What was within the scope was the evaluation of several curing methods based on the amount of moisture retained under given temperature conditions during the first 72 hr. in accordance with current practice (ASTM Designation C156-44T).

The data on core strengths was omitted as it did not add much information and space limitations had to be met. As a matter of information, the means of eight compressive strengths at approximately 80 days were as follows: waterpoof paper: 5,660 psi.; membrane and limewash: 5,480 psi.; no cure: 5,450 psi.; damp burlap: 5,370 psi.; liquid membrane seal: 5,260 psi.; but the variations encountered within each treatment were often larger than the differences between treatments. It is possible that if coring and testing had taken place when the concrete was 72 hr. old (end of curing period) instead of several months, less erratic data would have been obtained and a correlation established between compressive strength and curing methods.

The liquid-membrane seal had been approved as meeting specifications by the Division of Tests of the Virginia Department of Highways and, as already stated, was mechanically applied under the state inspector's direct supervision in a manner believed typical of current field practice.

As a matter of information, 3,025 gal. of liquid-membrane seal was used for the entire paving project of 4.874 mi. (an average coverage of slightly less than 204 sq. ft. per gal. to be compared with the specification of 200 sq. ft. per gal.)

CURING CONCRETE PAVEMENTS IN KANSAS

R. L. Peyton, *Concrete Engineer, Kansas Highway Commission*

● The present specification for curing concrete pavements in Kansas requires the use of moist burlap covers for the first 24 hr., after which the pavement is covered with earth to a minimum depth of 4 in. The earth cover must be maintained in a moist condition for 10 days, left in place for 20 days and all traffic including construction traffic is excluded for a total of 30 days. The only exception to these requirements is in the case of city sections where earth cover is difficult to obtain economically. In such cases, cotton mats may be used in lieu of earth cover; all other requirements of the specification apply when this option is exercised.

This curing system precludes the use of membranes, either bituminous, nonbituminous, clear or pigmented. Paper covers, ponding, calcium chloride, and other types are also prohibited.

There is nothing new in these requirements; actually they are almost exactly the same as the curing specifications used in this state in 1924. Only the depth of cover has been changed from 2 in. to 4 in.

The operation of curing concrete pavements may be defined as the process necessary to protect the fresh concrete from adverse action of the elements and other physical forces during the period in which the concrete is hardening and gaining strength. When this definition is examined in detail, it is apparent that proper curing involves protection from both high and low temperature extremes, driving rain, drying winds and the prevention of damage by premature loading of the slab.

In Kansas it is believed no method of curing other than the one in use at present is sufficiently versatile to accomplish all of these things. This conclusion was arrived at after a period of about 25 yr., during which time practically all types of curing systems were used as standard procedure at one time or another. Observation of the results derived from the use of various curing systems coupled with some investigations of the efficiency of some of the more modern types of curing have convinced Kansas that the present method is better than anything else available. A short review of the various requirements used throughout this period of time will indicate to some degree why the state returned to this early method of curing concrete pavements.

From 1920 until 1930 the requirements were essentially the same as those now in force. It was during this period that the so-called old-fashioned concrete pavements were constructed. In 1931 curing requirements were revised to permit the use of other methods "if approved by the commission," and the curing time was reduced to the period necessary for test specimens to acquire a transverse strength of 500 lb. per sq. in. These specifications remained unchanged until 1942. The introduction of the shorter curing period, governed by strength tests, made it practical for contractors to cure with burlap only, ponding, and with membranes. It was economically feasible to use these methods, under suitable conditions, when only four days curing was required. In 1942 our specifications were revised to permit the use of cotton mats, waterproof paper, and membranes, in addition to burlap and wet earth. A minimum curing time of 96 hr. was specified; additional time was required if at the end of the minimum period the transverse strength tests were less than 500 psi. These requirements remained in force until 1950. During this period a few projects were cured with waterproof paper, one or two with cotton mats, and many miles with transparent membranes. Under this system very few pavements were cured more than four days before heavy construction traffic was permitted. This varied experience has indicated the advantages and disadvantages to each system, if any, and since the decision to adopt the system now in use is based principally on this experience, a summary of opinion on each curing system may be pertinent.

CURING TIME

It is difficult to determine exactly the effects of opening new concrete pavements to traffic after 96 hr. of curing, or at such time as the transverse strength specimens indicated a flexural strength of 500 psi., because other factors in addition to curing are involved. Nevertheless, Kansas believes that such a short period for curing, whatever the method, was a serious mistake. This conviction is based upon an accumulation of information derived from a series of pavement condition surveys made in 1938, 1945, and 1950 and from strength tests made during the course of experimental paving projects in 1949.

