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BUREAU OF PUBLIC ROADS

VOL. 10, NO. 12 ▽ FEBRUARY, 1930

PLACING WET BURLAP IN ARLINGTON CURING EXPERIMENTS

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VOL. 10, NO. 12 FEBRUARY, 1930 R. E. ROYALL, Editor

TABLE OF CONTENTS

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THE ARLINGTON CURING EXPERIMENTS

A STUDY OF THE EFFECTS OF VARIOUS CURING TREATMENTS ON CONCRETE PAVEMENT SLABS

Reported by L. W. TELLER, Senior Engineer of Tests and H. L. BOSLEY, Assistant Materials Engineer, Division of Tests, Bureau of Public Roads

THERE is a widespread interest among engineers in curing methods for concrete pavements. It is generally realized that these pavements should be cured but there is a lack of definite information as to just what constitutes an adequate curing method. Concrete slabs, whose surfaces have had no protective curing treatment, have been found to have a very considerable strength and service value. The improvement in the quality of the concrete obtained by careful curing may be very marked or it may not be, depending largely upon the climatic and other conditions to which the fresh concrete is subjected. Conceivably there are conditions under which a pavement slab will benefit but little from even the best of curing treatments. However, by far the greater yardage of concrete pavement is laid during the hot, dry summer months and under these conditions it is an accepted fact that curing of some sort is necessary.

FINAL CONCLUSIONS CAN BE BASED ONLY ON A LARGE NUMBER OF TESTS CONDUCTED IN DIFFERENT PARTS OF THE COUNTRY

Earth curing has been widely used and it has been demonstrated many times that this method, properly carried out, is a very satisfactory one, so far as strength of the resulting concrete is concerned. There are two principal disadvantages to the method: First, the cost, arising from the large amount of material which must be handled and from the fact that the water supply must be maintained for the duration of the curing period; and, second, the possibilities of controversy between the engineer and the contractor over compliance with the curing specifications. This difficulty, too, tends toward increased cost.

Several other methods of curing, involving the use of other materials, have been promoted and because of the possibilities for economy, they are receiving serious consideration wherever concrete pavements are being laid. In an effort to determine the advantages and disadvantages of these various curing treatments a number of investigations or tests have been conducted by the various State highway departments and other agencies. The findings of the different investigators have not been wholly concordant and engineers, in general, have not been entirely satisfied with the information available.

Curing tests should be made on large specimens, under carefully controlled conditions, and the observations should cover a long period of time. It is very difficult to meet all of these requirements. Temperature and humidity are of vital importance, yet they can be controlled only in the laboratory. Specimens which can be handled in the laboratory are not well suited to a study of pavment concrete because of their limited size. Large field specimens, such as actual road slabs, may be affected to as great a degree by varying weather conditions as by the differences between the different curing methods. These difficulties have confronted the various investigators who have sought to overcome them in different ways and with varying degrees of success. Because of these uncertain influences it appears that accurate information and sound conclusions can be arrived at only by a thorough study of the indications from a large number of tests conducted under the different climatic conditions of the various parts of the country.

FIGURE 1.—FINISHING A SECTION CONTAINING ¾-INCH DEFORMED BARS

The Bureau of Public Roads has recently completed a study of the data obtained from curing experiments at the Arlington Experiment Farm, Virginia. The details of this investigation and a summary of the indications are set forth in the following report which is presented not as conclusive evidence for or against any of the treatments tried but rather as additional evidence regarding them.

Because of the opportunity afforded by these tests for obtaining further information concerning the influence of various quantities of steel reinforcement on the behavior of concrete slabs, a number of reinforced sections were added to the original program. The observations made on these sections are included in the report.

The object of the tests was simply to develop as much information as possible regarding the effect on concrete pavements of a number of curing methods and materials.

Broadly, the scheme of the tests was to construct a series of long, narrow concrete slabs of identical mix and general dimensions, to apply to these the various treatments whose effects it was desired to observe and then to note these effects in various ways and over an extended period of time. In order to obtain complete information concerning conditions which might have a bearing on the results, many collateral tests and observations were necessary. The effects described in this report are due to exposure to the elements only, as no loads of any kind were applied to the test sections.

A preliminary report on this investigation was published in Public Roads for December, 1926. The report contained a general description of the project, together with a few preliminary indications from data available at that time.

TEST CONDITIONS DESCRIBED

The series of test sections consisted of 40 slabs, each 200 feet long, 24 inches wide and 6 inches thick. Construction was begun during the latter part of July, 1926 and completed early in August. The mix used was 1:2:4, proportioned by loose volume, with a correction for the bulking of the sand. The attempt was made to have the concrete of a uniform consistency but in spite of all precautions some variation occurred. Careful notes were taken of these variations and their location. There appears to be no connection between the observed behavior of the sections and the observed variations in the consistency of the concrete. The aggregates used were Potomac River sand and Potomac River gravel. The cement was all of one brand and was tested prior to use.

Subgrade conditions were extremely uniform under the entire group of sections both as to soil and topography. The weather during the period of construction was, in general, hot and the humidity fairly low. Every effort was made to place the concrete at such a time as to expose it under the most adverse conditions possible in this section of the country. Figure 1 shows a view of the construction.

As mentioned before, a number of sections contained steel reinforcement; others were divided by construction joints into segments of various length. Under some of the sections the subgrade was very dry; under a few it was damp; and under another group it was thoroughly wetted. The details of construction and of the curing treatments applied are given in Table 1. Figure 2 shows the application of some of the curing treatments.

In general, the variables introduced were such that information would be had on the effect on concrete pavements of such factors as the following:

1. Moisture in the subgrade.
2. Covering the subgrade with tar paper.
3. Surface curing with earth, straw, burlap, bituminous materials, calcium chloride and sodium silicate.
4. Curing with calcium chloride mixed integrally.
5. Slab length.
6. Various amounts of steel reinforcement.

The effects of these factors on the different sections were observed over a period of more than two and one-half years, and additional data were obtained from numerous tests and studies made in conjunction with the curing slabs during this time. The most important information was obtained from the following observations and tests:

1. Transverse cracking of the test sections.
2. Local shrinkage cracking.
3. Visual inspection of the slab surfaces.
4. Tests for surface hardness.
5. Loss of moisture from the concrete during the curing period.
6. Tests on control specimens.
7. Subgrade friction.
8. Effect of steel reinforcement on volume change.

The purpose of careful curing is to obtain a pavement structure which is sound and strong, and the ideal curing procedure is one which insures the structure against stresses beyond its strength during the curing period and which leads to the development of a high final strength. The principal stresses against which the concrete pavement slab must be protected during the curing period are those produced by the tendency of the concrete to change its volume because of moisture or temperature changes. Thus a curing treatment which tends to reduce the range of either or both of these changes offers advantages over a treatment which does not. In general, the more complete the hydration of the cement the greater will be the final strength of the concrete. For this reason it seems that a satisfactory curing process is one which insures that the cement has available at all times the moisture required for hydration.

TABLE 1.—*Details of construction and curing of the test slabs*

Section	Subgrade condition	Reinforcement	Length of test slabs in feet	Curing method
1	Dry	None	200	None.
2	do	do	20, 30, 40, 50, 60	Do.
3	do	do	200	Tar after 24 hours.
4	do	do	200	Calcium chloride after 24 hours, 2 pounds per square yard.
5	do	do	200	Sodium silicate (4:1) after 24 hours.
6	do	do	200	Calcium chloride after 24 hours, 3 pounds per square yard.
7	do	do	200	Tar paper on subgrade; tar after 24 hours.
8	do	2 ¼-inch round deformed bars.	200	None.
9	do	2 ⅜-inch round deformed bars.	200	Do.
10	do	2 ½-inch round deformed bars.	200	Do.
11	do	2 ¾-inch round deformed bars.	200	Do.
12	do	2 ¾-inch plain bars painted and greased.	200	Do.
13	do	2 ½-inch round deformed bars.	20, 30, 40, 50, 60	Do.
14	do	2 ¾-inch round deformed bars.	20, 30, 40, 50, 60	Do.
15	do	None	200	Calcium chloride admixture, 2 per cent.
17	do	43.8 pound fabric	200	None.
18	do	23.6-pound fabric	200	Do.
19	do	43.8-pound fabric	20, 30, 40, 50, 60	Do.
20	do	None	200	Dry earth, after 24 hours, for 13 days.
21	do	do	200	Dry straw, after 24 hours, for 13 days.
22	Damp	do	200	Wet earth, after 24 hours, for 13 days.
23	do	do	20, 30, 40, 50, 60	Do.
24	do	do	200	Wet straw, after 24 hours, for 13 days.
25	Wet	do	200	Wet burlap for 24 hours, then wet earth for 13 days.
26	do	do	20, 30, 40, 50, 60	Do.
27	do	do	200	Wet burlap for 24 hours, then calcium chloride 2 pounds per square yard.
28	do	do	200	Wet burlap for 24 hours, then sodium silicate (4:1).
29	do	do	200	Calcium chloride after 24 hours, 2 pounds per square yard.
30	do	do	200	Sodium silicate (4:1) after 24 hours.
31	do	do	200	Calcium chloride admixture, 2 per cent.
32	do	43.8-pound fabric	200	Wet burlap for 24 hours, then wet earth for 13 days.
33	do	23.6-pound fabric	200	Do.
34	do	43.8-pound fabric	20, 30, 40, 50, 60	Do.
35	do	2 ¼-inch round deformed bars.	200	Do.
36	do	2 ⅜-inch round deformed bars.	200	Do.
37	do	2 ½-inch round deformed bars.	200	Do.
38	do	2 ¾-inch round deformed bars.	200	Do.
39	do	2 ½-inch round deformed bars.	20, 30, 40, 50, 60	Do.
40	do	2 ¾-inch round deformed bars.	20, 30, 40, 50, 60	Do.
41	do	None	200	Asphalt emulsion sprayed on immediately after concrete was finished.

TESTS SHOW THAT CURING CONDITION AFFECTS SLAB LENGTH

Shrinkage in concrete pavement slabs during and after the initial hardening period, either from loss of moisture, drop in temperature, or both, acting in conjunc-

Applying tar to the surface approximately 24 hours after placing

Brooming sodium silicate (4 parts sodium silicate 42 Baumé to 1 part water) on the surface approximately 24 hours after placing

Spreading the flake calcium chloride (2 pounds per square yard) on the surface of section 4, approximately 24 hours after placing

FIGURE 2.—APPLYING CURING TREATMENT TO SECTIONS

tion with the subgrade resistance, sets up tensile stresses which cause cracks to form in the concrete. These may be either complete transverse or short localized cracks. Transverse cracks occur at greater intervals than do local shrinkage cracks and generally differ in that they are longer, wider, and extend to the bottom of the concrete, whereas cracks of the other type develop in the surface of the concrete and usually are not over a foot or so in length.

Figure 3 shows the transverse cracks that developed in the different sections, and the age of the concrete, in days, at the time the crack was first observed. A study of this figure shows that the sections which were placed on a wet subgrade and provided with good surface curing developed fewer early transverse cracks than those placed on a dry subgrade. This was to be expected in view of the lower loss of moisture, lower shrinkage and lower subgrade resistance during the period when the concrete had the least strength.

Since, in general, the sections placed on the dry subgrade had, in addition, delayed or otherwise less effective curing than the sections which were placed on the wet subgrade, it was possible to arrange the sections in two groups and to obtain a general indication as to the effect of curing on slab length. Figure 4 shows the data concerning slab length for each of these groups from the time the sections were laid up to and including the 2½-year period.

These curves show that concrete cured under poor conditions developed most of the transverse cracks during the early period after placing, and resulted in an average slab length of approximately 34 feet at seven days, and approximately 29 feet at two and one-half years. Under good conditions of curing the average slab length at seven days is approximately 118 feet and approximately 36 feet at two and one-half years.

