subgrade	2	32.7	58.7	56
Calcium chloride, surface application, earth subgrade	3	32.3	31.3	103
Calcium chloride, surface application, tar paper on subgrade	1	43.3	47.0	92
Hunt process, earth subgrade	1	29.0	30.3	96
Do	2	41.0	37.7	109
Do	4	45.2	28.0	161
Hunt process, tar paper on subgrade	1	53.7	34.0	158
Barber asphalt emulsion, earth subgrade	1	46.3	32.7	142
Do	2	49.7	49.7	100
Do	3	52.3	36.3	144
Barber asphalt emulsion, tar paper on subgrade	1	68.7	52.7	130
Headley asphalt emulsion, earth subgrade	3	70.0	34.3	204
Headley asphalt emulsion, tar paper on subgrade	2	53.0	28.7	185
Tarvia K. P., earth subgrade	1	38.0	26.0	146
Tarvia K. P., tar paper on subgrade	1	66.0	46.0	144
Tarvia B—earth subgrade	1	50.0	58.0	86
Do	2	77.0	56.5	136
Do	3	41.3	39.7	104
Poor earth cure	1	47.7	31.3	152
Ponding	1	45.7	44.3	103
Do	2	41.0	37.7	109
Calcium chloride admixture, earth subgrade	1	34.0	38.3	89
Do	2	52.3	50.7	103

[1] The wear test rating is defined as the percentage which the depth of wear recorded for the research-cured side of the section bears to that recorded for the standard-cured side.

TABLE 7.—*Strength of beams cured on sides and top compared with beams cured on top only*

Type of cure	Strength of beams cured on top and sides, pounds per square inch				Strength of beams cured on top only, pounds per square inch				Strength of beams cured on top and sides as a percentage of strength of beams cured on top only			
	Age Days 3	7	14	28	Age Days 3	7	14	28	Age Days 3	7	14	28
Barber asphalt emulsion, earth subgrade	463	543	650	597	495	538	636	592	94	101	102	101
Barber asphalt emulsion, tar paper on subgrade	430	574	656	615	454	531	583	614	95	108	113	100
Headley asphalt emulsion, earth subgrade	344	592	530	588	397	541	620	671	87	109	86	88
Headley asphalt emulsion, tar paper on subgrade	351	530	683	782	297	572	676	745	118	93	101	105
Tarvia B, earth subgrade	283	475	458	634	249	428	469	686	114	111	98	92

It is not believed that very much weight should be attached to the results of the beam tests because of the manifest impossibility of producing a curing condition strictly comparable with that of the pavement. It seems advisable that future experiments of this character should be conducted in the laboratory under standard conditions; or else that tests for strength should be made on specimens taken directly from the full size sections.

CORE TESTS CONSIDERED OF MORE IMPORTANCE THAN BEAM TESTS

The significance of the core strength data lies in the information which they afford relative to the influence of the curing methods on the ultimate strength of the concrete. Core tests obviously have one advantage over tests on molded specimens in that they are made on specimens cut from the actual structure. A disadvantage (common to all core tests on concrete pavements) lies in the fact that each individual core represents such a small portion of the slab, which at best is far from uniform in quality, that it is necessary to average a large number of individual tests before the results become truly significant. In this investigation it was possible to drill only four cores from each test section so that each result given in Table 4 represents the average of only four tests. The lack of a sufficient number of individual values from which to compute average results probably accounts for certain erratic and apparently inconsistent results appearing in the core test data. In spite of this, the authors are inclined to give the core data somewhat more weight than the beam test data because the specimens were actually taken from the full size structure and to this extent should represent the effect of the curing agent under actual conditions of use.

GREATEST WEIGHT GIVEN DATA REGARDING FORMATION OF CRACKS

In considering the data presented in this paper, the authors believe that the greatest weight should be given to the amount of cracking which has developed on the several test sections. The primary function of any curing method is to retain moisture in or supply moisture to the concrete from the time the slab is placed until sufficient strength has been built up to resist the stresses due to contraction when the slab finally is allowed to dry. Failures of the curing agent to

30119——31——2

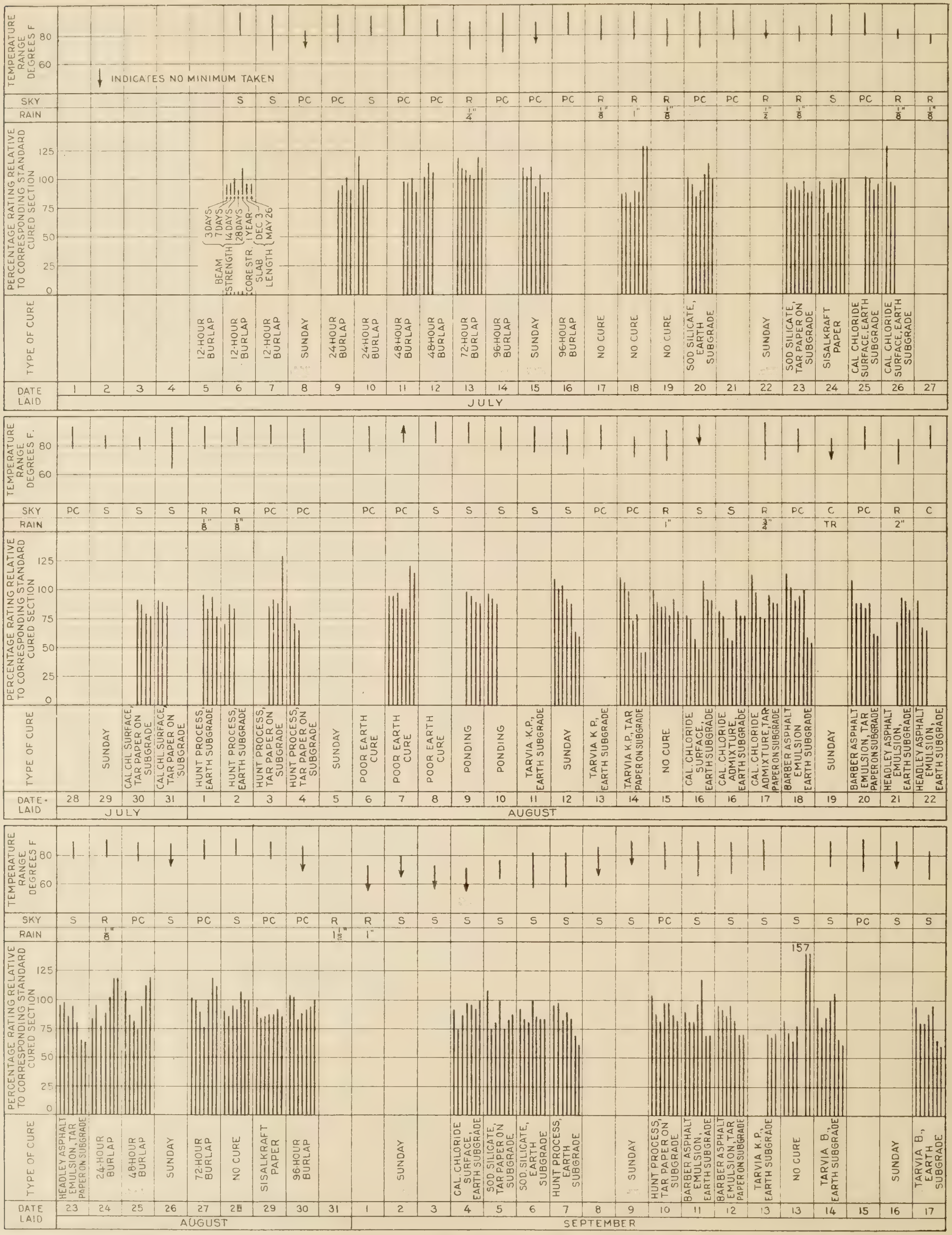


Figure 1.—Daily Record of Curing Tests, July 5 to September 17, and Diagram of Test Ratings for Each Section

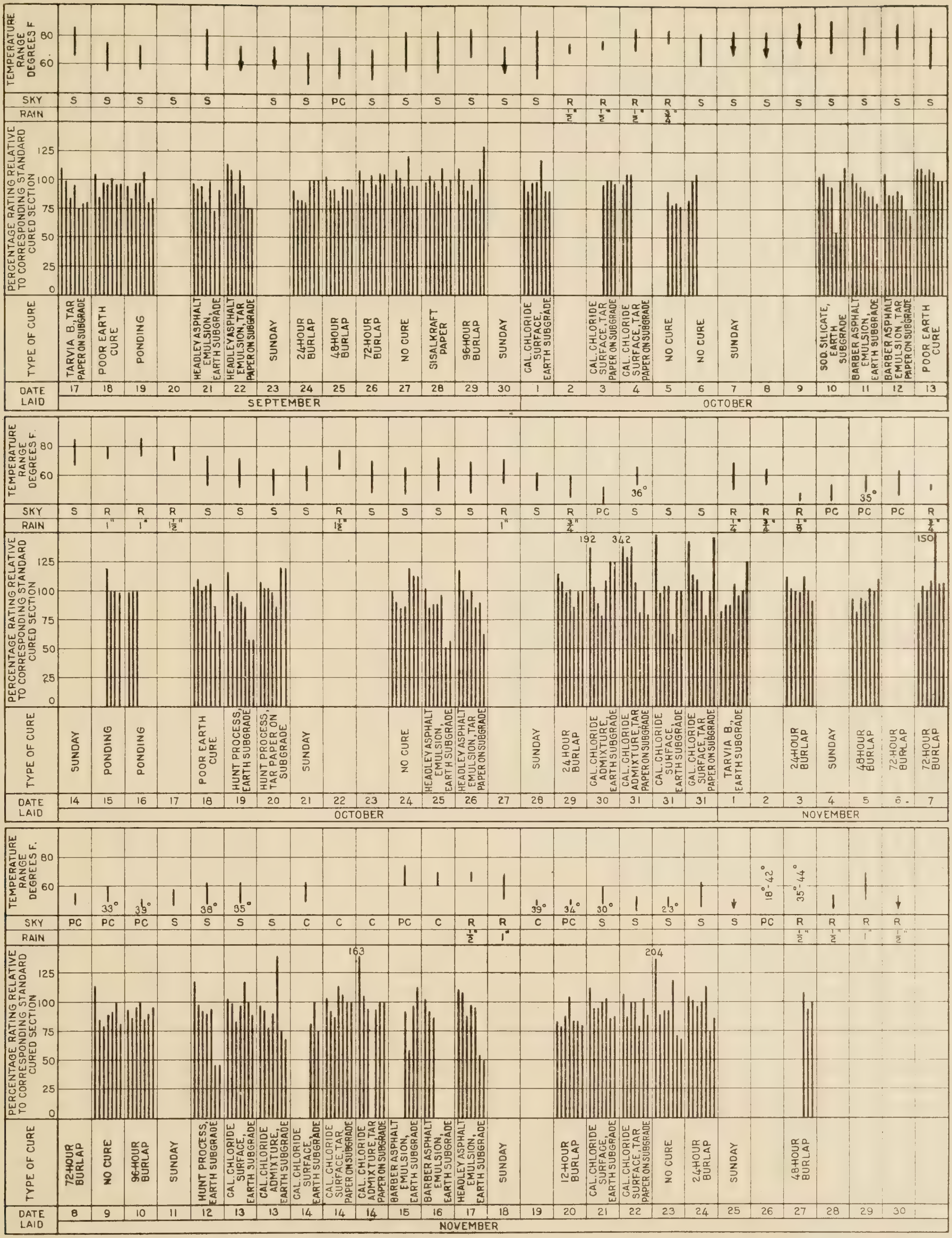
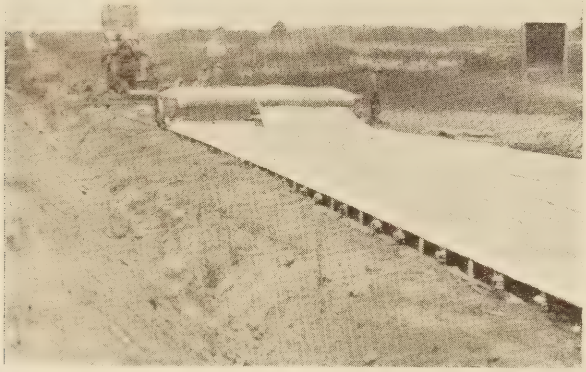


FIGURE 2.—DAILY RECORD OF CURING TESTS, SEPTEMBER 17 TO NOVEMBER 30, AND DIAGRAM OF TEST RATINGS FOR EACH SECTION

function in this respect should certainly be reflected in increased transverse cracking, particularly at the early ages. It is impossible to ignore the evidence supplied by the behavior of the road itself; and the cracking which has developed, although not always explainable, merits careful study. In this connection it should be stated that most of the cracks which have developed to date on this road are due probably to temperature or moisture changes or both, rather than to traffic. This conclusion is based not only on the general appearance and distribution of the cracks, but also on the fact that the pavement does not carry very heavy traffic and, moreover, was constructed on a uniform subgrade, a condition which still further reduces the tendency to failure through overloading.

