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CURING OF CONCRETE PAVEMENTS

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FOREWORD

The Current Road Problem Series was developed during World War II as a series of emergency pamphlets by the Highway Research Board. The Committee on Curing of Concrete Pavements prepared one such pamphlet, first published in 1942 as Wartime Road Problems No. 1, which contained the then current recommended practices for curing concrete pavements. It was revised in October 1952 as Current Road Problems No. 1-R, "Curing of Concrete Pavements" which also contained suggested specifications and test methods. It was again revised and updated in May 1963 and titled "Current Road Problems No. 1-2R, Curing of Concrete Pavements."

The current publication is a revision of Current Road Problems No. 1-2R by the Committee on Batching, Mixing, Placing and Curing of Concrete, up-dating the recommended practices and specifications.

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CURING OF CONCRETE PAVEMENTS

Definition

Curing is the process of maintaining a satisfactory moisture content and a favorable temperature in concrete during the period immediately following placement so that hydration of the cement may continue until the desired properties are developed to a sufficient degree to meet the requirements of service.

Need for Curing

Curing is recognized as an important process in the manufacture of durable concrete. Even if properly proportioned, mixed, and placed, concrete can develop its potential strength and durability only if kept under favorable conditions of temperature and moisture for an adequate period of time prior to being put into service.

The amount of mixing water in the concrete at the time of placement is normally more than the quantity needed to combine chemically with the cement. The products of hydration, however, can form only in water-filled space. Loss of mixing water by evaporation and by absorption into the aggregate and the subgrade may reduce the amount of water below that needed for proper hydration. Absorption may be eliminated by wetting the subgrade and the aggregates when they are dry. Loss of moisture by evaporation may be prevented by the proper use of any of several methods of curing.

It is especially important to keep the cement paste moist during the curing period, starting immediately following placement of the concrete, in order to prevent an excessive reduction in the moisture content of the paste. Such a reduction retards or stops hydration. Continued loss of moisture also results in drying shrinkage and cracks may develop in the paste much the same as they do in mud when it dries.

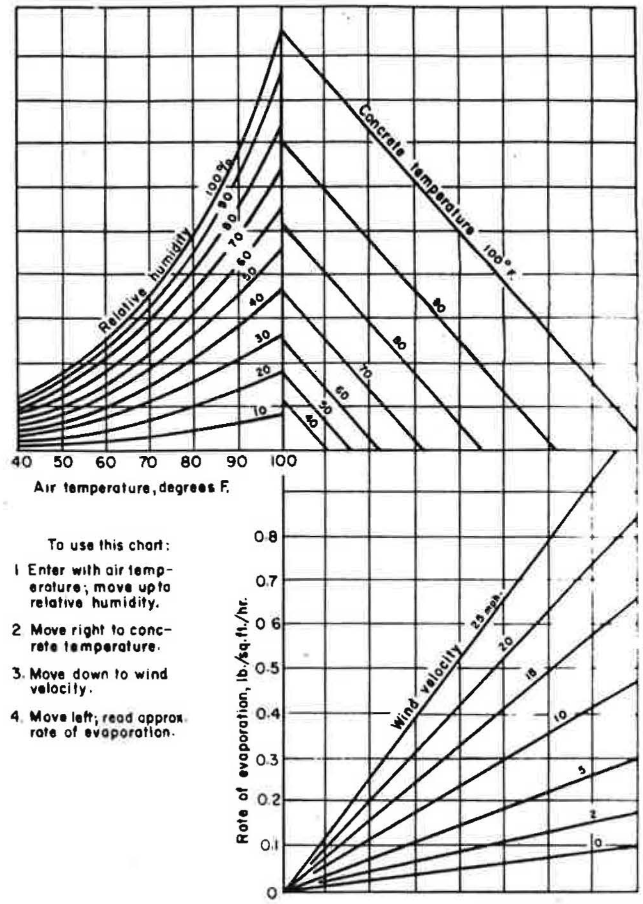
Cracks appearing in the surface of the concrete about the time the concrete is ready for finishing are known as plastic shrinkage cracks. Rapid evaporation removes water from the surface of the concrete faster than it can be replenished by bleeding. Conditions conducive to plastic shrinkage cracking include low humidity, wind, high concrete temperature, high air temperature, exposure to the direct rays of the sun, concrete of low bleeding tendencies, and large surface area in relation to depth. The danger of plastic shrinkage cracking becomes very high when the evaporation rate reaches or exceeds 0.2 $lb/ft^2/hr$ (0.98$kg/m^2/h$). See Chart 1.

Difficulties with plastic shrinkage cracking occur most often during the summer months, but this phenomenon may occur at other times, inasmuch as moisture loss can occur when the concrete temperature is high, 80 F (27 C), in relation to air temperature, 40 F (4 C), even though the relative humidity may be high.

Some of the measures which may alleviate plastic shrinkage cracking include:

1. Maintenance of a low initial concrete temperature by shading or sprinkling aggregate stockpiles, use of cool mixing water, avoidance of excessive mixing of the concrete, and prompt placement. Experience has shown that an important measure to prevent plastic shrinkage cracking is placement of the concrete in the forms at a concrete temperature of 60 F(16 C) or less.

Chart 1. Effect of concrete and air temperatures, relative humidity, and wind velocity on the rate of surface moisture loss from concrete. (Source: "Curing of Concrete," Concrete Information Sheet IS 55.02 T, Portland Cement Association, Chicago, 1966, 5 pages.)



2. Shading the concrete from the direct rays of the sun and providing windbreaks.

3. Covering the surface with plastic sheeting or wet covering between placement and finishing. Fog spraying has been used successfully but care must be exercised to maintain a fine mist. Windy conditions can make any type of coverage or spraying difficult.

