PROGRESS REPORT

SPECIAL INVESTIGATION ON CURING OF CONCRETE PAVEMENT SLABS

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The reports of 36 investigations (28 field and 8 laboratory) on curing of concrete pavements carried on in the United States during the past eight years have been studied. Field and laboratory research projects needed to provide additional information on the problem have been outlined Some investigations, in accordance with this outline, are under way and several more are assured for the coming year. An intensive survey of the surface condition of about 3000 miles of concrete pavements has been about 75 per cent completed

This report gives some tentative conclusions which have been drawn by the committee from a preliminary study of the data now available.

DEFINITION AND FUNCTION OF CURING

Curing and results of lack of curing are summarized in a concise manner in the 1929 report of A. S. T. M. Committee C-9, Sub-Committee XIII on Curing, as follows:

"For the purpose of clarifying the situation the sub-committee offers the following as to its understanding of what is meant by the term 'Curing' of Concrete and the results that may be expected from lack of 'Curing'

"By good 'Curing' of concrete is meant the setting up of favorable conditions for chemical action during the setting and early hardening period

"The general opinion at the present time is that the most favorable conditions exist when the concrete is warm and moist throughout. Temperatures that are regarded as favorable in practice, range from 70° F. to somewhat above 100° F.

"Our present knowledge of the behavior of portland cement and concrete while setting and hardening indicate that if these conditions of temperature and moisture are met:

"(a) A maximum amount of cement will be hydrated; and

"(b) The concrete will be subjected to a minimum amount of volume change during the period of low strength.

"There is also evidence that when improper or inadequate curing conditions prevail, the insufficient hydration of the cement will be revealed through low strength of the concrete and lack of durability with the passage of time, and that excessive cracking will result from the volume changes due to variations in temperature and in moisture content."

Properties Indicating Effectiveness of Curing

This Special Committee on Curing is of the opinion that information on the following properties of concrete will indicate the relative merits of various curing methods:

(1) Moisture retention during curing. There is evidence to indicate that the amount of mixing water retained in the concrete during the curing period is an important index of the effectiveness of the various curing methods
(2) Flexural and compressive strength.
(3) Volume changes at successive intervals.
  (a) Spacing, width and rate of formation of cracks.
  (b) Accurate measurements of changes of length.
(4) Surface condition
  (a) Scaling or surface disintegration.
  (b) Resistance to wear.
(5) Permeability and absorption
(6) Resistance to natural destructive agencies.
  (a) Physical such as freezing and thawing
  (b) Chemical such as sulphate waters

Factors Other Than Curing Which Affect Properties of Concrete

In carrying out curing studies the following factors which also affect the test results must be controlled:

(1) Uniformity of test specimens affected by such factors as
  (a) Materials, proportions, manipulation and subgrade
  (b) Moisture and temperature condition of specimen at time of test.
(2) Testing technique In order to avoid variations in methods it is recommended that American Society for Testing Materials procedure be followed whenever applicable

Existing Data

Summaries of the experimental data from 36 projects are shown in Tables I to V These investigations were mostly carried out by independent agencies under various conditions The results were frequently contradictory due probably to other variables than the curing conditions under consideration The committee has been much impressed with the necessity for coordinated research, rather than sporadic individual efforts Enough effort and money have been expended for curing investigations so that the problem should be almost, if not entirely, solved. This, however, is far from being the case Factors such as moisture content of the specimen at time of test were frequently not reported, and yet the variations in strength of the specimens due to moisture were probably greater than any differences due to curing Certain tendencies, however, may be noted from a study of the data obtained on strength, volume, change and surface condition

EFFECT ON STRENGTH

Table I summarizes the results of tests on beams and compression specimens made in the field and in the laboratory The values in the table are ratios, expressed as percentages, of the strengths obtained for a given method of curing to the strength of similar specimens cured with wet earth or straw For purpose of comparison the average values for tests at all ages and for 28-day tests only are included In order to show the range in results high, low and grand average values are reported In these tests, calcium chloride, Hunt Process (cut back asphalt) and Curcrete (asphalt emulsion) surface treatments generally show a small range in results and gave strength 90 per cent or more of the strength of concrete cured with wet earth or straw

In these tests sodium silicate surface treatment and calcium chloride used integrally showed strengths both above and below 90 per cent of the strength of concrete cured with wet earth or straw. Some relatively low strengths appear, particularly in the laboratory tests, which are in general lower than the field tests Further investigations are needed to disclose the conditions under which these variations in strength occur

Attention is called to the fact that for some of the newer methods of curing, particularly the bituminous surface treatments, only a few results were available.