Where bituminous materials were applied to the surface of the concrete as a curing agent, there was an increase in transverse cracking above the average for those sections (in their respective group) that were untreated or were treated with other than bituminous materials. This is clearly shown by section 41, which was treated with asphalt emulsion immediately after finishing. The increased early transverse cracking on this section over that of others in the same group can possibly be attributed to the effect of the black, heat-absorbent surface which served to increase the temperature range of the concrete thereby causing higher stresses in it during the period in which it was of low strength.

Section 7, placed on tar paper and surface treated with tar the following morning, shows a similar increase in transverse cracking after the bituminous material was applied.

BLACK COATING CAUSED HIGHER TEMPERATURES

When the sections were laid thermocouples were embedded in the concrete at several points at three different depths (1 inch, 3 inches, and 5 inches from the upper surface) and in the subgrade 1 inch below the concrete. From these thermocouples temperatures were determined periodically over a period of about two weeks immediately following the placing of the concrete. Among the sections in which these measurements were made were two which had bituminous treatments after 24 hours (secs. 3 and 7), one which had a dry earth covering after 24 hours (sec. 20), one which had wet burlap for 24 hours followed by wet earth for 13 days (sec. 25), and one which had no curing treatment (sec. 1). The temperature variations for each of these five sections, for the only 24-hour period during which continuous observations were

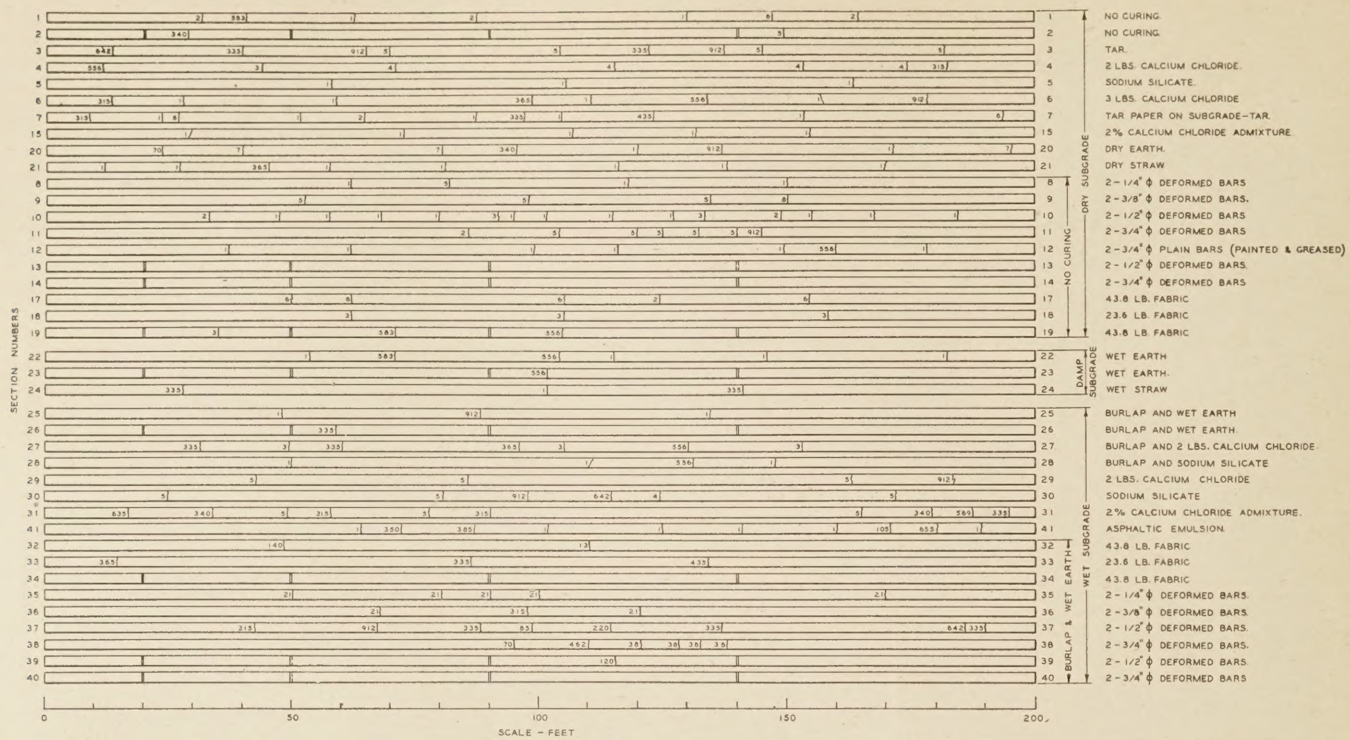


FIGURE 3.—PLAN OF CURING SECTIONS SHOWING TRANSVERSE CRACKS FORMED DURING A PERIOD OF 912 DAYS. THE NUMBER BESIDE EACH CRACK INDICATES AGE AT TIME THE CRACK WAS FIRST NOTED

made, are shown in Figure 5. In addition to the variation curves there is shown the range in temperature shown by each thermocouple from the maximum observed during the day to the minimum noted during the following night.

It will be observed that the increase in the range of temperature of the two sections which had bituminous treatments is quite marked. This effect was observed down through the concrete into the earth of the subgrade. While the maximum difference in temperature shown in Figure 5 between the concrete which was coated with a black material and that which was not is from 5° to 7° C., measurements made during the following summer showed that the temperature of the concrete coated with the bituminous material was as much as 10° C. higher than that of uncoated concrete, the conditions of exposure being the same. The insulating effect of the dry earth covering is also indicated in Figure 5.

EARLY BURLAP AND TRANSVERSE JOINTS REDUCED CRACKING

Referring to Figure 3, it will be seen that section 25, placed on a wet subgrade, covered with wet burlap immediately after it was finished and covered with wet earth the next day (this earth being kept wet for 13 days), shows a marked reduction in transverse cracking over that which occurred in section 22, which had no early burlap treatment. The difference in the moisture content of the subgrade may have had some influence although it is not believed that it is entirely responsible for the difference shown. Section 28 (early burlap cover with sodium silicate treatment after 24 hours) also shows less transverse cracking at all ages than section 30 where the burlap was omitted, all other conditions being the same. Sections 27 and 29 on which a surface treatment of 2 pounds of calcium chloride per square yard was applied do not show the same beneficial effect of burlap cover. For almost a year there were the same number of cracks in both sections. After two and one-half years there are seven cracks in the section which had the burlap cover and four in the one which did not. In spite of this exception it is believed that the data indicate a beneficial effect on average slab length of the immediate application of wet burlap.

There is no apparent explanation for the relative cracking which occurred in sections 15 and 31. These slabs contained a 2 per cent calcium chloride admixture. Section 15, which was placed on a smooth, dry earth subgrade, showed five transverse cracks after 24 hours while section 31, on a wetted subgrade, showed none. After five days section 15 still had only five cracks while section 31 had three. At the end of one year no new cracks had appeared in section 15 and section 31 showed eight. After two years had elapsed section 15 still showed only five transverse cracks and section 31 showed a total of 10 or twice the number in section 15. It does not seem possible that this difference is due to the initial difference in the subgrade moisture. The wetted subgrade might be expected to have a favorable effect by improving the curing conditions and thereby increasing the strength of the concrete. Such strength-test data as are available indicate that this was true. Flexure specimens tested at six months (fig. 14) indicated that the strength of the concrete in section 31 was somewhat greater than that of section 15. A series of 20 cores were drilled from each of the two sections after two and one-half years had elapsed, especially to obtain data on this point and showed an average compressive strength for section 15 of 3,480 pounds per square inch as against 4,685 pounds per square inch for section 31.

Since the cracking in section 31 occurred progressively over a long period of time and since it is most prevalent in the ends (a center portion of about 75 feet being unbroken) it appears that the excessive cracking might be due to subgrade settlement or swelling. The records of the heaving of the section are complete and show a

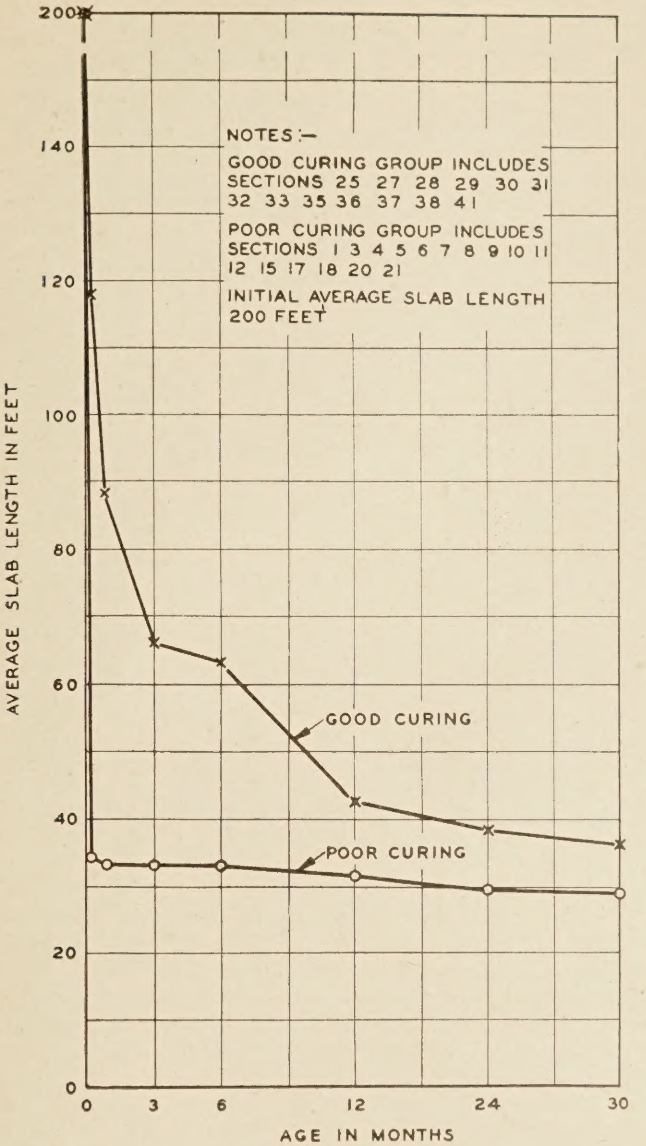


Figure 4.—Effect of Curing on Slab Length at Different Ages

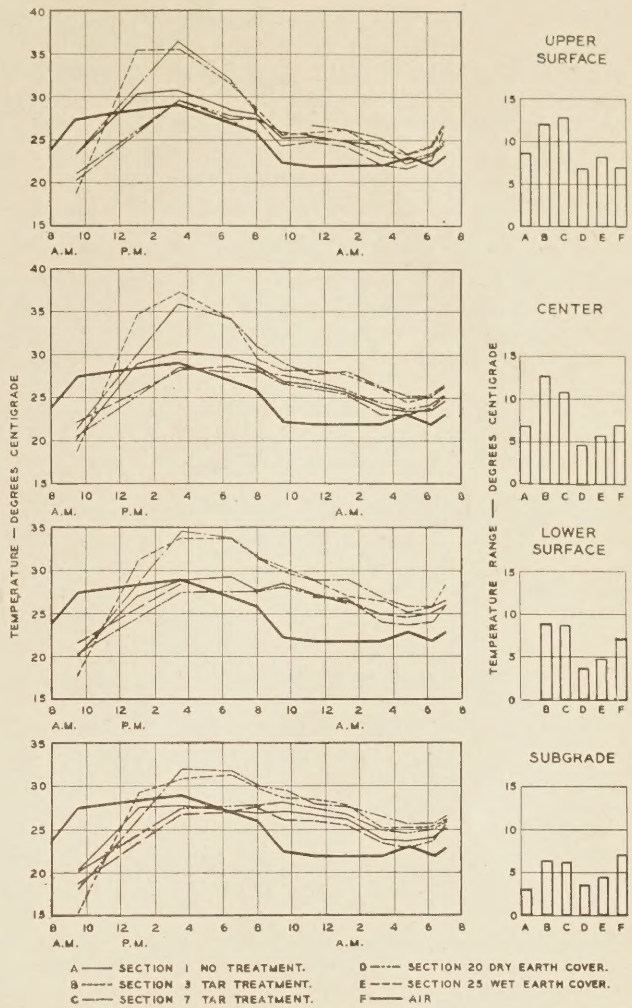


Figure 5.—Temperature Variation Curves and Temperature Range Charts Showing the Effect of Surface Covering Materials on the Temperatures of Concrete Slabs and of the Subgrade

fairly uniform seasonal rise and fall in no way different from that to which the adjoining slabs were subjected. Thus there is nothing in the available data which throws any light on what is thought to be excessive transverse cracking in section 31.