The use of admixtures may influence bleeding and time of setting in a variety of ways, thus influencing plastic shrinkage cracking tendencies. These include:

(a) When an air-entraining admixture is used in a concrete mixture, it normally aids in the reduction of bleeding as well as increasing the durability of the final hardened concrete.

(b) Water-reducing admixtures (Type A) can reduce the water requirements by at least 5 percent and still maintain the workability of the fresh concrete.

(c) Water-reducing, retarding admixtures (Type D) can reduce the water requirements (similar to Type A) and maintain the same workability as well as retard the initial set of the concrete. This type of admixture is used extensively in warm and hot weather to allow the concrete to be properly finished. Different brands of Type D Admixtures have different effects on rates of bleeding of concrete. A Type D admixture that increases bleeding is useful when the weather conditions indicate that plastic shrinkage cracking is probable, and extra bleed water can be used to an advantage in giving more moisture at the surface, thus preventing plastic shrinkage cracking. Hot weather concreting practices are still needed even with this extra bleeding. Air-entraining admixtures when used in conjunction with a Type D admixture will retard the rate of bleeding, but will not stop it entirely. Concrete finishers should be informed of admixtures that will be used so they can plan their finishing operation accordingly.

Alteration of bleeding by modifying aggregate grading or mix proportions is not a practical substitute for the foregoing precautions.

Curing During Hot and Cold Weather

Because curing is defined as the maintenance of favorable moisture and temperature conditions in the concrete during the period immediately following placement, there are times when steps must be taken in connection with the production of the concrete in order that the normal procedures of curing may accomplish their purposes.

During the summer months, when air temperatures are high, the temperature of the materials used to produce the concrete may reach undesirable levels. The heat content of the materials plus additional heat developed by hydration of the cement may result in excessive concrete temperatures during the curing period. In such cases it is necessary to insure that the temperature of the concrete be below some maximum value at the time it is discharged from the mixer. Use of chilled mixing water is often sufficient to accomplish this end. Use of crushed ice as part of the mixing water has an advantage over the use of all water in that each pound of ice removes 144 Btu (152 kJ) from the concrete in changing from ice at 32 F (0 C) to water at 32 F (0 C). Cooling of the coarse aggregate is also effective and is used when cooling of the water is not enough, because the amount of water used is small in relation to the other ingredients. Cooling of the cement has relatively little influence on concrete temperature. A concrete temperature of 60 F (16 C) or even lower, is desirable. A concrete temperature of 90 F (32 C) should be taken as the maximum and it should be remembered that difficulty may be encountered at temperatures approaching 90 F (32 C).

The reverse situation may prevail during winter months, when air temperatures may reduce the temperature of the materials. In this case heat must be added to the water, or the aggregates, or both. Under such circumstances the minimum temperature of the fresh concrete as mixed should be in the range of 55 to 70 F (13 to 21 C), depending primarily on the air temperature. Lower air temperatures require higher temperatures in the concrete. Aggregates should not be heated to a temperature higher than 125 F (52 C) and heating should be accomplished in such a way that absorbed water is not removed from the aggregates. Mixing water should not be heated higher than 180 F (82 C). Hot mixing water should never be placed in direct contact with the cement alone. Concrete used in pavements should have a minimum temperature of 50 to 55 F (10 to 13 C) immediately after placing and be maintained at that level for not less than 72 hours.

Moisture Control

Moisture is necessary to the hardening process of portland cement and constitutes the most essential factor of curing. When sufficient moisture is not present, little or no improvement in strength or quality of the concrete is obtained.

Methods used to assure the proper curing of concrete insofar as control of moisture is concerned may be divided into two general groups, as follows:

1. Those which prevent or minimize the loss of water initially in the concrete by interposing an intermediate source of water to counteract or prevent evaporation of initial mixing water from the concrete. The methods frequently used are: ponding; sprinkling; spraying; and application of wet burlap, wet earth, wet sand, wet sawdust, wet hay, or wet straw. For many years, concrete pavements were cured almost entirely by means of a thorough and continuous application of water or wet earth for periods up to 10 days after placement.

2. Those which prevent or minimize the loss of water by the application of waterproof paper, polyethylene sheeting, or impermeable liquid membrane-forming compounds.

Frequently a curing process is used that combines these two procedures: an initial curing period during which water or a moist covering is applied, followed by the application of waterproof paper, polyethylene sheeting, or liquid membrane-forming compounds.

Temperature Control

The rate of reaction between cement and water, or rate of hydration, increases as the temperature of the concrete increases. During construction, concrete temperatures below 50 F (10 C) are considered unfavorable for the development of early strength. Below 40 F (4 C) the developemnt of strength is greatly retarded; at freezing temperatures little, if any, strength develops. When concreting is permitted during cold weather, extra precautions should be considered, such as heating the mixing water or both the mixing water and the aggregates and subsequent protection by applying blanketing materials, such as hay or straw, to maintain suitable temperatures during hardening. Insulated covers or mats, either heated or unheated, may also be used.

The rate of reaction between cement and water during setting and early hardening is greater for concrete at higher temperatures than for concrete at lower temperatures. Tests indicate that when the concrete is maintained at the higher temperatures during setting and early hardening, later age strengths are lower than for similar concretes cured at lower temperatures during this early period. Thus, avoiding high concrete temperatures during curing not only will help to reduce the amount of random cracking on cooling but also will result in greater strength at later ages.

During the summer months, when air temperatures are high, an effort should be made to keep the temperature of the concrete low by using cool mixing water and aggregates and by protecting the concrete from the radiant heat of the sun during curing. Use may be made of the reflecting property of light-colored curing materials. Waterproof paper and polyethylene sheeting for curing should be white and liquid membrane-forming compounds should contain white pigment.