TABLE I

SUMMARY OF RESULTS OF 36 CURING INVESTIGATIONS

(Values in Parentheses Are the Number of Projects on Which Results for a Given Method of Curing Are Based)

Method of curing	Ratios of strengths for various methods of curing to strengths for wet earth or straw curing—per cent											
	Flexure tests						Compression tests					
	Field specimens			Laboratory specimens			Field specimens			Laboratory specimens		
	High value	Low value	Grand av.	High value	Low value	Grand av.	High value	Low value	Grand av.	High value	Low value	Grand
Average of Tests at Ages up to 1 Year (Average Age Less Than 28 Days)												
No curing	94	75	84(8)	87	69	81(7)	76	76	...(1)	81	66	73(4)
Calcium chloride surface	106	92	97(9)	117	95	102(4)	94	92	93(4)	...	..	..
Calcium chloride admixture	110	74	94(11)	84	66	75(5)	134	84	103(16)	97	68	89(5)
Sodium silicate (24 h.)	101	75	87(9)	99	58	79(4)	116	86	96(11)	93	58	79(4)
Hunt process	97	92	95(2)	97	97	97(1)	89	89	..(1)	99	99	..(1)
Curcrete	104	96	99(3)	93	93	93(1)	111	97	106(4)	90	90	..(1)
Misc. bituminous	98	89	..(2)	94	86	..(2)	...	..	...	98	98	..(1)
Average of 28-Day Tests												
No curing	93	72	83(7)	87	69	80(6)	73	73	...(1)	76	62	71(3)
Calcium chloride surface	109	88	98(9)	98	94	96(3)	93	93	...(1)	..	..	..
Calcium chloride admixture	108	71	91(8)	87	66	76(5)	113	91	106(5)	103	68	90(4)
Sodium silicate	98	72	87(9)	97	58	78(4)	96	90	92(2)	93	58	77(4)
Hunt process	93	88	90(2)	90	90	90(1)	90	90	...(1)	102	102	..(1)
Curcrete	104	95	98(3)	88	88	88(1)	109	100	107(2)	89	89	..(1)
Misc. bituminous	98	86	..(2)	94	86	..(2)	...	..	...	98	98	..(1)

TABLE II

Summary of Flexural Tests at Various Ages Averaged

RATIOS OF STRENGTH TESTS FOR VARIOUS CURING METHODS TO THE STRENGTHS OF CONCRETES CURED WITH WET EARTH OR STRAW

Source of data	Cured with wet earth or straw	Ages of tests averaged	Strength by tests, expressed as a percentage of the strength of corresponding concrete cured with wet earth or straw						
Number	Days	Days	No curing	Hunt process	Curcrete	Misc. bituminous	Sodium silicate 24 hrs.	Calcium chloride admix.	Calcium chloride surface
Field Tests									
1	9	7 — 28 — 90	78.8	92.3	97.0	...	88.4	90.4	95.7
2	9	4 — 7 — 28	...	...	...	...	92.0	92.7	94.3
10	10	10 — 14 — 90 — 360	...	...	...	...	...	96.1	...
3A	7 & 28	7 — 28	82.0	...	...	(c)89.0	82.0	...	97.5
3B	10	21 — 28 — 91	...	...	...	...	(b)91.6	...	91.8
4A	2 & 6	7 — 28 — 90	94.0	...	...	...	80.0	93.0	94.0
5	10	28	...	...	103.8	...	...	94.1	...
6	10	7 — 14 — 28	...	...	...	...	...	104.1	105.8
12	10	4 — 7	83.1	...	...	...	...	110.2	...
7A	14	28	84.7	...	...	(a)97.7	...	...	102.7
8	7	4 — 8 — 15 — 29	...	...	...	...	101.2	102.8	...
10D	10	7 — 14 — 90	...	...	...	...	...	89.8	...
9C	7 & 14	7 — 14 — 28 — 90	75.2	94.6	99.0	...	75.0	...	92.3
16	14	3–7 — 14 — 28–90 — 360	82.0	...	...	...	83.0	74.0	...
17	10	3 — 7 — 14 — 28	91.0	97.0	96.1	...	93.8	82.6	99.5
Average	..	.. ..	83.8	94.6	99.0	...	87.4	93.6	97.0
Laboratory Tests									
4B	3 & 10	7 — 14 — 21 — 28	86.5	...	...	...	...	79.0	96.6
7B	10	28	85.6	...	...	...	...	...	95.1
7C	14	28	87.0	...	...	(a)94.5	...	...	98.4
9A	13	14 — 28 — 90	74.5	97.0	93.1	...	78.1	72.1	...
10C	28	28	...	...	...	(d)86.3	80.4	75.1	...
11	10	7 — 28 — 90	86.2	...	...	...	99.0	84.0	116.7
10A	28	28	69.2	...	...	...	58.3	66.0	...
Average	..	.. ..	81.5	97.0	93.1	...	79.0	75.2	101.7

Note.—(a) Blown Asphalt. (b) Applied at 7 hours. (c) Av. of a thick and thin asphalt. (d) Tar.