The condition surveys have indicated that there is a marked difference between pavements constructed prior to about 1930 and those built since that date. It is fully realized that many factors other than curing are involved in judging the character of the concrete in these pavements, such as changed traffic conditions, increased speed of all construction operations, and changes in design. However, the element of curing is also present, and its influence has had an effect. In general, it can be stated that pavements constructed during the time short curing periods were permitted do not have the durability and serviceability of the older slabs, built under the old system with longer curing time.

In 1949, during the construction of an experimental pavement slab, some 400 specimens for flexural strength were made containing 12 different types of concrete. The specimens were cast in two sizes and, after a period of standard curing, tested for flexural strength. The beams of small cross-section (3 by 4 in.) averaged 15 percent higher in flexural strength at seven days than those of a larger cross-section (6 by 6 in.) did at ten days. Consideration of the former system of opening pavement slabs to traffic in relation to this information has indicated that although test specimens may indicate a flexural strength of 500 psi., by no means does this indicate that a pavement slab of the same materials has reached the same strength. If as indicated by this group of tests the apparent strength of concrete is increased as the cross-sectional dimensions of the flexural strength specimens are reduced, it is not reasonable to assume that the actual early strength of a concrete pavement slab is as high as the strength indicated by the small test specimens. Also in our former paving operations the specimens almost always received more uniform treatment and better curing than the slab they represented. This was particularly true in the case of membrane-cured pavements.

On multiple-lane pavements of post-war construction where the contractor was allowed to operate his equipment on the first lane after specimens representing the slab attained the required strength, an unusually large number of failures occurred at early ages. In these pavements the most frequent trouble has been scaling along the longitudinal joints between the first and second lanes. In the two years the burlap-and-wet-earth system with traffic excluded for 30 days has been used, none of this type of trouble has appeared. In addition, the concrete in these projects is of a tougher, more durable character, and strength tests on specimens stored on the projects have indicated continuous high strength.

From all of these various things it has been concluded that a lengthy curing period is essential to produce high-quality pavement slabs

PONDING

Ponding is a particularly disadvantageous curing system to use from the standpoint of administration. On rural jobs where any grades are involved it is exceedingly difficult to hold ponds on the grades. Only very short diked sections will work and the difficulties of building dikes and hauling sufficient water to keep the ponds filled are impractical to the degree that few contractors will even contemplate ponding if anything else is permissible. Also there have been cases, where pavements are laid on dry expansive soils, when the water loss from the ponds has caused considerable distress from unequal swelling of the subgrade.

PAPER COVERS

Probably the biggest disadvantage to this type of curing in Kansas is the difficulty of maintaining the covers in place, because of the high winds which are prevalent in many sections of the state. Also, these paper covers are not susceptible to re-use without considerable loss in handling and storage. The ability of paper covers to protect a new pavement from extremes of temperature is a point on which Kansas has no information. It is certainly questionable at this time. If this curing system were to be used under present requirements, the expense of providing sufficient covers for a 20-day curing period would be prohibitive.

COTTON MATS

Experience with this curing medium in Kansas is limited. Contractors report that these mats are difficult to obtain and that they sustain a heavy loss in handling and storage once they become wager-logged and impregnated with cement. The added weight and tendency to rot makes them expensive and unsatisfactory. Aside from these considerations cotton mats properly applied and maintained are a suitable curing medium. Present Kansas specifications permit their use on urban projects where earth covering is difficult and expensive to secure.

BITUMINOUS MEMBRANE (EMULSION)

Only one of our pavement projects, 3 mi. in length and constructed in 1936, has been cured with a bituminous membrane. Apparently once was enough to convince everybody concerned that such materials are an unsatisfactory curing medium. This particular project suffered from extensive scaling, which became evident in the first year after the project was constructed. Subsequently, the concrete deteriorated rapidly; heavy maintenance was required continually after the first few years of service. The road was resurfaced with asphaltic concrete after 14 years of use. It is not intended to imply that all the damage on this pavement was due to the curing process alone, but the elements of curing process and curing time were no doubt contributory factors. Bituminous membranes prevent the loss of water from the slab, but they offer no protection from extreme temperature effects and even tend to aggravate the undesirable effect of high temperatures. This fact, in addition to the mess created by the use of bituminous membranes, should be sufficient to outlaw their use as curing media for concrete pavements.