Rather limited field data are available showing the amount of temperature reduction due to the use of white paper in comparison with dark paper, white pigmented compared with clear liquid membrane-forming compounds, or white compared with clear polyethylene sheeting. Maximum difference reported for any of these is of the order of 10 F (6 C) at or 1 inch (25 mm) below the surface. Surveys of pavement surfaces made several years after construction reveal that those cured with white materials showed much less cracking than those cured with dark or clear materials. Also, that pavements placed in the morning had more cracks (primarily transverse ones) than those placed in the afternoon, other factors remaining the same. A need for close attention to details concerned with the control of temperature in the concrete was indicated by these surveys.

Calcium chloride (not in excess of 2 percent by weight of cement) in solution form may be added to the mixture in colder weather to accelerate hardening, but this does not eliminate the need for protective blanketing materials. When calcium chloride is used it should be added to the concrete materials as a solution and be considered as a part of the net mixing water. In quantities which will not adversely affect the concrete, calcium chloride will not lower the freezing point sufficiently to be of any practical value in protecting the concrete from freezing. Calcium chloride should be used in warm water or hot weather only under careful supervision.

Calcium chloride should never be used in any type of prestressed concrete due to the possible corrosion of the prestressing steel strands or cables. The recommendations of ACI Committee 201 should be followed with respect to the use of calcium chloride in reinforced concrete.

RECOMMENDED PRACTICE FOR CURING CONCRETE PAVEMENTS MADE WITH HYDRAULIC CEMENTS (Also suitable for floors, walks, and similar slabs on the ground)

This recommended practice covers materials and methods for curing concrete pavements and similar slabs on the ground, made with hydraulic cements, through the application of wet coverings, initial water spray, waterproof paper, polyethylene sheeting, or liquid membrane-forming compounds, and the protection of the concrete against low temperature or excessively high temperatures.

Materials

General

Materials used for the purpose of curing concrete should meet the specifications of ASTM or AASHTO.

In the case of burlap cloth, the requirements concern only the materials used and the manner of fabrication. In the case of waterproof paper, there are also acceptance requirements based on ability to retain moisture in the concrete, ability to reflect light, and tensile strength of the paper. For polyethylene sheeting the requirements include ability to retain moisture, ability to reflect light, and the tensile strength and elongation of the sheeting. For liquid membrane-forming compounds there are requirements for retention of moisture and reflectance of light. In the case of pigmented compounds, the tendency of the pigment to settle during shipment and storage on the job prior to use requires special attention and consideration. The pigment should not settle to the extent that it cannot be readily redispersed throughout the compound by moderate stirring or by agitation with compressed air immediately prior to application to the concrete. A thixotropic agent which is incorporated into the compound is sometimes used to retard settlement of the pigment.

ASTM has a method of test for retention of moisture (Designation: C 156), for reflectance of light (Designation: E 97), for tensile strength of paper (Designation: D 829), and for tensile properties of thin plastic sheets and films (Designation: D 882).

Requirements

Burlap Cloth--Burlap cloth (Fig. 1) made from jute or kenaf for use in curing concrete should conform to the requirements of "Specification for Burlap Cloth Made from Jute or Kenaf," of AASHTO Designation: M 182.

Figure 1. Curing with wet burlap. Mats are placed on the concrete and then kept wet for several days. This is now mainly used in smaller irregular sections of paving such as in cities.

Waterproof Paper--Waterproof paper (Fig. 2) should conform to the requirements for Waterproof Paper as shown in the specifications for "Sheet Materials for Curing Concrete," ASTM C 171 or AASHTO M 171.

Polyethylene Film--Polyethylene film (Fig. 3) should conform to the requirements for polyethylene film shown in the specifications for "Sheet Materials for Curing Concrete," ASTM C 171 or AASHTO M 171.

Liquid Membrane-Forming Compound--Liquid membrane-forming compounds should conform to the requirements of "Specifications for Liquid Membrane-Forming Compounds for Curing Concrete," ASTM C 309, or the AASHTO M 148. Two general types of compounds are included in the ASTM and AASHTO Specifications. The user should indicate the type desired.

Curing Water--There are two primary considerations involved concerning the suitability of water for curing concrete: (1) Does the water contain impurities capable of attacking or causing deterioration of the concrete? and (2) Does the water contain impurities that may cause staining or discoloration of the surface of the concrete?

Figure 2. Waterproof paper has been applied for curing. Rolls of paper for use on pavement surface in foreground are being distributed distributed by truck at right.

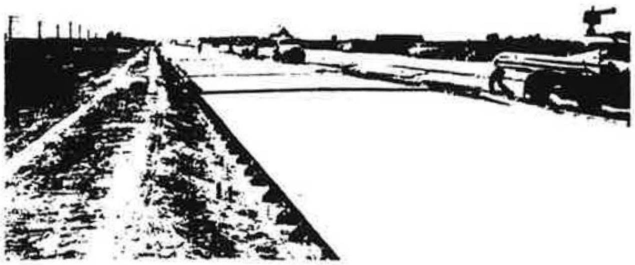


Figure 3. Large roll of white polyethylene sheeting carried on the back of a curing membrane applicator. Most paving contractors use polyethylene as an emergency protection in case of heavy rain which might damage the surface of a newly slipformed pavement.

In general, water suitable for use as mixing water may be used as curing water. If the water to be used in curing concrete is not from the same source as the mixing water, it is desirable that it meet the same requirements as the mixing water. The most common cause of staining is a relatively high concentration of iron or organic matter in the water. Staining or discoloration of pavement surfaces by curing water is not a serious problem and does not, as a rule, warrant the imposition of restrictions on the water to be used in curing operations.

Delecerious Effects--No deleterious effects are normally produced by the curing materials mentioned herein, but there is need for constant alertness to the inclusion of extraneous materials that may be harmful. Harmful effects may be identified by visual inspection in some instances, but in cases where more positive proof is needed, comparative tests may be made in the laboratory using a simple scratch test or following "Method of Test for Abrasion Resistance of Concrete by Sandblasting," ASTM C 418.