The efficiency of the various curing methods as regards cracking has been studied by direct comparison of the average lengths in feet of uncracked slab for the various methods as well as by comparison of each method with the corresponding earth and water cured section by means of the percentage rating referred to above. It will be recalled that every effort was made during the construction of the pavement to allow free longitudinal movement of the two sides with respect to each other. The test results indicate, however, that a complete separation was not attained. Reference to the test data given in Table 5 will show that the average spacing between cracks on those standard-cured sections opposite experimental sections which developed excessive cracking was much less than in those cases where only normal cracking developed on the research side. This matter will be discussed in some detail later. It is mentioned here simply to show why it is necessary to compare the actual average uncracked slab lengths for the various cures directly as well as to compare the length of uncracked slab for each experimental section with the corresponding standard cured section. Due to the practical certainty that the slabs were not entirely free along the longitudinal joint, the authors are inclined to believe that a somewhat truer comparison of cracking is obtained by the direct method.



Machine for Laying Burlap Follows the Mixer

The above discussion of the significance of the various methods for evaluating curing efficiency represent the authors' views as to how the data should be interpreted. The reader is of course free to interpret the test results in any way which seems logical to him. In order to permit him to do this, the results of all of the experimental data are presented barring only certain erratic individual beam test results which were eliminated by the method of least squares.

CURING METHODS DISCUSSED IN DETAIL

In order to give adequate consideration to the effect of weather conditions on the results of these tests, it is necessary to study the data obtained from each curing method for each cycle individually before any general comparisons are attempted. The first portion of this discussion, therefore, deals with the various experimental curing methods in order, with special reference to variations in results in the different cycles for the same method and the possible effect of variations in temperature, humidity, and rainfall on the results obtained. Tables 8 to 19, inclusive, give for each curing method a summary of the data presented in Tables 4 and 5 and Figures 1 and 2.

Concrete cured with wet burlap for various periods with no further curing.—A total of 18,810 feet of pavement was cured with wet burlap. This included 2 sections of 12-hour curing, 6 sections of 24-hour curing, 5 sections of 48-hour curing, 4 sections of 72-hour curing, and 4 sections of 96-hour curing. A summary of the data and test ratings for the sections cured in this manner is given in Table 8.

The 2 sections cured with wet burlap for 12 hours had the burlap removed after the end of the 12-hour period, regardless of the time of day. Care was taken to have the burlap thoroughly saturated during the entire 12 hours under cure. One of the two sections cured for 12 hours with burlap was laid July 5 to 7, and the other on November 20. It is interesting to note the low rating values obtained with the section laid November 20. These results emphasize the danger of curing for a short period during cool weather, thus permitting drying out before the concrete has attained sufficient strength to withstand shrinkage stresses. It will be observed by reference to Table 4 that the beam strength at 3 days of the concrete placed on November 20 was only 178 pounds per square inch or less than one-half the beam strength of the corresponding section laid July 5 to 7.

The 6 sections cured for 24 hours with wet burlap show somewhat erratic results as regards relative value. In some cases unusually high core strengths are noted for no apparent reason. In the cycles of August 24 and September 24 the beam strength rating is low. There is the same tendency for excessive cracking to develop when the concrete is cured for a short period at low temperatures, as may be noted by reference to cycle No. 6, laid November 24. Reference to Figure 1 will show that this concrete was exposed to very low temperatures immediately following the placing of the section. A modulus of rupture of only 87 pounds per square inch was attained at three days, although the strength of the concrete at later ages was approximately the same as for other sections laid during warmer weather.

There is nothing of particular significance to note regarding the 48-hour burlap period except to point out that the sections laid in warm weather show less cracking and the one laid on November 27 more cracking as of December 3, than the corresponding standard section. On May 26, 1930, the crack rating of the section laid November 27 had increased to 100 per cent. It will be noted, however, that the average slab length is only 33 feet.

The sections cured for 72 hours with wet burlap give a very good account of themselves, especially as regards cracking. All of the four sections show less cracking than the corresponding standard sections. It should

TABLE 8.—*Summary of data and test ratings for sections cured with wet burlap*

Duration of treatment	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
Hours			*Feet*	*°F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
12	1	July 5, 6, 7	1,392	93–76	⅜	96	98	101	89	109	53.6	51.6	96.2	96.3
	2	Nov. 20	661	55–35	2½	84	79	88	105	84	50.8	44.1	84.6	80.0
24	1	Aug. 24	1,022	85–78	2½	84	94	77	88	102	63.9	63.9	118.8	118.8
	2	July 9, 10	1,334	94–74	1½	92	96	102	93	122	58.0	58.0	95.6	100.0
	3	Oct. 29	285	60–44	1⅞	115	108	98	101	85	71.2	71.3	100.0	100.0
	4	Sept. 24	671	81–59	1½	92	83	84	82	100	95.9	83.9	100.0	100.0
	5	Nov. 1, 3	778	60–41	¾	113	101	100	98	113	77.8	70.7	100.0	90.9
	6	Nov. 24	917	53–36	2½	106	102	96	100	115	45.8	43.7	75.0	85.7
48	1	Aug. 25	1,005	83–79	2½	107	87	81	74	94	47.9	47.9	114.3	119.0
	2	July 11, 12	804	94–73	2	98	96	101	89	102	57.4	50.2	114.3	106.2
	3	Sept. 25	1,008	82–61	2¼	104	91	92	83	94	77.5	72.0	92.3	92.8
	4	Nov. 5	824	62–45	¾	93	87	94	91	101	82.4	82.4	100.0	110.0
	5	Nov. 27	718	61–46	2	-----	-----	-----	-----	110	35.9	32.6	95.0	100.0
72	1	Aug. 27	1,071	81–70	2½	102	100	90	76	99	53.6	46.6	120.0	113.0
	2	July 13	1,040	93–73	1⅞	117	111	108	104	100	69.3	65.0	120.0	112.5
	3	Sept. 26	867	82–63	2¼	110	100	93	105	96	61.9	57.8	107.1	106.6
	4	Nov. 6, 7, 8	1,161	65–48	1½	90	103	100	109	150	68.3	68.3	105.9	105.9
96	1	Aug. 30	867	81–61	2½	104	102	84	89	92	54.2	54.2	93.7	100.0
	2	July 14, 16	788	92–74	2	110	103	112	93	104	52.5	52.5	86.6	86.7
	3	Sept. 29	607	83–65	2¼	111	100	90	96	83	60.7	60.7	110.0	130.0
	4	Nov. 10	990	64–48	1½	92	87	94	99	85	52.1	52.1	89.4	94.8

be noted, however, that considerable rain fell either immediately after or shortly after the completion of the 72 hours of burlap cure on each of the first three cycles. Cycle No. 4, laid November 6, 7, and 8, received no rain after completion until November 17, six days after the completion of the 72-hour burlap cure and one day before the completion of the cure on the standard side. Analysis of this section is, however, complicated by the fact that three-fourths inch of rain fell on November 7, after 755 feet had been laid. Just what effect this rain had is uncertain. Reference to the detail crack survey indicates about the same number of cracks on the sections laid before and after the rain. It is obvious that any rainfall occurring during the 10-day standard curing period, especially on sections cured with water for only a short time, such as the burlap cures, may influence the relative efficiency of this type of cure to a marked degree.

In contrast with the 72-hour cures, the sections cured for 96 hours gave in general less favorable results than the standard method. However, the differences are not great and may possibly be accounted for by other factors than curing.

In general it may be said that, aside from the obvious tendency for increased cracking to develop on sections cured for short periods under low temperature conditions, the various burlap cures produce results very similar to those obtained by means of the standard earth and water method. As stated above, this conclusion must be qualified by recognition of the probable influence of rain upon the results obtained in this particular experiment. Any conclusions regarding the merits of burlap curing for periods up to 96 hours which may be based on these tests lose much of their significance because of this fact. It is exceedingly unfortunate that the season of 1928 was an exception to the general rule as regards rainfall in this territory and it is still more unfortunate that none of the burlap or "no-cure" sections, which were the ones most probably influenced by rainfall, were laid during the early part of September. No rain at all fell during this month except on the first.

"No-cure" sections.—For purposes of comparison, all artificial curing was omitted from nine sections totaling 7,524 feet, the individual sections varying in length from 322 to 1,259 feet. The word "artificial" is used advisedly, because here again rainfall may and probably did affect the results to a marked degree. Reference to Table 9 and Figure 1 will show that rain fell during the normal 10-day curing period on eight of the nine "no-cure" sections. The one exception is that laid on September 13. No rain fell on the section laid on October 5 and 6 until the ninth day. The rainfall indicated in Figure 1 for October 5 occurred in the early morning before any concrete was laid. The authors believe that it would not be fair to rate as a "no-cure" section any section of pavement upon which rain fell during the normal 10-day curing period, and no such comparisons will be made in this report. Referring then to the section laid on September 13 as one upon which no rain fell, we are confronted immediately with the surprising fact that the "no-cure" side of the pavement developed less cracking than the side cured under earth and water. It would be obviously absurd to conclude from this that no curing gives better results than the standard method and we are consequently forced to search further for a reason why this particular condition should have developed. Refer-

WET BURLAP ON ONE SIDE OF LONGITUDINAL JOINT, EARTH AND WATER CURE ON OTHER SIDE

TABLE 9.—*Summary of data and test ratings for sections on which no curing method was used*

Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
					3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
		Feet	° *F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
1	Aug. 15	695	90–75	2⅞	100	91	86	86	78	49.6	43.4	92.8	81.3
2	Aug. 28	1,117	81–66	2½	90	85	95	92	108	48.6	48.6	100.0	100.0
3	July 17, 18, 19	1,087	90–75	⅞	88	90	83	92	89	64.0	63.9	129.4	129.4
4	Sept. 27	1,055	82–64	2¼	97	110	101	95	120	48.0	48.0	95.4	95.4
5	Oct. 5, 6	1,259	86–67	2	91	78	80	77	83	74.0	74.0	100.0	105.8
6	Sept. 13	322	82–62	0	84	72	64	78	--------	46.0	46.0	157.1	157.1
7	Oct. 24	598	64–47	2⅞	99	93	86	87	121	85.4	85.4	114.4	114.3
8	Nov. 23	742	55–38	2½	204	90	93	94	120	30.9	28.5	70.8	69.2
9	Nov. 9	649	64–48	1½	113	87	83	88	91	81.1	64.9	100.0	80.0

TABLE 10.—*Summary of data and test ratings for sections cured with Sisalkraft paper*

Cycle No.	Date laid	Length of cycle	Duration of treatment	Average temperature range 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
		Feet	*Hours*	° *F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
1	Aug. 29	1,031	24	80–61	2½	94	84	86	88	88	41.3	36.8	92.0	85.7
2	July 24	1,008	48	89–76	½	98	93	72	99	97	56.0	56.0	100.0	100.0
3	Sept. 28	924	24	83–65	2¼	98	104	98	90	110	57.8	54.4	93.7	100.0

SISALKRAFT PAPER ON RESEARCH SIDE OF LONGITUDINAL JOINT

ence to Table 5 shows that the average uncracked slab length on the earth-cured side of this section was only 29.3 feet as compared with an average for the entire nine sections of 53 feet. A search for the reason for this excess cracking developed the fact that this portion of the pavement had been laid on a new fill on the north (or standard-cure) side and that the cracks observed were probably caused by settlement of this fill. It will be noted further that the section is only 322 feet in length. In view of the above condition it is obvious that this section should not be considered.

The section laid on October 5 and 6 remains, therefore, the only one which may possibly be rated as a "no-cure" section. It may be of interest to study this section in some detail. No rain fell until October 15, or nine days after the completion of the section. The average maximum temperature during the first 10 days was 86° F., the average minimum daytime temperature 67° F., and the weather was clear and sunny during the whole period. It will be observed that the section rates very low on both transverse and crushing strength. Average uncracked slab, length, however, is the same as for the standard cure side. This, in view of the temperature and general weather conditions prevailing, is a very good showing.

In general, it is believed that, due to the possible effect of rainfall upon the results, no use should be made of the data obtained from the so-called "no-cure" sections.

Sisalkraft paper.—On 2,963 feet of pavement laid in three cycles, a reinforced waterproof paper known as Sisalkraft was used in place of wet burlap. In the first and third cycles, the paper remained in place 24 hours; in the second cycle, 48 hours. None of these sections was entirely uninfluenced by rain during the first 10-day period. The one laid July 24 was subjected to the most severe conditions as the record shows that only ¼-inch of rain fell during the first seven days. Reference to Table 10 will show that this section behaved normally from the standpoint of cracking, but that the strength ratings are somewhat low.