In the nine sections in which transverse joints were used, dividing the 200 feet of concrete into subsections of 20, 30, 40, 50, and 60 foot lengths, there was a reduction of transverse cracking over identical full length slabs of 200 feet (fig. 3). At the end of the two and one-half years there are 59 transverse cracks in the full length slabs, as against 44 cracks and joints in the subdivided sections. Of this latter number 36 are transverse joints that were made at the time of placing the concrete. Five of the eight cracks occurred on the dry subgrade, one on the damp subgrade, and two on the wet subgrade.

There are 36 slabs in the full length sections with a length of 20 feet or less, as against 15 such slabs in the subdivided sections. Of this latter number, 9 were placed as 20-foot slabs. The following table gives the average slab length at different ages of the slabs (the joints being considered as cracks) and show the trend so far as each group is concerned.

It is apparent from an examination of the data that the constructed joints served to control the transverse cracks to a large extent.

Table 2.—*Average slab length at various ages for both full length and segmental sections*

	7 days	28 days	90 days	180 days	365 days	730 days	912 days
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Full length (secs. 2, 13, 14, 19, 23, 26, 34, 39, 40)	90	79	49	45	38	35	32
Segmental (secs. 1, 10, 11, 17, 22, 25, 32, 37, 38)	39	39	39	38	36	35	35

In the 45 subsections of the nine subdivided sections only eight cracks occurred, as mentioned above, and 37 of these subsections were without cracks at the end of two and one-half years. In no case is there more than one crack in a subsection. Of the eight cracks their occurrence is as follows:

- 20-foot subsections, none.
- 30-foot subsections, two.
- 40-foot subsections, two.
- 50-foot subsections, three.
- 60-foot subsections, one.

There is no apparent relationship between the subsection length and the number of cracks. It is obvious that a less number of transverse joints might have been used, with a consequent increase in the average length of slab, without a proportionate increase in the number of cracks. This indicates the possibility of an even better control than is shown by this investigation.

DATA ON SUBGRADE FRICTION OBTAINED

The resistance of the subgrade to the horizontal movement of concrete pavement slabs was measured under dry, damp, wet, and frozen subgrade conditions, for concrete placed on both the natural subgrade and also on tar paper. The amount of this resistance was determined, under these different conditions, by measuring the force required to move concrete slabs 6 feet long, 2 feet wide and 6 inches thick and weighing approximately 900 pounds each, over the subgrade. The displacement of the slab was measured with a micrometer dial.

Figure 6 shows some of the load-displacement curves obtained for the different subgrade conditions. These curves indicate that considerable moisture in the subgrade, when not in the frozen state, reduces the subgrade resistance, while a frozen subgrade increases it as much as five times over unfrozen conditions. They also show that the resistance is lower with each test after the slab has been moved once (successive tests having been made on the same slab).

Tar paper used between the concrete and the subgrade under both wet and dry conditions of the subgrade reduced the resistance to relatively large movements to about one-half of that which obtained where the concrete was placed directly on the subgrade. This lower subgrade resistance did not cause any reduction in early transverse cracking on Section 7. The curves of Figure 6 show that while the tar paper under the slab effected a very marked reduction in the maximum coefficient, there is no great difference in the subgrade resistance for small movements for the slabs on the smooth earth and those on the tar paper. It may be that this fact has a bearing on the apparent failure of Sections 3 and 7 to conform to the generally accepted idea that a layer of tar paper between the pavement and the subgrade will reduce transverse cracking through a reduction in the coefficient of friction since the actual contraction which took place when these transverse cracks formed is not known.

During the latter part of the first winter after the sections were laid, there was considerably more transverse cracking in the long slabs that were well cured than in the poorly cured sections which cracked into short slabs during their early life. This increase in transverse cracking during this particular time can probably be attributed to the increased coefficient of friction caused by the frozen subgrade which, acting over greater slab lengths on the well cured sections than on the poorly cured ones, developed stresses exceeding the strength of the concrete.

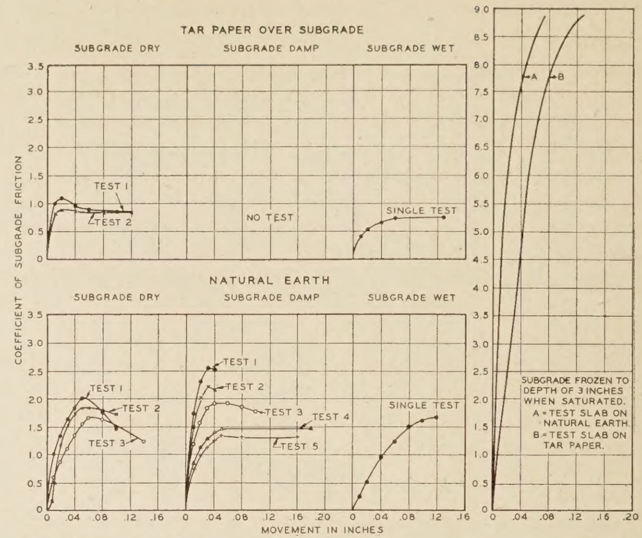


Figure 6.—Subgrade Friction Under Various Subgrade Conditions. Size of Section Used, 6 by 2 Feet and 6 Inches Thick. Weight Approximately 900 Pounds

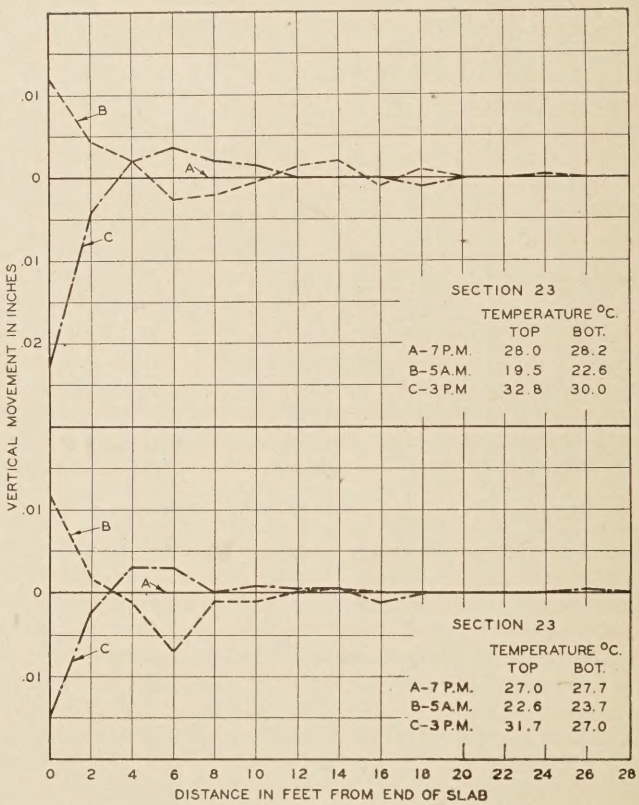


Figure 7.—Slab Curling Observed on Section 23

CURLING OR WARPING MEASURED

The amount of curling or warping which occurred on the different sections was measured with dials which showed the vertical movement of the slab in thousandths of an inch. These dials were mounted on iron stakes driven along the edge of the slabs at 2-foot intervals with the dial stem resting on the concrete. Readings were taken over 24-hour periods, with corresponding measurements of the temperatures in the top and bottom of the concrete. The temperatures were measured by means of thermocouples embedded in the concrete at the time of placing.

Curling or warping of a concrete pavement slab depends upon the relative length of the upper and lower surfaces. This difference in length may be due to a difference in the temperature or of the moisture content of the two surfaces. Considering temperature effects alone, if the top and the bottom of the slab have the same temperature the slab will be in the position as indicated by the line A in Figure 7. When the top is at a lower temperature than the bottom the slab will take the position indicated by the line B. If the reverse condition obtains, the slab will take the position indicated by line C. These deflections (fig. 7) represent actual measurement on the 6-inch curing sections. The curves resemble closely the theoretical curves for deflection developed by Doctor Westergaard.[1]

Figure 3 shows that in several cases transverse cracking developed near the ends of long slabs and also that cracks occurred at later dates in close proximity to earlier transverse cracks.

Typical examples of this will be found in the case of sections 3, 7, 20, and 31. It can be easily demonstrated that subgrade friction could not develop a tensile stress of sufficient amount to rupture concrete of even moderately good quality in such lengths of slab. Since the cracks could not be due to direct tension it seemed possible that they might be due to warping. The deflections measured are in fair accord with theory and it would be expected that the maximum bending moments in the warped slabs (and hence any cracks due to such flexing) would occur at approximately the position indicated by the theory. It will be found that the majority of the cracks referred to occur somewhat closer to the free end of the slab than is called for by the theoretical bending moment diagram. This may be due to greater subgrade stiffness than was contemplated in the theoretical analysis.

Cracks of this type do not appear in the reinforced sections. Measurements show that the presence of reinforcing considerably reduces the magnitude of the vertical movement both at the free ends of the slab and at transverse cracks through which the reinforcing is continuous.

MOVEMENT OF SLABS DUE TO SWELLING OF SUBGRADE FOUND TO BE UNIFORM

Swelling of the subgrade due to changes in moisture content or to freezing was determined by taking level readings from time to time on the sections, using permanent bench marks set below the frost line as references. These elevations were taken at points located along the center line of each section and spaced 10 feet apart.

These measurements indicate that the "heave" of all of the sections was fairly uniform throughout their respective lengths. The average changes in elevation were +0.05 of a foot and −0.02 of a foot. The maximum changes of +0.1 and −0.04 of a foot occurred on the north ends of sections 1 and 2 and extended for a distance of about 60 feet south. The greatest increase in elevation occurred at a time when the subgrade had been thoroughly saturated with water and had later frozen to a depth of 3 inches. Although the swelling that developed under this condition was the maximum measured, it was so uniform over the entire area covered by the sections that it is doubtful if any transverse cracks can be attributed to this action.

WET BURLAP FOUND TO BE EFFECTIVE IN PREVENTING SHRINKAGE CRACKS

Shrinkage in a concrete pavement is caused either by a loss of moisture or by a drop in temperature, or by both. During the early curing period the shrinkage due to loss of moisture is, in general, much greater than that due to a lowered temperature. In fact, it may be observed during this period that shrinkage is occurring while the temperature is actually rising.

In discussing shrinkage effects in this report a differentiation is made between distinctly local shrinkage cracks and the transverse cracks formed by the tendency of the slab as a whole to shorten. It will be recalled that what are referred to as "shrinkage" cracks differ from the "transverse" cracks in that they do not extend to the bottom of the concrete, nor do they extend to the full width of the slab when first formed. Under adverse curing conditions "shrinkage" cracks begin to appear almost immediately after the concrete has been finished and generally fully develop during the first 24 hours after the concrete has been placed. The extent and depth of these cracks depend largely upon the conditions to which the concrete is subjected during the initial curing period. The concrete during this period has little or no tensile strength and can not transmit the stresses produced any appreciable distance, with the result that under adverse conditions of temperature and moisture such cracks occur in close proximity and may be of such magnitude as to seriously impair the strength of the slab.

Table 3 shows the number of local shrinkage cracks that developed in the different sections during the first four months, together with the average relative humidity during the first 8 hours and also for the first 24 hours after the concrete was placed. These figures are the averages obtained by two observers, working independently, and counting all shrinkage cracks whose lengths were 1 inch or more in each section. Although the actual count reported was made after four months hadel apsed it was observed that practically all of the local shrinkage cracks formed during the very early life of the concrete.