Curing Procedure

The engineer should select one, or a combination, of the following described methods; wet coverings, water spray, waterproof paper, polyethylene sheeting, or liquid membrane-forming compound. If methods other than water spray are selected and there is a delay in applying them, they should be preceded by initial moist curing (such as a fog spray) between the time the water disappears from the surface of the concrete and the time when coverings are placed.

Wet Coverings

1. Burlap--After the final finishing operation and as soon as it is possible to do so without marring the surface, the concrete should be covered with wet burlap. (If reclaimed fabrics are used, care should be taken to make sure that no materials are present that have a deleterious effect on the concrete, such as sugar, molasses, or wool fat.) During application the burlap should not be dragged over the concrete or over burlap already spread. This covering should remain in place for not less than 72 hours and should be kept wet during that time by means of a water spray of such fineness and so applied during the first 12 hours that it will not damage the concrete surface.

2. Water spray--The surface of the concrete should be kept wet continuously for not less than 72 hours by means of a water spray, of such fineness and so applied during the first 12 hours that the surface will not be marred.

When concrete is kept moist by sprinkling, care must be exercised to prevent drying of the surface of the concrete between applications of water. Alternate cycles of wetting and drying of green concrete are conducive to cracking of the surface. A continuous constant supply of moisture in moderate amounts is much better than intermittent.

3. Ponding--As soon as the concrete is sufficiently hardened to withstand marring, the surface of the concrete should be kept wet by ponding until 72 hours have elapsed after the final finishing of the concrete surface.

4. Wet Earth, Wet Sand, or Wet Sawdust--As soon as the concrete is sufficiently hardened to withstand marring, the surface of the concrete should be protected immediately by not less than 1 inch of thoroughly wet earth, sand, or sawdust, and should be kept wet until 72 hours have elapsed after the final finishing of the concrete surface. The earth should be free from large lumps. If sawdust is used care must be taken that the sawdust contains no acids or other constituents harmful to the

concrete.

5. Wet Straw or Wet Hay--As soon as the concrete is sufficiently hardened to withstand marring, the surface of the concrete should be protected immediately by a 6-inch layer of wet straw, hay or similar material and kept wet until 72 hours have elapsed after the final finishing of the concrete surface.

Waterproof Paper, Polyethylene Sheeting, or Other Impermeable Materials

1. After the final finishing operation and immediately after any bleeding water that had collected on the surface has disappeared, the concrete should be entirely covered with waterproof paper, polyethylene sheeting, or other impermeable sheet materials in such a manner that the surface will not be marred. Whenever the surface of the concrete is not moist immediately prior to the placing of the impermeable sheet material, such surface should be moistened by use of an atomizing spray of water. The impermeable sheet materials should be lapped at least 12 inches and should be placed and held in intimate contact with the surface covered. If checking develops in the surface before finishing is completed, the engineer may require fog spraying or covering of the concrete with the impermeable sheet material during the interval between placing and the final finishing operation. On windy days a wet covering procedure should be used unless it is possible to hold down the impermeable sheet material by placing earth or other weights on the sheeting without marring the surface of the concrete.

2. The waterproof paper, polyethylene sheeting or other impermeable sheet materials should remain in place for 72 hours.

3. The waterproof paper, polyethylene sheeting or other impermeable materials may be reused as long as they provide a moisture-proof seal over the pavement. When they no longer provide a satisfactory seal, they should be properly repaired or rejected for further use and be removed from the site of the work.

Removal of Curing Cover for Sawing of Joints

When it is necessary to remove the curing cover (Fig. 4) temporarily for the sawing of joints, the area uncovered should be not greater than needed for the sawing operation. The curing cover should be removed just prior to the beginning of the sawing operation for each joint and should be replaced immediately following the completion of sawing. The surface of the concrete should be thoroughly wetted before replacing the curing cover. The surface of the pavement should not be left unprotected during the sawing of a joint for a period of more than one-half hour.

Liquid Membrane-Forming Compounds

Liquid membrane-forming compounds are of two types: clear or translucent and white pigmented. The white-pigmented type (Fig. 5) reflects radiant heat from the sun and results in less of an increase in temperature within the pavement slab throughout the curing period than do the other types. With the pigmented types it is usually possible to detect nonuniform application by careful visual inspection provided the pigments have been uniformly dispersed in the liquid at the time of application. A fugitive dye of a color contrasting well with the

Figure 4. Curing paper is temporarily removed for sawing of a transverse joint, then replaced upon completion of sawing operation.

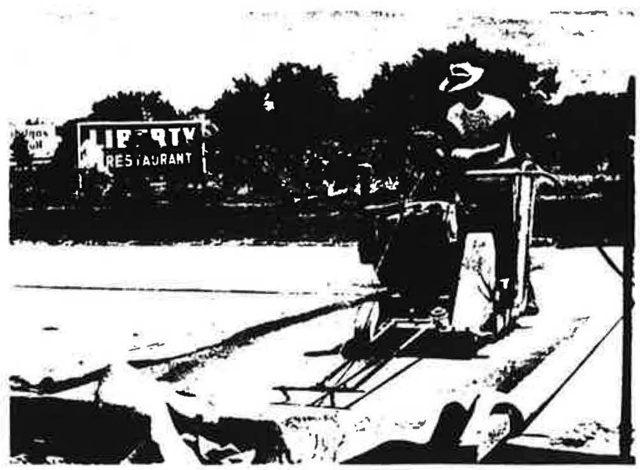
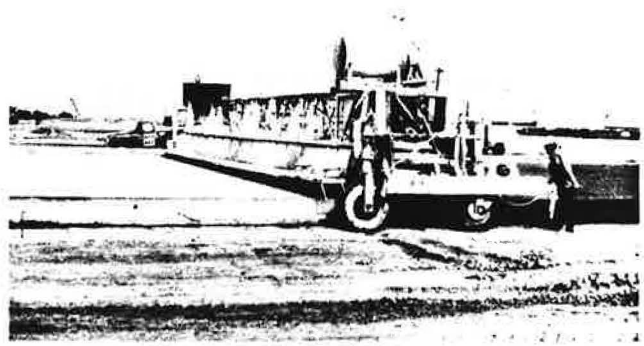