TABLE III

Summary of Flexural Tests, Age 28 Days

RATIOS OF STRENGTH TESTS FOR VARIOUS CURING METHODS TO THE STRENGTHS OF CONCRETES CURED WITH WET EARTH OR STRAW

Source of data	Cured with wet earth or straw	Strength by tests expressed as a percentage of the strength of corresponding concrete cured with wet earth or straw						
Number	Days	No curing	Hunt process	Curcrete	Misc. bituminous	Sodium silicate 24 hours	Calcium chloride admix.	Calcium chloride surface
Field Tests								
1	9	78.0	92.9	96.6	...	88.9	89.3	97.2
2	9	...	...	...	...	92.0	96.0	96.0
3A	7 & 28	88.0	...	...	(c)86.5	85.0	...	95.0
3B	10	...	...	...	...	(b)91.7	...	94.7
4A	2 & 6	93.0	...	...	...	90.0	90.0	99.0
5	10	...	...	103.8	...	...	94.1	...
6	10	...	...	...	...	...	107.6	109.0
7A	14	84.7	...	...	(a)97.7	...	...	102 7
8	7	...	...	...	...	97.6	90.4	...
9C	7 & 14	72.0	...	...	...	74.0	...	88.0
16	14	74.0	...	...	...	72.0	71.0	...
17	10	92.9	87.5	95.1	...	95.5	92.6	96.7
Average	..	83.2	90.2	98.5	...	87.4	91.4	97.6
Laboratory Tests								
4B	3 & 10	81.5	...	...	...	...	86.2	93.6
7B	10	85.6	...	...	...	...	...	95.1
7C	14	87.0	...	...	(a)94.5	...	...	98.4
9A	13	73.1	89.8	88.5	...	74.4	67.9	...
10C	28	...	...	...	(d)86.3	80.4	75.1	...
11	10	85.4	...	...	...	97.4	87.0	...
10A	28	69.2	...	...	...	58.3	66.0	...
Average	..	80.3	89.8	88.5	...	77.6	76.4	95.7

NOTE.—(a) Blown asphalt. (b) Sodium silicate applied at 7 hours. (c) Average of thick and thin asphalt. (d) Tar.

TABLE IV

Summary of Compressive Tests—Various Ages Averaged

RATIOS OF STRENGTH TESTS OF VARIOUS CURING METHODS TO THE STRENGTHS OF CONCRETES CURED WITH EARTH OR STRAW

Source of data	Cured with wet earth or straw	Ages of tests averaged	Type of specimen	Strength by tests expressed as a percentage of the strength of corresponding concrete cured with wet earth or straw						
Number	Days	Days		No curing	Hunt process	Curcrete	Misc. bituminous	Sodium silicate 24 hr.	Calcium chloride admix.	Calcium chloride surface
Field Tests										
1	9	6 — 29 — 90	Beam ends	75.9	88.8	97.1	...	87.9	98.8	94.0
2	9	7 — 28	6 by 12 cyl.	...	...	...	...	85.5	96.0	...
2	9	90	Cores	...	...	...	...	87.0	84.0	92.0
10	10	10 — 14 — 90 — 360	6 by 12 cyl.	...	...	...	...	...	97.5	...
10D	10	7 — 14 — 28 — 90	6 by 12 cyl.	...	...	...	...	...	95.8	...
5	10	28	Beam ends	...	...	107.6	...	...	120.9	...
5	10	28	6 by 12 cyl.	...	...	107.2	...	...	117.6	...
5	10	28	Cores	...	...	111.3	...	...	101.4	...
13	10	75 to 130	Cores	...	...	...	...	115.7	117.5	...
13	10	120	Cores	...	...	...	...	...	...	93.4
14	10	210	Cores	...	...	...	...	95.9	...	93.9
6	10	7 — 14	6 by 12 cyl.	...	...	...	...	...	116.4	...
8	7	28 — 120 — 180 — 360	Cores—1	...	...	...	...	92.5	90.2	...
8	7	180 — 360	Cores—2	...	...	...	...	108.5	103.4	...
8	7	7 — 14 — 28	Cyl.—1	...	...	...	...	98.7	97.3	...
8	7	8 — 15 — 28	Cyl.—2	...	...	...	...	98.1	134.0	...
8	7	28 — 90 — 360	Cores	...	...	...	...	101.5	92.7	...
16	14	360	Cores	...	...	...	...	89.0	89.0	...
Average	..	... .		75.9	88.8	105.8	...	96.4	103.3	93.3
Laboratory Tests										
11	10	7 — 28 — 90	6 by 12 cyl.	80.5	...	...	...	91.9	97.0	...
9A	13	7 — 14 — 28 — 90	6 by 12 cyl.	66.3	99.2	89.7	...	73.2	77.3	...
10A	28	28	6 by 12 cyl.	74.9	...	...	...	57.6	67.6	...
10B	(a)	2 — 7-28 — 90 — 360	6 by 12 cyl.	...	...	...	...	...	109.0	...
10C	28	260	6 by 12 cyl.	...	...	...	(b)98.2	92.9	93.7	...
9B	3	120	6 by 12 cyl.	71.9	...	...	...	...	...	...
Average	..	... .		73.4	99.2	89.7	...	78.9	88.9	...

Note.—(a) Stored in Wet Sand until Tested. (b) Tar.

