The data used for constructing Figure 8 were obtained from an interesting investigation made at the laboratory of the Iowa Highway Commission Mortar slabs 13 by 14 by 2 inches were poured and left in pans. The slabs were cured under wet burlap in an incubator for the initial curing periods shown At the end of the initial wetting period the specimens were allowed to dry out in an incubator where the temperature was controlled between 92 and 100°F with an average of 95 8°F and the relative humidity varied from 30 to 40 per cent with an average of 38 5 per cent This diagram shows that the points representing the percentage of retained water for the different initial curing periods are on a straight line, and also the importance of the first day's curing The mortar slabs were sawed up and flexural tests made on 2 by 2 inch beams and compression tests on 2 inch cubes at 28 days age All specimens were immersed in water for 24 hours The strength corresponded to the percentage of retained water

This is submitted as a progress report In its 1929 report this committee stated, "There is evidence to indicate that the amount of mixing water retained in the concrete during the curing period is an important index to the effectiveness of the various curing methods " These data appear to corroborate this statement The committee is also of the opinion that these data indicate that satisfactory curing may be obtained in humid areas with a short initial wet curing period In some localities where climatic conditions are favorable this may be 24 hours The committee expects to continue the investigation

THE USE OF PAPER FOR CURING CONCRETE PAVEMENTS

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SYNOPSIS

A review of data relating to the use of specially prepared paper as a curing medium, obtained from pavement construction in Missouri, Minnesota and Iowa and from laboratory experiments The experience thus far indicates that within certain limits as to number of repetitions of use, the paper will serve to retain the moisture in the concrete and the concrete will attain strength that compares favorably with that from other curing methods in common use

THE PAPER

Papers prepared for use in curing concrete pavements are of two types, those consisting of a single sheet of paper, heavily impregnated and thoroughly coated with waterproof waxes particularly adapted to this purpose, and a compound type composed of two or more single sheets of paper cemented together with asphalt and reinforced with a network of string, twine, or a thin, open layer of vegetable fibers

A cross-section of the compound paper shows, in the order named, a sheet of paper, a film of asphalt, a layer of reinforcing material, and the second sheet of paper, and for some brands, another film of asphalt and a third sheet of paper. This additional asphalt and paper is used to waterproof that side of the cords or twine which in some of the methods of preparation receive little if any asphalt coating at the point of contact with the second sheet of paper In these cases, the third sheet of paper and its cementing film of asphalt are necessary to complete the construction of a waterproof paper blanket The final result for either the two or the three sheet papers is a tough, strong, heavy, light tan or neutral colored product which, if properly used, appears to be capable of providing a satisfactory curing condition for concrete pavements which are protected during their curing period by coverings made from it

ITS USE

The use of paper to any appreciable extent for covering concrete has been brought about during the past two or three years. The compound type, which is usually referred to commercially as duplex, corded or reinforced paper, has attracted the most attention. Although considerably more expensive in its first cost than the simple type of paper, it has some real advantages such as ease of application, resistance to exposure and ability to withstand a number of repetitions of use. Due to certain inherent deficiencies in desirable properties, paper of the simple type has been used apparently only on experimental projects, while the compound type, without such handicaps, has had rather extensive use on routine construction projects, particularly during the past two years In that period, seventeen state highway departments, three cities and one airport corporation have permitted its use on one or more paving projects

METHODS OF CURING

Since the use of the material for this purpose is new, and since the influence of local opinions and conditions always greatly affect the manner of use of a material until generally recognized standard practices have been developed, paper as a curing agent has been applied in many different methods. The principal variation is found in the requirement for the initial curing period This may be the application of fine water spray until the concrete has attained its initial set, protection with wet burlap until that time, protection with wet burlap until the concrete has attained its final set, or protection with burlap for definite lengths of time, within 10 to 24 hours after the concrete is placed The paper itself may be applied directly to the surface of the pavement at any time after the concrete has set up enough to prevent the marring or marking which might occur while placing it The length of time the paper covering is required varies from a minimum of 48 hours to a maximum of 9 days, the variation depending in part, on the nature and length of the initial curing, and, in part, on the judgment of the user.

RESULTS OBTAINED FROM FIELD INVESTIGATIONS

Indications of the success which may attend the use of paper in some of these methods of curing are revealed by the data obtained independently by three state highway departments, Missouri, Minnesota and Iowa, from observations made during the construction of concrete pavements upon which paper curing was used. The most comprehensive of these investigations, is that conducted during the construction season of 1930, by Reagel in Missouri, upon two sections of a paving project on which a number of methods of curing were studied. Hansen, in Minnesota, investigated in considerable detail several methods of using the paper during the construction of an 18.8 mile paving project built under his supervision during the summer of 1932. Morris in Iowa reported briefly on three projects built in Iowa during 1931.

