EXPERIMENTS IN CURING CONCRETE PAVEMENTS

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SYNOPSIS

Thirteen years of experience in curing concrete pavements with a great many types and kinds of cures form the background for this report. Among those methods used were wet earth, wet burlap, various bituminous types, calcium chloride both externally and internally, the Hunt process and others. From these several experiments a few brief conclusions were drawn as follows:

1. Earth and water curing provides the most desirable results of any that were studied.
2. The curing treatment applied during the first few hours after the concrete is placed has the greatest effect upon its strength.
3. The effect of a curing method upon strength may be predicted from laboratory tests for prevention of moisture loss.
4. While under the climatic conditions existing in Iowa, differences of strength due to differences in curing methods tend to decrease with the age of the concrete, they do not disappear entirely for a very long time.
5. The difference in slab length due to differences in methods of curing tend to disappear with increasing age of the pavement.

The term "curing" as applied to concrete is understood to mean its artificial environment during some relatively brief period immediately following its placement. It is intended to provide conditions favorable to the development of desirable characteristics in the material. These favorable conditions are believed to be a reasonably high uniform temperature and the prevention of the rapid loss of moisture. Specifications for curing are influenced by such practical considerations as cost, convenience and time. It is generally conceded that an ideal method for curing concrete pavements would be to cover the surface as quickly as possible with some light material which is kept wet, followed after the concrete has hardened by some material with considerable heat insulating value which is also kept continuously wet for a period of a month or more. However, such a method is not always practical from considerations of cost and convenience. For this reason there has been for several years intensive study of methods of curing that might prove satisfactory alternates for the method conceded to be good.

The Iowa State Highway Commission began extensive studies of the curing of concrete pavements 13 years ago and has continued these studies to the present. Much of the information accumulated has been reported to committees of national technical societies. Within the past few months some interesting observations have been made as to the relative effects of various methods of curing after a lapse of several years. This report contains a brief summary of the earlier work and a more detailed report of the more recent observations.

FIELD TESTS—CALCIUM CHLORIDE ADMIXTURE

The fact that the addition of calcium chloride to concrete hastens its hardening suggests that its use as an admixture might shorten the time during which other curing treatment is necessary.

Of 9.5 miles of pavement built in Mahaska County in the fall of 1926, a part was cured with wet burlap for one day followed by wet earth for an additional nine days. The concrete in the remainder contained 2 lb. of calcium chloride per bag of cement and was cured with wet burlap for one day. The 17 miles built in the spring and summer of 1927 were cured in the same way except that the concrete containing the calcium chloride admixture was kept covered with wet burlap for two days. Beam specimens 6 by 6 by 30-in. and 6 by 12-in. cylinders were molded as the work progressed and placed on the pavement surface when removed from the molds to receive the same curing treatment as the pavement.

For the materials used and the conditions surrounding this project, it appears that neither method of curing was consistently superior in compressive strength.

Surface Scaling

In order for a method for curing concrete pavements to be satisfactory it must have no unfavorable effect upon the pavement surface. In the winter of 1928-29 a survey was made of 1630 miles of pavement built in the years 1918 to 1928 inclusive, to observe the relative amounts of surface scaling classified according to the curing methods. In this survey a scaled area having a dimension of 1 ft. measured parallel to the center line of the pavement would be reported as 1 ft. of scaled pavement regardless of the dimension of the scaled area in any other direction. Table 2 gives the comparison for pavements built in 1926, 1927 and 1928.

From the figures in Table 2 it appears that certain conditions conducive to scaling must have existed on the work done in 1926 which did not prevail in the two following years. It is remembered that in 1926 whenever the finishing crew experienced difficulty in finishing, they were in the habit of sprinkling water on the surface of the concrete. Difficulty in finishing was encountered more generally with concrete that contained calcium

TABLE 1

EFFECT OF METHOD OF CURING ON COMPRESSIVE STRENGTH—MAHASKA COUNTY PROJECT

Year built	Aggregate	Compressive strength—lb. per sq. in.			
		Cylinders		Cores	
		Earth cured	$CaCl_2$ admixture	Earth cured	$CaCl_2$ admixture
1926	Limestone........	(23) 4290	(54) 4667	(10) 4390	(39) 4452
1927	Limestone........	(58) 5609	(57) 5073	(23) 6503	(23) 6411
1927	Gravel...........	(25) 5274	(47) 5280	(11) 6459	(26) 5737

NOTE: The figures in parentheses indicate the number of specimens tested.