TRANSPARENT AND PIGMENTED MEMBRANES

The widespread use of these materials for curing concrete pavements has taken place with little or no consideration given to their effectiveness as a satisfactory curing agent. True, they have been examined many times for their ability to retain moisture in the slab. It can be admitted without argument, we believe, that the wax membranes are capable of satisfactory water retention, provided the slab is protected by an *unbroken* membrane for the necessary curing time and the membrane is applied early enough to prevent evaporation. Even under these conditions the retention of all the water in the slab is not necessarily desirable and is not considered a satisfactory cure for concrete pavements by some observers in this field (*4*). The fact that it is virtually impossible to produce and maintain an unbroken membrane over the total exposed area of the slab has apparently escaped a great many people in the paving industry. Kansas' experience in this respect has been that once the membrane is applied as required the curing operations are considered finished. Workmen walked on the slab, form-stripping crews scarred up the edges, construction traffic moved on the slab, particularly on the end of a previous day's pour, and public traffic frequently got on and moved up and down the slab after the first day. We have observed that these things happen not only in our own projects but in other places on other types of jobs in spite of diligent efforts on the part of the inspectors to prevent them.

The inability of the transparent membranes to protect concrete from the effects of extreme temperatures is too well known to dwell on here. The rather recent introduction of the pigmented membranes to overcome this deficiency with respect to high temperatures has been investigated by several interested agencies with apparently satisfactory results (*1*). However, the pigmented type is no better than the clear for protection against premature loading and abrasive action of various kinds.

Prior to 1945 scaling had not been prevalent on concrete pavements in Kansas but began to appear on post-war paving projects at early ages. Figure 1 is an example of serious scaling which developed on a project paved in the fall of 1948. The scaling became evident within 90 days after the project was finished. Other projects paved in 1945 to 1947 were affected in the same manner. All of these pavements were cured with transparent membranes. This occurrence, coupled with the fact that prior to the use of this curing method very little scaling had taken place in the state, led to the investigation of the strength and durability of concrete pavements cured by the membrane method and by the burlap-and-wet-earth method.

In 1949 a 6-mi. project was constructed in central Kansas on US 40, half cured with transparent membrane and half with burlap and wet earth. The curing period was 96 hr for both methods, but due to construction procedure the earth cover remained in place somewhat longer. The membrane was, of course, left in place until worn off by traffic.

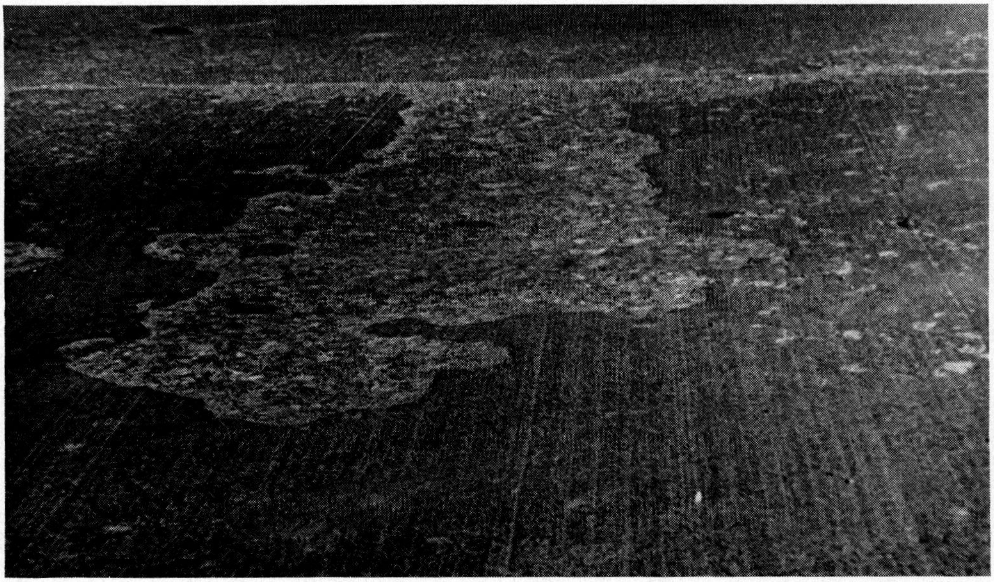

Figure 1. Scaled pavement at 90 days of age.

During the course of this work, field specimens (beams) were prepared and cured by the two methods for a period of 4 days. They were then returned to the laboratory and subjected to various tests for strength and durability. Table 1 contains results of flexural-strength tests before and after standard freezing-and-thawing tests. Figure 2 is a plot of the expansion and sonic frequency of the specimens measured during the standard freezing-and-thawing tests.