Referring to Table 3, it will be seen that under adverse conditions an excessive number of shrinkage cracks developed. This is shown by those sections which were placed on a dry subgrade without curing treatment during the first 24 hours; those sections placed on a wet subgrade, with immediate curing treatments, having, in general, comparatively few shrinkage cracks. These experiments indicate most strongly that the immediate application of wet burlap can be depended upon to aid greatly in the elimination of the local shrinkage cracks which tend to form before the concrete has attained its final set. The following data extracted from Table 3 illustrate this point:

Section	Curing	Local shrinkage cracks
22	Wet earth	137
25	Burlap and wet earth	14
30	Sodium silicate	701
28	Burlap and sodium silicate	138
29	Calcium chloride	336
27	Burlap and calcium chloride	7

The section on which the asphalt emulsion was applied was almost entirely free from this type of crack.

In general, those sections which were placed when the humidity was low and without adequate early curing developed more local shrinkage cracks than those placed without adequate early curing but under conditions of somewhat higher humidity. These data emphasize the importance of adequate early curing treatment of the concrete, under conditions of low humidity.

Careful visual inspections were made, at regular intervals, of all of the sections to note any effect of the

[1] Analysis of the Stresses in Concrete Roads Caused by Variations in Temperature, by H. M. Westergaard, Public Roads, vol. 8, No. 3, May, 1927.

TABLE 3.—*Number of local shrinkage cracks, relative humidity and method of curing*

Section	Reinforcement, etc.	Curing method	Relative humidity: First 24 hours	Relative humidity: First 8 hours	Number of local shrinkage cracks
		DRY SUBGRADE			
1	None	None	50	33	1,560
2	None, joints	do	50	33	1,156
3	None	Tar after 24 hours	50	33	-------
4	do	Calcium chloride after 24 hours, 2 pounds per square yard.	59	33	96
5	do	Sodium silicate (4 : 1) after 24 hours.	59	33	619
6	do	Calcium chloride after 24 hours, 3 pounds per square yard.	50	33	128
7	do	Tar paper on subgrade, tar after 24 hours.	59	33	-------
8	2 ¼-inch round deformed bars.	None	65	53	482
9	2 ⅜-inch round deformed bars.	do	65	53	689
10	2 ½-inch round deformed bars.	do	54	50	722
11	2 ¾-inch round deformed bars.	do	65	53	952
12	2 ¾-inch plain bars, paint and grease.	do	64	52	839
13	2 ½-inch round deformed bars, joints.	do	73	67	471
14	2 ¾-inch round deformed bars, joints.	do	64	52	1,038
15	None	Calcium chloride admixture, 2 per cent.	50	33	869
17	43.8-pound fabric	None	69	50	1,588
18	23.6-pound fabric	do	73	67	238
19	43 8-pound fabric	do	55	48	1,451
20	None	Dry earth after 24 hours for 13 days.	59	33	823
21	do	Dry straw after 24 hours for 13 days.	50	33	1,602
		DAMP SUBGRADE			
22	None	Wet earth after 24 hours for 13 days.	59	48	137
23	do	do	59	48	93
24	do	Wet straw after 24 hours for 13 days.	59	48	45
		WET SUBGRADE			
25	None	Wet burlap for 24 hours, then wet earth for 13 days.	54	50	14
26	None, joints	do	54	50	61
27	None	Wet burlap for 24 hours, then calcium chloride, 2 pounds per square yard.	54	50	7
28	do	Wet burlap for 24 hours, then sodium silicate (4 : 1).	60	54	138
29	do	Calcium chloride after 24 hours, 2 pounds per square yard.	60	54	336
30	do	Sodium silicate (4 : 1) after 24 hours.	60	54	701
31	do	Calcium chloride admixture, 2 per cent.	60	54	587
32	43.8-pound fabric	Wet burlap for 24 hours, then wet earth for 13 days.	55	48	192
33	23.6-pound fabric	do	70	63	133
34	43.8-pound fabric, joints	do	70	63	94
35	2 ¼-inch round deformed bars.	do	75	59	1
36	2 ⅜-inch round deformed bars.	do	75	59	1
37	2 ½-inch round deformed bars.	do	70	63	20
38	2 ¾-inch round deformed bars.	do	64	52	0
39	2 ½-inch round deformed bars, joints.	do	69	50	4
40	2 ¾-inch round deformed bars, joints.	do	64	52	0
41	None	Asphalt emulsion sprayed on immediately after concrete was finished.	69	50	1

treatments on the surface of the concrete. Photographs were taken to show typical surface conditions which were observed. Illustrations A, B, C, and D of Figure 8 show the effect of the immediate application of a curing treatment in the almost entire absence of local shrinkage cracks. Illustration A shows a somewhat pitted appearance due to the use of a spray nozzle which was not entirely suited to the material being applied. Illustration B shows the surface appearance typical of those sections on which flake calcium chloride was applied. The appearance is different from that of the other sections in that a thin film of whitish appearance and extremely fine texture covers most of the surface. Illustrations E and F of Figure 8 and Figure 9 show the condition of sections where the immediate application of wet burlap was omitted and local shrinkage cracks are prevalent. Illustration E shows a surface appearance typical of section 15 where the curing treatment consisted of a 2 per cent admixture of calcium chloride without surface curing of any kind. This surface condition is of interest in connection with the discussion of crazing which follows:

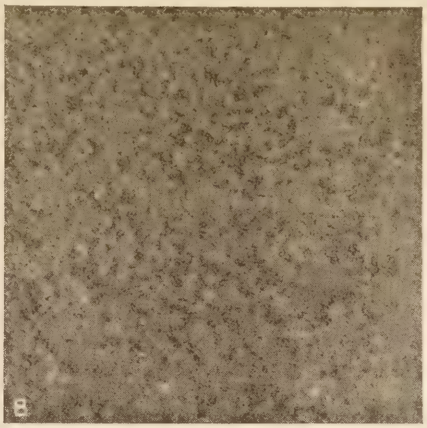
The test sections were very carefully examined for evidence of the condition commonly known as "crazing" where areas of the surface of the concrete are covered with a network of fine cracks of apparently little depth. It was observed that this condition appeared only in those areas where the surface of the concrete had been covered with a film of water, from which a skin of laitance had deposited. There is some evidence of crazing in the surface of those sections where the surface was protected and moistened with wet burlap. On these sections slight crazing is to be found in areas where the burlap was not in actual contact with the concrete because of wrinkles in the burlap, depressions in the concrete, or other causes. Where the surface skin was broken up by contact with the burlap no crazing is to be found. There seems to be a tendency for crazing to occur in the surface of those sections on which flake calcium chloride was used. The whitish, fine-grained surface which seems to result from this treatment appears to be particularly subject to these fine crazing cracks. There is also considerable crazing in the surface of Section 15 (see fig. 8, E) where a 2 per cent calcium chloride admixture was used without other curing treatment. No scaling has followed the appearance of crazing cracks on any of the sections, but it should be kept in mind that the weather is the only destructive agency to which these surfaces have been exposed.

In several cases the shrinkage cracks which appeared during the initial curing period have developed later into full transverse cracks. Examples of such cracks are shown in Figure 10.

Some observations were made to determine the depth to which local shrinkage cracks penetrated into the concrete. Cores were drilled so as to include some of these cracks in the top of the core. A solution of gasoline and a red dye (which was insoluble in water) was prepared and was poured into the cracks until they were filled. The liquid was allowed to dry and the core was then broken in a testing machine in order that the depth of the penetration into the crack could be measured. The maximum depth of crack was found to be about 2 inches and, in general, they were from one-fourth inch to 1 inch in depth.

The slab which was sprayed with asphalt emulsion originally had a black surface of uniform texture but this has since weathered off and now presents a mottled appearance, with but little of the bituminous material remaining. The appearance is not pleasing, but, as this surface had no traffic on it, it is perhaps not representative as to appearance.

Section 41, wet subgrade, asphalt emulsion sprayed on the surface immediately after finishing, surface free from local shrinkage cracks



Section 27, wet subgrade, wet burlap for 24 hours, then 2 pounds per sq. yd. of flake calcium chloride, surface free from local shrinkage cracks

Section 25, wet subgrade, wet burlap for 24 hours, then wet earth for 13 days, note burlap imprint and surface free from local shrinkage cracks

Section 28, wet subgrade, wet burlap for 24 hours, then an application of sodium silicate (4 parts sodium silicate, 42 Baumé to 1 part water), imprint of burlap evident and surface free from local shrinkage cracks

Section 15, dry subgrade, 2 per cent calcium chloride admixture with no surface curing treatment, note local shrinkage and crazing cracks

Section 30, wet subgrade, no curing treatment during the first 24 hours, then an application of sodium silicate (4 parts sodium silicate 42 Baumé to 1 part water), the local shrinkage cracks developed before the application of the sodium silicate

Figure 8.—Condition of Surface Produced by Various Methods of Curing

METHOD OF CURING AND SURFACE HARDNESS COMPARED

Tests to determine the relative surface hardness of some of the sections were made after the concrete was two years old. The apparatus used for making these tests has been described in Public Roads, volume 10, No. 5, July, 1929. It consists of a device which causes three narrow steel wheels, placed tangentially to a circular path, to roll along this path at a constant speed and under a constant load. The depth of wear produced in the circular path by any given number of wheel passages is used as a measure of the hardness of the surface being tested. In testing the curing sections the steel wheels used on the wear machine were not heat treated or hardened.

Table 4 shows the surface wear of a number of the sections on each type of subgrade and cured under different conditions. The values are tabulated in order of their relative hardness as determined by measured depth of abrasion. The figures given are the average values from five tests on each section. The curves in Figure 11 are the average curves for four of these sections and are representative of the data obtained. Differences in wear between sections having different curing methods indicate that there may be an effect of these different methods of curing on the surface hardness of the concrete. Sections which were covered

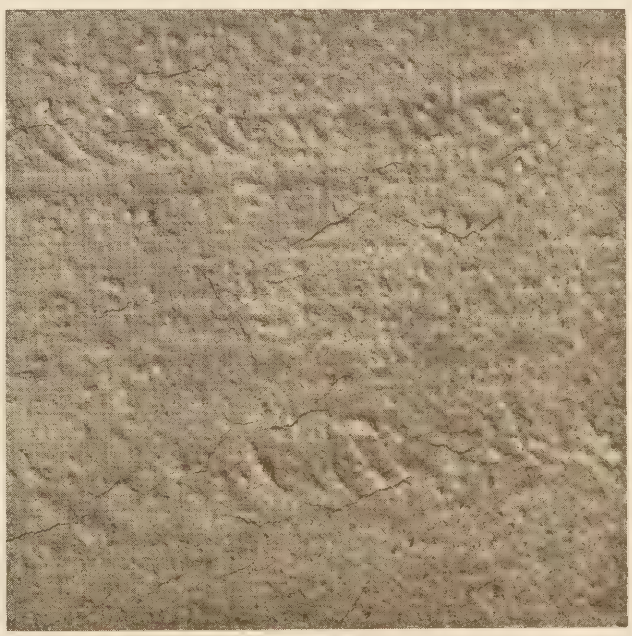
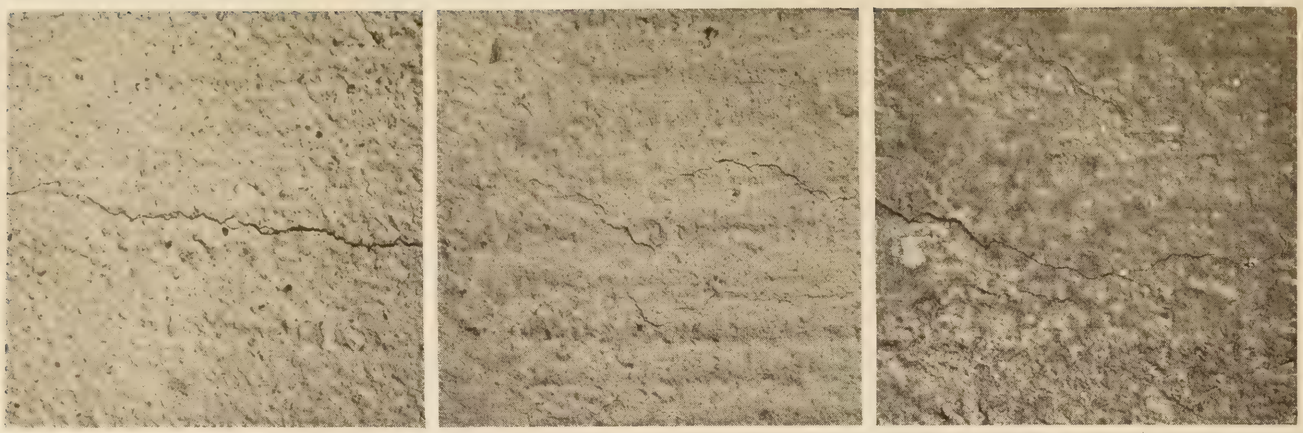


Figure 9.—Section 1, Dry Subgrade, no Curing. Local Shrinkage Cracks Caused by Rapid Drying of the Concrete During the Early Curing Period.



