EVALUATION OF SEVERAL TYPES OF CURING AND PROTECTIVE MATERIALS FOR CONCRETE

Final Report On Part II

Installation Report and Initial Condition Survey of Bridge Decks

by

Howard H. Newlon, Jr.
Assistant State Highway Research Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway Research Council
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SUMMARY

Thirty-nine test panels were installed on three interstate bridges to evaluate several combinations of curing and protective treatments for concrete. Panels were cured with white pigmented liquid membrane and white polyethylene, both with and without subsequent treatments using linseed oil. One panel received a chlorinated rubber sealer marketed as a combined curing and protective material. On some panels a monomolecular film was used to reduce evaporation prior to regular curing.

Detailed observations of construction operations and atmospheric conditions were recorded and important properties of the freshly mixed and hardened concrete determined. Periodic condition surveys are planned.

Results of this study led to the following observations and conclusions, and recommendations:

Observations and Conclusions

1. The operations of the contractor were efficient as reflected in the lack of rejections of concrete, the low coefficients of variation, and the timing of his various operations. The uniformity achieved will greatly reduce the influence of the concrete on the behavior of the performance of the curing and protective treatments.

2. The uniformly satisfactory air contents indicate a good probability of good performance of the deck surfaces.

3. The results of laboratory freezing and thawing tests of concrete specimens made during construction and cured, treated and stored in the field, agreed well with and confirmed the results of similar tests reported in Part I of this report. Specimens treated with linseed oil showed reduced scaling and weight loss as compared to those without the treatment and those cured with chlorinated rubber.

4. Coverage rates of sprayed curing materials were lower than those specified. It is probable that materials meeting the more restrictive requirements of the Virginia Department of Highways need not be applied at the rates of 150 - 200 $ft.^2$ gal. commonly specified for materials meeting AASHO requirements.

5. Polyethylene coverings were applied later than the sprayed curing materials. The average difference was about 45 minutes.

6. Linseed oil coverage rates were very close to the target value of 0.040 $gal/yd.^2$ At this coverage rate, the presence of the linseed oil is barely discernible after a month or two.

7. The performance of the chlorinated rubber was unsatisfactory. It developed a very tenacious film which blistered and reduced skid resistance by about 25 percent. It is believed that the bleeding

608 characteristics of the concrete, which contained a water reducing-set retarding admixture, and the severe atmospheric conditions significantly contributed to this behavior; however, these are always present in bridge decks built under Virginia Department of Highways Specifications during the summer when curing requirements are most critical. The conditions did not develop in supplementary tests on a rest area using paving concrete.

8. Desirable benefits of the monomolecular film in extending time available for finishing and for use in emergency situations was qualitatively confirmed. The reduced moisture loss prior to application of curing was also verified although the observed test panels were comparatively few.

9. Difficulties with finishing were associated with days when the computed evaporation rates exceeded 0.10 lb./ft.^{2}/hr.

10. High mixture temperatures combined with high air temperatures were reflected in a measurable reduction of compressive strengths and acceleration of setting.

Recommendations

1. The currently specified curing procedures for concrete bridge decks followed by linseed oil treatments continue to be the most satisfactory of the several alternatives practically available for improved durability.

2. Application of the linseed oil treatments following curing with a white pigmented resin based compound of the type specified by the Virginia Department of Highways was once again shown to be satisfactory.

3. Procedures for utilization of the monomolecular film should be initiated so that it can be available in situations where it is needed. These include (1) days with high evaporation potential, (2) delayed application of curing, and (3) equipment breakdowns. Specification of its use for all decks is not desirable.

4. Unless penetration can be demonstrated, no further consideration should be given to materials designed to cure and protect in a single application since the two functions are mutually exclusive (i.e., one requires keeping water in while the other requires keeping it out) and they should be thought of as two separate operations.

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Concern for improving the durability of concrete in bridge decks has spawned widespread research to develop and evaluate protective coatings. This research has generated numerous technical reports, publications, and pieces of promotional literature. The most recent and comprehensive of the technical publications have been discussed in Part I of this report (Newlon — 1970). Concomitant with the research effort, use of a variety of protective coatings has proceeded on an operational level, in some cases on a routine basis.

In spite of the volume and competency of the research and operational usage, there are conflicting opinions as to the effectiveness of the various materials, undoutbedly due, at least in part, to the numerous factors influencing the durability of concrete. Much of the research has been conducted in laboratories under accelerated and simulated conditions, and most of the reported field experience was not research oriented and thus has not included the controls, replication, and documentation necessary to permit definitive conclusions. These two factors, combined with the variability inherent in the performance of concrete subjected to a variety of environmental factors, in large measure account for the conflicting ideas as to the efficacy of various protective coatings.