Sodium solicate.—A solution of sodium silicate, applied as recommended by the manufacturers, was used on 4,112 feet of pavement, laid in five sections, on two of which tar paper was placed on the subgrade before the placing of the concrete. The data relative to these sections are summarized in Table 11. From the standpoint of severity of curing conditions as evidenced by lack of rain, the sections laid on September 5 and 6 are the most interesting. No rain fell on either of these sections, totaling 2,196 feet, until October 2, almost an entire month. The average maximum temperature during this period was 84° F., the average minimum daytime temperature 61° F., and the number of 100 per cent sunny days was 21. Evidence of the severity of the curing condition is found in the relatively low rating attained by these sections from the standpoint of both strength and cracking. Reference to Table 11 brings out the fact that these sections failed to rate as high as 90 per cent of standard in either core strength or uncracked section length. The data also indicate that the use of tar paper on the subgrade did not affect the results. It will also be noted that the average slab length on the sections laid September 5 and 6 are relatively low, indicating again a lack of curing. Some rain fell on the sections laid July 20 and 23. To just what extent rain may have affected these results is problematical. It is interesting to note, however, that from the standpoint of uncracked slab length, the section laid on July 20 (earth subgrade) is rated 100

TABLE 11.—*Summary of data and test ratings for sections cured with sodium silicate*

Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
			Feet	*° F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	July 20	823	88–76	⅞	101	96	85	89	103	63.3	54.9	115.4	100.0
	2	Sept. 6	1,087	89–68	0	93	84	81	100	86	40.3	40.2	85.2	85.2
	3	Oct. 10	305	80–62	3½	102	106	95	95	53	43.6	38.1	100.0	112.5
Tar paper	1	July 23	788	89–76	½	97	92	93	91	97	49.2	43.8	87.4	88.9
	2	Sept. 5	1,109	88–67	0	108	76	81	100	75	44.4	42.6	80.0	88.5

per cent of standard on May 26, whereas the section laid on July 23 (tar-paper subgrade) shows only 89 per cent of standard. The section laid July 20, it will be noted, received a ½-inch rainfall on July 22, whereas the section laid on July 23 received only very slight rainfall on the 26th and 27th.

APPLYING SODIUM SILICATE TO SURFACE OF PAVEMENT

Calcium chloride surface application.—Thirteen sections of pavement, totaling 9,746 feet in length, were cured with a surface application of calcium chloride, applied at the rate of 2 pounds to the square yard. Individual sections varied in length from 219 to 1,635 feet. Table 12 gives in summarized form the results obtained from these tests. Here again the most interesting section from the standpoint of rainfall is the one laid on September 4. This section was subject to the same weather conditions as the two sodium silicate sections mentioned above. The section is rated less than 100 per cent from the standpoint of strength. The uncracked section length rating was 93 per cent on December 3 but rose to 100 per cent on May 26, due to the fact that two additional cracks had developed on the standard side to only one on the research side. It should be noted, however, that the average length of uncracked slab on this section was only 39.2 feet on May 26. This may be compared to an average of 48.8 feet for all eight sections laid on earth subgrade. (See Table 5.) The length of the corresponding

SPREADING CALCIUM CHLORIDE ON PAVEMENT

standard-cured side, moreover, was only 39.2 feet as against an average of 53.3 feet for the eight sections. This condition illustrates the possibility of restraint along the longitudinal joint and its influence on the amount of cracking developing on the standard side.

In direct contrast with this section, we may note the section laid on October 1. Although the uncracked slab rating for this section is only 89 per cent, the average length of slab on May 26 was 86.5 feet, or more than two times the length of slab on the section laid September 4. It will be noted that over 2 inches of rain fell on this section during the three days immediately following its construction. On the other hand, the section laid on November 21 shows relatively short crack spacing. This section, it will be observed, was laid during very cold weather, the temperature going below freezing on the second day. It is possible that this fact, coupled with the possibility that drying out took place between November 21 and November 27, the date of the first rain following the laying of the section, accounts for the relatively large number of cracks observed. On October 31, a short section (198 feet) was laid which showed an average uncracked slab length of 66 feet on May 26. This section was laid in somewhat warmer weather than the one placed on November 21 and, moreover, received considerable rainfall for three days following its placing.

In regard to the sections laid on tar paper, it may be of interest to discuss the possible reasons for the relatively large amount of cracking which has taken place on the section laid on July 30 and 31, as compared with most of those laid later in the year. Reference to the notes taken during construction indicate that great difficulty was experienced in obtaining sufficient water for curing just at this time. This section was laid at the beginning of a new set-up at the extreme west end of the project in Shelby County, and it was necessary to pump water a distance of approximately four miles.

TABLE 12.—*Summary of data and test ratings for sections cured by surface application of calcium chloride*

Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
			Feet	*°F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	Aug. 16	330	90–75	2⅞	77	74	58	49	107	30.0	27.5	90.9	91.6
	2	July 25, 26	1,635	90–76	⅜	101	100	93	96	127	56.4	51.1	96.6	93.7
	3	Oct. 1	779	84–68	2¼	100	88	97	98	117	86.6	86.5	88.9	88.9
	4	Sept. 4	588	87–66	0	92	74	87	97	96	42.0	39.2	92.8	100.0
	5	Oct. 31	198	59–44	1⅞	147	99	104	105	64	66.0	66.0	100.0	100.0
	6	Nov. 21	891	54–36	2½	114	95	95	100	103	40.5	37.1	86.4	87.5
	7	Nov. 14	219	62–45	1½	----	----	----	----	80	73.0	54.8	100.0	75.0
	8	Nov. 13	625	63–45	1½	102	99	82	96	119	78.1	69.4	100.0	88.9
Tar paper	1	July 30, 31	1,139	93–79	¼	92	87	80	77	92	34.5	31.6	90.9	86.2
	2	Oct. 3, 4	1,178	86–66	¾	91	100	100	96	94	69.3	69.3	105.9	105.8
	3	Oct. 31	493	59–44	1⅞	143	115	110	100	80	70.4	54.8	100.0	122.2
	4	Nov. 22	966	54–35	2½	109	87	100	100	80	48.3	38.6	105.0	88.0
	5	Nov. 14	705	62–45	1½	103	91	86	114	107	88.1	88.2	100.0	100.0

APPEARANCE OF FRESHLY SPREAD CALCIUM CHLORIDE

The inspector's notes show that extreme difficulty was experienced in obtaining sufficient water for burlap curing and it is possible that this fact may account in part for the relatively large amount of cracking. It is interesting to note also that this is the only calcium chloride section on which scaling was observed. A small amount of thin scale has developed at the west end of the section.

In Figure 3 the average slab lengths on the sections cured with sodium silicate and calcium chloride (surface application) have been plotted against the total rainfall in inches on the sections during the normal 10-day curing period. An inspection of this figure indicates that rainfall may possibly have influenced the behavior of certain of these sections to a considerable extent. It is significant that in every case when the rainfall was one-half inch or less the distance between cracks was relatively short. Only one of the six sections showed a spacing as high as 50 feet. Conversely, eight out of the 12 sections upon which more than one-half inch rain fell showed average uncracked slab lengths of 55 feet or more. Of the other four, two were laid in very cold weather (November 21 and 22). The section laid on August 16 also shows a relatively large amount of cracking. Here again reference to the construction notes indicates trouble with the water supply and it is possible that this section also received an inadequate burlap cure prior to the application of the calcium chloride.

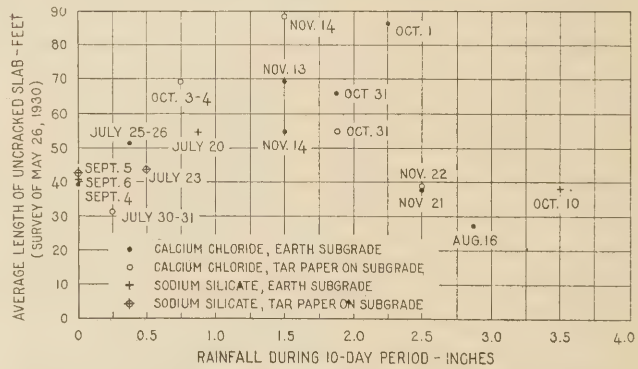


FIGURE 3.—RELATION BETWEEN RAINFALL DURING THE 10-DAY CURING PERIOD AND AVERAGE LENGTH OF UNCRACKED SLAB FOR SECTIONS CURED BY MEANS OF SURFACE APPLICATIONS OF CALCIUM CHLORIDE AND OF SODIUM SILICATE

Calcium chloride admixture.—A calcium chloride admixture in the proportion of 2 pounds to a bag of cement was used in the concrete on six sections of this project, totaling 1,818 feet. Three of the sections were laid on earth subgrade and three on tar paper. Inasmuch as it was impossible to lay concrete containing an admixture on one side only, the practice was followed, in the case of the calcium chloride admixture, of laying the experimental pavement for the full width and comparing the behavior of this full width section with the adjacent earth and water cured half-section laid on the same day. The data regarding these sections are summarized in Table 13. In so far as beam strength in concerned, four of the sections show the characteristic high early (3-day) strength of concrete in which calcium chloride is used as an admixture, but in all cases the strength ratio, as compared to the earth-cured beams, rapidly falls off at the later periods. In every case but one the rating at 28 days is considerably less than 100 per cent. Core strengths for the individual cycles are somewhat erratic. With one exception, however, the crushing strength rating is above 90 per cent of standard cure.

The spacing of cracks in these sections also varies widely, with respect to both average length and ratio to the corresponding earth-cured sections. The sections laid on August 16 and 17 both show less than 90

TABLE 13.—*Summary of data and test ratings for sections cured by admixture of calcium chloride*

Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings: 3-day	Beam strength ratings: 7-day	Beam strength ratings: 14-day	Beam strength ratings: 28-day	Core strength rating at one year	Average slab length: Dec. 3, 1929	Average slab length: May 26, 1930	Slab length rating: Dec. 3, 1929	Slab length rating: May 26, 1930
			Feet	*° F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	Aug. 16	266	90–75	2⅞	82	76	59	56	91	29.6	29.6	77.8	77.8
	2	Oct. 30	507	60–44	1⅞	192	104	90	79	108	63.4	63.4	125.0	125.0
	3	Nov. 13	280	62–45	1½	97	93	77	91	138	35.0	31.1	75.0	66.7
Tar paper	1	Aug. 17	338	89–76	2⅛	113	98	77	75	96	37.6	37.6	88.9	88.9
	2	Oct. 31	227	59–44	1⅞	342	129	139	106	83	56.7	45.4	100.0	80.0
	3	Nov. 14	200	62–45	1½	163	105	95	----------	94	100.0	100.0	100.0	100.0

TABLE 14.—*Summary of data and test ratings for sections cured by Hunt Process*

Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings: 3-day	Beam strength ratings: 7-day	Beam strength ratings: 14-day	Beam strength ratings: 28-day	Core strength rating at one year	Average slab length: Dec. 3, 1929	Average slab length: May 26, 1930	Slab length rating: Dec. 3, 1929	Slab length rating: May 26, 1930
			Feet	*° F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	Aug. 1, 2	1,459	92–78	0	97	84	95	78	73	31.0	28.6	89.4	86.4
	2	Sept. 7	800	89–69	0	96	98	83	90	86	26.7	23.5	70.0	61.8
	3	Oct. 19	336	70–50	3¼	116	95	98	91	88	22.4	22.4	60.0	60.0
	4	Nov. 12	1,073	63–46	1½	118	97	91	90	94	21.5	19.5	46.0	45.5
Tar paper	1	Aug. 3, 4	1,367	92–77	0	86	93	89	132	86	27.3	24.4	72.0	66.1
	2	Sept. 10	975	86–65	0	105	90	83	99	99	29.5	25.6	87.9	84.2
	3	Oct. 20	482	68–49	3¼	107	103	103	99	86	48.2	48.2	120.0	120.0

per cent rating as compared with earth cure. Average spacing of cracks in both cases is less than 40 feet. Both of these sections were laid during a period of acute water shortage. This fact is noted and commented upon, not as a definite reason for the excess cracking during this period, but simply as a possible reason for the condition observed.

On November 13 and 14 two short sections were laid which are interesting in that the section laid on earth subgrade (November 13) showed an average uncracked slab length of only 31 feet, whereas the one laid on tar paper showed an average of 100 feet. There is nothing in the record which would account for this wide difference. It should be noted, however, that both of these sections were very short (less than 300 feet) so that the possibility of accidental variables affecting the results is considerably increased.

Hunt Process.—Seven sections totaling 6,492 feet were cured by means of the so-called Hunt Process method, which consists in spraying specially prepared cut-back asphalt material upon the surface of the concrete at about the same interval after placing as burlap would ordinarily be applied. Burlap as well as all subsequent curing is eliminated by this method.

By reference to Table 14 and Figures 1 and 2 it will be observed that in so far as beam strength is concerned the modulus of rupture at various ages up to 28 days is in general in excess of 90 per cent of that for the corresponding earth cured specimens. There is also noted a tendency for the ratio to fall off at later periods which may be accounted for by the fact that the specimens were not protected on the sides by the seal coat. However, as has been already noted, this matter was investigated during the third cycle by coating the sides as well as the top of the specimens. Reference to Table 7 will show no consistent trend in either direction as the result of this treatment. As to core strength, all of the sections cured by Hunt Process show less than 100 per cent of the strength shown by the standard-cured sections. These data would indicate that this method of cure results in a somewhat lower crushing strength of the concrete than is attained by the standard earth and water method.

Referring now to the cracking which has developed on the sections cured with Hunt Process, we note a condition which appears to be common to practically all of the sections cured with asphalt or tar. Table 14 shows that transverse crack spacing on these seven sections averaged only about 25 feet. This is far less than the average spacing for any of the cures which do not involve the application of asphalt or tar and is also much less than that occurring in the corresponding earth-cured sections. The section ratings as regards cracking range from 45.5 to 86.4 for sections laid on earth and from 66.1 to 120.0 for sections laid on tar paper. The section laid on tar paper on October 20 is the only one which shows more cracking on the standard-cured side. There is nothing to indicate why this section should have behaved in a manner so different from the one laid the day before (October 19) on earth subgrade. Both sections are comparatively short (less than 500 feet), so that the presence of one crack more or less has a much larger influence on the section rating than in the case of longer sections.