TABLE V

Summary of Compressive Tests—Age 28 Days

RATIOS OF STRENGTH TESTS OF VARIOUS CURING METHODS TO THE STRENGTHS OF CONCRETES CURED WITH WET EARTH OR STRAW

Source of data	Cured with wet earth or straw	Type of specimen	Strength by tests expressed as a percentage of the strength of corresponding concrete cured with wet earth or straw						
Number	Days		No curing	Hunt process	Curcrete	Misc. bituminous	Sodium silicate 24 hours	Calcium chloride admix.	Calcium chloride surface
Field Tests									
1	9	Beam ends	72.7	90.3	99.9	...	90.4	101.3	93.0
2	9	6 by 12 cyl.	...	...	...	...	...	97.0	...
10D	10	6 by 12 cyl.	...	...	...	...	...	91.1	...
5	10	Beam ends	...	...	107.6	...	...	120.9	...
5	10	6 by 12 cyl.	...	...	107.2	...	...	117.6	...
5	10	Cores	...	...	113.3	...	...	101.4	...
8	7	Cores—Sec. 1	...	...	...	...	88.9	81.4	...
8	7	Cyl.—Sec. 1	...	...	...	...	97.1	106.4	...
8	7	Cyl.—Sec. 2	...	...	...	...	101.0	156.8	...
8	7	Pav. Cores	...	...	...	...	97.6	90.4	...
Average	..		72.7	90.3	107.0	...	92.0	106.4	93.0
Laboratory Tests									
11	10	6 by 12 cyl.	75.5	...	...	...	88.8	103.0	...
9A	13	6 by 12 cyl.	61.7	102.1	89.4	...	68.1	70.2	...
10A	28	6 by 12 cyl.	74.9	...	...	...	57.6	67.6	...
10B	(a)	6 by 12 cyl.	...	...	...	...	...	114.0	...
10C	28	6 by 12 cyl.	...	...	...	(b)98.2	92.9	93.7	...
Average	..		70.7	102.1	89.4	...	76.9	89.7	...

Note.—(a) Stored in wet sand until tested. (b) Tar.

EFFECT ON VOLUME CHANGE

Reports indicate that volume changes, due to temperature and moisture content were affected by curing processes. These are ordinarily shown in pavements by the spacing of contraction cracks. In order to obtain information on this important subject, a comprehensive field survey of pavements subjected to a wide range of climatic conditions will be made In addition certain projects are under way and others contemplated to obtain accurate measurements of changes of length of concrete cured by different methods.

EFFECT ON SURFACE CONDITION

Little definite information on the relation between curing methods and surface condition has been available. Reports from various localities indicated the need of a study of the possible relation between surface scaling and the use of a surface application of calcium chloride As a result an extensive survey has been recently made and although there has not been sufficient time to assemble and study the data accumulated, a brief preliminary report is included herein.

CURRENT RESEARCH PROJECTS

Extensive research projects in curing have been recently carried out by the California, Iowa, Kansas, Tennessee and Wisconsin highway departments, the Portland Cement Association and Ohio State University. The data will be available for study the coming year The methods outlined by this committee last June were used in some of these researches. The following research agencies have indicated their intention to conduct investigations as recommended by this committee during the coming year: Iowa, Missouri, Rhode Island, Tennessee and Wisconsin highway departments, the Portland Cement Association and Texas State College.

The "Outlines for Curing Investigations" recommended by the committee are included with this report. Careful coordinated researches in many sections of the United States are necessary for the solution of the curing problems.

SURVEY OF SURFACE CONDITION OF PAVEMENTS CURED WITH SURFACE APPLICATION OF CALCIUM CHLORIDE AND OF PAVEMENTS CURED WITH EARTH AND WATER

The Curing Committee at its meeting in June, '29, recommended that a survey to ascertain the relation between surface application of calcium chloride and surface scaling be made In view of the fact that a large mileage of concrete pavement cured in this way is available for study, it was thought that a detailed survey of a large mileage of these pavements and of corresponding pavements cured with earth and water would develop the true facts of the case

The Field Survey was started on August 23d, and completed on November 20th Approximately 2000 miles of pavement was observed in the states of Minnesota, Wisconsin, Missouri and Illinois. One hundred samples of scale and 96 pictures of the scaled pavement were obtained Due to the limited time available this report contains only a general statement of the problem and the unanalyzed findings The projects to be surveyed were selected at random This in most cases was an arbitrary selection by the investigator, who knew nothing of the surface condition of the pavements The State Highway Department in each state generously furnished means of transportation and an engineer to act as an additional observer.

The observational data on each project were obtained while traversing the pavement at a speed of 10 to 15 miles per hour These data included the speedometer reading at the start of project and at the places where scale occurred The area of scale at each place was also determined by estimation This method of determining the area was used because the actual measurement of the areas, due to their unsymmetrical trends would be laborious and slow, and it was felt that the results by estimation were sufficiently accurate.

The occurrence of the scale in respect to the pavement surface, location and other special construction features was also noted.

The taking of the pictures and obtaining the samples of scale completed this phase of the survey.

All of the above observational data were recorded on a special form

The construction data, materials record and quality tests of the different projects were obtained and recorded on another special form. It is believed that the analysis and interpretation of these data in relation to the extent of scaling will reveal interesting information of sufficient quantity to permit the derivation of sound conclusions.

The typical disintegrated concrete scale was also omitted from this survey, although a few samples were taken This scale is generally in excess of .25 inch in thickness.

From Table VI it is noted that the average thickness of the scale is approximately the same for wet earth and calcium chloride surface application method of curing.