The data of these three investigations, taken collectively, offer a considerable amount of evidence concerning the behavior of concrete cured by some one of a small group of methods using paper as the curing agent. In each instance, the effects upon certain characteristics or properties of the concrete cured under paper were compared to the effects of curing by some well recognized standard method such as the ponding, or the moist earth methods.

In every case, the effect upon strength was given early consideration. The results of compression tests on cores drilled from the pavements in Missouri and Iowa indicate that the concrete cured under paper had from 92 to 105 per cent of the strength of that of concrete cured by the wet methods used as standards. On the basis of beam tests made during the construction of the Minnesota project, a similar relationship may be predicted as the paper cured beams from it had average moduli of rupture values of from 97 to 102 per cent of those for specimens cured under water. These results indicate satisfactory performance for the paper curing, insofar as the strength of the concrete is concerned.

In connection with the field observations, Reagel and Hansen kept a continuous record of the temperature beneath the paper on the surface of the pavement. Reagel reported that at its maximum this temperature was 15 degrees (F.) greater than that of the air at its maximum for the day. Hansen reported a difference of 19 degrees (F.). Differences in the color of the paper and differences in the peak air temperatures for the day, without doubt account for the difference in the two observations. They are sufficiently in accord to establish the fact that the temperature beneath the paper will be higher than that of the air outside.

Further, both observers noted that the temperature under the paper had a range of 4 to 10 deg. greater than that of the air outside, and that the lowest temperature beneath the paper was well above the low of the temperature for the day Apparently this is due to the insulating effect of the paper against loss of heat from the slab by radiation This effect appears to be of some magnitude when it is realized that the temperature beneath the paper is from 15 to 19 deg greater during the heat of the day, yet the range of that temperature is but 4 to 10 deg. greater than that of the air temperature for the day

There is, naturally, a close relationship between the temperature of the concrete and its volume changes Reagle reported extensively on direct measurements of dimensional changes, obtained by means of strain gages These data are difficult to abstract for brief presentation, but suffice it to say here that the changes in dimension were found to be but little greater for the paper cured concrete than for the ponded concrete The difference, regardless of its numerical order, seems to have been relatively insignificant in its effect on transverse cracking, for the average slab length of the paper cured section was 108 per cent of that of the ponded sections

MOISTURE CONTENT

In the field, means for determining accurately the amount of moisture lost or gained by the pavement slab when subjected to any method of curing are yet to be devised Resource must be had to some means of comparing these losses on a purely relative basis The only data available on paper curing even on this basis were those obtained by Hansen in Minnesota The losses for the several methods of paper curing studied by him are for are percentages of the original water content of the concrete for 72-hour curing periods

For a single thickness of paper, which was used from one to seven times, and which was applied to the specimen two hours after the concrete was placed in the molds, the moisture losses were 12 5 to 22 0 per cent of the original moisture content Paper which had been used from 8 to 13 times lost 19 0 per cent, and double thicknesses of paper which had been used 10 times lost 8 0 per cent Specimens cured in the air and sun for two hours, under wet burlap for 24 hours and paper 48 hours, showed a net moisture loss of four per cent Those with the same initial curing, 48 hours of burlap and 24 hours of sun and air, also had about a four per cent loss All of these specimens were exposed to the weather except as protected by the curing agent Another series of specimens, air cured in the shelter of a field laboratory from the time of molding, lost 45 per cent of the original water content

These small specimens undoubtedly show greater losses than would be probable for the concrete, but similar relationships may be expected for concrete slabs It is significant to note that the specimens subjected to an initial curing under 24 hours of wet burlap had comparatively small moisture losses

SUMMARY OF FIELD DATA

These field data indicate that paper curing may be expected to provide for the attainment of a strength of concrete comparable to that secured by standard wet methods of curing, such as ponding, wet burlap or moist earth Effects on the other properties of concrete, both during and following the curing, are somewhat less conclusive However, the higher curing temperatures do not appear to have caused, in the cases studied, sufficient differences between the volume changes of the paper cured and standard cured slabs, to result in any greater transverse cracking in one than the other The data for moisture losses are inconclusive, and somewhat inconsistent, even within themselves as a group They are presented in this report, not so much for the purpose of establishing a fact with respect to the efficiency or inefficiency of a curing method, but rather to show what may be expected from field determinations of this rather exacting test Since the deterioration of the paper with use can be measured only by an accurate moisture test, the data here fail to establish clearly the effect of use The occurrence of holes, breaks or tears can be seen and remedied by patching, and this was done on the Minnesota project The gradual appearance of small holes and practically invisible cracks is much less readily detected by visual examination That these occur at a fairly definite rate has been established, as will be observed later, by laboratory tests