These specimens received identical treatment in the laboratory after the initial four-day curing period with the two alternate

TABLE 1

FLEXURAL STRENGTH OF CONCRETE BEAMS CURED BY TWO METHODS

Method of curing	Specimen set No.	7 days	30 days	60 days	90 days	After freeze and thaw
		psi				
Transparent membrane	M1	674	720	831	787	349
	M2	680	703	739	924	246
Wet earth	D1	633	698	878	989	438
	D2	631	634	876	792	466

methods. They were stored in an air-conditioned laboratory at 76 F., 50 percent relative humidity. The specimens for freezing and thawing were soaked in water for four days before the tests were started. Freezing-and-thawing tests were initiated at from 73 to 79 days of age.

A special freezing-and-thawing test, in which the specimens were frozen with the top surface covered with a saturated salt solution, was also used. The character of the specimens was such that the results could only be evaluated by observation.

In addition to these tests, an attempt was made to determine the relative hardness of the pavement surface after curing by the two different methods.

The description and results of these tests are contained in an unpublished report (2) but may be briefly summarized here.

The membrane-cured specimens subjected to the freezing-and-thawing test with brine were heavily scaled and began to disintegrate at the end of ten cycles. The earth-cured specimens exposed to this test endured 15 cycles before comparable degrees of scaling and disintegration occurred. Since this test is one which exposes the specimens to extremely rugged conditions, the fact that the earth-cured specimens endured 50 percent more cycles of the test than the membrane-cured specimens is considered significant.

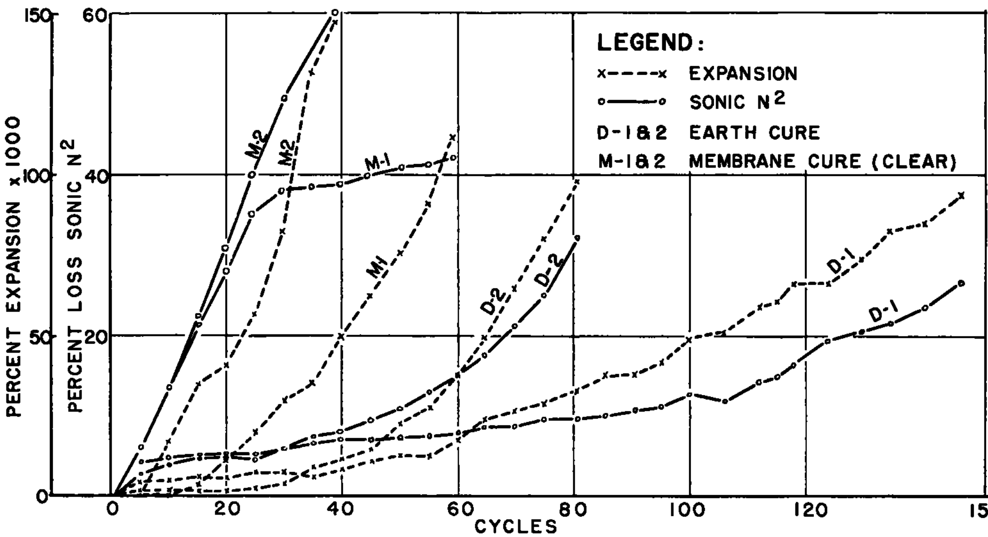

Figure 2. Clear-membrane and earth-cure tests, Ellis County, 1949.

TABLE 2

FLEXURAL STRENGTH OF CONCRETE BEAMS CURED BY TWO METHODS

Method of curing	70 days	90 days	Freeze and thaw	Loss flexural str.	Reduction sonic freq	Spec. set
	psi	psi.	psi.	percent	percent	No.
Pigmented membrane	773	852	341	60	42.9	F-4-0
Earth	707	784	515	34	11.1	F-5-0

The strength tests tabulated are averages of sets of three in each case.

In the standard freezing-and-thawing test the superiority of the earth-cured specimens over the membrane-cured ones is indicated in the results given in Table 1 and Figure 2. The specimens were exposed to the test until the loss in sonic frequency was approximately 50 per cent. The membrane-cured specimens endured from 38 to 59 cycles before this point was reached. The earth-cured specimens were subjected to 148 cycles before the test was discontinued. The loss in sonic frequency at the end of the test was only 23 percent. Based on the 90-day strength of pilot specimens, the membrane-cured specimens suffered an average reduction of 65 percent in flexural strength; the earth-cured specimens were reduced an average of 48 percent, although they were exposed to nearly three times as many cycles

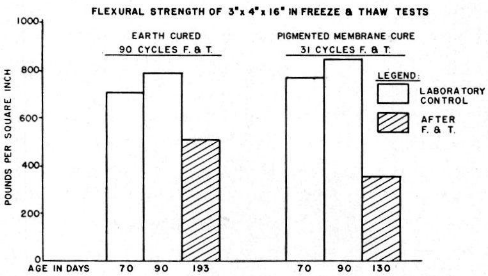

Figure 3. Pigmented-membrane and earth-cure tests, Ford County, 1950.