Barber asphalt emulsion (Curcrete).—A total of 6,897 feet of pavement, in seven sections, was cured by means of a spray application of curcrete, an asphaltic emulsion manufactured for the purpose.

First discussing beam strength, we find on reference to Table 15 and Figure 1 much the same trend as in the case of Hunt Process. With only one or two exceptions the strength ratings are less than 100 per cent of earth cure, with the same tendency to lower ratings at the later ages. In the third cycle on earth subgrade as well as in the third cycle with tar paper on the subgrade, a double set of beams was cured for the purpose of ascertaining the effect of leaving the sides unprotected. This matter has previously been discussed and is mentioned here simply to indicate that, in this particular case, the same tendency to lower relative strengths with increase in age was noted for the specimens cured on both sides and top as in the case of the specimens cured on the top only. (See Table 15.) It would seem therefore that, in so far as it is possible for specimens of this type to indicate concrete strength, the method of procedure used in these tests was as

TABLE 15.—*Summary of data and test ratings for sections cured with Barber asphalt emulsion*

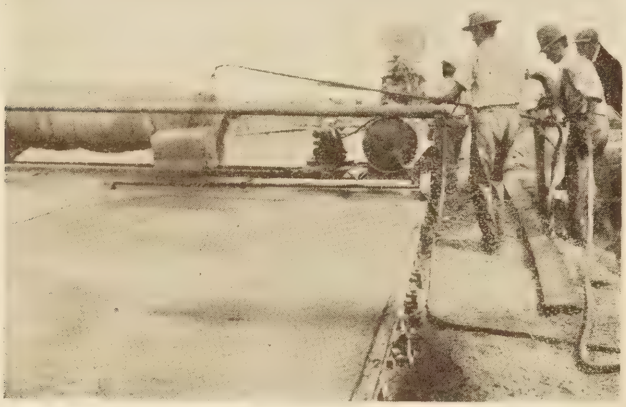
Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings[1]				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
			Feet	*°F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	Aug. 18	1,016	89–76	2⅛	115	101	90	95	98	21.6	19.6	57.4	53.8
	2	Sept. 11	1,097	86–64	0	92	83	82	98	119	21.5	20.3	70.6	70.4
	3	Oct. 11	1,003	79–61	3½	107	99	95	92	86	35.8	33.4	85.7	80.0
						100	100	97	92					
	4	Nov. 15, 16	1,021	56–38	1½	92	58	97	112	103	46.4	44.4	90.9	87.0
Tar paper	1	Aug. 20	1,003	89–76	2⅛	107	87	88	83	88	25.1	22.3	62.5	60.0
	2	Sept. 12	1,063	84–63	0	97	93	88	96	82	25.9	23.6	70.7	71.2
	3	Oct. 12	694	78–60	5	106	87	88	92	88	36.5	34.7	73.6	70.0
						100	94	99	92					

[1] Where two sets of results are shown for a given section the figures given on the upper line represent tests of beams coated on top only, while those on the lower line represent tests of beams coated on sides as well as top.

TABLE 16.—*Summary of data and test ratings for sections cured with Headley asphalt emulsion*

Subgrade	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings[1]				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
			Feet	*° F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Earth	1	Aug. 21, 22	1,085	87–78	2⅝	72	93	90	82	91	20.9	20.1	67.3	64.8
	2	Sept. 21	909	79–52	0	97	91	93	81	99	34.9	34.9	73.1	92.4
	3	Oct. 25	1 004	62-46	2⅞	101	86	89	89	97	24.5	22.8	51.2	56.8
						88	94	76	78					
	4	Nov. 17	485	53–35	1½	111	109	87	97	95	25.5	24.2	52.6	50.0
Tar paper	1	Aug. 23	1,050	87–78	2⅝	94	98	86	94	18	22.8	20.6	65.2	62.8
	2	Sept. 22	773	79–54	½	116	111	89	112	96	38.6	36.8	75.0	76.2
	3	Oct. 26	531	61–45	2⅞	118	101	94	99	86	53.1	37.9	90.0	64.2
						140	94	95	104					

[1] Where two sets of results are shown for a given section, the figures given on the upper line represent tests of beams coated on top only, while those on the lower line represent tests of beam coated on sides as well as top.



SPREADING BITUMINOUS MATERIAL ON RESEARCH SIDE OF PAVEMENT

satisfactory as it was possible to devise. The core strength ratings for these sections parallel quite closely the corresponding values for Hunt Process. Only in one case, that of cycle No. 2, earth subgrade, was the crushing strength of the concrete appreciably higher. It so happens that this particular cycle received no rain for three weeks. However, the corresponding section on tar paper subgrade laid on the following day shows a core strength rating of only 82 per cent of standard. In general, the same conclusion may be drawn as in the case of Hunt Process: That the crushing strength of the concrete is somewhat reduced by the use of this curing method.

The same tendency to excess transverse cracking is noted on all of the seven sections cured with Curcrete, as was shown in the case of Hunt Process. The individual section ratings vary from 54 to 87 per cent of standard. The average uncracked slab length as of May 26 is about 25 feet. This figure is in striking contrast with the average of about 55 feet for the 21 burlap cured sections. It is of interest to note that two of the sections showing the greatest cracking were laid on September 11 and 12. These sections received no rain at all for a period of three weeks. It is also notable that the section laid on August 18 showed excessive cracking in spite of a two-inch rainfall on August 21. Another point worthy of note is that cycle No. 4, laid November 15 and 16, showed a crack spacing of 44.4 feet, considerably greater than that of any of the sections laid earlier in the year. Reference to Figure 1 will show that temperatures following the laying of this section were rather low.

Headley asphalt emulsion.—This asphaltic emulsion was used on seven sections for a total of 5,837 feet. The essential data are given in Table 16. The same general tendencies as regards beam and core strength apply to these sections as to those cured by Hunt Process and by Curcrete. There are no particularly unusual results and it is believed that the same general conclusions regarding strength may be drawn.

Similar comments may be made regarding cracking. The average rating for the seven sections is approximately 65 per cent of standard and the average uncracked slab length is about 26 feet. The sections laid September 21 and 22 show less cracking than those laid August 21 and 23 and also less than the section laid November 16 and 17. The section laid October 26 also shows relatively few cracks, although the section rating is low (64 per cent).

Tarvia K. P. and Tarvia B.—Three sections were cured by means of a spray application of Tarvia K.P. This is a cut-back tar product used in cold patch work, having a specific viscosity (Engler, at 40° C.) of 78.4. The results obtained from these tests are summarized in Table 17. One of these sections, laid on September 13, was only 259 feet long and it is reported that, on this section, the spraying was very unsatisfactory. No beam strengths are available for this section and the core strengths are low. The crack rating is higher than for any other of these sections, but the uncracked slab length is only 14.4 feet. Both the remaining sections show characteristics very similar to those exhibited by the sections cured with asphalt. The same

Table 17.—*Summary of data and test ratings for sections cured with Tarvia K. P. and Tarvia B*

Type of treatment	Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings[1]				Core strength rating at one year	Average slab length		Slab length rating	
						3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
			Feet	*Degrees F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
Tarvia K. P., earth, subgrade	1	Aug. 11, 13	1,551.5	90–74	3¾	111	103	104	93	88	26.3	24.2	64.4	60.9
Do	2	Sept. 13	259	82–62	0					72	16.2	14.4	68.7	72.2
Tarvia K. P., tar paper on subgrade	1	Aug. 14	816	90–74	3⅞	110	106	98	74	79	18.5	17.0	45.4	45.8
Tarvia B, earth subgrade	1	Sept. 17	440	77–52	0	95	80	80	90	96	22.0	21.0	65.0	61.9
Do	2	Sept. 14	371	80–57	0	94	78	86	100	107	17.7	15.5	66.7	62.5
Do	3	Nov. 1	270	58–44	1⅝	83	90	89	106	95	67.5	67.5	100.0	125.0
						94	100	87	98					
Tarvia B, tar paper on subgrade	1	Sept. 17	719	77–52	0	111	99	84	88	75	37.8	36.0	78.9	80.0

[1] Where two sets of results are shown for a given section the figures given on the upper line represent tests of beams coated on top only, while those on the lower line represent tests of beams coated on sides as well as top.

strength tendencies are noted and also the same excess cracking. The section laid August 11 and 13 had an uncracked slab length rating of 60.9 per cent and an average slab length of 24.2 feet. For the corresponding section laid on tar paper these values become 45.8 per cent and 17 feet.

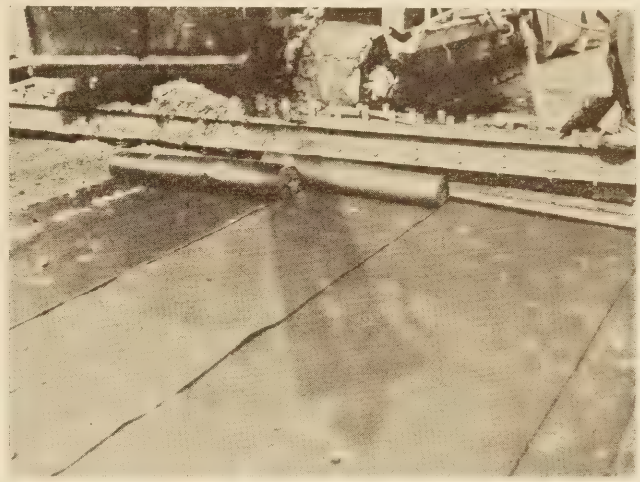
Tarvia B was applied in four short sections. This is a tar product used in the cold surface treatment of roads. The data for these sections are also given in Table 17. The material used had a specific viscosity (Engler, at 40° C.) of 17.7. Tarvia B gave essentially the same results as the asphalt cures, although the sections are in reality too short to permit of trustworthy analysis. The only section which is out of line with the general results is the one laid November 1, which showed relatively wide crack spacing. This section is only 270 feet in length. Considerable rain fell on the section during the first few days and this fact, together with the low temperature immediately following the placing of the section, probably accounts for the favorable result.

GENERAL COMMENTS REGARDING CRACKING ON ASPHALT AND TAR-CURED SECTIONS

The most reasonable theory to account for the relatively large number of cracks which have developed on the sections cured with asphalt and tar is that the absorption of heat by the black surface followed by cooling at night produced a greater temperature range in slabs cured in this manner than in those cured by the standard earth and water method and that this increased temperature change in turn caused excessive cracking. Measurements conducted by the Bureau of Public Roads and reported in Public Roads for February, 1930 [1] indicate that, for comparable conditions of exposure, concrete coated with bituminous material may show a temperature 10° C. higher than uncoated concrete. Evidence that this excess cracking is a temperature effect is also indicated by the fact that considerably more cracking developed on those sections placed in the morning and immediately sprayed with bituminous material than on that portion of the pavement placed in the afternoon. The concrete placed before noon was of course exposed to the sun for a considerably longer period, so that when cooling took place at night a greater drop in temperature occurred. This condition was noted repeatedly during these tests. A typical illustration will be cited.

The Hunt Process section laid on tar paper on September 10 was subjected to practically 100 per cent sunlight and high temperature during the first three weeks of its life. The section is 975 feet in length. The joints were 200 feet apart with the exception of the last section. which measured 175 feet. Approximately the same length of pavement was laid in the forenoon as in the afternoon. On September 11, the day after the concrete was laid, five cracks had appeared in the section laid in the forenoon and none in that laid in the afternoon. On November 9, 1928, a survey of this section showed 14 cracks in the forenoon work and only 8 in the afternoon work. Furthermore, of the 14 morning cracks, 9 appeared in the first 200-foot slab, or more than in the entire afternoon run of approximately 500 feet. On May 26, 1930, the cracks had increased to 20 in the morning work and to 14 in the afternoon, with 12 cracks showing in the first 200 feet.

[1] "The Arlington Curing Experiments," by L. W. Teller and H. L. Bosley



Laying Tar Paper on Subgrade

This section is cited simply as an illustration of a condition which is typical of most of the sections cured with bituminous materials. Unfortunately the crack spacing at early periods was not determined for the sections laid in November, so we are unable to say just how these would compare with those laid in warmer weather. In so far as final cracking is concerned, reference to Table 5 will show in general a greater crack spacing for those sections laid under cold weather conditions. The following examples may be noted: Hunt Process, October 20, 48.2 feet; Barber Curcrete, October 11, 33.4 feet; Barber Curcrete, November 15–16, 44.4 feet; Barber Curcrete, October 12, 34.7 feet; Headley emulsion, October 26, 37.9 feet; Tarvia B, November 1, 67.5 feet. Certain other sections showed excessive cracking even in the cooler weather, such as Hunt Process, November 12, 19.5 and Headley emulsion, October 25, 22.8 and November 17, 24.2 feet.