The Location of Scale on Pavement Surface

By far the most scale appeared in a strip two to three feet wide along the outer edge of the pavement The area adjacent to the center line showed the next greatest tendency to scale and the oil covered lane down the center of each half of the pavement showed the least These conditions were especially true if the scaling was not extensive In the latter case the whole surface was affected The lack of scale in the oil covered area may be attributed to the resistance to moisture absorption by this area and the absence of abrasion by traffic

Mechanics of Scaling

To demonstrate the true action or behavior of scaling will require a reproduction of the phenomena under direct and controlled methods From field observations it appears that its occurrence is a function of the variation in the density of the surface layer and the concrete immediately underneath The possible conditions that may effect this density and on which the accumulated data will undoubtedly give valuable information are: (1) Harsh mix, (2) Over finishing, (3) Too much mixing; (4) Fine and silty sand, (5) Frost action and (6) Misapplication in the use of the curing medium.

Table VI shows the general extent and nature of the surface scale found by this survey.

Expressing the extent of scaling by percentage of total area, although furnishing a suitable index of the general action of the respective curing method on the pavement surface, does not give an entirely true picture of conditions, because several of the projects have no surface defects, regardless of the curing method, while other projects show considerable scaling. In the final analysis of this survey it is hoped to show this phase by grouping the projects on a scale percentage basis

TABLE VI

Wet Earth Curing

State	Miles surveyed	Total sq yds. surveyed	Total sq yds of scale	Per cent by area	Average thickness of scale samples (Inches)
Minnesota	90.20	953,780	886 0	0 093	0 120
Wisconsin	88 00	952,138	2,149 0	0.226	0 112
Missouri	102 10	1,034,880	172 0	0 017	0 110
Illinois	297 98	3,099,009	4,557 6	0 147	0 198
Total or Average	578.28	6,039,807	7,764 6	0 129	0 163

Calcium Chloride Surface Curing

State	Miles surveyed	Total sq yds. surveyed	Total sq yds of scale	Per cent by area	Average thickness of scale samples (Inches)
Minnesota	114 40	1,270,248	4,937 0	0 389	0 150
Wisconsin	129 00	1,481,094	3,184 0	0.215	0 118
Missouri	260.20	2,749,444	1,929 0	0 070	0 139
Illinois	605 78	6,402,222	10,835 1	0 168	0 165
Total or Average	1,109.38	11,903,008	20,885 1	0 175	0 152

Average age of wet earth cured concrete pavements—8 yrs
Average age of Calcium Chloride cured pavements—5 yrs
NOTE.—There is an additional 320 miles to be compiled and added to this table

Classification of Scale

The survey included only the type of scaling which was of an appreciable depth The thin surface peel, commonly called " Paper Scale," was not classed as a scale This " Paper Scale " is always less than .05 per cent inch in thickness and is unnoticeable except when driving at a low rate of speed and with a favorable angle of light reflection from the pavement.

OUTLINE FOR SUGGESTED CURING INVESTIGATIONS

This outline is based on the assumption that there are five distinct qualities to which a curing agent should be subjected before a final value is placed on its effectiveness These are: (1) Flexural and compressive strength, (2) Volume change, (3) Surface condition, (4) Permeability, and (5) Durability as revealed through freezing and thawing.

The field tests recommended are for the purpose of clearing up the situation as respects the characteristics of the various methods in vogue at the present time, in so far as possible

The laboratory tests proposed are a start toward developing the fundamental principles upon which proper curing depends.

FIELD TESTS

(1) *General Proposal.* The project contemplates investigation of several methods of curing of which one would be a good curing method to be used as a standard for comparison and one would be a minimum curing method to furnish information as to the extent of curing offered by the natural conditions prevailing during the tests. It is assumed that several other methods will be investigated progressively on the same project. It is assumed that the unit for each method of curing will be the length of pavement to be placed in one day's operation, say about 1000 feet Each change of curing method should take place at noon and the same method of curing then continued until the following noon. This constitutes one unit for comparison

The following alternation of curing methods is suggested·

(1) Minimum curing unit
(2) Standard unit.
(3) Experimental unit No 1.
(4) Standard unit.
(5) Experimental unit No. 2.
(6) Standard unit.
(7) Experimental unit No 3

If more than three experimental methods are used the units involving them should be alternated with standard unit as above, finishing with the last experimental unit.

The operation up to this stage will constitute one round of tests. This round should be followed by at least one more round carried out in the same manner. More should be added if possible.

The following outline gives recommended details regarding the procedure:

(2) *Standard of Comparison.* Wet burlap for first 24 hours, then 2 inches of moist earth for nine days. Require report to indicate frequency of wetting and approximate quantity of water.

(3) *Minimum Curing.* Wet burlap for first 24 hours. See that no accidental curing occurs by leakage from hose or other preventable sources.

(4) *Experimental Methods* These optional with experimental agency Suggested methods:

(a) Curcrete, Hunt process and any other bituminous coatings
(b) Calcium chloride, surface application.
(c) Sodium silicate, surface application
(d) Calcium chloride admixture (2 lbs per bag of cement).

(5) *Suggested Procedure for Experimental Methods.* ((a) to (d) above.)