PURPOSE AND SCOPE

This project was designed to provide a field evaluation under carefully documented conditions of several of the more widely used curing and protective materials. Nine combinations of materials were included on 29 test panels. The materials were selected on the basis of results from the preliminary evaluations reported in Part I of this study (Newlon — 1970). In addition to the observations made during construction, the study will include performance evaluations for a five year period.

LAYOUT OF TEST SECTIONS

Three structures on Interstate Route 64 in Albemarle County were chosen for application of the selected materials. Two structures (B651 and B652), each with three spans, are on the mainline; and one (B648) carries a secondary route over I-64. Applications on the mainline structures were intended to be duplicated on the secondary structure in order to gain an indication of the effect of differences in traffic volumes and frequencies of deicer application as well as differences in the orientation of the structures.

On the basis of the preliminary screening tests the materials and combinations given in Table I were selected for application.

TABLE I

CURING AND PROTECTIVE COATING COMBINATIONS USED IN THE FIELD TESTS

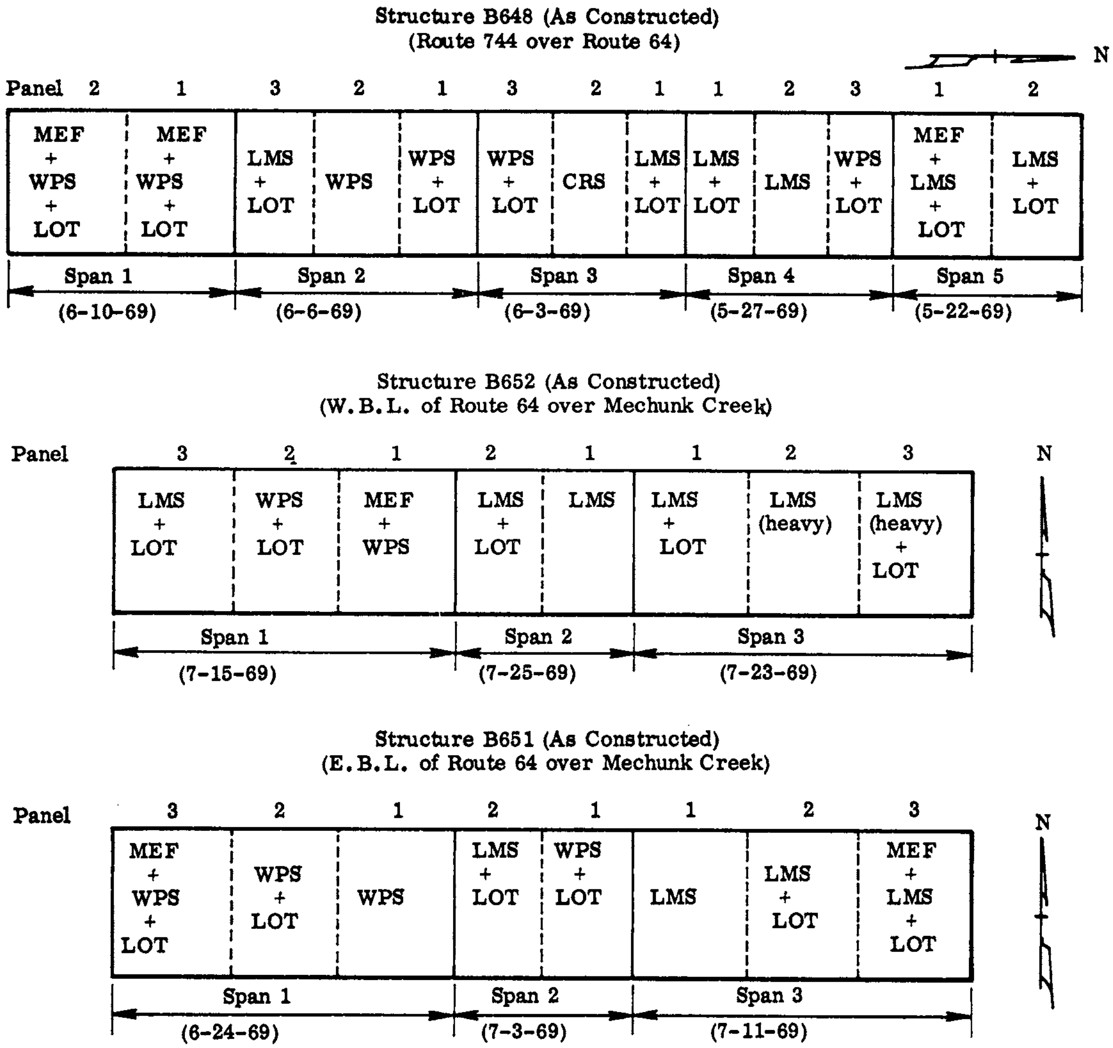
Condition*	Material
1	Liquid Membrane Seal (LMS)
2	White Polyethylene Sheeting (WPS)
3	LMS plus Linseed Oil Treatment (LOT)
4	(WPS) + (LOT)
5	Monomolecular Evaporation Film (MEF) + (LMS) + (LOT)
6	MEF + WPS + LOT
7	MEF + LMS
7-A**	MEF + WPS
8	Chlorinated Rubber (CRS)