In general, it is believed that the temperature effects of such bituminous cures as were used in this experiment are sufficiently severe to indicate that these methods are unsatisfactory under the general climatic

TABLE 18.—*Summary of data and test ratings for sections cured by "poor earth" method*

Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
					3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
		Feet	*°F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
1	Aug. 6, 7, 8	1,280	92–75	1¾	91	91	97	84	83	55.6	47.4	121.8	114.7
2	Sept. 18	1,121	78–52	0	106	86	96	95	101	70.1	70.2	93.7	93.8
3	Oct. 13	346	76–59	5	110	110	105	110	107	86.5	86.5	100.0	100.0
4	Oct. 18	571	71–50	2½	103	110	100	104	105	81.6	63.5	85.7	66.7

TABLE 19.—*Summary of data and test ratings for sections cured by ponding*

Cycle No.	Date laid	Length of cycle	Average temperature range, 10-day period	Rainfall, 10-day period	Beam strength ratings				Core strength rating at one year	Average slab length		Slab length rating	
					3-day	7-day	14-day	28-day		Dec. 3, 1929	May 26, 1930	Dec. 3, 1929	May 26, 1930
		Feet	*°F.*	*Inches*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Feet*	*Feet*	*Per cent*	*Per cent*
1	Aug. 9, 10	570	91–74	1¾	99	95	90	89	97	40.7	38.0	92.8	86.7
2	Sept. 19	1,330	79–53	0	94	83	96	96	108	63.4	55.4	80.9	83.3
3	Oct. 15, 16	305	73–52	3	119	100	100	98	98	61.0	61.0	100.0	100.0

conditions which obtained during these tests. Furthermore, the data seem to indicate that somewhat lower crushing strength results when the bituminous seals are used.

It has been claimed that the relatively poor showing of the bituminous cures is due to the fact that the edges of the pavement were not sprayed with the bituminous material immediately upon removal of the forms. It should be pointed out in this connection that no criticism of the method used was advanced by any representative of an interested company during construction, in spite of the fact that such representatives were present. It seems hardly possible that failure simply to spray the edge of the pavement could have permitted sufficient drying to cause the excessive cracking noted. The area of the outside edge in comparison with the total volume of concrete is so small as almost to preclude the possibility of such action. Furthermore, the manufacturers of bituminous curing materials claim that much of the effectiveness of their material is lost if it is not sprayed on the concrete before final set takes place. This obviously is impossible in the case of the edge, which can not be sprayed until the next day. Moreover the same excessive cracking has been observed in other concrete pavement construction in which the edges of the pavement were treated with bituminous material upon removal of the side forms.

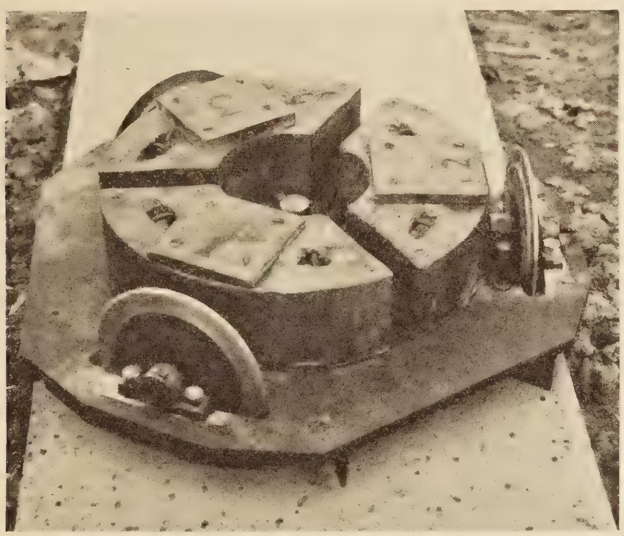
Poor earth cure.—Four sections of pavement, totaling 3,318 feet, were cured by means of earth kept only moist in an effort to simulate what might be termed "poor earth curing." The results are summarized in Table 18. The section laid September 18 is of interest because of the fact that no rain fell until October 2, or fourteen days after placing. This section is rated above 100 per cent in core strength and above 90 per cent in uncracked section length. The average slab length on May 26, 1930, was 70.2 feet. This may be considered an excellent showing. The section laid August 6 to 8 also showed up fairly well from the standpoint of cracking, although low as regards core strength. No rain fell on this section until August 15, seven days after laying. The sections laid October 13 and October 18 are of no great significance, due to the rain which fell during the 10-day period. In general, the sections cured in this manner gave results which compare very favorably with the standard method.

PONDING ON ONE SIDE, STANDARD EARTH AND WATER CURE ON THE OTHER

Ponding.—On three sections totaling 2,205 feet, the surface of the concrete was cured by ponding in the usual manner. Table 19 gives the essential data regarding these sections. The section laid September 19 is the most interesting due to the fact that no rain fell until October 2, or 13 days. This is a section comparable with that laid on September 18 and cured by the "poor earth" method. The results are somewhat similar, although the crack rating on the ponded section is considerably lower than on the "poor earth" section. The average uncracked slab length on May 26 is also considerably less, amounting to only 55.5 as compared to 70.2 feet for the "poor earth cure." These results are, of course, directly opposed to accepted engineering thought on this subject, which has always held that ponding constitutes the most efficient method of cure possible to apply. No explanation is offered except the possibility that the blanket of dry earth used on the "poor earth cure" section may have acted as an insulating agent, so that the total range in temperature of the concrete was reduced beyond that which was attained by the ponded slab. There are, of course, no test data upon which such a conclusion could be based. The theory is simply noted as a possible explanation for an observed condition which can be explained in no other way. It is certainly true that extreme temperature variation in concrete slabs should be prevented as much as possible especially during the early periods, when it is also essential to retain moisture for hydration. Investigations should be conducted for the purpose of determining the insulating effect of dry earth and dry straw on new concrete, compared to wet earth, wet straw, or ponding.

RESULTS OF SURFACE HARDNESS TESTS DISCUSSED

The tests for surface hardness, using the apparatus developed by the Bureau of Public Roads, were run on selected sections for each of the curing methods. The test, which is fully described in the July, 1929, issue of Public Roads, consists essentially of subjecting the surface of the pavement to the wear produced by three solid steel wheels, 8 inches in diameter and one-fourth inch wide, traveling in a circle 21 inches in diameter. The wheels are mounted on a flat horizontal plate which is operated by a vertical spindle driven by an electric motor. The total weight on the wheels is approximately 450 pounds, and the plate turns at the rate of approximately 35 revolutions per minute. The action of the test is to cut a circular groove in the mortar surface, the depth of which is measured by means of an Ames dial, suitably mounted. Readings are taken after any given number of revolutions of the spindle.



The Machine for Testing Surface Hardness

The results of the hardness tests, which are given in Table 6, are repeated in graphic form in Figure 3. Depths of wear were measured after 1,000 revolutions, and are recorded in decimals of an inch. It will be noted that the maximum wear in any case was 0.077 inch (or less than one-tenth inch) so that the test is in reality a test of the hardness of the mortar top. Any coarse aggregate appearing during the test would obviously affect the results considerably, especially if the particles were appreciably harder than the mortar, which was the case in this concrete.

In Table 6 the hardness rating is reported as the percentage which the wear on the research side bears to the wear on the standard side, so that values less than 100 indicate harder concrete on the research side and values more than 100 indicate softer concrete on the research side. In making the comparisons at any given location, great care was exercised to select two portions of the surface which were, so far as visual appearance is concerned, identical. This was done in order to eliminate as far as possible variation due to method of finishing, water content, etc. Each value reported in Table 6 represents the average of three tests taken at different locations on the section indicated.

Referring now to the table as well as to Figure 4, on which the results are shown graphically, and considering first the burlap cures, we observe that, in all cases, somewhat less wear was obtained with the experimental method. Tests on the burlap cured sections were all run on sections placed during the first

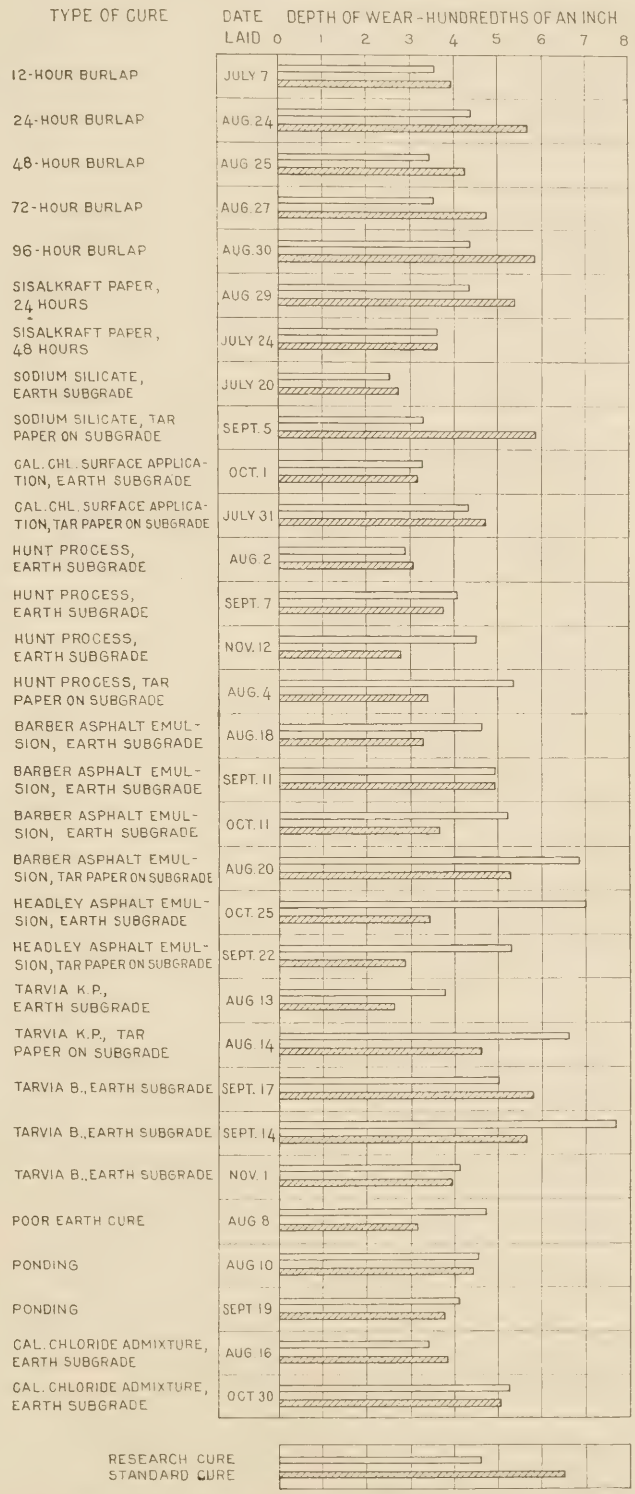


Figure 4.—Results of Hardness Tests of Sections Cured by Various Methods, Compared With the Results Obtained for the Corresponding Standard-Cured Sections

cycle and for this reason the results are obscured somewhat by the effects of rainfall. The 12-hour section was unquestionably the most severe condition from the standpoint of lack of moisture. This section showed 90 per cent of the wear of the corresponding earth and water cured section, indicating very little difference in surface hardness between the burlap and the standard method. The same comments apply to the concrete cured with sisalkraft paper.

Tests on the section laid September 5 and cured with sodium silicate are interesting. It will be recalled that this section received no rain for a month after laying. The wear on the standard, or earth-cured side, was almost double that on the side cured with silicate. This indicates a definitely harder mortar surface in the case of the silicate cure.

Making Surface Hardness Tests on the Tennessee Curing Project

Tests on sections cured with a surface application of calcium chloride indicate no difference in the hardness of the concrete as the result of this treatment. Essentially the same results were secured on both sections. In the case of the admixture, somewhat less wear was obtained on one of the sections tested (cycle No. 1, earth subgrade), whereas on the other no appreciable difference is noted.

The results of hardness tests on the sections cured with bituminous materials are significant in that a distinct softening of the surface is noted in many cases. On 12 of the 15 bituminous-cured sections on which wear tests were conducted, the depth of wear was greater on the research side. On 10 of these sections the wear was appreciably greater, whereas in only one case was it appreciably less. It is believed that the data indicate definitely that the wear resistance of concrete is not increased and is probably decreased by the use of these bituminous curing methods.

RESEARCH-CURED BEAMS SHOW HIGHER STRENGTH THAN THOSE NOT CURED

In Table 4 are given, for each test section, the results of beam tests made on specimens which were given no curing treatment of any kind, together with the ratios, in each case, of the research-cure specimens to the corresponding no-cure specimens. These data are of interest in showing the efficiency of the several research cures as affecting beam strength under various weather conditions. It will be noted that in general the research-cured beams show substantially higher strength than beams which were not cured. No detailed analysis of these data will be given in this report. The data are made available, however, in case the reader desires to make such an analysis.

Beams Treated With Asphalt Emulsion

GENERAL DISCUSSION

In order to obtain a general idea of the behavior of the several curing methods under average weather conditions, the average values of beam and core strength and uncracked slab length for each curing method have been plotted in Figures 5 to 9, inclusive. Figure 5 gives the ratings for the beam strength tests at each of the four ages; Figure 6, the ratings for core tests at one year; Figure 7, the average uncracked slab length ratings in per cent; Figure 8, the corresponding data in feet, and Figure 9, the average ratings of the various cures, arranged in order of descending value when measured in terms of extent of cracking as compared with the corresponding standard-cure sections.