STRENGTH TESTS

The uncontrolled variables, such as weather and variations in construction procedures which are likely to be encountered in any field study of this kind seem to have influenced the results of this study, particularly the transverse strength tests. In this case it appears that although at one day the calcium chloride transverse strengths were greater, at the age of 90 days for the concrete placed in the fall of 1926 and at the age of 21 days for that placed in the spring and summer of 1927 the transverse strengths were practically the same for the two kinds of concrete.

The compressive strengths of the field cylinders and of cores drilled from the pavement were more consistent. The average strengths of cylinders tested at 90 days and of cores tested at ages from 12 to 17 months are given in Table 1.

chloride than with plain concrete. Strict instructions against this sprinkling of the surface were issued early in 1927.

Table 3 gives the results for all the methods of curing used in the ten-year period.

TABLE 2

RELATIVE EFFECT OF CALCIUM CHLORIDE ADMIXTURE AND EARTH CURING UPON SCALING

Year built	Method of curing			
	Wet burlap plus wet earth		$CaCl_2$ integrally plus wet burlap	
	Miles laid	Percent of length scaled	Miles laid	Percent of length scaled
1926.........	65.7	4 25	24.1	27.87
1927.........	205.9	0.67	100.8	0.64
1928.........	623.8	0.18	77.6	0.03

gravel used in this concrete was composed almost entirely of siliceous particles.

TABLE 3

EFFECT OF METHOD OF CURING ON SURFACE SCALING

Pavements constructed 1918 to 1928 inclusive, surveyed in winter of 1928-29

Method of curing	Miles surveyed	Percentage of total length showing scale
Wet canvas or wet burlap plus wet earth..........	1406	1 35
Calcium chloride integrally plus wet burlap..... ..	203	3.65
Wet canvas or wet burlap plus calcium chloride on surface................	18	15.06

TABLE 4

RELATIVE EFFECT OF CALCIUM CHLORIDE ADMIXTURE AND EARTH CURING ON AVERAGE SLAB LENGTH

Year built	Coarse aggregate	Average slab length—ft.			
		1929 survey		1939 survey	
		Earth and water cured	$CaCl_2$ and wet burlap cured	Earth and water cured	$CaCl_2$ and wet burlap cured
1926	Limestone.....	50.3	22.1	....	....
1926	Gravel........	....	18.1	....	....
1927	Limestone.....	71.9	21.9	36.7	17.6
1927	Gravel........	39.7	19.5	25.3	16 9

Table 4 gives the results of observations of the spacing of transverse cracks on the experimental project at two times approximately ten years apart. The pavement was built without transverse joints.

The 1929 survey covered the entire project. The 1939 survey covered only about two miles of representative sections for each set of conditions. These results indicate that differences in the method of curing caused a difference in the number of transverse cracks which has persisted for 10 years, although this difference is decreasing with age. The

LABORATORY TESTS—CALCIUM CHLORIDE ADMIXTURE

In 1927 some laboratory work was done to determine the effect upon strength of the addition of calcium chloride to mortar and concrete at a rate of 2 lb. per bag of cement. Specimens which contained calcium chloride were cured in the same way as similar specimens which contained no calcium chloride. Seven different brands of cement were used.

The mortar specimens, made with natural sand, was molded into standard briquettes which were stored in a moist closet for 1 day and then in water until tested in tension at ages of 1, 2, 4, 7, 14, 21, 90 and 180 days. The addition of calcium chloride caused an increase in strength at one day for six of the seven brands of cement. The increase in strength at 180 days due to the addition of calcium chloride was very slight for any brand, and in one case it caused a decrease.

The concrete specimens were 6 by 6 by 30-in. beams which were stored under wet burlap until removed from the molds, after which they were stored in the laboratory air until tested.

The same cements and the same sand as was used in the briquettes were mixed with gravel and with crushed limestone to produce concrete, having the proportions 1:1.93:2.91 by weight with a water-cement ratio of 0.417. Similar specimens were made with and without an admixture of 2 lb. of calcium chloride per bag of cement. They were tested as beams after which the broken ends were squared with a saw to provide 6 by 6 by 10-in. prisms for compressive tests.