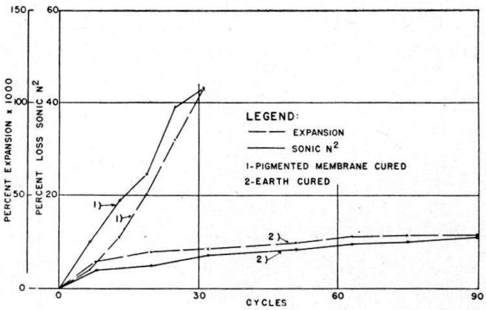

Figure 4. Pigmented-membrane and earth-cure tests, Ford County, 1950.

of freezing and thawing as the membrane-cured specimens.

The test for surface hardness was made with a standard pavement grinder and indicated that the earth-cured slab was about 25 per cent more resistant to this type of abrasion than the membrane-cured surface.

In 1950 these test procedures were repeated on a project cured with burlap and wet earth under the requirements now prevailing, *i.e.*, 24 hr. under moist burlap, 10 days under 4 in. of wet earth, 20 days under earth cover, and 30 days without traffic. A section 500 ft. long was cured with white-pigmented membrane for comparative purposes.

The description and results of these tests are also contained in an as yet unpublished report (*3*).

Table 2 is in a summary of the strength tests before and after standard freezing and thawing.

In this set of tests the pigmented-membrane-cured specimens were subjected to 31 cycles

Figure 5(a). Freezing and thawing with brine, 19 cycles: pigmented-membrane cure.

Figure 5(b). Freezing and thawing with brine, 19 cycles: earth cure.

of freezing and thawing and the earth-cured specimens 90 cycles. On the basis of the 90-day flexural strength of pilot specimens, the pigmented-membrane-cured specimens were reduced 60 percent and the earth-cured specimens 34 percent by the test cycles. The sonic frequency of the membrane-cured specimens was reduced 43 percent while the earth-cured specimens were reduced only 11 percent.

Figures 3 and 4 are graphical representations of these data.

The freezing-and-thawing test with brine was repeated on specimens in this series of tests also. Both sets of specimens were subjected to 19 cycles of the test. Figure 5 shows the condition of the specimens at the end of the test.

At the conclusion of these tests the specimens cured with pigmented membrane were heavily map-cracked and three of the six were partially disintegrated. The earth-cured specimens had slightly scaled surfaces but were otherwise sound and whole.

The surface-hardness test with a standard pavement grinder was also repeated on this project with inconclusive results. This test was made in both of these series of tests because it had been observed (*4*) that on test projects the surfaces of the slabs cured by the two methods were of a different character and that after six months of use the membrane projects had a "softer surface."

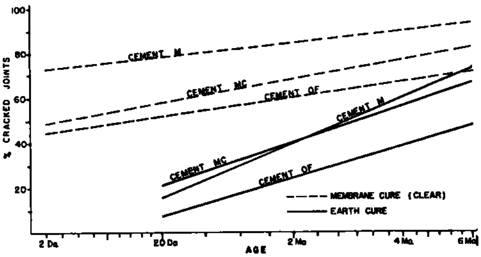

Figure 6. Concrete shrinkage measured by contraction-joint openings, Topeka Test Road condition survey.

Examination of these data indicates rather conclusively the superior character of the earth-cured specimens. The differences in durability of the alternate types, as measured by the two freezing-and-thawing tests, combined with the observations noted regarding the surface character of membrane-cured slabs and the limited data from surface-hardness tests, apparently indicates that the membranes used in these tests are adversely reactive with concrete. The nature of this reaction is not clear. Swayze (*4*), in his paper on "Durable Concrete Surfaces," expresses the opinion that it is a function of early drying, present with this system of curing, and that the cement paste in the surface of a membrane-cured slab is not completely hydrated, resulting in an inferior quality concrete in the surface of the slab.

BURLAP AND WET EARTH

In 1949 two concrete-pavement test roads were constructed in Kansas. The purpose of one was to demonstrate the efficiency of various pozzolanic additions in controlling a form of disintegration common to concrete composed of sand-gravel aggregates, which are widely used in this state; the purpose of the second project was to evaluate the durability of concrete containing three different types of cement.