*The notation in this report is consistent with that used throughout Part I. The materials are referred to by the letter designation throughout the report.

**Not evaluated in preliminary tests (Part I).

When the LOT was used, it was applied without any surface preparation other than sweeping. The effectiveness of LOT applied without prior removal of the liquid curing material (LMS) had been demonstrated in Part I of this study.

Originally, it was proposed to include several other materials but some were eliminated from results developed in the preliminary screening phase and several panels were interchanged to provide minimal inconvenience for the contractor. The initially planned layout is included in Appendix A, along with the reasons for elimination of specific materials. The final layout of test panels is shown in Figure 1. Within a given span, the numerical sequence coincides with the order of placing.



(WPS) — White Polyethylene Sheeting
(LMS) — Liquid Membrane Seal
(LOT) — Linseed Oil Treatment
(MEF) — Monomolecular Evaporation Film
(CRS) — Chlorinated Rubber Sealant

Figure 1. Test panels for evaluation of concrete curing and protective materials.
0064-002, B648, B651, B652
I 64-2 (55) 93

MATERIALS

Curing and Protective Materials

Special provisions, supplementing the Standard Specifications of the Virginia Department of Highways, were prepared prior to the advertising of the project. These are also included in Appendix A.

The Virginia Department of Highways requirements for liquid membrane curing material are, briefly, as follows:

1. It must contain a white nonreactive pigment.
2. It must be free of oils or waxes that would tend to prevent bonding of traffic paints.
3. It must disappear by gradual disintegration in not less than 30 nor more than 60 days.
4. When tested in accordance with the Virginia modification of T 155 (Newlon — Part I, 1970) it must
   (a) dry to the touch in one hour and dry through in not more than four hours,
   (b) permit a moisture loss when sprayed at a coverage of one gallon per 200 square feet not greater than:
   at 24 hours 0.075 gm/in^2 (.0116 gm/cm^2)
   at 72 hours 0.150 gm/in^2 (.0232 gm/cm^2)
   (c) exhibit a daylight reflectance of not less than 60 percent of that of magnesium.

As stated in Appendix A, materials meeting these specification requirements were intended to be applied "in reasonably close conformity to the rate of one (1) gallon per 150 square feet of surface area". Insofar as possible, the requirements for the materials and their application were intended to apply to all liquid materials.

The important properties of the curing materials are given in Table II.

It can be seen that the two sprayed materials (LMS and CRS) showed approximately the same moisture retention and, while close to the VDH limit at 24 hours, were well within the AASHO and Federal requirements.

TABLE II

PROPERTIES OF CURING MATERIALS

Materials	Number of Independent Samples	Moisture Loss, Va. Modification of AASHO T155 $gm/in.^2$ (gm/cm^2)		Daylight Reflectance, Minimum %
		24 hours	72 hours	
LMS	2	0.071 (.011)	0.123 (.019)	68.3
CRS	2	0.080 (.012)	0.121 (.019)	*
WPS	1	0.004 (.001)	0.009 (.002)	92.6
VDH requirements		0.075 (.0116)	0.150 (.0232)	60
AASHO requirements		—	(.055)	60
Federal requirements			(.039)	65

*Supplied unpigmented

The measured properties of the linseed oil, prior to dilution with 50% mineral spirits, were:

Specific gravity	0.860
Saponification Value	103
Acid Value	2.60
Nonvolatile Content	55.1%

Concrete and Concrete Materials

The cement met the requirements of AASHO M 85 for Type II. The coarse aggregate was a crushed granite gneiss and the fine aggregate a natural siliceous sand. The aggregates and the cement were from the same sources used in the preliminary evaluation reported in Part I. Air was entrained by use of a commercial neutralized vinsol resin and the water reducing and retarding admixture was of the organic acid type.