The results of compressive tests indicate that with two exceptions, the addition of calcium chloride caused some increase in strength for all cements with both kinds of coarse aggregate at all the ages of test; namely 4, 7, 14, 21, 28, 90 and 180 days. One brand of cement with gravel coarse aggregate showed practically the same strength for the two kinds of concrete at an age of 7 days. Another brand showed a slightly higher strength for plain concrete with limestone coarse aggregate at 90 days.

The fact that the beams were not soaked before testing to produce a uniform distribution of moisture throughout the cross section of the specimen causes some doubt as to the reliability of the transverse tests.

They indicate, however, that adding calcium chloride admixture has a more consistent effect upon compressive than upon transverse strength of specimens subjected to the curing treatment that these received.

A further study of the effect of the admixture of varying percentages of calcium chloride with seven different brands of cement in mortars of three consistencies was made in 1930. Natural local sand was used in the proportions of 1-2.06 by weight. The amount of mixing water used was basic, 1.2 basic and 1.4 basic as described by Talbot and Richart. The amounts of calcium used in the mixture corresponded to 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 4.0, 7.0 and 10 lb. per bag of cement for 5 of the cements while the maximum used with one of the brands was 3.0 and the maximum for the seventh was 4.0. The specimens which were 2 by 2 by 14-in. beams were stored in a moist closet in the molds for 24 hours, then removed from the molds and stored in moist sand for 48 hours, after which they were stored in the laboratory air until 12 hours before testing. During the last 12 hours they were stored in water. Transverse tests were made at 4, 7, 14, 28, 90 and 180 days and compression tests were made on prisms sawed from beam ends at 28, 90 and 180 days.

In these tests the addition of some quantity of calcium chloride caused an increase in strength at some age and at some consistency for every cement. However, the optimum quantity of calcium chloride for one brand of cement at one age and one consistency might cause a decrease in strength for another age or consistency for the same cement. The optimum quantity of calcium chloride admixture varied from ½ lb. to 10 lb. per bag for different brands of cement, age at test and consistency.

The conclusion drawn from this series of tests was that the determination of the optimum quantity of calcium chloride admixture was so complicated that its use was impractical for the conditions affecting highway work in Iowa.

VARIOUS METHODS OF CURING—1928

In 1928 a more extensive study of curing was made through the construction of 42 concrete slabs each 10 ft. wide, 11 ft. long and 6 in. thick. They were built out-of-doors on the ground near the laboratory in 4 series as given in Table 5.

In order to insure uniform temperature and humidity during the placing and finishing all of the concrete was mixed between 10:00 a. m. and 2:30 p. m.

TABLE 5

Series	No. of slabs	Dates built	Average mean daily temperature	Average relative humidity
I	14	July 31 to August 10..........	88	68
II	12	August 14 to 17..............	87	65
III	11	September 18 to 21...........	66	56
IV	5	November 13 and 14..........	54	..

Of the 15 different methods of curing used, the following are of interest:

1. Wet burlap 24 hr., moist earth 9 days.
2. Wet burlap 24 hr.
3. Wet burlap 72 hr.
4. Wet burlap 24 hr., moist earth 27 days.
5. Wet burlap 24 hr., surface application of calcium chloride at 2½ lb. per sq. yd.
6. Calcium chloride integrally at 2 lb. per bag of cement, wet burlap 48 hr.
7. Wet burlap until initial set, sodium silicate.
8. "Curcrete."
9. Wet burlap 24 hr., sodium silicate.
10. No curing.
11. "Hunt Process."

These slabs were sawed into 6 by 6 by 30-in. beams which were tested in cross bending at 7, 28, 90 and 360 days. Compression tests of 6 by 6 by 10-in. prisms sawed from the ends of broken beams were made at 8, 29 and 90 days.

In 1929 six slabs each 2 ft. wide by 6 in. thick by 80 ft. long composed of the same kind of concrete as used in the 1928 series were constructed out-of-doors near the laboratory for the purpose of studying the effect of method of curing on change in volume. In the summer of 1939 pieces from the ends of these slabs were sawed into 6 by 6 by 24-in. beams and tested for transverse strength. The ends of these beams were squared with a saw to provide 6 by 6 by 10-in. prisms which were tested in compression. Tables 6 and 7 show the relative strengths for the various methods of curing. The values for ages 7 days to 360 days are the averages for the first 3 series in the 1928 work.