Laboratory tests had indicated that concretes containing pozzolanic additions are slow in early rates of hydration and that they have relatively high coefficients of linear shrinkage. Wet burlap and earth curing was therefore specified for this job in order to provide a continuous supply of water for late hydration of the portland-pozzolan-cements and to control the effects of high temperature on the fresh concrete, since this project was located in central Kansas, where high summer temperatures prevail.

During the course of construction on this project, the results of using this curing system were observed by recording the number of plastic shrinkage cracks which appeared in the surface of the slab and by counting the number of contraction joints which were open. No shrinkage cracks were observed in this project until 20 months. The observations were made at 24 hr., 30 days, 6 months, 12 months, and 20 months. Very few contraction joints (spaced at 20-ft. intervals) were open at 24 hr. At 30 days of age an average 25 percent of the joints were open in a 6-mi. project. All of the joints were open at 6 months of age.

The second project was constructed in 36 sections, each approximately 1000 ft. long, half of which were cured with wet burlap and earth and half with transparent membrane. Observations were made on this project at 24 hr., 20 days, 2 months, 4 months, and 6 months to determine the number of open contraction joints. The rate of shrinkage, as measured in this manner, is shown in Figure 6. In the earth-cured sections no open joints were observed at 24 hr., at which time the burlap was removed and the earth cover applied. When the earth cover was removed at 20 days of age, from 8 to 20 percent of the joints had opened. At six months of age, from 45 to 72 percent of the joints were open; the cement type influenced the rate of shrinkage which accounts for the range. In the membrane-cured sections, from 45 to 75 percent of the joints were open at 24 hr. and at six months of age 70 to 95 percent of the joints had opened, the range due to cement type.

The favorable results derived from the use of moist-burlap-and-earth curing on these two projects, together with a report from the contractors that there was no radical increase in cost for this method as compared to the use of membrane, led to the adoption of this system as a standard procedure in 1950.

Two construction seasons have now elapsed since this system of curing was specified. All of our paving contractors have had an opportunity to work under these conditions and become familiar with the procedures and equipment necessary to cure pavements in this manner. Several methods of application have been tried. Cranes, whirly plows and extended blades, truck dumping, and concrete spreaders all have been used. The most successful and satisfactory method is to put the dirt on with a large dragline. The burlap is removed ahead of the crane for several hundred feet and the slab flooded with water. The earth cover secured from the shoulder fill is then cast over the slab and wet down as it is spread. A full-width drag hauled by two farm tractors is then pulled along the slab to level the surface and fill in the open spots. Hand labor is sometimes used in place of the drag. Water is hauled to the site in tank trucks equipped with pressure pump and hose. There is generally very little additional watering required after the first day or two. Although only 4 in. of earth cover is required, this method of application usually results in from 6 to 12 in. of dirt on the slab. The cover is left in place for 20 days then removed with a motor patrol and used to shoulder the new slab.

Curing is a subsidiary item in Kansas contracts, so state cost records are not available. However, some cost data secured from two contractors relative to the price of burlap-and-earth curing versus membrane curing are available. The costs of curing six projects, each approximately 6 mi. in length and cured with burlap and wet earth were reported. The maximum was 21 cents per sq. yd. and the minimum was 6.6 cents and the average was 12.5 cents per sq. yd. The wide variation in price per sq. yd. is attributed to the weather conditions during the curing period and the type of soil available for this purpose. Three projects, each approximately 6 mi. in length and cured with transparent membrane, were reported. The cost on these projects for curing was identical, 10.4 cents per sq. yd. All labor, materials, and equipment rentals are included in these costs. From these figures it is apparent that under average or better than average conditions with respect to weather and soil types the cost of burlap and wet earth curing is approximately equal to the cost of membrane curing; in some cases less.