(a) Spray bituminous coatings on surface in amounts recommended by manufacturers as soon as practicable after finishing operations.
(b) Cover with wet burlap 24 hours and follow immediately with application of 2 lbs. calcium chloride per square yard.
(c) Cover with wet burlap 24 hours and follow immediately with application of sodium silicate (soda-silicate ratio 1 to 3 25) solution approximately 37 degrees *Be'* sprayed or broomed over surface using 1 1 lbs of the solution per square yard of surface.
(d) Use admixture of 2 lbs * calcium chloride per sack of cement dissolved in mixing water. Cover with wet burlap first 24 hours

(6) *Data to be Secured and Reported*

(a) Strength of cores at ages of 28 and 90 days and 1 year; at other ages if desired The cores should preferably be 5½ inches in diameter Each round of cores should be taken so as to give one specimen for each age, all from a single batch Six rounds, one from each of six different batches from each section will constitute a set. Three of the batches selected should be from those placed in the forenoon and three in the afternoon

The cores should preferably be drilled not earlier than 5 days prior to the date on which they are due to be tested. It is recommended that for transporting the cores be wrapped in paper.

It is recommended that the ends of the cores be made plane and parallel by grinding. If this is not practicable, capping with baselite (see *Engineering News-Record,*

* Under some conditions it may be desirable to use less than 2 lbs to give proper finishing

Nov 22, 1928, p 777) or other satisfactory materials recommended.

Caps should be plane and parallel They should be as thin as possible, especially if the capping material is not more rigid than the concrete of the core All cores shall be soaked prior to testing The following periods of soaking are recommended: 28 day cores, 24 hr.; 90 day cores, 48 hr.; 1 year cores, 96 hr.

Specimens should be weighed immediately before and after soaking to determine amount of absorption

(b) Complete test reports on all materials including cement
(c) Proportions (absolute volume) and method of measuring
(d) Time of mix and type of mixer.
(e) Amount of water and method of control.
(f) Subgrade:
  (1) Character: Detail survey for each section
  (2) Treatment.
(g) Placement and finishing methods
  (1) Type of finishing machine.
  (2) Number of times finishing machine operation was repeated
  (3) Report in detail all manipulation of surface
  (4) Character of surface after finishing, dry, wet, glistening, soupy, etc
(h) Elapsed time between finishing concrete and placing burlap
(i) Notation and extent of cracks or other surface defects present before placing burlap or other covering. or on removal of burlap.
(j) Temperature record beginning with placement of concrete
  (1) Air, wet and dry bulbs.
  (2) Concrete at top and bottom surfaces and at intermediate points if possible Minimum of two locations per 1000 foot section; one in a m. and one in p. m Readings to be taken hourly until heat of reaction has been dissipated and three times a day until normal cycles have been established.
(k) Amount of sunshine.
(l) Rainfall. Amount, time and duration
(m) Strain measurements on top surface Longitudinally and transversely at a point 6 feet from outside edge of slab Ell (L) shape figure at two places in each section

adjacent to temperature stations. Take readings at same time intervals as for temperature See attached instructions for strain gage measurements

(n) Crack and check survey.

(1) Examine before covering with burlap or bituminous coatings and plot all cracks giving data of appearance.

(2) Repeat on removal of burlap and at intervals thereafter sufficiently frequent to determine characteristic rate of formation of cracks.

NOTE—The use of a light film of oil will bring out cracks not easily detected otherwise

(7) *Surface Condition.*

(a) Note any surface scaling.

(b) Wear resistance The absence of a suitable wear machine for field use has greatly obstructed the acquiring of valuable data on this important quality of concrete in relation to curing The Bureau of Public Roads has recently developed a machine for determining surface wear of pavements and is at present determining its practicability. A description of this machine and the test data obtained will be made through the official publication of the Bureau of Public Roads in the near future

(c) Moisture retained in surface If practicable determine moisture retained in the top 2 inches or less of concrete by specimens secured from the pavement by the following method. Embed 2 ply cheese-cloth 2 inches (or less) below the surface as shown in Figure 1.

(6) Remove the disc of concrete at the following periods, (1) immediately after placing, (2) at end of 1, 7, and 28 days Weigh concrete and dry at 105° C. to constant weight and weigh again. Take three specimens for each section for each age.

(8) *Permeability.* This quality of the concrete cannot be determined in the field, and for that reason will be omitted. Sections of the drilled cores or the disc for moisture retained in surface may be used for this test at laboratory

(9) *Durability as Revealed Through Alternate Freezing and Thawing* These cycles cannot be accelerated in the field as they depend upon climatic conditions and for that reason cannot be standardized. Periodical surveys in conjunction with the number of cycles and the

temperature intensity may reveal valuable data on this phase of the concrete quality.

(10) *General Remarks* In carrying out the field tests, it is suggested that some mutual agreement be completed with the contractor either in the form of some special clause in the original contract or by some other amicable arrangement. The inconveniences to the contractor were kept in mind throughout the outline and are believed to be minimized to the limit, in obtaining the necessary information.