Figure 5. Mechanical curing membrane applicator used to apply white pigmented curing membrane to 50-ft wide 17-in slab placed in one pass by a slipform paver at a recently constructed major airport.



concrete and disappearing within several hours after application in the clear type provides a means of detecting nonuniform application provided the dye has been uniformly dispersed in the liquid. Inspection of application of the clear type, however, is less certain than that of the pigmented types and must be made shortly after application. Although visual inspection provides a fair means of detecting nonuniformity of application, it is possible to vary the rate of application without achieving adequate coverage although producing a uniform appearance. Satisfactory methods of securing uniform distribution of pigments and dyes are agitation by mechanical means or by compressed air. The compounds should be thoroughly mixed before application. Agitation should be continued constantly during application and the compound should be constantly recirculated from the spray head to the drum. This is of particular importance with the pigmented types, which have a tendency to settle rapidly. The trend toward deeply textured pavements (Fig. 6) such as those textured with a steel wire comb requires a larger quantity of curing membrane than pavements textured with a broom or a burlap drag. A good uniform heavy application is needed (Fig. 7).

Figure 6. A closeup of transverse grooves formed in fresh concrete by a steel wire comb. This type of texture, 1/8-in by 1/8-in grooves at approximately 1/2-in centers, requires a larger quantity of curing membrane than pavements textured with burlap or fine brooms.

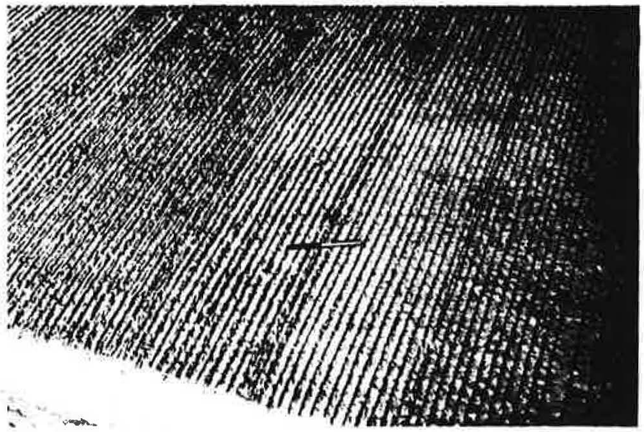
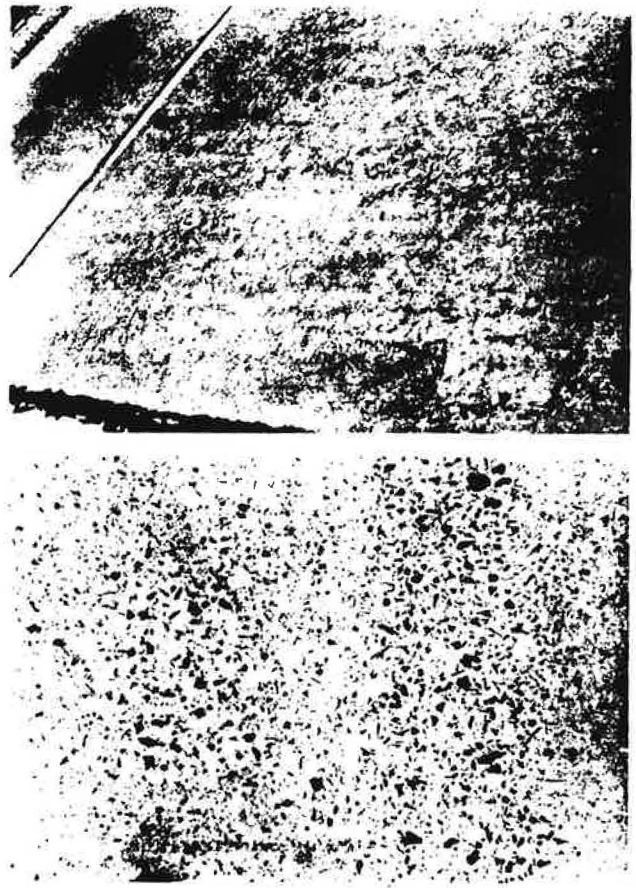


Figure 7. Pavement with transverse grooves that has been cured with white pigmented membrane. A very uniform heavy application has been attained.

1. Method--Immediately after the final finishing operation and immediately after the bleeding water has disappeared, all exposed surfaces of the concrete should be sealed by spraying thereon the curing material as a fine mist in such a manner as to provide a continuous, uniform water-impermeable film without marring the surface. The spraying operation should be performed using approved mechanical equipment in preference to hand-operated equipment. A burlap curtain or metal screen should be provided to prevent excessive loss of the curing material by the wind. Care should be taken that none of the membrane compound is permitted to enter the expansion or contraction joints if the joints are to be filled subsequently with joint-sealing compound.

A simple, quick and convenient method of checking the amount of compound applied is the use of mortar plaques 6 inches (15 cm) square and about 3/4 inch (2 cm) thick, to which the required amount of covering of membrane-forming compound has previously been applied. A quick visual check of the sufficiency of the application to the surface of the pavement may be made by laying one of the plaques on the cement (Fig. 9). The area of coverage by each drum or other container should also be checked.