Beams Under Cure

On reference to Figure 5, it is immediately apparent that, in the great majority of cases, the strength of earth and water cured beams was not attained by the experimental methods. The data also indicate in most cases a falling off in relative strength for the research cure with increase in age. This condition would indicate one of two things: Either that the particular manner of curing the test specimens used in this investigation was at fault, or that the curing method, in itself, was inadequate to retain the moisture. The authors will admit the probability of the first assumption being the true one, and repeat their recommendation that, in future work, strength data on effect of curing be obtained in the laboratory under standardized conditions or that arrangements be made to take specimens from the full-size structure.

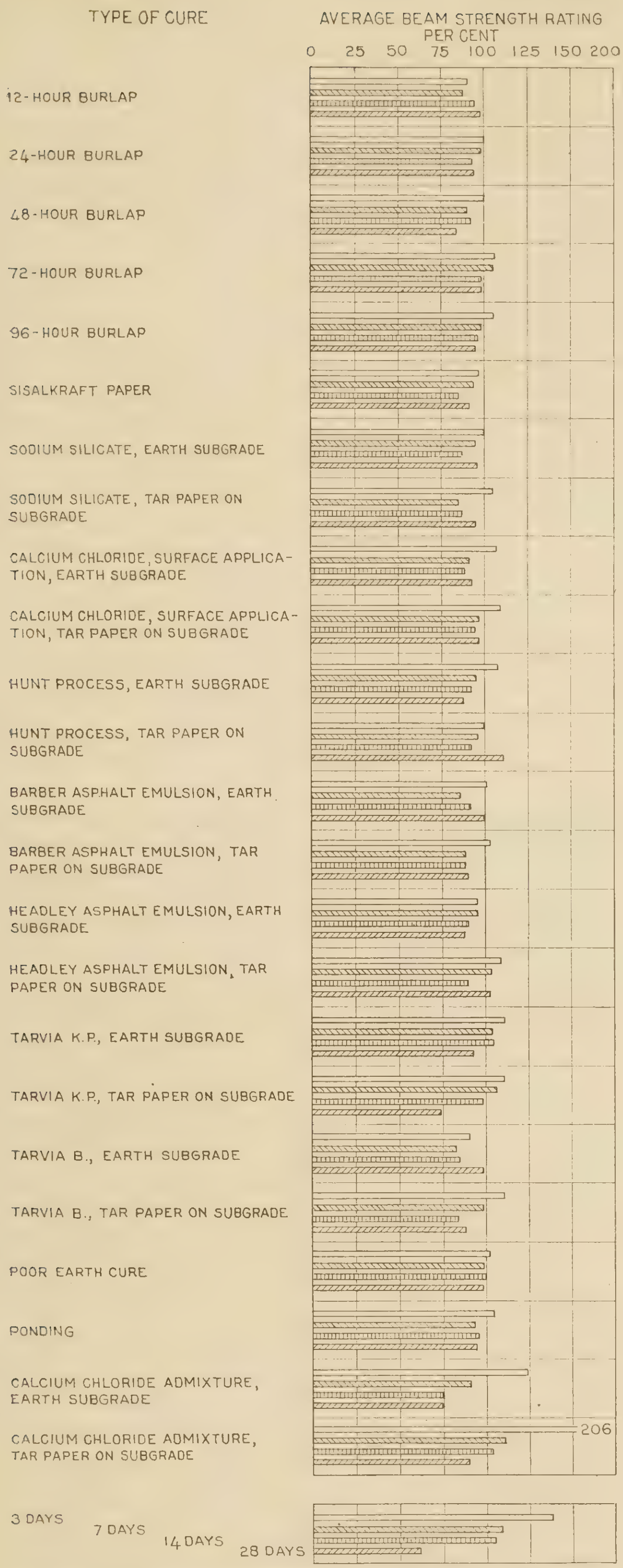


Figure 5.—Relative Strengths of Molded Beams at Various Ages Compared With Similar Specimens Cured by the Standard Wet-Earth Method. Average Beam Strength Ratings are Expressed as Percentages of the Strengths Obtained for Corresponding Standard-Cured Beams

The average crushing strength ratings shown in Figure 6 are also of interest in that they indicate lower

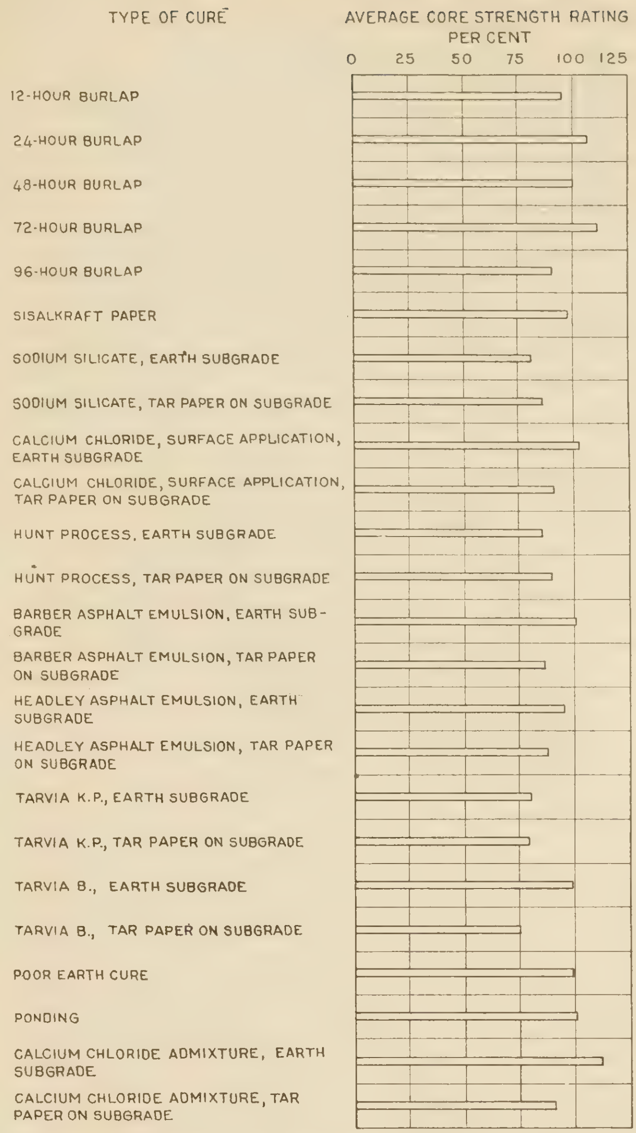


Figure 6.—Relative Strengths of Concrete Cores at One Year Compared With Similar Specimens Drilled From Concrete Cured by the Standard Wet-Earth Method. Average Core Strength Ratings are Expressed as Percentages of the Strengths Obtained for Corresponding Standard-Cured Cores

relative strength in the case of sodium silicate and most of the bituminous cures. Burlap cures in general as well as ponding and poor earth cure show results as good as or better than those given by the standard cure. Calcium chloride, both as a surface application and as an admixture, shows relatively high average crushing strength in the case of the sections laid directly on earth subgrade, and relatively low strength in the case of those sections which were laid on tar paper. No explanation is offered for this and the authors are inclined to believe that it is not significant. Attention is also called to the fact that of the eight cases where earth subgrade sections may be compared to similar sections laid on tar paper, six sections show lower relative strength when laid on tar paper. This difference seems to be quite well marked in the case of curcrete, Tarvia B and the calcium chloride sections. A reversal, however, is indicated for Hunt Process and sodium silicate.

Drilling Cores for Compression Tests

Figures 7 and 8 give the average results in regard to cracking. The basis of comparison in Figure 7 is rating in terms of corresponding earth cure, whereas in Figure 8 the comparison is on the basis of average lengths in feet. Figure 7 is of interest in showing that in nearly all cases the extent of cracking is greater on the experimental side of the pavement. Except in the case of the bituminous cures, the difference is not great. In fact there was a general tendency for nearly the same number of cracks to occur on both sides of the longitudinal joint. The graphical record of the crack survey, which is omitted from this article for lack of space, shows that the greater number of these cracks are continuous across both sides of the pavement, a few additional cracks occurring on one or both sides. The fact that so many cracks were carried across the longitudinal joint indicates that there was considerable restraint along this joint, in spite of the precautions which were taken to prevent it. Because of this condition, Figure 8, giving the average uncracked slab length, is the better criterion for judging the relative efficiency of the different research cures. In the comparison of a given research cure with the standard cure, Figure 7, giving the slab length rating, is significant in spite of the existence of restraint across the joint, for the presence of additional cracks on one side of the pavement or the other indicates inferior curing. It is to be recognized, of course, that the variable weather conditions under which the numerous test sections were laid made precise comparisons impossible. However, the averaging of data for sections laid at various times during the construction season tends to iron out the effect of these varying conditions, permitting general deductions to be drawn.

Judged by either Figure 7 or Figure 8, the bituminous cures show unfavorable results in comparison with the standard earth and water cure and the other research cures. The effect of restraint across the joint is clearly indicated by the fact that the standard-cured sections laid opposite to those subjected to bituminous cures show average slab lengths much less than the standard-cured sections laid opposite to the other types of cure. It will be observed that, among the research-cured sections, those cured with burlap, ponding, and poor earth show the greatest uncracked section lengths (about 55 feet) with calcium chloride, Sisalkraft paper, sodium silicate, and the several bituminous cures following in the order named. It will also be noted that very little cracking occurred between December 3, 1929, and May 26, 1930.

SIGNIFICANT DATA SUMMARIZED FOR VARIOUS TYPES OF CURING

The object of a concrete pavement curing agent is not only to supply moisture to the concrete but also to prevent or minimize the internal stresses which may develop during the early hardening period. These internal stresses may be caused by loss of moisture or excessive temperature change or both, and will of course develop transverse cracking in proportion to their magnitude. It should be possible therefore to measure the extent to which the various treatments function in this regard by noting the relative amount of cracking which has developed, especially in those sections subjected to the most severe conditions of temperature change and lack of rainfall. In drawing the conclusion to this report, major consideration has therefore been given to the behavior of

Bituminous-Cured and Standard-Cured Sections After Formation of Cracks. Note Crack Spacing on Either Side of Longitudinal Joint

those sections upon which the least rain fell during the normal 10-day curing period. The report will be summarized with a brief statement regarding the behavior of that section for each curing method which, from the above standpoint, gave the method its severest test. Certain curing methods are not represented in this summary. Ponding, for example, is not affected by rainfall. In the case of calcium chloride admixture considerable rain fell on all the sections, which were, moreover, of insufficient length to afford a very significant comparison with other methods. The sections cured with Sisalkraft paper were also subjected to considerable rainfall. As regards Tarvia K. P., the section laid September 13, on which no rain fell, was only 259 feet in length. For these reasons it was thought best to omit these types of cure from consideration in the final summary.

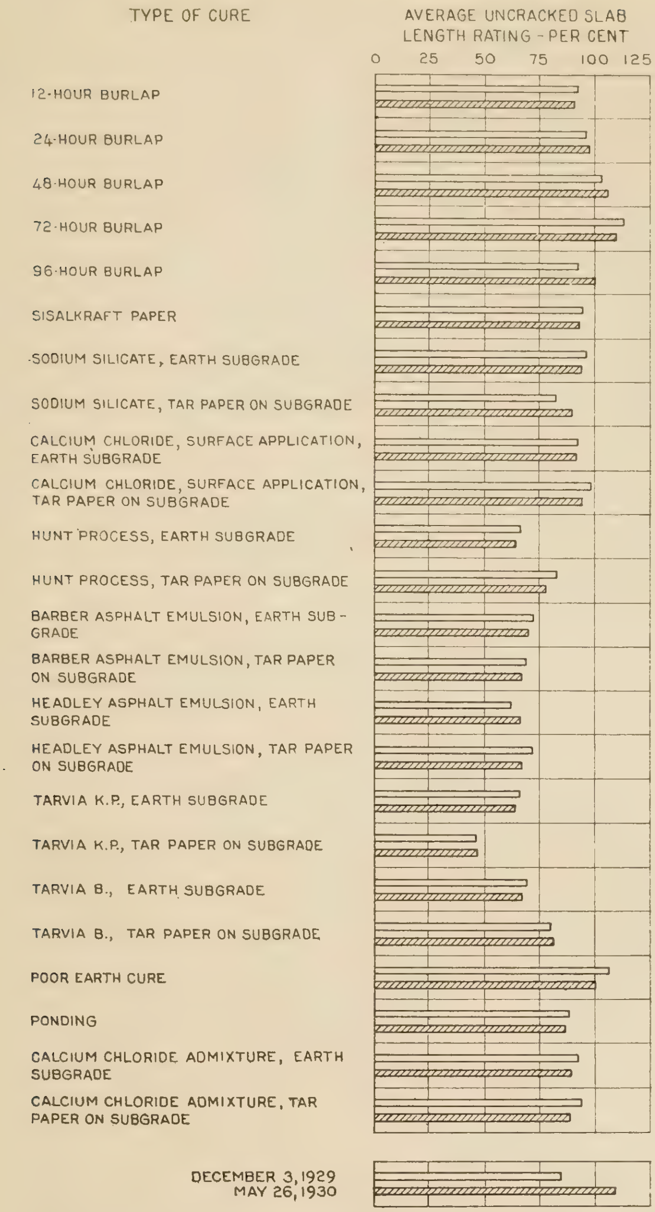


Figure 7.—Relative Average Length of Uncracked Slab Compared With Corresponding Sections Cured by the Standard Wet-Earth Method. Average Uncracked Slab Length Ratings are Expressed as Percentages of the Average Lengths for the Corresponding Standard-Cured Sections

1. *Burlap applied for 24 hours.*—Section laid August 24, 1,022 feet in length. Average temperature during ten days, maximum 85°, minimum 78°. One and one-half inch rain on the seventh day, one inch rain on the 8th day.