SUMMARY

After two years' experience in the use of wet-earth curing, Kansas is convinced that no other type serves the purpose as well. Wet earth curing is not expensive in Kansas. Obviously it would be an uneconomical system to use in rocky locations or on airports where shoulder dirt is not present in sufficient quantities for this purpose. Fortunately, these conditions are not present in state highway work in Kansas. The use of damp burlap for the first 24 hr. without the addition of any more water than that necessary to keep the burlap damp, not wet or soaking, provides initial protection from rapid drying and carbonation of the surface from carbon dioxide in the atmosphere. It also permits slow evaporation of the excess mixing water from the slab, which tends to equalize the differences in water content between the top and bottom of the slab set up by sedimentation during the earlier periods. The application of wet earth at age 24 hr. then provides additional curing water to promote complete hydration of the cement. These functions are those recommended by Swayze (*4*) in his article on "Durable Concrete Surfaces," as most necessary for the production of high-quality concrete pavements. The earth cover continues to protect the slab from the extremes of temperature which may occur in the following 18 days, and the ill effects arising from early use of the slab are avoided. The end product seems much stronger and more durable than slabs cured by other means. This state has had occasion to remove cores and slabs from some earth-cured projects and membrane-cured projects in the past three years. In every case the men in charge of this work report that drilling time is longer and work required to remove pieces of slab from the earth-cured pavements is noticeably more difficult, due to the toughness of the concrete, than that required for similar work on the membrane-cured slabs. Kansas has, at present, eight projects under study in which beam specimens are stored and exposed to the elements in the same manner as the slab, with the exception of traffic loadings. Records to date indicate exceptionally high flexural strength in these specimens and a continuous slow gain in strength.

All too often the curing operation on a paving project and on structures as well is a hit or miss proposition that is given too little attention or neglected altogether. Burlap and wet earth curing is almost fool-proof and through its use many of the undesirable results obtained by inadequate attention to the application of the curing medium are avoided, whatever the criteria used to measure the results. Greater and more lasting benefits may be secured from an adequate curing medium properly applied and left in place for the length of time necessary to fully develop the potential characteristics of strength and durability in a concrete slab, than from any other single operation performed during the construction of a concrete pavement.

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DISCUSSION

R. E. Madison, *Technical Director, Truscon Laboratories, Devoe & Reynolds Company, Inc.*—We hold that the paper is misleading, because no information is supplied regarding the type, physical characteristics, performance, and application of the membrane curing compound and the specimens from which the conclusions are drawn do not, under the conditions of the tests, represent the pavement slabs. Specifications for cement, sand, and aggregate have been well established in the past and possibly need not be mentioned in an investigation of the current type. But no uniformity of specification on performance and application exists today on membrane-type of curing compound. Each state highway department as well as each federal department has its own specification. As a consequence, it is heavily incumbent upon the author to include a detailed story on the specification under which the membrane was procured, together with the methods by which it was applied.

Our reasons for dwelling on this particular point are easily made clear. During our experience in the manufacture of membrane compounds, beginning in approximately 1940, we have consistently endeavored to arouse interest in a specification which would require the highest water retention possible at not only the temperatures commonly used in testing cabinets but also at temperatures which are attained under field conditions due to the radiant energy of the sun. We observed through investigations in our laboratory that there was a marked difference in the performance of membrane compounds offered on the market; we know that certain types of wax-base membranes retain very little water at the temperatures reached in the concrete during hot, sunny days. We also observed that these membranes penetrate into or are absorbed by the top layers of the concrete, resulting in a softened surface.

Our laboratory first began tests on sunlight testing in 1943. As soon as we discovered that certain wax type membranes were adversely affected by the temperatures obtained in the fresh concrete during the periods the sun shone on it, we immediately made our findings available in an article published in the February 1944 issue of *Concrete*. We urged that specifications should include a special test to determine efficiency under infra-red heating. Many states went ahead with this idea.

The paper states: "It can be admitted without argument, we believe, that the wax membranes are capable of satisfactory water retention, provided that the slab is protected by an unbroken membrane for the necessary curing time, and that the membrane is applied early enough to prevent evaporation." We do not believe that wax-type membranes are capable of satisfactory water retention, especially when subjected to the radiant energy of the sun during and immediately after application. In fact, we submit that the paper is written on this assumption and that the author was unaware of this basic deficiency of certain wax-type membranes.

The paper mentions that due to certain observations Kansas was led to investigate the strength and durability of concrete pavements cured by both the membrane method and by burlap and wet earth. We submit that the paper presents data only on the membrane allowable under the specification then in force and does not evaluate the membrane method, as such.