The values in Table 6 for ages 7 to 360 days inclusive are each computed from the average of 80 to 89 tests. The values in Table 7 for ages 7 to 360 days inclusive are each computed from the average of 28 to 30 tests. The values for age 10 years in both tables are each computed from the average for 5 tests.

These results indicate that under the climatic conditions to which this concrete was exposed, differences in strength due to the effects of curing methods tend to disappear but that great differences will not disappear entirely for a very long time.

The work described for concrete was supplemented by laboratory tests on

TABLE 6

RELATIVE EFFECT OF CURING METHOD ON TRANSVERSE STRENGTH

Method of curing	Modulus of rupture—lb. per sq. in.				
	7 day	28 day	90 day	360 day	10 yr.
"Standard"—Wet burlap 24 hr. plus wet earth 9 day	621	748	771	864	967
	Modulus of rupture—percent of "standard"				
Wet burlap 24 hr.	86	82	88	89	...
Wet burlap 72 hr.	92	91	93	92	...
Wet burlap 24 hr. plus wet earth 27 day	95	100	104	101	...
Calcium chloride integrally plus wet burlap 48 hr.	82	84	87	97	...
Wet burlap until initial set plus sodium silicate	82	84	87	92	...
No curing	77	78	83	86	94
"Curcrete"	86	97	101	105	98
"Hunt Process"	90	93	92	96	97
Wet burlap 24 hr. plus $CaCl_2$ @ 2½ lb. per sq. yd.	95	94	95	94	98
Wet burlap 24 hr. plus sodium silicate	86	89	90	94	98

TABLE 7

RELATIVE EFFECT OF CURING METHOD ON COMPRESSIVE STRENGTH

Method of curing	Compressive strength—lb. per sq. in.			
	8 day	29 day	90 day	10 yr.
"Standard"—Wet burlap 24 hr. plus wet earth 9 day	3268	4372	4943	7530
	Compressive strength—percent of "standard"			
Wet burlap 24 hr.	86	80	84	....
Wet burlap 72 hr.	93	91	93	....
Wet burlap 24 hr. plus wet earth 27 day	92	93	96	....
Calcium chloride integrally plus wet burlap 48 hr.	97	101	97	....
Wet burlap until initial set plus sodium silicate	76	78	80	....
No curing	75	73	79	96
"Curcrete"	97	99	95	96
"Hunt Process"	92	90	83	100
Wet burlap 24 hr. plus $CaCl_2$ @ 2½ lb. per sq. yd.	97	93	91	90
Wet burlap 24 hr. plus sodium silicate	86	90	85	94

mortar specimens to determine the relationship between moisture loss and strength.

This work which was reported to the Curing Committee of the Highway Research Board led to the following conclusions:

1. So far as its effect upon strength is concerned, the efficiency of a curing method is measured by the degree to which the method prevents the loss of water from the concrete during its early age.
2. Laboratory studies of mortar under controlled temperature and humidity conditions provide a reliable means for evaluating the efficiency of curing agents.

Early in 1929 a specification was adopted by the Iowa Highway Commission covering the use of impervious coatings as curing agents. The acceptability of such curing agents was based on the results of moisture loss tests of mortar specimens subjected to a temperature of 90° to 100° F. and a relatively humidity of 30 to 50 per cent.

RELIABILITY OF LABORATORY TESTS

The reliability of laboratory tests for moisture loss of mortar as a measure of the efficiency of a curing agent may be indicated by the following experience:

A part of a paving project built in 1931 was cured with earth and water, a part with an application of asphaltic emulsion containing 35 per cent of asphalt, and a part with an emulsion containing 52.5 per cent of asphalt. The emulsion was whitewashed to reduce the temperature effects of the sun. The results are shown in Table 8.

TABLE 8

COMPARISON OF LABORATORY AND FIELD TESTS OF THE EFFICIENCY OF A CURING AGENT

Laboratory tests				Field tests		
Emulsion, 52 percent asphalt		Emulsion, 34 percent asphalt		Average compressive strength of cores, age 4 mo.—lb. per sq. in.		
Moisture loss, 6 day	Trans. strength @ 7 day	Moisture loss, 6 day	Trans. strength @ 7 day	Wet earth curing	Cured with 52.5 percent emulsion	Cured with 35 percent emulsion
Percent		*Percent*				
5.5	(5) 694	25	(5) 554	(8) 6494	(8) 6552	(6) 5655

Figures in parentheses show numbers of specimens.