Concrete used in bridge decks in Virginia is designated as "Class A-4" and is intended to meet the requirements given in Table III. For each project, the contractor submits mixture proportions based upon ACI Recommended Practice 613 (ACI — 1968). These proportions then become the requirements for the job. These characteristics are also given in Table III.

TABLE III

SPECIFIED CHARACTERISTICS OF CONCRETE FOR THE BRIDGE DECKS OF THE PROJECT

Property	VDH Specifications (general)	Requirements for I-64 Project
Minimum Cement Factor, sk/$_{yd^3}$	6.75	6.75
Maximum Water Cement Ratio, gal/sk.	5.25	4.75
Slump, inches	3 ± 1	3 ± 1
Air Content, percent	$6\frac{1}{2} \pm 1\frac{1}{2}$	$6\frac{1}{2} \pm 1\frac{1}{2}$
$\frac{\text{Fine Aggregate}}{\text{Total Aggregate}}$	not specified	.358
Intended Strength, f'_c, psi at 14 days	3400*	3400*

*Based upon 85 percent of intended 28-day strength of 4000 psi.

The concrete for all of the bridges was ready mixed, as is practically all of the structural concrete used by the Virginia Department of Highways. The procedures and requirements for its mixing and delivery in general conform to those contained in AASHO M157. The contractor is given the option of holding back one gallon of water per cubic yard at the plant for addition at the job site. When the concrete arrives at the job site he has the option of using any or all of this water in a single addition. The decision as to the amount of water to add at the job site is made by the contractor based on the appearance of a small portion of concrete discharged into the discharge chute. After the water is added and mixing is completed, or if no additional water is needed, the concrete is presented to the inspector for acceptance testing. Concrete is discharged into the bucket and a sample taken from the upper portion of the bucket. Slump, air content, and mixture temperature are measured prior to placement of any concrete from a given truck. This procedure is followed for each truckload delivered. In some cases the ball penetrometer (Kelly Ball) is used in lieu of the slump cone to measure consistency and in most instances the Chace air indicator is used for measure ment of air content. In case of measurements outside of specification values, results from the slump cone and pressure air meter must be used as a basis for rejection.

No restrictions or requirements beyond those normally employed in bridge deck construction were imposed upon the concrete or the inspection procedures except for designating the locations for applications of the various curing and/or protective materials. The contractor made the decisions as to when to apply the materials based upon his experience and normal operating procedures. Additional testing of the concrete and gathering of information for the research aspects of the project were accomplished by personnel of the Research Council, while testing and decisions relating to acceptance of the concrete were handled conventionally by job personnel based upon their independent tests.

OBSERVATIONS DURING CONSTRUCTION

Contractor's Procedures

The contractor constructed the eleven slabs that made up the three test structures using a consistent and systematized routine. The bridge crew and supervisory personnel were experienced and had worked together as a "team" for a considerable period. The owner of the company, a registered engineer, was present and in direct charge during all concreting. Thus the "quality" of the construction was well above average when compared against observations made during earlier studies of bridge deck construction (Hilton, Newlon, and Shelburne — 1965). This efficiency in operations was reflected in the test data that will subsequently be presented.

The construction sequence, the equipment, and the procedures presented in Figures 2 - 8, were as follows:

Delivery: The concrete was delivered in trucks with capacities of $8\frac{1}{2}$ $yd.^3$ The haul distance from plant to the job was approximately 9 to 11 miles, depending upon the specific structure. The concrete was discharged into buckets holding 3/4 yd^3 for depositing on the slab. One randomly selected bucketful from within each area treated by a specific combination of curing materials was selected for sampling. This bucketful was swung by the sampling area and a sufficient sample discharged. The remainder of the concrete was placed into the deck and the location noted (Figure 2).

Depositing: The concrete was deposited on the deck and distributed, using the crane and bucket. This operation was well done without the buildup of large piles of concrete that would subsequently have required excessive manipulation (Figure 3).

Screeding: The mechanical screed moved and its oscillations were longitudinal (parallel to the centerline of the roadway). While oscillating longitudinally, the screed pan moved transversely across the deck in a sawing motion. Two passes of this screed were sufficient in practically all cases. A key to the successful use of this equipment appeared to be the manual raking of the concrete in front of it so that the screed was not confronted with a greater amount of concrete than it could handle (Figure 4).