At this point we believe it pertinent to discuss some of the functions of a membrane curing compound. One of the prime requirements of a membrane is to retain water under hot sunny conditions, thereby affording a means to control plastic shrinkage cracks. In addition to the fact that this water retention feature must go into play immediately after application to the fresh concrete, especially under sunny conditions, the membrane should also have an ability to slowly decrepitate and disappear from the pavement, beginning after approximately 10 to 12 days. This latter effect is dependent on the ultra-violet light in the sun's rays plus the abrasion of traffic. Thus it can be seen that through this decrepitation effect the pavement can soon begin to have the extra curing value of rain which falls on it. Therefore, with respect to the author's laboratory specimens he has excluded a very important natural function which occurs in connection with the actual pavement. In other words, where the actual condition would have been (1) four days of burlap and earth plus 90 days of weather curing, and (2) four days membrane plus 90 days of weather curing, the author actually only evaluated an arrested cure of four days of earth cure against four days membrane by bringing the specimens into the laboratory after four days and storing in air. (Regarding the amount of rainfall, see 1941 Year Book of Agriculture, *Climate and Man*, U. S. Department of Agriculture, which shows that in the concreting months there is, on the average, a rainfall of 14 in. in the extreme west and up to 26 in. in the east of Kansas).

The same comments can be made on the description of the project constructed in 1950. In other words, the paper compared an arrested earth cure to an arrested membrane cure, and this is not representative of the pavement itself, regardless of the type of membrane.

The author makes reference to the fact that "it had been observed that on our test projects the surfaces of the slabs cured by the two methods were of a different character and that after six months of use the membrane projects had a 'softer surface.' " He also notes that Swayze had also observed these slabs. We submit the following as the explanation as contrasted to their views: The wax membrane used had practically no powers of water-retention when subjected to the sun's heat on the concrete.

In addition, this wax-type membrane has a very definite tendency to liquify and become absorbed into the top layers of the concrete under sun conditions. The Kansas specification calls for a two-coat application resulting in a coverage of 100 sq. ft. per gal. However, a wax membrane does not become more effective at lower spreading rates, under sun conditions, and in addition, the permeation or absorption into the concrete is intensified by the application of the heavier film. Because of the inability of this type membrane to retain water under the sun's heat, a definite layer immediately under the membrane will become almost completely dehydrated. In addition, because of the liquifying action, this layer will become permeated with the waxes of the membrane. The combination will effectively prevent the normal progressive hydration of the concrete upon further exposure to water, with the result that the surface will be softer. We submit that the early opening of the joints on the membrane-cured portion at 24 hr. is fairly good evidence that this membrane was not functioning as a water-retaining agent under road conditions and was apparently not required to do so by the then current specification. This is to be contrasted against the action of a resin-type membrane, which can be specified to retain water under the action of the sun's rays and which will not permeate into the top layers of the slab. After normal decrepitation of the resin membrane, which is not absorbed, the concrete is permitted to proceed with natural weather curing.

With reference to the remarks on the cost of membrane method against the burlap and wet earth, we believe that records are fairly well established in other states and governmental agencies that the cost of applying the membrane curing is much lower than the figures indicated for the burlap and wet earth cure. It is to be noted that his specification calls for a two-coat application. This might have been felt necessary in connection with the wax membrane used. However, most states and other governmental agencies have been able to successfully apply their material in only one-coat, using a fully automatic spraying machine. Naturally, if a double coat were used, the cost for applying a membrane curing compound would be double what it should be. The cost of membrane curing under proper specifications will be much less than the cost of damp burlap and wet earth.

We suggest that the conditions described in this paper, were due in part to the use of a membrane which was not heat resistant and had a high degree of penetration into the concrete. However, it also appears evident that certain aggregate reactions are definitely involved in some of the undesirable characteristics observed in the concrete. Further, we believe that the conclusions should be drawn only with reference to the particular membrane used and that it should be acknowledged that the concrete test specimens do not represent the pavement slabs. In addition, we cannot agree that the curing system of damp burlap, wet earth, and earth removal will cost no more than the automatic application of an adequately specified resin membrane, and finally it does not seem a valid argument for or against any method of curing to say that the surface *cannot* be kept free of undesired early loading or traffic.

R. L. Peyton, *Closure*—The subject of curing concrete pavements is apparently extremely controversial throughout the paving industry. There are many facets of opinion on the worth and utility of curing systems whatever the type. The paper under discussion was prepared and presented as a report on the present method used in Kansas, and the reasons therefore.

The use of any curing system for curing concrete pavements should have as its objective the production of high-quality, durable concrete pavements with maximum service life. It is our opinion that at present this objective can best be attained in Kansas by using damp burlap and wet earth. When it can be demonstrated that other systems of curing will produce concrete pavements of equal or better quality under the particular circumstances in which concrete pavements are constructed in this state, they will be considered.

It is believed that through the free expression of opinion and the exchange of ideas as represented by this paper and the subject discussion that eventually a completely satisfactory method for curing concrete may be developed which will include all the desirable and necessary characteristics and which will exclude those factors which are considered detrimental to the production of high-quality concrete pavements.