Figure 8. About one-half the specified amount of liquid membrane-forming compound containing a fugitive dye was applied to this pavement surface, due to inadequate supervision. The pavement was more than 10 years old when the pictures were taken. Upper photo shows scaling and some crazing of the surface; lower photo indicates non-uniform surface wear.



2. Number of Coats--The material should be applied in one or two separate coats as may be required for compliance with the requirement of the test for water retention.

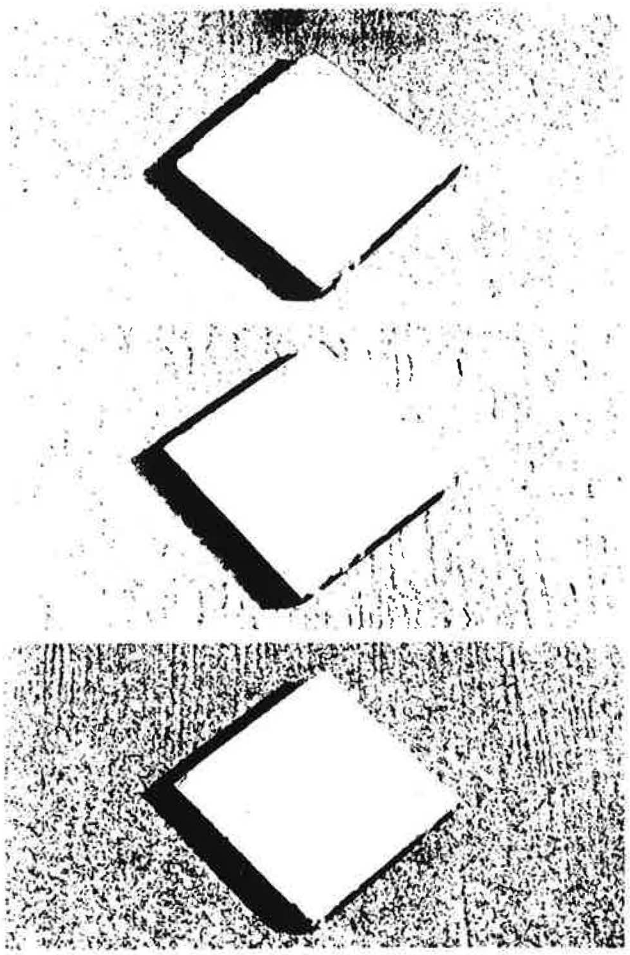
3. Rate of Application--The rate of application should be such that one gallon of compound covers not more than . . . square feet.

(Use rate of application as shown by samples complying with the requirements of the test for water retention. The usual values for coverage are 150 to 200 square feet per gallon (3.5-5 square metres per litre). Deeply textured pavements such as those textured with a steel wire comb require a larger quantity of curing membrane.)

Edge Protection of Pavement Slabs

The edges of the pavement should be cured as provided for the surface, or by an approved alternate method. If pavement forms are used the trench left by their removal should be filled immediately with

Figure 9. Field checking of the amount of white pigmented liquid membrane-forming compound may be done readily by applying the required amount to a 15- x 15-cm (6- x 6-in) mortar plaque and then comparing the appearance of the treated pavement surface with that of the mortar plaque. Top photo shows adequate coverage; center photo, moderate coverage; lower photo, inadequate coverage.



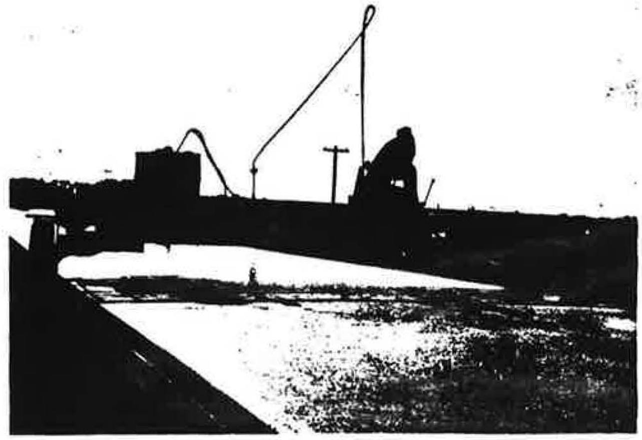
earth which should be kept thoroughly wet until the end of the curing period. The top surface and edge of the pavement should not be left unprotected for more than one-half hour.

Control of Temperature

If existing or anticipated air temperatures are such that the newly placed pavement may be subjected to low temperatures or to freezing, the concrete should be so protected as to prevent the temperature at the surface from going below 50 F (10 C) for a period of 7 days, except that where high-early-strength portland cement is used, 3 days is considered to be sufficient. This requirement is intended to apply to the placing of concrete in those seasons of the year, or in such places, where the possibility of freezing or continued low temperatures is to be expected. It is not intended to apply where temperatures below 40 F (4 C) are a rarity. In any case, however, concrete should be protected from freezing temperatures at any time during the first 72 hours, or 24 hours where high-early-strength portland cement is used.

Protective coverings should consist of: (1) 12 inches (30 cm) of dry hay or straw covered with one layer of curing paper in addition to the surface

Figure 10. Special equipment applying liquid membrane-forming curing compound to surface of a slip-form pavement.