Figure 2. View of concrete discharge, sampling and testing area on B 648. One 3/4 yd^3 bucket is filled and waiting for the return of crane, which has just completed discharge on the deck.

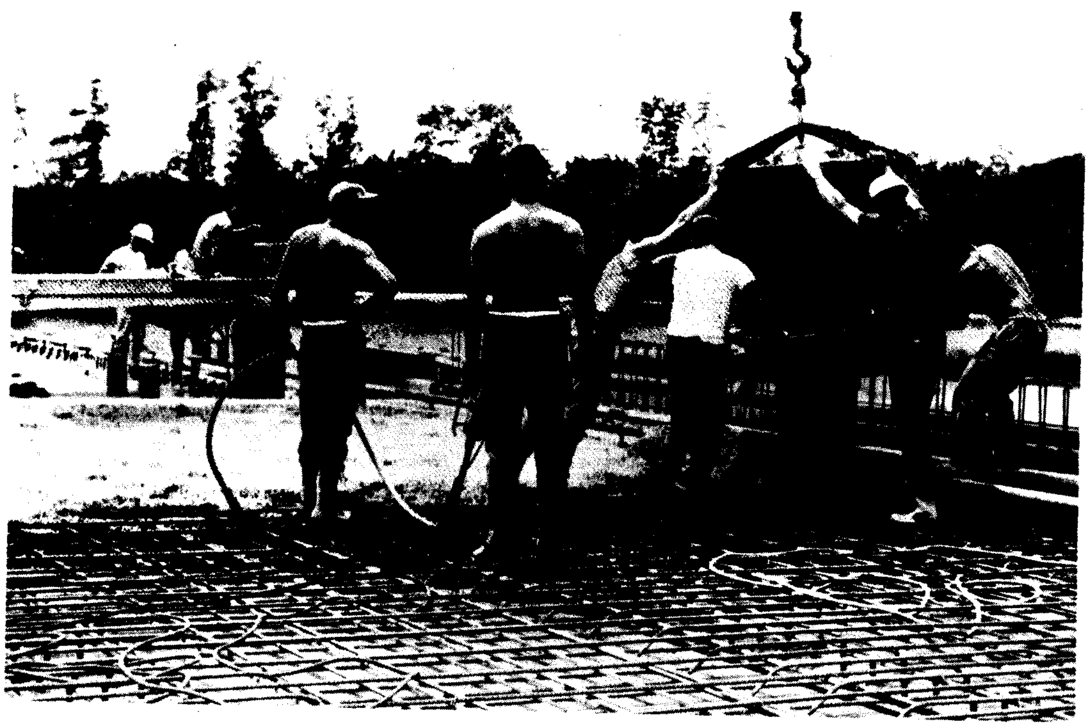


Figure 3. Depositing concrete on deck.