Average slab length rating, per cent	119
Average slab length, feet	64
Core strength rating at one year, per cent	102

2. *Burlap applied for 96 hours.*—Section laid August 30, 867 feet in length. Average temperature during ten days, maximum 81°, minimum 61°. One and

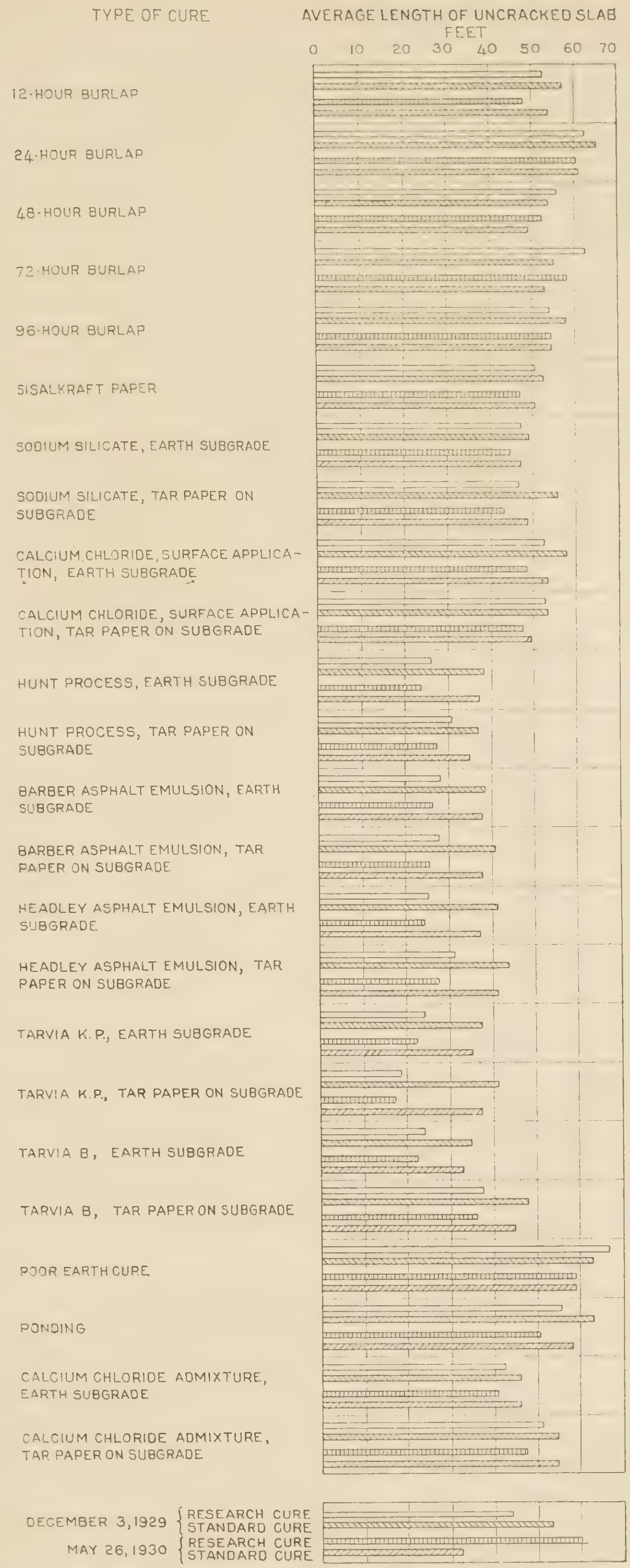


Figure 8.—Results of Crack Survey. Average Length of Uncracked Slab for Each Type of Cure Compared With That for the Corresponding Standard-Cured Section

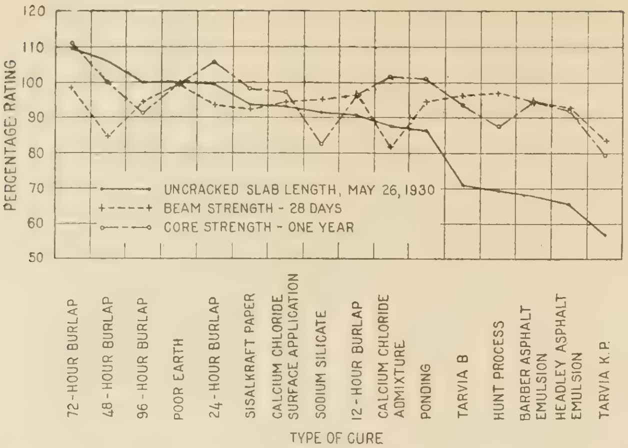


FIGURE 9.—COMPARISON OF AVERAGE RATINGS IN RESPECT TO UNCRACKED SLAB LENGTH, BEAM STRENGTH AT 28 DAYS, AND CORE STRENGTH AT ONE YEAR, FOR VARIOUS CURING METHODS. THE CURING METHODS ARE ARRANGED IN DESCENDING ORDER OF AVERAGE UNCRACKED SLAB LENGTH RATING

one-half inches rain on first day and one inch rain on second day. No further rain until October 2. All rain fell before burlap was removed.

Average slab length rating, per cent	100
Average slab length, feet	54
Core strength rating at one year, per cent	92

3. *Sodium Silicate.*—Section laid September 6, 1,087 feet in length. Average temperature during ten days, maximum 89°, minimum 68°. No rain on this section for 26 days.

Average slab length rating, per cent	85
Average slab length, feet	40
Core strength rating at one year, per cent	85

4. *Calcium chloride, surface application.*—Section laid September 4, 588 feet in length. Average temperature during ten days, maximum 87°, minimum 66°. No rain on this section for 28 days.

Average slab length rating, per cent	100
Average slab length, feet	39
Core strength rating at one year, per cent	96

5. *Hunt Process.*—Section laid August 1, 2, 1,459 feet in length. Average temperature during ten days, maximum 92°, minimum 78°. One-eighth inch rain on August 2 (from 6 to 7 p. m.).

Average slab length rating, per cent	86
Average slab length, feet	29
Core strength rating at one year, per cent	73

6. *Barber asphalt emulsion* (*Curcrete*).—Section laid September 11, 1,097 feet in length. Average temperature during ten days, maximum 86°, minimum 64°. No rain fell on this section for 21 days.

Average slab length rating, per cent	70
Average slab length, feet	20
Core strength rating at one year, per cent	119

7. *Headley asphalt emulsion.*—Section laid September 21, 909 feet in length. Average temperature for 10-day period, maximum 79°, minimum 52°. No rain fell on this section for 11 days.

Average slab length rating, per cent	92
Average slab length, feet	35
Core strength rating at one year, per cent	99

8. *Tarvia B.*—Section laid September 17, total length 1,159 feet. Average temperature during ten days, maximum 77°, minimum 52°. No rain fell on these sections for 15 days.

Average slab length rating, per cent	[2] 71
Average slab length, feet	[2] 28
Core strength rating at one year, per cent	[2] 86

9. *Poor earth cure.*—Section laid September 18, 1,121 feet in length. Average temperature during ten days, maximum 78°, minimum 52°. No rain fell on this section in 14 days.

Average slab length rating, per cent	94
Average slab length, feet	70
Core strength rating at one year, per cent	101

CONCLUDING STATEMENT

It is believed that the results of this investigation justify the following comments relative to the merits of the various curing methods as compared with the standard method of curing with earth and water, under the conditions pervailing during the progress of these tests.

1. *Burlap curing.*—Results indicate that the method of cure involving the application of wet burlap for periods varying from 24 to 96 hours without further curing compares quite favorably with the standard method. No final conclusions can be drawn until additional tests under more severe weather conditions are made.

2. *Sisalkraft paper.*—The rather meager results indicate that the application of Sisalkraft paper for periods of 24 to 48 hours without further curing is a reasonably satisfactory method of cure as compared with the standard method.

3. *Poor earth cure.*—Indications are that it is not necessary to keep the earth saturated with water for the entire 10-day curing period.

4. *Sodium silicate.*—Indications are that this method of cure gives results somewhat less satisfactory than those given by the standard method.

5. *Calcium chloride, surface application.*—This method appears to give results very nearly as satisfactory as the standard method.

6. *Calcium chloride admixture.*—The authors feel that the sections on which the admixture was used are too short to warrant any conclusion as to the merit of this method.

7. *Bituminous materials.*—Indications are definite that curing with bituminous materials, as used in these test, is unsatisfactory, because of the marked evidence of increased transverse cracking.

8. *Tar paper on subgrade.*—Results indicate that nothing is gained by the use of tar paper on the subgrade.

[2] Average of section laid on earth and section laid on tar paper.

RECENT PUBLICATIONS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS

The American Society for Testing Materials has recently issued its Book of A. S. T. M. Standards, a triennial publication containing all specifications, methods of testing, and definitions fully approved and adopted, and the 1930 Book of A. S. T. M. Tentative Standards, an annual publication, containing those specifications, methods of testing, etc., having a tentative status. The society has also published its annual Index to A. S. T. M. Standards and Tentative Standards.

BOOK OF A. S. T. M. STANDARDS

The Book of A. S. T. M. Standards is published in two parts, Part I on metals (1,000 pages) containing the standards relating to metallic materials and Part II on nonmetals (1,214 pages) containing standards covering nonmetallic materials.

Part I.—Of the 179 standards on metals published in Part I, 105 cover the ferrous metals, steel, cast iron, wrought iron, alloy steel, and ferro-alloys, and 67 relate to the nonferrous metals, nickel, copper, aluminum, etc., and many alloys, while 7 are of general interest.

The standards in Part I, assembled in a sequence determined by the specific materials or products to which they apply cover steel rails and accessories; wheels and tires; structural and boiler steels; steel for welding, concrete reinforcement steel; bar steels; spring steel and springs; steel castings, chain, forgings, and axles; steel tubes and pipe; tool steel, steel for high-temperature service; zinc-coated wire and wire products; wrought-iron bars, castings, plates, and pipe; pig iron; cast-iron and finished castings; malleable castings and ferro-alloys. The specifications in the nonferrous group cover ingot copper, zinc, lead, nickel, aluminum and aluminum alloys, copper wire and cable, brasses and bronzes, solder metal, white-metal bearing alloys, copper and brass plates and tubes. Methods are also included for Brinell hardness tests, metallographic testing, preparation of micrographs for metals and alloys, and a recommended practice for radiographic testing of metal castings. Definitions of terms relating to wrought iron, to methods of testing, to metallography and to specific gravity are also included. New standard specifications have been adopted this year for steel tie-plates, iron and steel chain, gray-iron castings for valves, seamless copper tubing, and bronze and hard-drawn copper trolley wire, as well as several specifications for galvanized wire and wire products and specifications for zinc (hot galvanized) coatings on structural steel shapes and plates. Included in addition to these specifications are new standard methods of sampling rolled and forged steel products for check analysis and test methods for galvanized wire and wire products and a test for change of resistance with temperature of electrical heating materials. Standard specifications for open-hearth steel rails, concrete reinforcement bars, steel pipe and boiler tubes, hot-rolled bar steels and cold-finished shafting, malleable castings, and wrought-iron bars, plates, and pipe that were revised during the year have also been included.

Part II.—The 251 standards in Part II cover the following miscellaneous groups of nonmetallic materials and products: Cement, lime, gypsum, concrete and concrete aggregates; brick and refractories; pipe and drain tile; hollow building tile; paints, pigments, shellacs, and varnishes; petroleum products and lubricants; bituminous and nonbituminous road materials; coal and coke; timber and timber preservatives, waterproofing and roofing materials; insulating materials and rubber products; textile materials; and thermometers for general use. Included in this volume are new standards adopted this year comprising specifications for paving and building brick; sand-lime brick; wall, floor, and partition hollow clay tile; Keene's cement and gypsum plasters; gravel for bituminous concrete; several specifications for tar cements for road application; tolerances for cord-tire fabrics and other fabrics; methods of testing concrete aggregates, gypsum, and gypsum products; analysis for color of paints; tests for sulphur in gasoline; melting point of petrolatum; test for autogenous ignition temperatures of petroleum products; mechanical analysis of coal; and test methods for electrical porcelain. The specifications for Portland cement, revised to include higher tensile strength requirements, and the methods of testing cement, changed by the inclusion of tolerances on weights and dimensions of apparatus, are also included. Of particular interest are the revised standard specifications for structural wood, joists and planks, beams and stringers, and posts and timbers.

1930 BOOK OF A. S. T. M. TENTATIVE STANDARDS

The Book of Tentative Standards (864 pages), an annual publication, contains 155 tentative specifications, methods of test, definitions of terms, and recommend practices, 28 relating to metals and 127 to nonmetallic materials and products. The tentative standards are issued for one or more years with a view to obtaining criticisms. Although in the trial stage of A. S. T. M. procedure, they represent the latest thoughts of the committees on the subjects covered and are therefore being applied in the various industries. Many of the tentative standards are frequently used in conjunction with the A. S. T. M. standards.