Section 20, full transverse crack that developed from a local shrinkage crack 7 days after the concrete was placed

Section 1, transverse crack that developed from shrinkage cracks 583 days after the concrete was placed

Section 3, transverse crack that developed from shrinkage cracks 335 days after concrete was placed

FIGURE 10.—EXAMPLES OF TRANSVERSE CRACKS

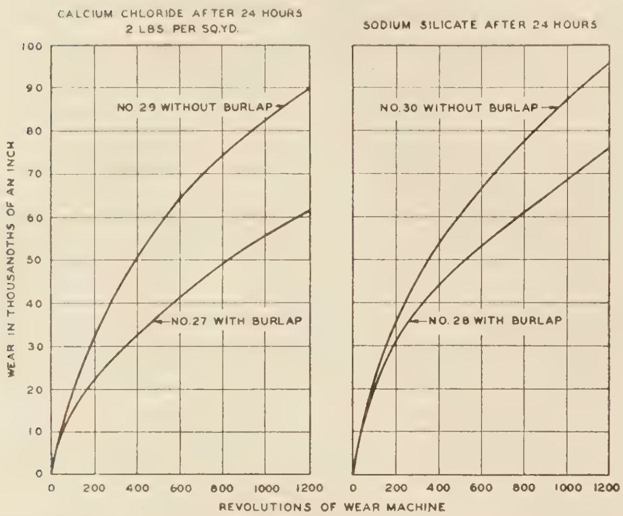


FIGURE 11.—EFFECT OF EARLY BURLAP TREATMENT ON THE SURFACE HARDNESS OF CONCRETE. EACH CURVE IS THE AVERAGE OF FIVE TESTS

TABLE 4.—*Relative surface hardness of concrete cured by different methods as determined with wear machine. Test made at 2 years*

DRY SUBGRADE

Section	Curing method	Surface wear in thousandths of an inch: 100 revolutions	400 revolutions	800 revolutions	1,200 revolutions
8	No curing	15	38	55	68
15	Calcium chloride admixture, 2 per cent	14	43	65	81
	WET SUBGRADE				
27	Wet burlap for 24 hours, then calcium chloride, 2 pounds per square yard	15	33	49	62
25	Wet burlap for 24 hours, then wet earth for 13 days	19	44	61	75
28	Wet burlap for 24 hours, then sodium silicate (4 : 1)	20	44	61	76
31	Calcium chloride admixture, 2 per cent	16	42	67	86
29	Calcium chloride after 24 hours, 2 pounds per square yard	20	50	74	90
30	Sodium silicate (4 : 1) after 24 hours	22	53	78	96
41	Asphalt emulsion sprayed immediately after finishing concrete	24	55	81	104

with wet burlap immediately after they were finished and then treated with either calcium chloride or sodium silicate did not show as much wear as did those on which the same surface application was used but on which the burlap was omitted.

LOSS OF MOISTURE FOUND TO VARY CONSIDERABLY WITH METHOD OF CURING

Two methods were used in the field to obtain the loss of moisture from the concrete. The first consisted of taking a pan of concrete (about 30 pounds) as it came from the mixer, striking off the surface and weighing, then placing it in the sun and weighing it at hourly intervals. Thus, a measure of the loss of moisture through surface evaporation of concrete which is not protected by a curing treatment was obtained.

The other method consisted of casting (concurrently with the long field sections) small slabs 24 by 12 inches in area and 6 inches thick and weighing the concrete for each as it came from the mixer. The upper surface of each slab was treated in the same manner as the corresponding long section. After 24 hours the forms were removed and the edges of all the small slabs were painted with tar for the purpose of restricting the loss in mois-

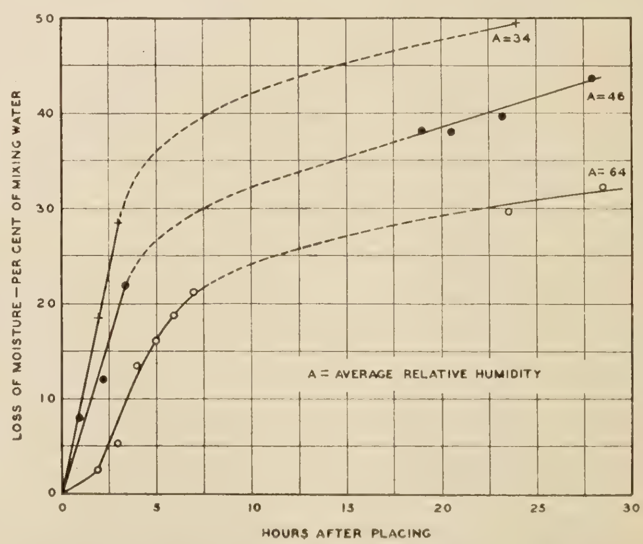


FIGURE 12.—CURVES SHOWING THE EFFECT OF HUMIDITY ON THE LOSS OF MOISTURE FROM THE SURFACE OF CONCRETE WHICH WAS NOT PROTECTED BY A CURING TREATMENT

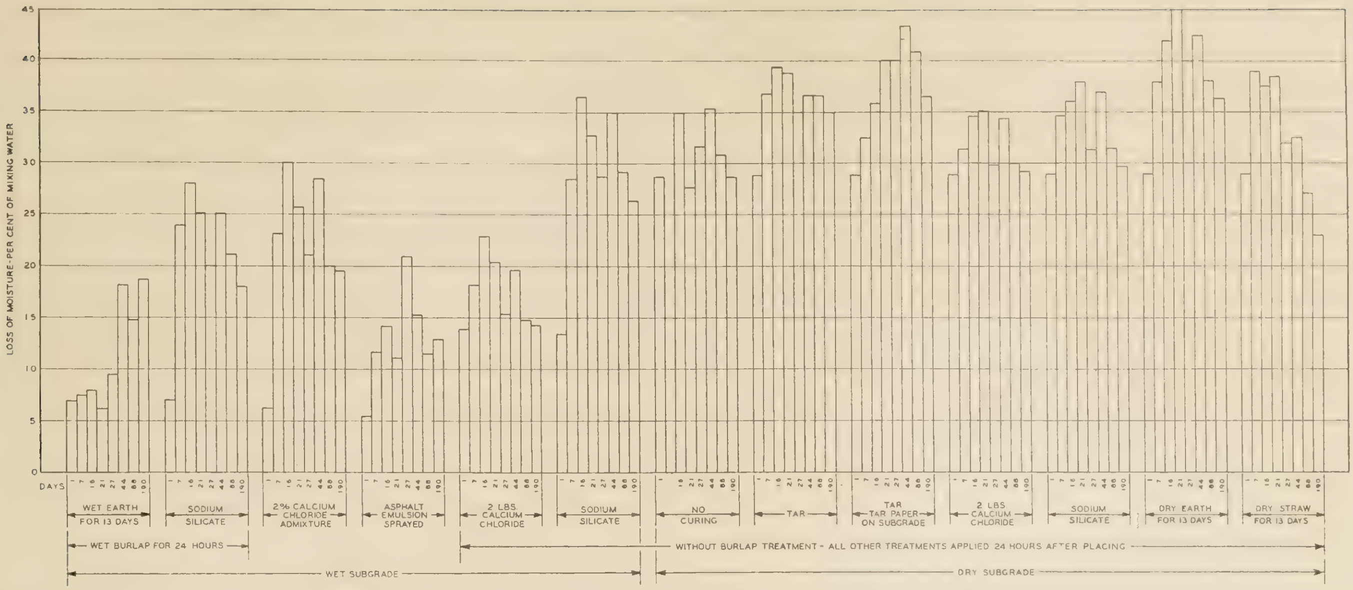


FIGURE 13.—LOSS OF MOISTURE FROM CONCRETE SPECIMENS (6 BY 12 FEET BY 24 INCHES) CURED SIMULTANEOUSLY AND IDENTICALLY WITH THE CORRESPONDING CURING SECTIONS

ture to the top and bottom surfaces. Twenty-four hours after placing and at intervals thereafter, these slabs were weighed to determine the loss in moisture that had occurred. From these specimens data were obtained on the comparative value of the various treatments of the surface and of the subgrade for preventing moisture loss from the freshly laid concrete.

Figure 12 gives the loss of moisture from several 30-pound pan specimens (expressed as a percentage of mixing water) at intervals during a period of approximately 24 hours, together with the average relative humidity for the period. These curves show that the greatest loss occurs during the first few hours after the concrete is placed. Almost 50 per cent of the mixing water evaportated from the surface of the unprotected concrete during the first 24 hours when exposed to an average humidity of 34. The curves also show the effect humidity has on the rapid drying out of the concrete during the early curing period.

Figure 13 gives the loss of moisture obtained with the small slabs having the different curing treatments, expressed as a percentage of the mixing water. A lower loss occurred during the first 24 hours on those slabs which were placed on a wet subgrade and whose surfaces were immediately protected than on any of the others. A comparison of the loss of moisture from the concrete during this period, shows that the slabs placed on a wet subgrade and having a curing treatment during the first 24 hours lost approximately 7 per cent of their mixing water and these slabs also show a low total loss over an extended period. The slabs which were placed on the wet subgrade but which received no surface protection for the first 24 hours lost about 14 per cent of their mixing water during this time. When placed on a dry subgrade this 24-hour loss amounted to about 29 per cent for specimens whose surface was not protected from moisture loss. These data bring out the advantage of subgrade moisture and of immediate surface protection for the prevention of moisture loss during the early life of the concrete. It will be noted that for otherwise comparable curing treatments the wet subgrade reduced the loss during the first 24 hours to about one-half of that which occurred in the specimens on the dry subgrade and that immediate protection reduced the loss to about one-half of that which occurred from the unprotected specimens during the first 24-hour period. It is also shown that, under adverse curing conditions, pavement concrete may lose as much as 40 or 45 per cent of the original mixing water during the first few weeks after it has been placed.

The data relative to wet burlap, calcium chloride admixture, and asphalt emulsion, the three immediate treatments studied, all show a low loss of moisture during the early life of the concrete, while wet earth, asphalt emulsion, and calcium chloride surface treatments show the least loss between 24 hours and 7 days.

The data given in Figures 12 and 13 show that under normal conditions, when no provision is made for early protection, a large portion of the mixing water is lost from the concrete during the first few hours after placing. It appears that after the concrete has obtained its initial set, the remaining retained moisture is not then so susceptible to the conditions that bring about a large loss during the earlier period. It follows, therefore, that a satisfactory treatment against the loss of moisture from the concrete during the period of hydration must necessarily be applied and be effective immediately after finishing is completed.