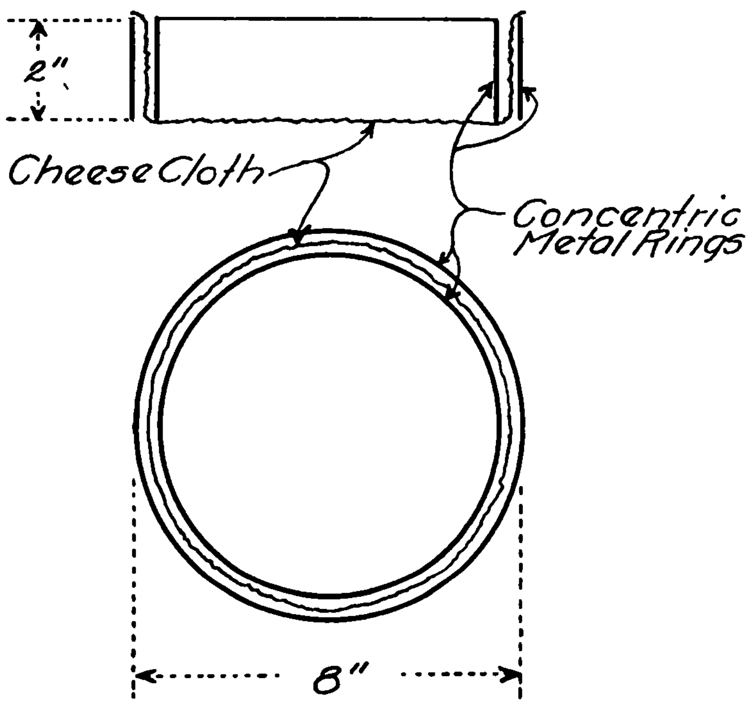

Figure 1. Method for Securing 2 by 8 Inch Disk from Pavement Surface for Moisture Tests

LABORATORY TESTS

(A) The following curing methods are suggested.

(1) Wet sand.

(2) No—curing.

(a) Tested as cured.

(b) Tested wet.

(3) Hunt process. Two different amounts.

(4) Curcrete. Two different amounts.

(5) Sodium silicate surface.

(6) Calcium chloride admixture.

(7) Calcium chloride 1¼ lb Admixture with hot materials.
(8) Calcium chloride surface.
(9) 72 hours of wet burlap (allowed to evaporate).
(10) Materials hot. No cure

(B) Moisture retention.
(1) Measure moisture loss daily for seven days, then at following intervals: 14, 28, 90 and 365 days.

(C) Strength tests
(1) Ages of test, 3, 7, 28, 90 and 365 days.
(2) 6 x 6 x 32 inches beams End of beams or cores from beams desirable for compressive strength tests.
(3) Make specimens in rounds so that one specimen for each method of curing is made on each day for five different days These five specimens for each curing method shall constitute a set.

(D) Proportions.
(1) Absolute volume Materials available shall be proportioned by weight to conform to an absolute volume mix of 1.2 67 : 3 75 (This is equivalent to a 1 : 2 : 3 arbitrary volumetric mix in which the coarse aggregate contains 40 per cent voids and the sand 36 per cent voids and the specific gravity of both is 2.65)
(2) Cement. (Standard Portland.)
 (a) Constant (Same brand and shipment)
 (b) Mix the cement and store in air-tight containers
 (c) Standard physical tests.
  (1) Beginning of test.
  (2) End of test
 (d) One set of chemical tests.
 (e) Must meet A S T. M requirements.
(3) Sand.
 (a) Must meet requirements C-33-28T A. S. T. M.
 (b) All passing ¼ mesh sieve.
(4) Coarse Aggregate.
 (a) Maximum size 1½ inches
 (b) Separate into three sizes.
(5) Aggregates in general.
 (a) All aggregates in stock at start of test.
 (b) Proportion separately by dry weight.
 (c) Use aggregates with as low absorption as possible.

(d) Uniform composition.

(e) Use aggregate with no surface moisture Allow for absorption and surface mositure.

(6) Water content.

(a) Water-cement ratio constant.

(b) Plastic mix.

(c) Report water-cement ratio

(d) Measure and report slump and flow

(e) Use tap water tempered to 70° F.

(7) Mixing.

(a) Use laboratory concrete mixer (tilting mixer if possible).

(b) Mix two (2) minutes.

(c) Clean mixer at start with water and between batches, being careful to get water out of drum.

(d) Dump concrete into pan and mix with shovel to avoid segregation

(8) Beam construction.

(a) Use tin lined forms (details of construction will be available).

(b) Place concrete in one layer and spade sides. Strike off top with combined transverse and longitudinal motion with wooden straight edge after water sheen disappears. Finish with one application of wood float. (Caution against surface laitance.)

(9) Treatment of beams after construction for the various curing methods

Standard.

(a) Cover with wet burlap Test one set of beams in damp condition after continious curing in moist room.

(b) Cover two sets of beams with wet burlap and cover burlap with canvas on some water-proof paper for 12 to 24 hours. Place 2 inches or more of wet sand and keep saturated for 9 days. Test one set immediately after removing covering up to 7 days and the remainder of beams in this set to be tested in condition which exists when due to be tested The second set of beams to be soaked for periods indicated under no curing prior to testing.