Time has not yet been sufficient to establish the effects of paper curing on permeability, durability, surface defects, scaling and softness The accumulation of evidence for these things must await the passage of time and the collection of data from many widespread and independent sources

LABORATORY INVESTIGATIONS

The laboratory data on paper curing available for use in this report were supplied by the Portland Cement Association and the Iowa State Highway Commission These investigations were, for the most part, undertaken several years prior to the field use of paper, some portions of them were, however, conducted concurrently with the field projects Data presented here, like those from the field studies, are derived from a study of papers of the compound type

The laboratory researches, as may be expected, consider first the effect of paper curing upon strength The comprehensive work of the Portland Cement Association as reported by Gonnerman dealt extensively with the relationships between strength and the method of curing For 6 by 12 inch cylinders cured in paper bags, he obtained practically the same strength results at the different ages as for cylinders cured in the moist room for 13 days At the ages of 28, 90 and 360 days, paper cured cylinders had, when tested in saturated condition, 99, 97 and 73 per cent of the strength of water cured cylinders of the same respective ages Also, paper cured cylinders of these ages had, similarly, 99, 104 and 85 per cent of the strength of water cured cylinders of the same ages Moduli of rupture, were at the ages of 28, 90 and 360 days, 105, 102 and 106 per cent, respectively, of the values for water cured beams at these ages, when all tests were on saturated specimens The corresponding values for the paper cured beams, when tested in the "as cured" condition at these ages were 86, 76 and 86 per cent, respectively, of water cured specimens The compression test results in the laboratory seem consistent with field data, excepting those at the age of one year This may be due to the fact that the field concrete in the pavement has the advantage of natural curing conditions for the continuance of hydration processes, while these must cease in the laboratory specimens when the loss of moisture has become in excess of some certain value, and will resume only when additional moisture again becomes available

For moisture losses on the basis of the original water content, Gonnerman reported for the cylinders, 5 8 per cent at 28 days, 15 4 per cent at 90 days, and 27 2 per cent at 360 days This loss for the beams was 7 6 per cent at 28 days, 15 0 per cent at 90 days and 25 1 per cent at 360 days The water cured specimens showed gains at these ages varying from 11 to 27 per cent of the amount of the original water content This gain in moisture has been shown by Morris to contribute to a higher strength value than would be obtained for concrete held at a constant water content This would have the effect in this case of discounting somewhat the strength of the paper cured specimens when compared with that of the water cured specimens, especially at the later ages

The Iowa data on strength show that paper cured compression specimens had 100 per cent of the strength of moist cured specimens when tested wet at the age of 7 days, 88 per cent at 28 days, 86 per cent at 90 days and 89 per cent at 360 days At the same ages the values for modulus of rupture were 95, 91, 92 and 92 per cent of those for the standard moist earth cured concrete These specimens were sawed from slabs cured out-of-doors during the extremely dry year of 1930 This may be reflected in the low strengths of the paper cured specimens

Considerable data has been obtained in Iowa on the efficiency of various papers in preventing moisture losses from mortar For suitably prepared papers these losses, when determined in a manner to insure that all of the loss must be through the paper, and for the conditions of constant exposure in an atmosphere having a relative humidity of 30 to 40 and an average temperature of 95°F , are found to be small, being 0 61 to 1 50 per cent at the end of six days, and from 2 00 to 5 00 at the end of 27 days The strength data derived from this series of tests indicates a close relationship between the amount of retained water and the strength value Low moisture losses for the early curing period were always accompanied by high strength values Consequently, if the paper could be applied in the field so as to take full advantage of its abilities to retain moisture, satisfactory strength values would follow

This same series of tests gave evidence of the slow but gradual loss with repetitions of use of the abilities of the several papers for retaining moisture The first use resulted in a marked impairment of this ability and each succeeding use up to the fifth, when the experiment stopped, showed a small but constant further impairment At the end of the experiment, papers originally permitting the loss of but 1 25 per cent of moisture, showed losses of 7 87 per cent after five uses, and those originally losing as little as 0 61 per cent when new, after three uses lost 1 83 per cent, at the end of six days These losses at this age are well below the probable limits for good curing and are cited only to show the effect of repeated use and continued exposure upon the efficiency of the paper On the basis of these tests, seven to ten uses of suitably prepared papers seem to be safe limits