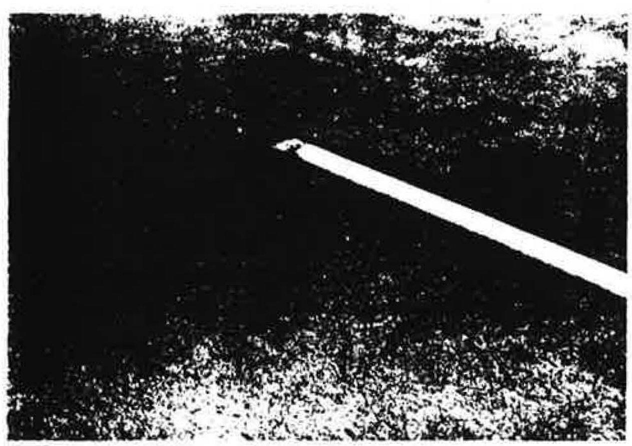


protection provided for curing, or (2) other satisfactory thermal protective covering approved by the engineer.

Protection Against Excessively High Temperature

Moist curing is preferable as protection against the development of excessively high temperature, but paper or other films of sheet materials and pigmented seals, preferably of white opaque surfaces, may be used. Clear seals should not be used when air temperature exceeds 80 F (27 C). It is helpful in the prevention of random cracking to sprinkle the surface with water frequently after the curing compound has set, the resulting evaporation aiding in reducing the rise in temperature of the concrete. As soon as there is an indication of a rapid or extended drop in temperature, 3°F (1.5°C) or more per hour the surface spraying with water should be discontinued.

Figure 11. Cracking of this portland cement concrete pavement several days old was attributed to shrinkage due to loss of water. Application of more liquid membrane-forming curing compound greatly reduced the amount of cracking.



Curing of Field Test Specimens

Proper curing of concrete test specimens made in the field is very important, because improper curing may produce strengths that are not indicative of the actual strength of the concrete. Field

Figure 12. Curing materials applied to the surface of a concrete pavement need to be protected from damage to prevent a lessening of the effectiveness of curing. Damage done to liquid membrane-forming compound by foot and wheeled traffic, as shown here, should be repaired immediately.

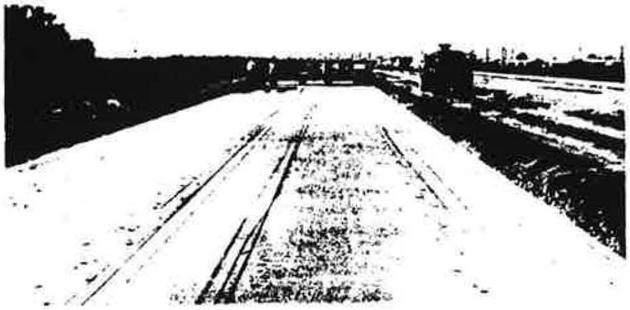
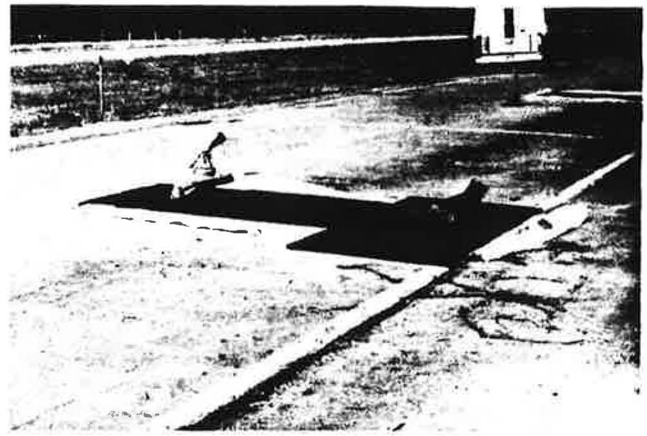


Figure 13. To provide a vapor barrier to retain the original moisture in test cylinders, one state highway department supplies plastic curing covers with its fiber cylinder molds. The curing cover, applied as soon as the test cylinder is finished and properly marked, is not intended to replace normal curing conditions. The cylinders with covers in place are cured in a damp environment and with the temperature properly controlled. These covers are designed to fit snugly. If difficulty is encountered, the cover can be stretched sufficiently by inserting both hands as far as the wrists, and spreading gently apart as shown at left. The curing cover is applied by pulling it down over the cylinder until the skirt reaches the bottom of the mold, as shown at right.

Figure 14. White pigmented curing membrane being applied with a hand-held sprayer to full-depth concrete patches.

Figure 15. Full-depth patches made with Type III cement and calcium chloride cured with membrane, polyethylene, and insulation board to retain the heat of hydration to insure high early strength. These full-depth pavements are open to traffic in as little as 4 hours.



test specimens are made for the following purposes: (1) to check the adequacy of the laboratory design for strength; (2) as the basis for acceptance of the concrete; and (3) to determine when the pavement may be put into service.

Proper curing of the concrete test specimens during the first 24 hours is highly important because curing during this period has a significant influence on the development of strength. Both compression and flexure test specimens, according to ASTM Method C 31, regardless of the purpose for which they are made, must be kept moist and the temperature immediately adjacent to the specimens must be held within the range of 60 to 80 F (16 to 27 C). At the end of 24 hours the specimens are removed from the molds and cured according to the purpose for which they were made. Some engineers, however, prefer to cure test specimens used to determine when the pavement may be put into service under the same temperature conditions as the job concrete is cured during the first 24 hours.

Compression and flexure specimens made to check the adequacy of laboratory design for strength or as the basis for acceptance of the concrete are placed in moist storage and the temperature maintained at 73.4 $\pm$ 3 F (23 $\pm$ 1.5 C) until the time of test.

Test specimens made to determine when the pavement may be put into use should be cured as nearly as practicable in the same manner as the concrete in the pavement. Test specimens for the flexure test, which is often used for this purpose, should be removed from the molds at the end of 24 hours, placed on the ground in a suitable location, and the sides and ends banked with damp earth or sand which shall be kept wet during the curing period of the pavement. The same curing treatment used on the surface of the pavement should be applied to the surface of the test specimens. Surface curing of the specimens should be discontinued at the same time the curing of the section of pavement represented by the test specimens is stopped, but the wet earth or sand bank around the test specimens should be maintained until the specimens are removed for testing. Many flexure specimens are tested in the field because field testing equipment for this purpose is readily available.