EFFECT OF DARK COLORED COATINGS ON SPACING OF TRANSVERSE CRACKS

A considerable mileage of pavement built in 1929 was cured by the application of an asphaltic emulsion to the fresh concrete. There was evidence that transverse cracks would develop at more frequent intervals in concrete cured by this method than in pavements cured by some other methods. Therefore, on each project where the emulsion was used, a section approximately one mile in length was cured with earth and water.

Table 9 shows the results of five crack surveys that have been made over this work. The slab lengths reported for the pavement cured with emulsion refer only to the sections contiguous to the sections cured with earth and water and of approximately the same length.

These results indicate that while the method of curing had a considerable effect on the number of visible transverse cracks that developed at early ages, the difference in slab length due to curing method is diminishing with time.

Table 10 shows the strengths of cores drilled from some of the same sections as those reported in Table 9.

strength in this case is probably due to some cause other than the curing.

Table 11 gives information on the length of slab as affected by some methods of curing used during 1932.

TABLE 9

LENGTH OF SLAB AS AFFECTED BY TIME AND METHOD OF CURING

Pavement Built in 1929, Without Joints. Averages for 6 Projects of Each Kind of Coarse Aggregate

Date of survey		Nov. 1929	Nov. 1930	Feb. 1932	Dec. 1933	Nov. 1939
Coarse aggregate	Curing	Average slab length—ft.				
Limestone	Wet earth....	138	92	83	62	32
Limestone	Emulsion.....	77	53	51	48	28
Gravel....	Wet earth....	103	52	43	35	23
Gravel....	Emulsion.....	43	32	29	26	20

Earth curing consisted of wet burlap for 1 day followed by earth kept wet for 6 days.
Emulsion curing consisted of asphaltic emulsion applied to fresh concrete.

TABLE 10

COMPRESSIVE STRENGTH OF CORES DRILLED FROM PAVEMENT, AS AFFECTED BY TIME AND METHOD OF CURING

Pavement Built in 1929

Project	Coarse aggregate	Average compressive strength—lb. per sq. in.					
		Age 9-12 mo.			Age 10 yrs.		
		A earth	B emulsion	B/A percent	A earth	B emulsion	B/A percent
Carroll...	Limestone	(5) 5914	(9) 5592	94.6	(5) 6906	(5) 6712	97.2
Clarke....	Limestone	(4) 4912	(9) 5333	108 6	(5) 6790	(5) 6954	102.4
Dubuque	Limestone	(5) 5844	(9) 5478	93.7	(5) 8718	(5) 7982	91.6
Jackson .	Gravel....	(5) 5376	(11) 5291	98.4	(5) 7644	(5) 7608	99.5
Jones.....	Gravel....	(7) 5823	(8) 5196	89.2	(5) 7678	(5) 7042	91.7
	Average. .	5574	5378	96.5	7547	7260	96.2

Figures in parentheses show the number of specimens.

The results indicate that while the differences in strength apparent at early ages are decreasing with age, they still exist to some degree after 10 years.

There is some question as to the reliability of the comparison for the Clarke County Project. The specimens from the earth cured section were observed to be much more porous than those from the emulsion cured section. The difference in

PAPER AS A CURING AGENT

Mark Morris reported in 1932 on "The Use of Paper for Curing Concrete Pavement."[1] This report showed that at an age of 7 months cores drilled from sections of a Story County project that had been cured with wet burlap for 1

[1] *Proceedings*, Highway Research Board, Vol. 12, p. 339.

day followed by an application of heavy waterproof paper had a strength 93.8 per cent of similar cores drilled from sections cured with wet burlap and wet earth. Cores drilled from the same sections in 1939 showed that at an age of 8 years the paper cured concrete had 94.5 per cent of the strength of concrete cured with earth and water.

WET BURLAP FOLLOWED BY IMPERVIOUS COATING

Experiments as to the effect of method of curing on length changes which were reported to the Highway Research Board in 1931 [2] indicated that the unusual frequency at which transverse cracks occurred in pavements cured with an asphaltic coating applied to the fresh concrete might be due to the great volume changes caused by the unusual heat absorption of the dark colored surface. This suggested two expedients for reducing this effect.