The data concerning the effect of humidity on the loss of moisture from the concrete during the early period of hardening brings out the important bearing this factor has on the problem of concrete curing. With only moderate differences in humidity the corresponding differences in the drying out of unprotected concrete were found to be as great as the differences found between extreme methods of curing on the concrete sections.

CONTROL SPECIMENS TESTED

It is doubtful if satisfactory strength data can be obtained from small test specimens in an investigation of this nature. The difficulty is that the exposure of the concrete in the test specimens to most curing treatments does not reproduce the condition of exposure which is met by the concrete in the pavement slab. This was realized when the program of these tests was formulated but it was thought advisable to make and test a certain number of such specimens in conjunction with the long slabs for whatever relative information they might furnish.

Compression tests on 6 by 8 inch cylinders, tension tests on 6 by 21 inch cylinders and flexure tests on 6 by 6 by 24 inch beams were made at 1, 3, 7, 21, and 180 days.

In the data from the cylindrical specimens there appeared to be no significant indication and it was in the case of these specimens that it was most difficult to obtain a curing condition which was at all representative of that of the test slab. For this reason these data are not included in the report.

With the beams it was possible to simulate the test slab conditions of curing more closely and it is believed that this is the reason that the data obtained from these tests appear to have some significance. These data are presented in Figure 14 in which the average values from the flexure tests are plotted as percentages of the strength obtained from specimens corresponding to section 25, which was cured with wet burlap and wet earth.

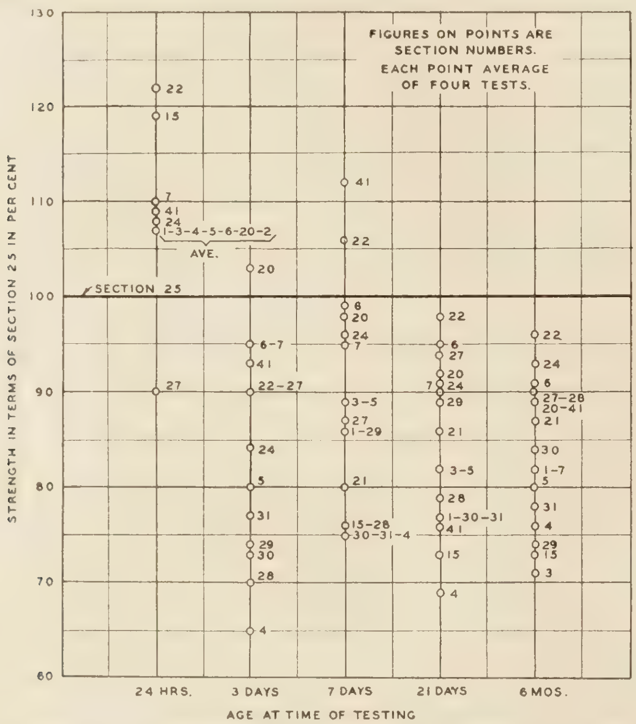


Figure 14.—Strength of Control Specimens in Terms of that Obtained from Specimens Cured with Burlap and Wet Earth

The data from the flexure tests show the comparative effect of the different curing methods on the strength of the concrete. Conditions of curing that permitted rapid drying or early set developed relatively high early-strength concrete. However, at the later ages, the strength of such concrete is, in general, less than that of concrete cured under conditions which cause slow drying and slow setting. This is clearly indicated by the comparative modulus of rupture as shown in Figure 14.

All of the specimens were taken from the field and immediately tested with the exception of those tested at six months. The 6-month specimens were stored indoors for several days before they were tested. Since moisture in concrete affects its strength, it is possible that some of this variation in the early strength results was due to the differences in moisture content and is not entirely an effect of the curing treatment.

EFFECT OF VARIOUS AMOUNTS OF STEEL REINFORCING ON THE FREQUENCY AND WIDTH OF CRACKS STUDIED

As stated earlier in the report, a series of sections with steel reinforcement, was included in this investigation, to obtain information regarding the effect of the different amounts and types of reinforcement on the cracking of concrete pavements.

Three types of reinforcement were used in the different sections, as follows: Deformed bars of ¼, ⅜, ½, and ¾ inch diameter placed continuously or segmentally; plain round ¾-inch bars, painted and greased, placed continuously; and welded rectangular fabric of both 23.6 and 43.8 pound weights (per 100 square feet) placed continuously and segmentally. All steel was placed 3 inches below the surface of each slab. In the case of the sections where the bars were used, two bars were placed in each section 12 inches apart and 6 inches in from the edges.

The continuous bar reinforcement seems to have a very definite effect on the transverse cracking as shown in Figure 3. This effect is not brought out by a consideration of the average slab length of the entire slab because in a number of cases the presence of the reinforcement operated to produce long uncracked slabs at the ends of the test section. If the two end slabs of each section are disregarded and the average slab length between the first and last transverse cracks in each section is computed, then the effect of the steel on the average slab length becomes clearer. These data for the four sections on both the dry and the wet subgrades are shown below.

Average length of reinforced slabs

[End slabs disregarded]

Section	Reinforcement	Average slab length, in feet
8	¼-inch deformed bars	29
9	⅜-inch deformed bars	33
10	½-inch deformed bars	11
11	¾-inch deformed bars	10
35	¼-inch deformed bars	30
36	⅜-inch deformed bars	26
37	½-inch deformed bars	21
38	¾-inch deformed bars	9

These figures indicate that, as the percentage of continuous steel-bar reinforcement is increased, the tendency is for the transverse cracks to form at more frequent and (from fig. 3) at rather regular intervals. Also, it was observed in every case that the larger the bars the more tightly are the fractured surfaces held together. In the reinforced segmental slabs there are some few transverse cracks but in every case these are held tightly shut by the steel, whereas those appearing in similar plain slabs are open from one thirty-second to one-eighth of an inch.

It is shown by the data obtained from section 12 that large bars, painted and greased, can be used continuously without greatly stressing the slab since the bonding qualities of the bars have been almost entirely destroyed by such treatment. With this type of reinforcing the transverse cracks occurred at intervals comparable to those found in unreinforced slabs and the width and appearance of the cracks is much the same in both cases. The advantage of this type of reinforced pavement over plain concrete lies in the doweling effect of the steel at all transverse cracks, preventing settling

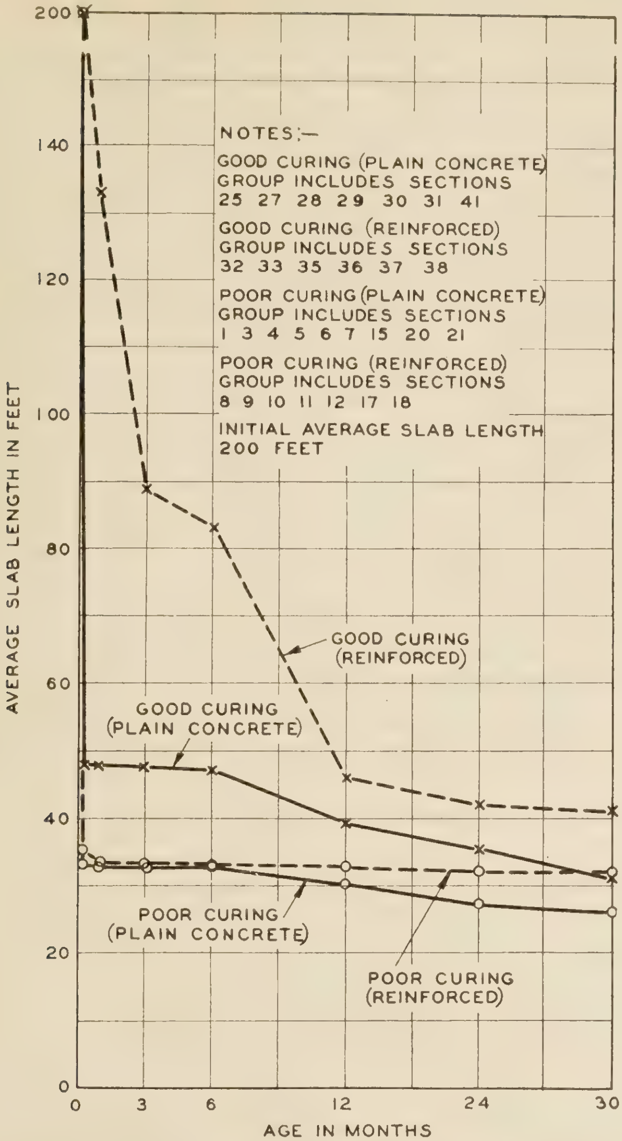
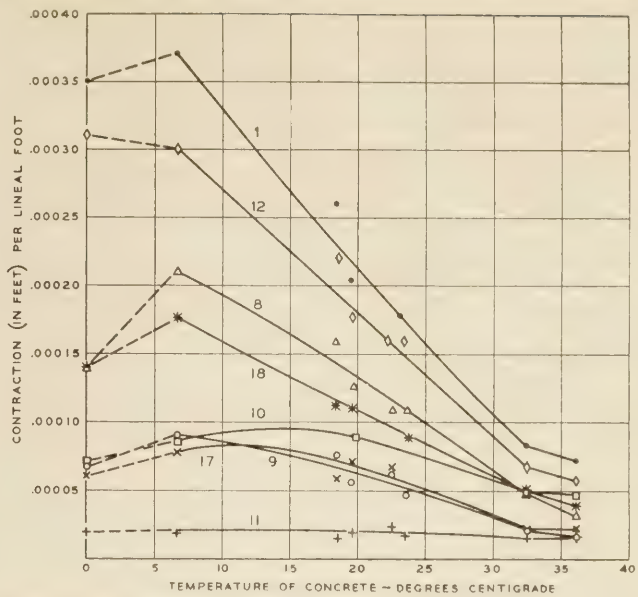


Figure 15.—The Effect of Plain and Reinforced Concrete (Cured Differently) on the Slab Length at Different Ages



Section 1, plain concrete.
Section 12, 2 ¾-inch plain bars painted and greased.
Section 11, 2 ¾-inch deformed bars.
Section 10, 2 ½-inch deformed bars.
Section 9, 2 ⅜-inch deformed bars, area 0.220 square inch.
Section 8, 2 ¼-inch deformed bars, area 0.098 square inch.
Section 17, 43.8 pounds rectangular fabric, area 0.240 square inch.
Section 18, 23.6 pounds rectangular fabric, area 0.132 square inch.

Figure 16.—The Effect of Continuous Reinforcing on the Contraction of Concrete Sections. Readings at Zero Temperature Made when Concrete was Expanded from Moisture.

that would cause new unsupported edges and the development of supplementary transverse cracks adjacent to the first crack.

The comparative effect of both plain and reinforced sections on the average slab length at different ages of the concrete is shown by the curves in Figure 15. Again, as in Figure 4, considering the sections that are placed on the dry subgrade as having poor curing and those placed on the wet subgrade as having good curing, the curves shown in this figure represent the average slab length in feet for each of these conditions for both plain and reinforced sections from the time they were placed up to and including the two and one-half year period. Sections in which steel reinforcement was used, placed under conditions of poor curing, developed nearly all of the transverse cracks during the early period after placing, and give an average slab length of approximately 35 feet at seven days, and at the two and one-half year period of approximately 32 feet. These average slab lengths are just slightly geater than for the sections of plain concrete. Under good conditions of curing the average slab length of steel reinforced slabs at 7 days is 200 feet, as against approximately 50 feet for plain concrete. At the two and one-half year period this relative position still holds, the steel reinforced sections averaging 42 feet while the plain concrete is approximately 31 feet.

The effect of continuous reinforcing on the contraction of concrete slabs over a range of different temperatures is shown by the curves in Figure 16. These data were obtained, from time to time, on the different sections by measuring the width of cracks with a special measuring microscope. The contraction of the concrete per lineal foot was arrived at by obtaining the total width of all the transverse cracks in a section in feet for a certain concrete temperature, dividing this figure by the effective length of the slab, i. e., the distance in feet between the extreme cracks, plus one-half the distances from the extreme cracks to the ends of the section.