Similar treatment should be given to compression test specimens. It is often necessary to ship compression specimens to a central laboratory for testing. Shipment should not be made until at least three-fourths of the time has elapsed between making of the specimens and the scheduled time for testing. Test specimens should be wrapped and protected to prevent physical damage during transport and loss of moisture prior to testing as illustrated in Fig. 13.

Curing of Patched Areas

It is essential to properly cure concrete patched areas in paving. This will avoid rapid loss of moisture from the surface and excessive drying shrinkage. The quickest and most effective method is by spraying on a heavy membrane curing compound (Fig. 14).

New methods of patching full depths use a Type III cement and calcium chloride admixture for rapid setting. In this type of patch (Fig. 15) polyethylene plastic is placed over the textured patch immediately after initial set. The insulation board is placed on top and weighted down in order to retain strength. Many of the full depth patched concrete pavements have been opened to traffic in as little as four hours.

APPLICABLE STANDARD SPECIFICATIONS AND TESTING PROCEDURES FOR CURING MATERIALS

Specifications for Burlap Cloth Made from Jute or Kenaf	AASHTO M 182
Specifications for Sheet Materials for Curing Concrete	AASHTO M171 or ASTM C 171
Specifications for Liquid Membrane-Forming Compounds for Curing Concrete	AASHTO M148 or ASTM C 309
Method of Test for Water Retention by Concrete Materials	AASHTO T155 or ASTM C 156
Method of Test for 45-Deg. 0-Deg. Directional Reflectance of Opaque Specimens by Filter Photometry	ASTM E 97
Method of Test for Wet Tensile Breaking Strength of Paper and Paper Products	ASTM D 829
Method of Test for Abrasion Resistance of Concrete by Sand Blasting	ASTM C 418
Method of Making and Curing Concrete Test Specimens in the Field	AASHTO T23 or ASTM C 31
Specifications for Air Entraining Admixtures for Concrete	AASHTO M154 or ASTM C 260
Specifications for Chemical Admixtures in Concrete	AASHTO M194 or ASTM C 494

SELECTED BIBLIOGRAPHY

1. Jackson, F. H. and Pauls, J. T., "Curing Concrete Pavements." Proc. HRB, 7: Pt. 1, 221 (1927).

2. Jackson, F. H. and Werner, G., "Field Experiments in the Curing of Concrete Pavements." Pub. Roads, 9: 139 (1928).

3. Lang, F. C., and Burggraf, F., "Progress Report of Special Investigation on Curing of Concrete Pavement Slabs." Proc. HRB, 9: 369 (1929).

4. Gonnerman, H. F., "Study of Methods of Curing Concrete." Proc. Amer. Concrete Inst., 26: 392 (1930).

5. Lang, F. C., and Burggraf, F., "Progress Report of Committee on Curing of Concrete Pavement Slabs." Proc. HRB, 10: 370 (1930).

6. Lang, F. C., "Intermittent Curing of Concrete." Proc. HRB, 12: Pt. I, 331 (1932).

7. Morris, M., "The Use of Paper for Curing Concrete Pavements." Proc. HRB, 12: Pt. I, 339 (1932).

8. "Report of Committee on Curing of Concrete Pavement Slabs." Proc. HRB, 13: Pt. II (1934).

9. Carlson, R. W., "The Function of Water in Hardening Concrete." Proc. HRB, 16: 216 (1936).

10. Meissner, H. S., and Smith, S. E., "Concrete Curing Compounds." Proc. Amer. Concrete Inst., 34: 549 (1938).

11. Jackson, F. H., and Kellerman, W. F., "Tests of Concrete Curing Materials." Proc. Amer. Concrete Inst., 34, 481 (1939).

12. Myers, B., "Experiments in Curing Concrete Pavements." Proc. HRB, 19: 284 (1939).

13. Marr, R. A., Jr., "The Cost of Curing Concrete Pavements with Cotton Mats." Pub. Roads, 20: 11, 215 (1940).

14. Vollmer, H. C., "Influence of Various Curing Methods on Strength and Abrasive Wear Resistance of a Portland Cement Concrete." Proc. HRB, 24: 207 (1944).

15. Blanks, R. F., Meissner, H. S., and Tuthill, L. H., "Curing Concrete with Sealing Compounds." Proc. Amer. Concrete Inst., 42: 493 (1946).

16. Powers, T. C., "A Discussion of Cement Hydration in Relation to the Curing of Concrete." Proc. HRB, 27, 178 (1947).

17. Rhodes, C. C., and Evans, J. R., "An Appraisal of the Membrane Method of Curing Concrete Pavements." Bull. 108, Michigan Eng. Exper. Sta., East Lansing, Mich. (1949).

18. Peyton, R. L., "Curing Concrete Pavements in Kansas." Proc. HRB, 13: 156 (1952).

19. Rhodes, C. C., "Michigan's Experience in the Use of White Pigmented Membrane Curing Compounds." Proc. HRB, 30: 252 (1950).

20. Rhodes, C. C., "Curing Concrete Pavements with Membranes." Proc. Amer. Concrete Inst., 47: 277 (1950).

21. Walker, S., and Bloem, D. L., "Effects of Curing and Moisture Distribution on Measured Strength of Concrete." Proc. HRB, 36: 334 (1957).

22. Proudley, C. E., and Morgan, A. D., "Effect of Method of Curing on Internal Temperatures of Concrete Pavements in North Carolina." Proc. HRB, 36: 347 (1957).

23. "Curing of Concrete." HRB Bibliography 18 (1956).

24. "Curing of Concrete: 1925-1960." HRB Bibliography 32 (1963).

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