1. To apply some light colored coating to the bituminous coating as soon as practicable after the bituminous coating was applied.
2. To delay the application of the bituminous coating until the concrete had gained some strength to withstand the stresses induced by volume change due to changes in temperature.

Therefore, the specifications which have applied to the use of bituminous curing agents on highway work in Iowa since 1931 have provided that the concrete shall be cured with wet burlap for one day before the bituminous coating is applied, and that a coating of whitewash shall be applied over the bituminous coating.

It was suggested by those interested in the sale of bituminous material for use as a curing agent that perhaps the initial curing with wet burlap was not necessary if the bituminous coated surface were whitewashed or that the benefits derived from the initial wet burlap were not proportional to its cost.

TABLE 11

LENGTH OF SLAB AS AFFECTED BY METHOD OF CURING
Pavement Built in 1932—Crack Survey in November 1939

Coarse aggregate	Number of projects	Spacing of expansion joints	Curing treatment			
			Earth	Burlap-emulsion-whitewash	Emulsion-whitewash	Paper
			Slab length ft.—Nov. 1939			
		Feet				
Gravel	9	60	23	22	..	..
Limestone	5	80	34	37	..	..
Limestone	1	80	..	23	29	..
Gravel	1	60	28	27	26	..
Limestone	1	80	49	..	..	50

Earth curing consisted of wet burlap for 1 day followed by earth kept wet for 6 days.
Burlap-emulsion-whitewash curing consisted of wet burlap for 1 day followed by asphaltic emulsion which was whitewashed. Paper curing consisted of wet burlap for 1 day followed by paper left in place for 7 days.
It will be noted that after 7 years the method of curing shows little effect upon slab length.

[2] *Proceedings,* Highway Research Board, Vol. 13, Part II.

For this reason it was arranged to experiment with the two methods of using bituminous materials as a curing agent on two paving projects.

Table 12 gives the results observed at 28 days and at 7 years after the concrete was placed.

These data indicate that the initial curing with wet burlap was responsible for an appreciable increase in the strength of the concrete and that this advantage has not disappeared at the end of 7 years.

Since wet burlap followed by wet earth is the commonly accepted standard for curing concrete pavements it is interesting to study the data shown in Table 13.

These values seem to indicate that when the application of an impervious coating is preceded by an initial curing with wet burlap, strengths approximately equal to those for earth and water curing may be attained.

TABLE 12

EFFECT OF TIME OF APPLICATION OF ASPHALTIC EMULSION CURING AGENT UPON COMPRESSIVE STRENGTH OF CORES

Method of curing	Compressive strength—lb. per sq. in.			
	Boone Co. project		Mitchell Co. project	
	Age 28 day	Age 7 yr.	Age 28 day	Age 7 yr.
Emulsion applied to fresh concrete........	(15) 4982	(5) 7052	(18) 3944	(5) 6588
Emulsion applied after 24 hr. wet burlap...	(20) 5439	(5) 7784	(25) 4597	(5) 7272

Figures in parentheses show number of specimens.

TABLE 13

EFFECT OF METHOD OF CURING ON COMPRESSIVE STRENGTH OF CORES, 1932

Method of curing	Compressive strength of cores—lb. per sq. in. Age 7 yr.				
	Boone	Grundy	Iowa	Dallas	Marion
Wet burlap and earth..........	(5) 7686	(5) 7465	(5) 8288	(5) 7280	(5) 6970
Wet burlap and emulsion	(5) 7784	(5) 6864	(5) 8164	(5) 7150	(5) 7554
Wet burlap and emulsion cured in percentage of earth cured..	101.3	91.9	98.5	98.2	108.4

Figures in parentheses show number of specimens.

FIELD EXPERIMENTS

Various Methods of Curing—1929

A field experiment conducted in 1929 involving a comparison of earth and water, "Curcrete," "Hunt Process," calcium chloride applied on the surface, sodium silicate and wet burlap curing has provided some information as to the relative effects of these methods of curing. The strength values are given in Table 14.

It should be mentioned that the concrete cured with wet burlap was laid about the middle of October when the temperature was low. Therefore, the strength values reported cannot be considered as typical for that method of curing and serve only to indicate the degree of recovery from unsatisfactory curing in a period of 10 years.