No Curing. Use no wet burlap. Test one set dry or in cured condition and immerse the other set in water after removing forms (tin) for:

Period of test	Duration of immersion
3 day	6 hours
7 day	24 hours
28 day	48 hours
90 day	72 hours
365 day	7 days

Hunt process. No wet burlap. Apply bituminous covering immediately after water sheen disappears. On one set of beams use amount of material recommended by manufactures and on the other set use 50 per cent additional to that recommended. Apply with suitable spray using extreme caution to see that covering is properly and uniformly applied. Must have absolute record of amount put on Also carefully observe surface with large reading glass for pin holes in bituminous coatings.

Curcrete Same as Hunt

Sodium silicate. The method of application, ratio of sodium to silicate, concentration and the time of application to conform with recommendation of manufacturers. Use wet burlap for first 24 hours if application is on following day

Calcium chloride. Admixture, 2 pounds per bag of cement dissolved in mixing water. Surface, 2 pounds per sq. yard. In both cases use wet burlap for just 24 hours (Use manufacturer's recommendations.)

GENERAL REMARKS

After specimens have set in tin lined forms for 24 hours, place a heavy asphalt or melted paraffin around edges of all the beams in such a manner that the crack between the tin form and the concrete specimen due to shrinkage is completely sealed. This can be accomplished by placing the asphalt (or paraffin) in a small ridge, so that about ¼ inch of the edges of the concrete is coated and extending over the crack and adhering to the vertical outside face of the tin for a ¼ or ½ inch below the top edge. This will prevent moisture losses from other than the cured surface. Prior to testing, beams to be soaked in water for periods indicated under no curing.

(E) Surface condition.

Abrasion tests are desirable, but methods are not sufficiently developed. Laboratory may develop method suitable for this test.

The following methods are used:

(1) Jones—Talbot Rattler Test (Bulletin 10 Structural Materials Research Laboratory).

(2) Ball Indentation Test. (Bulletin No. 12. Engineering Experiment Station, Purdue University.)

(3) Dory Hardness machine and modifications of this test. (Dory hardness machine standard equipment in most highway laboratories.)

(4) National Crushed Stone Association Method.

(5) Bureau of public roads field machine for wear (To be reported soon in Public Roads.)

(F) Shrinkage.

(1) Strain gage measurements.

Strain Gage Measurements

The type of strain gage to be used probably will depend largely upon what is most accessible. The Berry Strain Gage can be used very satisfactorily. Somewhat better results have been obtained with the Whittemore gage of the type used on the Stevenson Creek Dam. (Manufactured by H. L Whittemore Bureau of Standards, Washington, D C.) A 10-inch gage length has been found to give as small error in inches per inch as a 20-inch gage length.

The Berry gage is put out in 8-inch and 20-inch gage lengths. Probably of these the 20-inch gage length would be best. With the Whittemore gage, probably 10-inch would be best.

For using the strain gage, metal plugs made by cutting 1-inch lengths of ½-inch round bars may be set in the concrete at the proper distance apart with one end of the plug flush with the surface of the concrete, or slightly below the surface for protection of the plug. For the long-time tests it is desirable that a non-corrosive metal such as stainless steel or monel metal be used for the plugs.

A No. 54 drill is suitable for drilling the gage holes. The use of a special drill with the twist portion only about ⅛-inch long helps greatly in obviating breakage of drills The holes may be drilled either before or after placing the plugs Probably drilling after placing will generally be the most satisfactory. The holes should not be countersunk, but removal of burr from the edge of the hole is desirable This may be done by inserting the point of a center punch in the hole and turning the punch at the same time that light pressure is applied by hand The best finishing of the holes is that which comes from continued use of the strain gage point in them. Therefore, there is great value from the standpoint of accuracy in taking a number of sets of zero readings

To guard against accidental changes in the strain gage, readings should be taken on standard reference bar of constant length at intervals not less frequent than at the beginning and end of each series of readings It should not be difficult to secure invar steel with a coefficient of expansion as low as 0 0000012 inches per inch per degree F. (this is about ⅕ the coefficient of ordinary steel), though the coefficients differ with different lots of invar Such steel as this should be satisfactory for use as a standard reference bar. However, an ordinary steel bar kept in ice would also serve as a satisfactory reference bar but this is usually more troublesome than to secure invar bar.

Usually strain gages are made of invar steel, but if one is used which is made of ordinary steel more complete dependence upon a standard reference bar is necessary and in this case readings on the reference bar should be taken at intervals of not more than 10 minutes at the beginning of a series of readings when the instrument is being warmed up by contact with the hands, and not more than 20 minutes after it has been warmed up. Great care must also be used to keep the hands off the side bars of a plain (not invar) steel instrument and to handle it only at the ends It is well, but not essential, to observe the same precaution in handling an invar steel gage Felt coverings have some times been applied to strain gages to protect them from temperature effects.

The subject of strain gage operation has been discussed at length in a paper, "The Use of the Strain Gage in the Testing of Materials" by W. A. Slater and H. F Moore, Proceedings, American Society for Testing Materials, 1913, p. 1019, and in Bulletin 64, University of Illinois Engineering Experiment Station, "Testing of Reinforced Concrete Buildings under Load," by A N Talbot and W A. Slater Much improvement in strain gages has been made since these papers were written, but this does not affect greatly the discussion of use except as to the degree of dependence upon readings on a standard bar