Plain concrete and that in which plain bars, painted and greased, were used showed a higher contraction per lineal foot than sections in which continuous steel bars of different sizes in high bond were used.

It appears from the data that ¾-inch smooth bars painted and greased have less effect on the contraction of the concrete than do an equal number of ¼-inch deformed bars in good bond. This is a matter of interest to those who use this type of "continuous dowel" in their designs.

It is also interesting to note that, so far as the data may be compared, it is indicated that equal percentages of longitudinal steel, whether in the form of welded fabric or deformed bars, produce, equal effects on the contraction of the concrete. The 23.6-pound fabric (sec. 18) shows an effect less than that of ⅜-inch deformed bars (sec. 9) but greater than that of ¼-inch deformed bars (sec. 8), which corresponds to the relation

(Continued on p. 228)

NEED FOR SIMPLIFICATION OF SIZES IN SAND AND GRAVEL INDUSTRY[1]

By F. H. JACKSON, Senior Engineer of Tests, Division of Tests, United States Bureau of Public Roads

FOR many years engineers and aggregate producers have discussed "standardization" of specifications for aggregate sizes and have even gone so far as to propose a series of so-called standard sizes which were adopted as tentative a number of years ago by the American Society for Testing Materials. It now appears that possibly our efforts in this direction have been largely misdirected because we have been endeavoring to establish definite specifications for a single series of standard sizes for materials which occur in nature in widely different sizes and gradings. From the point of view of the engineer there appears to be no reason why absolute standardization should be affected throughout the United States. The producer of gravel in the Detroit region is not interested in specifications drawn by the cities of Boston or San Francisco. He is, however, vitally interested not only in the specifications which may be drawn by the city of Detroit but also in those which may be prepared by all other users of gravel in the territory which he serves. Furthermore, the multiplicity of sizes which may be required by users within his territory is just as confusing and works just as great a hardship upon him as any similar situation in the larger national field.

REDUCTION OF NUMBER OF AGGREGATE SIZES REQUIRED IN DIFFERENT AREAS DESIRABLE

The outstanding need in the way of simplification of sizes of aggregates is the reduction of the number of different sizes demanded of the producer in each of the major centers of production and distribution. The producer of sand and gravel, while a manufacturer in a certain sense, is not a manufacturer in the same sense as the producer of such products as paving brick. In the production of paving brick the size to be manufactured is directly under the control of the manufacturer and is not influenced by the character of the raw material. The same is true of most manufactured products. With sand and gravel, however, the producer is faced with the necessity of utilizing the material which nature has furnished to the best advantage. The sizes and gradings of the finished products which can be economically supplied are influenced to a marked degree by the size and grading of the pit run material. The producer can not supply material with a 2-inch maximum size when the largest gravel in his pit is 1 inch. Neither can he economically supply an aggregate complying with a specification which calls for a preponderance of the larger sizes when to do so would mean the wasting of large quantities of the smaller sizes. Specifications for sand and gravel in any given region are of necessity dependent upn the character of the materials available in that region which of course means that specifications for materials for the same use in different sections of the country may and probably should be quite different.

Too many specifications are written in rule of thumb fashion without regard to the most economical use of the available material. Engineers are slow to recognize that the exact limiting sizes or exact range in sizes for a given product are not nearly so important as is the question of uniformity of successive shipments of the particular size and grading specified. This is particularly true where the aggregate is to be used in designed mixes of Portland cement concrete as opposed to the method of designating arbitrary proportions. The engineer should be able to design a mixture of the required quality with any given aggregates regardless of the exact grading of the aggregates furnished. He should, however, have assurance that aggregates of the size and grading from which he established his design can and will be furnished on the job from start to finish. The same is true of other uses of sand and gravel.

Uniformity is far more important than adherence to some arbitrary size limit and simplification by reduction of the number of sizes required within a given territory will unquestionably facilitate compliance with requirements for uniformity. The producer, having to manufacture and stock only a few distinct grades instead of many grades differing only slightly in size, is in a much better position to make uniform and mutually satisfactory deliveries on any given project. Aggregate producers are willing and anxious to comply with the specifications and it is obvious that the task will be greatly simplified if there is only one instead of a dozen specifications to meet for a given use.

On the other hand, the engineer is responsible for the quality of construction and he must be convinced that the size which he will be required to use under a simplification program will be as satisfactory as the sizes which he has been using. Simplification should be a matter of joint effort between producer and consumer.

ADOPTION OF SERIES OF NOMINAL SIZE LIMITS PRACTICABLE

For the above reasons it is believed that national standardization of specifications for sand and gravel is neither necessary nor desirable. However, there is good reason for the simplification by reduction of the unnecessarily large number of sizes now specified in the various production regions. It will also be helpful to adopt a series of nominal size limits covering the major uses of sand and gravel, such as has been recommended by the committee on standards of the National Sand and Gravel Association. Since these are merely nominal maximum and minimum size limits they would in no sense be considered as specifications but would be subject to further definition by the insertion of suitable intermediate size requirements, tolerances, etc., to meet local conditions.

As the first step in the simplification program, the suggested size limits could be used as a frame upon which to build the simplified specification requirements

[1] Presented at the annual meeting of the National Sand and Gravel Association, Memphis, Tenn., Jan. 29, 1930.

best suited to each production district. The adoption of actual specification limits would, of course, be a matter of joint action by producer and consumer in each case and this would have to be accomplished before any real benefits from simplification would accrue to either producer or consumer. A paper presented before the meeting of the American Concrete Institute[2] describes efforts made along this line in the Detroit area and illustrates a type of joint effort which should accomplish results. It is understood that similar efforts are being made in the Pittsburgh and other districts.

With regard to the recommendation made by the standards committee of the National Sand and Gravel Association for limiting sizes for standard grades of sand and gravel, it is desired to make a few comments. Two grades of sand and five grades of gravel have been recommended, as shown in Table 1.

TABLE 1.—*Recommendations of standards committee of National Sand and Gravel Association for commercial sizes of sand and gravel*

SAND

Commercial sizes		Typical uses
Square sieves	Round screens	
0 to No. 8		Sheet asphalt, bituminous concrete, plaster mortar, grout, etc.
0 to 3/8 inch	0 to 7/16 inch	Concrete, etc.
GRAVEL		
No. 4 to 1/2 inch	1/4 to 5/8 inch	Thin concrete sections, concrete building units, bituminous surface treatment, etc.
No. 4 to 3/4 inch	1/4 to 7/8 inch	Light reinforced concrete construction, maintenance gravel roads, etc.
No. 4 to 1 inch	1/4 to 1 1/4 inches	General use as concrete aggregate.
No. 4 to 1 1/2 inches	1/4 to 2 inches	Concrete highway construction and general concrete work.
No. 4 to 2 inches	1/4 to 2 1/2 inches	Concrete highway construction and heavy reinforced concrete work.
No. 4 to 2 1/2 inches	1/4 to 3 inches	(same as above)

The various size limits in Table 1 have been given in terms of both square-mesh sieves and round-hole screens. Reference to both types is necessary, as a single standard method of measuring size of coarse aggregates has not yet been agreed on.

It is believed that the 3/8-inch maximum size for sand for concrete is somewhat high and is not in proper relation to the minimum size of gravel which is given in all cases as the No. 4 screen. The 3/8-inch square-mesh sieve has a round hole equivalent of about seven-sixteenths inch or almost one-half inch, which is larger than the usual limit for concrete sand.

Another comment is in regard to the method of designating all material from the No. 4 sieve to the maximum size, say 2 inches as a single size. It is recognized that in many plants the gravel is not screened into several primary sizes while in others, particularly in many of the larger plants, this practice is followed. The other method of size designation is preferred; that is, each primary separation is considered as a primary size and combinations of them are considered as combination sizes. In other words, the primary gravel sizes would then be:

No. 4 sieve to 1/2 inch.
1/2 inch to 3/4 inch.
3/4 inch to 1 inch.
1 inch to 1 1/2 inches.
1 1/2 inches to 2 inches.
2 inches to 2 1/2 inches.

[2] Williams, L. E., Confusion of Specifications for Aggregates. Proceedings American Concrete Institute, vol. 25, 1929, pp. 642-650.

PROPOSED PLAN WILL FACILITATE SHIPPING OF AGGREGATE IN SEPARATED SIZES

It would not be necessary for every gravel producer to screen his product into these five separate products. A specification could still require, for example, No. 4 sieve to 1 1/2 inches with suitable intermediate requirements, tolerances, etc. Such a specification would simply mean that the specified material includes four of the primary sizes. Whether the material is made up of the four sizes previously screened and then blended to conform to the specification or whether only two sizes have been originally made, say No. 4 sieve to 3/4 inch and 3/4 inch to 1 1/2 inches is a matter of local control. The material might be produced without any separations whatever between the upper and lower limits provided it is possible to do so and still meet the specifications.

Designating the primary separations in the manner indicated above, has one obvious advantage. It makes possible, under favorable circumstances, the shipping of gravel to the job in two or more separated sizes. In such a case, the engineer specifies the number of tons of each size desired and the producer ships each size separately. It is believed that the time is not far distant when engineers will realize the advantages in the way of increased uniformity to be gained by batching the coarse aggregate in more than one size. It is practically a physical impossibility to handle a shipment of coarse aggregate in which the size ranges from No. 4 to, say, 1 1/2-inch square mesh without segregation. It is believed that we will eventually discard the present unscientific and haphazard method of handling coarse aggregate in favor of a method which will insure that every batch of concrete will be like every other batch. Nothing will contribute more to this end than the adoption of this practice in handling aggregates.

Let us look into the matter from the producer's standpoint. What change in present manufacturing and distributing practice would be involved? In the first place, how many important gravel plants handle material running up to, say 2 inches in size, which do not make at least one intermediate separation at either three-fourths inch or 1 inch? In the large producing centers the demand for most if not all of the sizes listed by the committee is sufficient to require the installation of screens for each maximum size specified. However, in many plants, instead of separating the product into a number of primary sizes, and then recombining them, gravel of any desired maximum size is obtained by screening out the oversize gravel, which is either crushed or wasted as local conditions dictate. Most of the large gravel plants have more or less complicated combinations of screens, bins, and chutes arranged and added to from time to time in an effort to manufacture graded products to meet definite specification requirements. In some plants these installations are so complicated that it is difficult for anyone but the plant superintendent to understand them. Even though these arrangements may be so designed as to blend sizes perfectly in the bin or in the car, segregation in handling will frequently undo the work. It seems desirable to adopt the rational and simple method of screening the product into the number of primary sizes dictated by the character of the material and the demand and avoid all this trouble. Such a plan will require a radical change in construction practice and it will be necessary to convince both the engineer and the producer as to its desirability.

SIMPLIFICATION ATTAINABLE ONLY THROUGH COOPERATION OF PRODUCER AND CONSUMER

The matter of separated sizes though related in a general way to the subject under discussion, is not the question of primary interest. The question of immediate concern is how to reduce the number of sizes of sand and gravel which commercial producers are now required to produce and stock. As has been stated, acceptance of the recommended nominal standard sizes by the industry and the user appears to be the first step. The Division of Simplified Practice of the Department of Commerce is admirably equipped to cooperate with the industry in carrying forward this part of the program. However, acceptance of these limiting sizes will not relieve the producer who is harassed with a number of specifications differing as to intermediate size requirements even though the upper and lower limits may be the same. The specifications of the various users for any aggregate for a given purpose must be the same in any given production region before the problem is solved.

Regional committees made up of representatives of both the producers and the consumers should be formed for this purpose. In this work the producer should take the initiative. He is, as a rule, better organized than the consumer. His interests in the matter are also more obvious though perhaps not more real than those of the consumer. The regions or areas into which this phase of the simplification program would be divided would correspond obviously to the centers of greatest commercial activity; that is, the regions within shipping radius of the large centers of population. We have already noted activity of this sort under way in at least two such areas—Detroit and Pittsburgh. It can be extended to other areas where similar problems have arisen. The national association, through its representative members in these regions, is the logical organization to initiate the program.