Crack surveys of this project have been made from time to time with interesting results. The slab lengths are given in Table 15.

The slab length for calcium chloride cured pavement decreased from 272 ft. to 165 ft. during the first 15 months, remained constant for the next 21 months

TABLE 14

EFFECT OF VARIOUS METHODS OF CURING UPON COMPRESSIVE STRENGTH OF CORES

Hamilton County Project, Built in 1929

Method of curing	Compressive strength—lb. per sq. in.	
	Age 4 mo.	Age 10 yr.
Wet burlap and earth...........	(67) 5070	(5) 7834
	Percent of earth cured	Percent of earth cured
"Curcrete"........	(6) 88.1	(5) 96.6
"Hunt Process"....	(11) 99.8	(5) 95.6
$CaCl_2$—Surface	(11) 91.3	(5) 94.6
Sodium Silicate....	(12) 80.7	(5) 90.9
Wet burlap........	(12) 79.3	(5) 82.2

Figures in parentheses show number of specimens.

TABLE 15

Method of curing	1929		1939	
	Slab length, ft.	Per-cent of earth cured	Slab length, ft.	Per-cent of earth cured
Calcium chloride...	271.1	131	65.5	144
Wet earth.........	207.8	100	45.6	100
Sodium silicate....	168.3	81	92.3	202
Wet burlap.......	164.9	79	74.1	162
"Curcrete"........	111.2	54	47.1	103
"Hunt process"....	101.1	49	38.1	184

and then decreased to 65 ft. in the next seven years. The age-slab-length curve for the earth cured pavement has a shape similar to that for calcium chloride curing. The slab length for sodium silicate curing decreased for 12 months from 168 ft. to 144 ft. and then remained constant for the next 45 months and then decreased to 92 ft. in the next 5 years.

The slab length of pavement cured with bituminous coatings did not decrease appreciably from 2 to 57 months. The decrease in the next 5 years was at approximately the same rate as for the other methods of curing. These data are shown in Figure 1.

The relationship between slab length and strength of concrete on this project raises the question as to whether or not the methods of curing resulting in lower

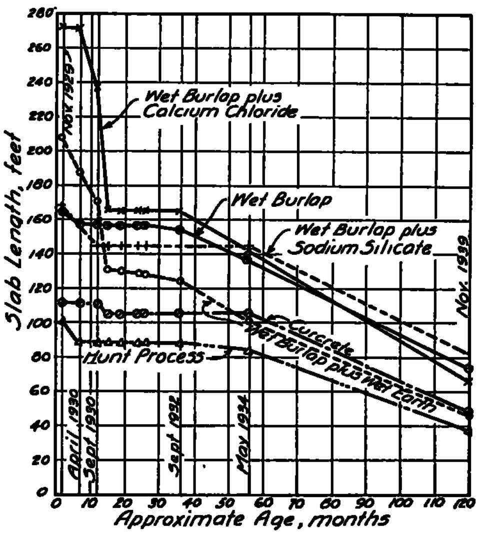

Figure 1. Effect of Kind of Curing on Rate of Change in Length of Slab. Built, Fall of 1929.

strengths and greater slab lengths may not have produced concrete having lower moduli of elasticity. It has been observed that concrete having a low modulus of elasticity develops transverse cracks at less frequent intervals than that having a higher value for this modulus.

GENERAL CONCLUSIONS

The brief general conclusions that we have drawn from the data presented in this paper are:

1. Earth and water curing provides the most desirable results of any that we have studied.

2. The curing treatment applied during the first few hours after the concrete is placed has the greatest effect upon its strength.
3. The effect of a curing method upon strength may be predicted from laboratory tests for its prevention of moisture loss.
4. While under the climatic conditions existing in Iowa, differences of strength due to differences in curing methods tend to decrease with the age of the concrete, they do not disappear entirely for a very long time. The significance of the gain in strength with advanced age will depend upon whether or not the pavement survives the effect of stresses imposed upon it at early ages.
5. The differences in slab length due to differences in methods of curing tend to disappear with increasing age of the pavement.

A list of the men who should be given credit for assistance in this work would be very long and will not be included in its entirety. Special credit is due R. W. Crum, who directed the earlier part of the work; to Mark Morris, who directed a large part of the work; and to James W. Johnson, who has been connected with it throughout practically its whole history.