Included in this volume are 21 new tentative standards developed this year. In the metals group are new specifications for austenitic manganese-steel castings, open-hearth iron plates; aluminum alloy (duralumin) sheet; aluminum-manganese alloy sheet and magnesium-base alloy castings; aluminum-base alloy castings and ingots and copper-base alloys in ingot form; and a method of test for thermoelectric power. A specification for high early-strength Portland cement is an important contribution to the construction field, as are also new specifications for reinforced-concrete pipe and reinforced-concrete culvert pipe, and specifications for gypsum sheathing board, timber piles, glazier's putty, test methods for natural building stone, and a flexure test for concrete. Of interest in the automotive field are the test for dilution of crankcase oil and a test for vapor pressure of natural gasoline. A test method is also included for comparing the thermal conductivities of solid electrical insulating materials. New tentative specifications have been developed for several lacquer solvents and diluents, namely, amyl acetate, amyl alcohol, butyl propionate, and ethyl lactate. Revisions were also made in 25 of the tentative standards developed in former years in order to keep them abreast of current practice.

INDEX TO A. S. T. M. STANDARDS AND TENTATIVE STANDARDS

An index (110 pages) of all A. S. T. M. standards and tentative standards has been prepared and is being distributed without charge. The index is a compilation, under appropriate key-word subjects covered by the standards, of titles of all standards, together with volume references to the publications in which they appear, namely, Parts I and II of the 1930 Book of A. S. T. M. Standards and 1930 Book of A. S. T. M. Tentative Standards and the Annual Proceedings. The index is designed to be of service to those familiar with the society's standards in locating specifications, methods of test, or definitions in the bound publications in which they appear, as well as to those interested in ascertaining if the society has issued any standards on a specific subject.

INDEXES TO VOLUMES NOS. 8 AND 9 OF PUBLIC ROADS AVAILABLE

Indexes to volumes 8 and 9 of Public Roads have recently been printed and are available for distribution upon request. The indexes to volumes 6 and 7 were issued some time ago, and a supply of these indexes is still available for distribution. It is planned to issue indexes to volumes 10 and 11 during this year and thereafter to issue an index annually.

ROAD PUBLICATIONS OF BUREAU OF PUBLIC ROADS

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

ANNUAL REPORTS

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

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.
*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.
*463D. Earth, Sand-Clay, and Gravel Roads. 15c.
*532D. The Expansion and Contraction of Concrete and Concrete Roads. 10c.
*583D. Reports on Experimental Convict Road Camp, Fulton County, Ga. 25c.
*660D. Highway Cost Keeping. 10c.
*670D. The Results of Physical Tests of Road-Building Rock in 1916 and 1917.
*691D. Typical Specifications for Bituminous Road Materials. 10c.
*724D. Drainage Methods and Foundations for County Roads. 20c.
1216D. Tentative Standard Methods of Sampling and Testing Highway Materials, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road construction.
1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

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

TECHNICAL BULLETIN

No. 55T. Highway Bridge Surveys.

MISCELLANEOUS CIRCULARS

No. 62M. Standards Governing Plans, Specifications, Contract Forms, and Estimates for Federal-Aid Highway Projects.
*93M. Direct Production Costs of Broken Stone. 25c.
109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails, Flood Relief, and Miscellaneous Matters.

MISCELLANEOUS PUBLICATIONS

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

SEPARATE REPRINTS FROM THE YEARBOOK

No. *914Y. Highways and Highway Transportation. 25c.
937Y. Miscellaneous Agricultural Statistics.
1036Y. Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

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

Report of a Survey of Transportation on the State Highways of Vermont.

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

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

Report of a Survey of Transportation on the State Highways of Pennsylvania.

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

CURRENT STATUS OF FEDERAL-AID ROAD CONSTRUCTION

AS OF

DECEMBER 31,1930

STATE	COMPLETED MILEAGE	UNDER CONSTRUCTION					APPROVED FOR CONSTRUCTION					BALANCE OF FEDERAL-AID FUNDS AVAILABLE FOR NEW PROJECTS	STATE
		Estimated total cost	Federal aid allotted	MILEAGE			Estimated total cost	Federal aid allotted	MILEAGE				
				Initial	Stage[1]	Total			Initial	Stage[1]	Total		
Alabama	2,178.0	$ 3,496,935.94	$ 1,674,991.27	130.2	26.8	157.0	$ 1,458,484.06	$ 722,810.35	70.9	4.2	75.1	$ 5,168,890.72	Alabama
Arizona	892.1	3,564,582.34	2,793,740.90	135.6	142.3	277.9	413,986.62	288,674.87	7.9	10.0	17.9	2,237,201.64	Arizona
Arkansas	1,806.9	6,017,891.94	2,806,259.89	179.2	46.7	225.9	1,222,178.99	605,670.13	23.7	13.5	37.2	2,772,912.42	Arkansas
California	1,945.3	7,353,774.31	3,105,385.74	166.6	25.1	191.7	1,838,958.45	878,686.86	26.2	5.9	32.1	4,076,099.79	California
Colorado	1,284.4	4,136,823.75	2,196,311.34	137.9	57.9	195.8	871,697.68	489,545.35	38.7	32.5	71.2	3,736,615.25	Colorado
Connecticut	252.9	2,190,070.59	959,644.61	12.9		12.9	456,213.95	84,060.00	5.6		5.6	1,262,645.45	Connecticut
Delaware	318.9	106,632.85	53,316.42	4.4		4.4	320,693.10	153,372.55	8.5		8.5	495,696.89	Delaware
Florida	533.8	4,637,253.81	2,206,061.92	76.0	5.5	81.5	754,310.87	348,842.51	27.4		27.4	2,569,374.50	Florida
Georgia	2,662.4	6,258,848.20	2,984,108.86	156.3	123.8	280.1	2,992,194.25	1,391,694.41	84.2	37.9	122.1	4,197,361.93	Georgia
Idaho	1,292.1	2,093,187.46	1,277,606.17	143.6	11.6	155.2	712,959.91	428,013.57	58.4	8.2	66.6	1,630,931.81	Idaho
Illinois	2,167.3	20,362,857.76	9,261,863.43	576.2	68.6	644.8	1,357,755.66	645,586.15	47.7		47.7	7,133,268.00	Illinois
Indiana	1,569.1	2,332,076.25	1,133,362.55	75.3		75.3	4,641,094.20	1,693,935.86	98.6		98.6	4,003,555.80	Indiana
Iowa	3,229.0	105,290.11	1,892.77		4.0	4.0	2,810,112.18	1,151,015.00	41.6	47.8	89.4	2,194,055.62	Iowa
Kansas	2,973.8	4,785,313.73	2,247,984.50	258.4	31.6	290.0	2,678,742.08	1,306,112.46	169.4	52.9	222.3	3,059,397.74	Kansas
Kentucky	1,519.3	5,670,327.62	2,346,264.11	166.2	85.0	251.2	2,468,783.53	555,481.98	46.9	28.3	75.2	1,480,640.71	Kentucky
Louisiana	1,409.7	4,344,555.40	2,104,665.85	156.8	19.1	175.9	2,046,277.86	925,702.88	60.1	12.7	72.8	1,888,529.98	Louisiana
Maine	580.4	2,518,595.24	846,864.82	54.5		54.5	542,428.70	271,214.35	.4		.4	1,918,144.20	Maine
Maryland	684.7	1,016,034.12	473,123.38	9.0	13.2	22.2	158,535.70	41,957.10		2.4	2.4	899,144.32	Maryland
Massachusetts	711.8	6,762,321.06	1,802,841.34	52.6		52.6	1,894,170.88	378,667.93	24.5		24.5	2,469,042.29	Massachusetts
Michigan	1,786.1	7,941,942.34	3,299,485.53	202.3	22.9	225.2	1,149,845.63	505,940.00	41.8	1.5	43.3	4,186,778.95	Michigan
Minnesota	4,314.0	2,141,865.83	790,564.13	23.1	92.9	116.0	5,172,293.19	1,995,745.64	57.3	156.4	213.7	980,922.68	Minnesota
Mississippi	1,830.0	779,216.74	385,918.51	35.7	17.9	53.6	518,222.51	259,111.25		29.8	29.8	5,371,326.61	Mississippi
Missouri	2,588.5	8,630,891.61	3,085,330.09	147.3	54.1	201.4	1,814,392.70	768,271.18	66.3		66.3	2,778,159.75	Missouri
Montana	1,892.3	7,343,731.48	4,144,714.08	573.6	40.9	614.5	844,387.72	458,157.47	98.0	11.5	109.5	4,806,623.57	Montana
Nebraska	3,818.3	5,067,556.32	2,427,549.44	269.5	96.5	366.0	1,470,173.25	632,227.18	51.5	20.9	72.4	3,696,667.01	Nebraska
Nevada	1,278.0	1,005,734.41	871,720.23	52.5	63.4	115.9	10,142.81	9,011.88		.8	.8	1,881,583.08	Nevada
New Hampshire	382.3	1,039,256.91	377,839.66	17.7	1.6	19.3						572,280.18	New Hampshire
New Jersey	551.1	3,296,951.94	826,666.32	23.4		23.4						2,548,366.76	New Jersey
New Mexico	1,957.5	4,149,839.98	2,753,339.06	187.1	51.9	239.0	350,278.43	300,409.23	14.3		14.3	2,358,585.03	New Mexico
New York	2,665.2	18,563,910.33	3,612,755.00	243.9		243.9	4,892,246.10	1,179,345.50	79.1		79.1	11,774,405.54	New York
North Carolina	1,882.7	4,013,858.02	1,917,847.55	128.3	33.2	161.5	1,090,869.13	520,260.11	61.4	14.7	76.1	4,024,001.91	North Carolina
North Dakota	4,593.2	1,688,804.02	843,299.08	219.8	133.2	353.0	1,181,379.47	590,307.63	180.2	126.6	306.8	2,501,532.32	North Dakota
Ohio	2,504.4	13,749,210.96	4,267,180.04	194.6	18.5	213.1	630,333.50	179,798.24	2.6	1.2	3.8	4,509,133.88	Ohio
Oklahoma	1,943.9	5,182,867.33	2,463,615.76	138.5	87.8	226.3	1,186,751.61	641,882.61	85.6	7.3	92.9	2,278,994.68	Oklahoma
Oregon	1,229.2	5,472,382.47	3,218,383.67	221.2	75.3	296.5	894,046.45	509,999.04	32.9	3.4	36.3	1,593,476.38	Oregon
Pennsylvania	2,655.6	7,520,500.18	2,693,140.26	48.9		48.9	64,282.12	24,838.06	.5		.5	5,146,620.04	Pennsylvania
Rhode Island	209.5	1,720,027.14	664,901.84	26.4		26.4						626,545.33	Rhode Island
South Carolina	1,850.7	5,967,224.17	2,412,013.31	108.4	122.7	231.1	779,067.73	387,468.70	.2	27.1	27.3	1,220,875.55	South Carolina
South Dakota	3,795.8	2,829,464.56	1,564,586.70	276.4	76.2	352.6	636,974.55	350,335.92	90.7	19.7	110.4	2,284,864.67	South Dakota
Tennessee	1,329.2	4,331,480.96	1,948,251.19	162.7	41.4	204.1	806,731.68	403,365.83	19.7		19.7	3,306,324.89	Tennessee
Texas	6,954.2	13,340,855.59	5,531,065.92	540.9	158.4	699.3	2,568,987.69	994,464.59	146.6	47.5	194.1	9,840,681.79	Texas
Utah	1,036.6	692,233.93	511,813.03	66.7	20.0	86.7	807,205.22	582,203.41	32.0	55.9	87.9	1,395,711.86	Utah
Vermont	299.7	384,278.14	80,949.10	6.6		6.6						613,889.05	Vermont
Virginia	1,613.8	3,768,942.60	1,803,700.57	151.2	9.4	160.6	585,192.00	248,550.91	14.4	5.1	19.5	2,213,225.90	Virginia
Washington	983.5	2,963,271.03	1,282,600.00	55.1	36.3	91.4	1,540,845.73	737,000.00	59.5		59.5	2,237,160.58	Washington
West Virginia	724.3	4,668,999.02	1,696,549.73	114.2	34.1	148.3	828,840.20	347,496.27	8.6		8.6	1,086,032.06	West Virginia
Wisconsin	2,467.0	3,870,493.22	1,692,500.00	101.1	17.6	118.7	179,803.32	85,000.00	8.8		8.8	2,577,770.40	Wisconsin
Wyoming	1,755.6	2,635,627.61	1,756,255.62	179.4	91.3	270.7	553,044.41	359,603.25	5.4	82.6	88.0	1,166,957.70	Wyoming
Hawaii	41.2	882,655.31	374,008.63	21.7		21.7	197,730.75	98,865.37	9.0		9.0	1,852,769.59	Hawaii
TOTALS	88,845.3	233,397,046.62	99,572,832.92	7,029.9	2,058.7	9,088.6	60,393,635.17	25,530,501.36	2,007.1	868.3	2,875.4	144,725,776.57	TOTALS

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

U. S. GOVERNMENT PRINTING OFFICE: 1931