The Bureau of Public Roads is thoroughly in sympathy with the simplification of sizes and varieties of the various manufactured products used in the construction of roads. The recommendations of the Division of Simplified Practice in the matter of grades of asphalt and varieties and sizes of paving brick have been widely followed by both the industries involved and the user and there is every reason to believe that similar success will attend the efforts which the National Sand and Gravel Association is about to initiate in the matter of simplification of sizes of sand and gravel.

(Continued from p. 225)

between their areas. The 43.8-pound fabric (sec. 17) appears to have about the same effect as ⅜-inch deformed bars and their unit sectional areas are approximately the same.

GENERAL INDICATIONS PRESENTED

In summarizing what seem to be the most important indications of the data obtained from this investigation no attempt is made to establish the relative merits of the various curing materials used. It is believed that the evidence obtained is neither sufficiently comprehensive nor sufficiently conclusive for such a purpose. However, there are indications which seem quite clear and these are presented below.

1. Careful attention to curing improves the quality of the concrete both from the standpoint of strength and that of surface appearance.
2. Any curing method, to be effective, must commence as soon as the concrete surface is finished.
3. All things considered, the wet burlap-wet earth curing method used in these tests was more effective than any of the other methods used.
4. The immediate application of wet burlap largely prevented the surface checking so prevalent in those slabs where the curing was delayed.
5. Under adverse conditions concrete may lose as much as 40 to 45 per cent of the original mixing water during the first few weeks after placing and, more important, under these conditions as much as 75 per cent of this loss may occur during the first 24 hours.
6. The application of a black surface to concrete slabs causes greater temperature variations and consequent volume changes to take place than would otherwise be the case and under certain conditions this may result in an abnormal amount of transverse cracking.
7. The use of transverse joints which will allow free longitudinal movement of the slab ends is of material benefit for the control of transverse cracking.
8. The method used for curing a concrete pavement may affect its surface hardness.
9. Increasing the percentage of continuous longitudinal reinforcing steel decreases the average slab length.

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.

DEPARTMENT BULLETINS

No. *136D. Highway Bonds. 20c.
220D. Road Models.
257D. Progress Report of Experiments in Dust Prevention and Road Preservation, 1914.
*314D. Methods for the Examination of Bituminous Road Materials. 10c.
*347D. Methods for the Determination of the Physical Properties of Road-Building Rock. 10c.
*370D. The Results of Physical Tests of Road-Building Rock. 15c.
386D. Public Road Mileage and Revenues in the Middle Atlantic States, 1914.
387D. Public Road Mileage and Revenues in the Southern States, 1914.
388D. Public Road Mileage and Revenues in the New England States, 1914.
390D. Public Road Mileage and Revenues in the United States, 1914. A Summary.
407D. Progress Reports of Experiments in Dust Prevention and Road Preservation, 1915.
463D. Earth, Sand-Clay, and Gravel Roads.
*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.
1259D. Standard Specifications for Steel Highway Bridges, adopted by the American Association of State Highway Officials and approved by the Secretary of Agriculture for use in connection with Federal-aid road work.
1279D. Rural Highway Mileage, Income, and Expenditures 1921 and 1922.
1486D. Highway Bridge Location.

DEPARTMENT CIRCULARS

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

TECHNICAL BULLETIN

No. 55. 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.
*109M. Federal Legislation and Regulations Relating to the Improvement of Federal-Aid Roads and National-Forest Roads and Trails. 10c.

SEPARATE REPRINTS FROM THE YEARBOOK

No. 914Y. Highways and Highway Transportation.
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 Connecticut.
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

JANUARY 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	2,086.9	$ 3,076,933.76	$ 1,521,251.16	103.4	21.0	124.4						$ 3,381,902.50	Alabama
Arizona	799.3	3,747,166.63	3,051,810.65	162.4	119.0	281.4	$ 794,195.75	$ 597,949.95	0.3	17.1	17.4	1,986,050.63	Arizona
Arkansas	1,764.5	3,384,408.09	1,615,697.81	142.0	28.7	170.7	392,830.31	169,199.40	19.1	8.2	27.3	2,579,165.77	Arkansas
California	1,833.6	6,833,102.19	3,058,612.81	176.7	10.2	186.9	596,093.07	158,491.79	4.0	9.0	13.0	2,268,295.91	California
Colorado	1,181.1	4,375,825.53	2,325,559.02	169.5	33.2	202.7	357,025.81	186,666.78	18.5	1.1	19.6	2,406,684.31	Colorado
Connecticut	240.3	915,395.25	367,981.09	6.0		6.0	890,986.61	380,786.16	4.1		4.1	893,257.10	Connecticut
Delaware	249.3	601,315.95	222,817.99	16.6		16.6						411,606.39	Delaware
Florida	467.2	4,637,473.11	2,086,706.02	92.7	5.5	98.2	322,356.82	161,178.40	9.3		9.3	1,606,141.26	Florida
Georgia	2,675.2	1,673,244.10	804,202.62	81.4	11.4	92.8						3,996,268.40	Georgia
Idaho	1,182.0	1,067,170.55	641,988.33	71.3	24.2	95.5	99,627.73	60,623.92	8.6	3.7	12.3	1,364,961.66	Idaho
Illinois	2,025.3	15,479,650.54	6,839,118.06	439.6		439.6	528,000.00	264,000.00	18.3		18.3	5,699,860.05	Illinois
Indiana	1,344.0	7,509,467.02	3,525,586.95	233.1		233.1	374,724.44	178,170.00	11.9		11.9	1,944,445.43	Indiana
Iowa	3,131.6	818,396.20	343,538.63	15.1	18.5	33.6	3,671,877.04	1,624,826.27	31.3	105.9	137.2	412,481.91	Iowa
Kansas	2,686.5	5,598,104.12	2,320,604.37	315.2	15.7	330.9	605,944.59	292,193.75	19.1	2.9	22.0	2,115,720.55	Kansas
Kentucky	1,397.8	4,238,953.63	2,013,037.35	235.5	20.2	255.7						1,846,732.84	Kentucky
Louisiana	1,357.8	3,495,753.19	1,737,237.78	114.7	4.8	119.5	580,769.52	255,364.64	17.7	7.7	25.4	1,781,069.10	Louisiana
Maine	520.0	1,905,021.13	736,937.56	47.5		47.5	87,912.01	43,956.00	5.6		5.6	1,513,409.27	Maine
Maryland	627.3	1,310,720.60	625,028.85	54.7		54.7	399,114.90	110,344.89	12.6		12.6	549,512.16	Maryland
Massachusetts	655.7	1,923,972.80	590,682.62	21.5		21.5	750,292.55	242,585.99	16.7		16.7	2,254,978.11	Massachusetts
Michigan	1,607.7	8,997,926.25	3,861,615.50	208.4	19.6	228.0	1,215,000.00	438,488.31	27.1	10.9	38.0	2,122,650.68	Michigan
Minnesota	4,101.3	4,778,291.76	1,409,300.00	140.7	75.2	215.9	5,000,337.73	1,085,165.90	77.3	143.0	220.3	505,679.23	Minnesota
Mississippi	1,782.2	2,241,732.70	914,691.15	94.2	7.7	101.9						2,635,793.47	Mississippi
Missouri	2,373.0	7,372,981.15	2,799,146.91	103.8	92.1	195.9	2,467,142.11	775,881,64	16.4	52.4	68.8	1,809,916.02	Missouri
Montana	1,722.2	6,857,483.66	4,028,569.07	475.5	12.0	487.5	1,271,972.59	678,804.59	98.9	16.1	115.0	3,177,427.01	Montana
Nebraska	3,584.8	6,595,412.91	3,196,628.88	331.1	158.9	490.0	396,762.02	183,657.74	19.9	15.1	35.0	2,410,180.31	Nebraska
Nevada	1,154.9	1,042,810.53	917,458.20	120.4	66.0	186.4	131,589.26	116,917.05		17.6	17.6	906,071.23	Nevada
New Hampshire	350.6	414,924.02	111,495.00	5.4	2.1	7.5						449,153.36	New Hampshire
New Jersey	500.2	4,136,550.77	852,015.00	56.8		56.8						1,091,124.08	New Jersey
New Mexico	1,935.1	2,453,620.46	1,553,539.20	132.8	2.0	134.8	436,292.14	270,039.54	36.0	.1	36.1	1,498,977.70	New Mexico
New York	2,458.3	17,932,217.76	3,661,055.00	244.8		244.8	3,293,000.00	538,350.00	36.0		36.0	6,827,080.99	New York
North Carolina	1,764.1	1,183,861.49	581,314.21	55.4	23.4	78.8	695,850.06	347,338.23	55.1		55.1	2,691,786.09	North Carolina
North Dakota	4,176.8	1,196,709.89	482,732.47	205.4	101.7	307.1	1,651,883.93	844,717.41	323.1	110.8	433.9	1,148.079.02	North Dakota
Ohio	2,158.9	13,005,059.21	3,902,875.17	219.8	18.3	238.1	4,476,551.10	1,241,427.56	63.5	25.5	89.0	2,971,813.12	Ohio
Oklahoma	1,822.0	3,396,855.20	1,557,260.52	113.0	42.8	155.8	193,405.59	89,723.70	7.2	2.8	10.0	1,833,020.49	Oklahoma
Oregon	1,146.1	2,567,420.79	1,580,757.80	154.9	56.2	211.1	1,722,995.72	988,658.86	59.7	19.4	79.1	733,465.55	Oregon
Pennsylvania	2,261.3	13,729,797.43	3,309,334.44	203.4	14.1	217.5	3,535,803.27	969,080.10	56.9		56.9	2,448,624.88	Pennsylvania
Rhode Island	184.8	1,288,121.21	353,218.58	15.6		15.6	93,697.64	42,480.00	2.8		2.8	614,769.90	Rhode Island
South Carolina	1,894.9	3,036,983.61	1,054,207.62	86.6	24.1	110.7						1,392,889.31	South Carolina
South Dakota	3,434.5	3,682,053.67	1,984,786.15	417.1	119.5	536.6	216,582.39	119,120.29	37.2	20.0	57.2	1,104,975.55	South Dakota
Tennessee	1,243.4	1,708,518.59	735,475.82	63.5		63.5	197,948.17	98,974.07	11.3		11.3	2,451,332.15	Tennessee
Texas	6,553.9	14,396,576.85	5,995,864.11	421.9	165.5	587.4	1,100,233.50	432,618.15	33.5		33.5	4,485,616.30	Texas
Utah	988.9	597,367.93	387,997.67	25.8		25.8	172,237.07	124,581.68	6.3	.3	6.6	926,349.40	Utah
Vermont	257.8	524,815.88	209,489.96	9.3		9.3						428,497.48	Vermont
Virginia	1,402.8	2,373,527.45	1,143,378.52	116.1	12.0	128.1	1,289,312.55	547,390.04	41.3	3.6	44.9	1,023,423.47	Virginia
Washington	898.9	3,789,074.44	1,407,000.00	80.4	40.3	120.7						1,357,179.87	Washington
West Virginia	707.3	3,190,708.83	1,294,271.77	81.0	12.5	93.5						806,239.69	West Virginia
Wisconsin	2,196.2	6,780,292.95	3,117,307.07	237.8	4.0	241.8						1,626,032.86	Wisconsin
Wyoming	1,757.2	1,402,899.36	906,367.11	128.0	14.7	142.7	41,252.20	27,082.06		9.6	9.6	964,555.97	Wyoming
Hawaii	39.5	402,261.10	137,428.82	6.6		6.6	562,688.38	247,259.61	16.6		16.6	1,438,289.16	Hawaii
TOTALS	82,684.0	213,668,932.24	87,874,979.39	7,054.4	1,397.1	8,451.5	40,614,288.57	14,934,094.47	1,223.2	602.8	1,826.0	92,893,537.69	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.