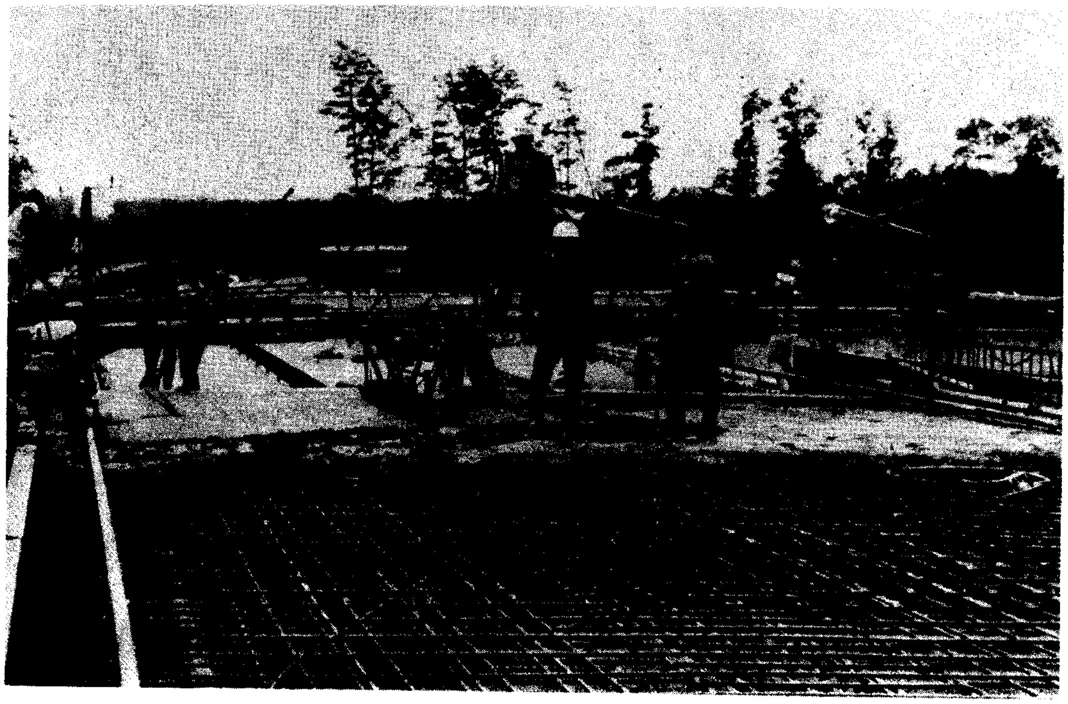


Figure 4. Screed in operation near the beginning of a deck placement. Two workmen in foreground have completed preliminary raking. The screed is moving toward the reader.

Finishing: Several passes with a 10-ft. aluminum float followed the screeding. No hand finishing was required except in the areas of the screed rails, which extended two feet inward from the edge of the slab (Figure 5).

Texturing: Final texturing was accomplished with burlap. The resulting texture was not very severe but consistent with that currently obtained on most bridge decks (Figure 6).

Curing: Liquid curing materials were applied by hand-pressure sprayers from a work bridge (Figure 7). A completed span showing three types of curing is shown in Figure 8.

Protective Coating: Panels designated to receive the LOT were sprayed with a hand-pressure sprayer using two applications; the first at an intended rate of 0.025 gal/yd.^{2} and the second at 0.015 gal.yd^2 (Figure 9).

Figure 5. Finishing with 10-ft. aluminum float. The screed in the background is moving away from the reader. The concrete in the foreground has received no additional work beyond screeding and floating evident in the picture.

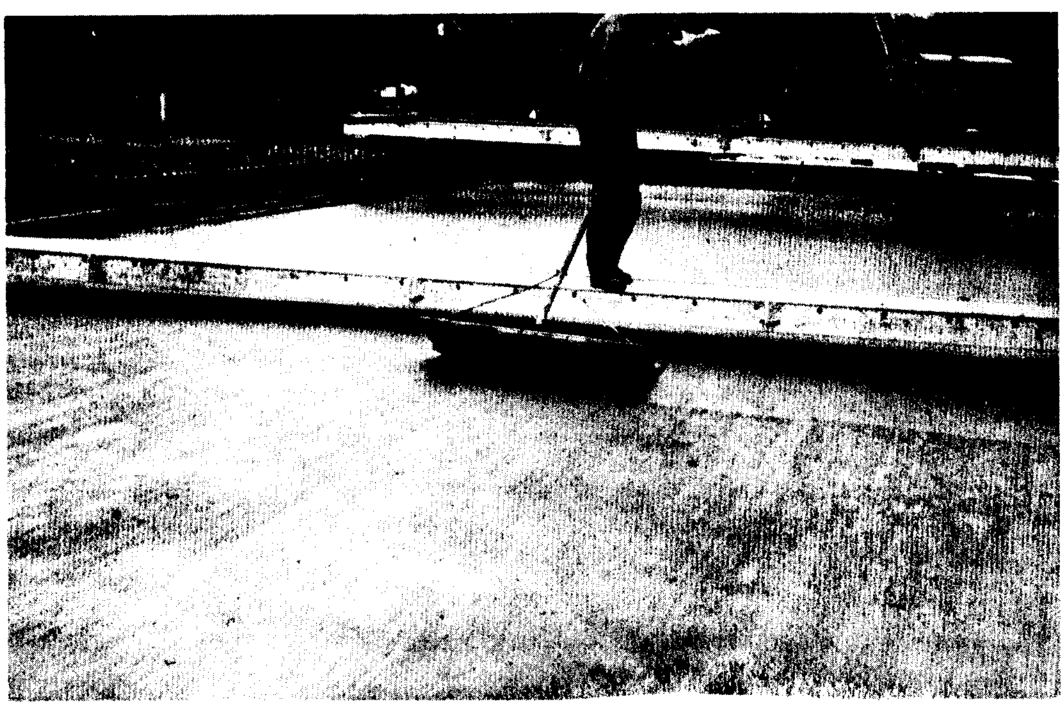


Figure 6. Application of texture by burlap in area shown in Figure 5.

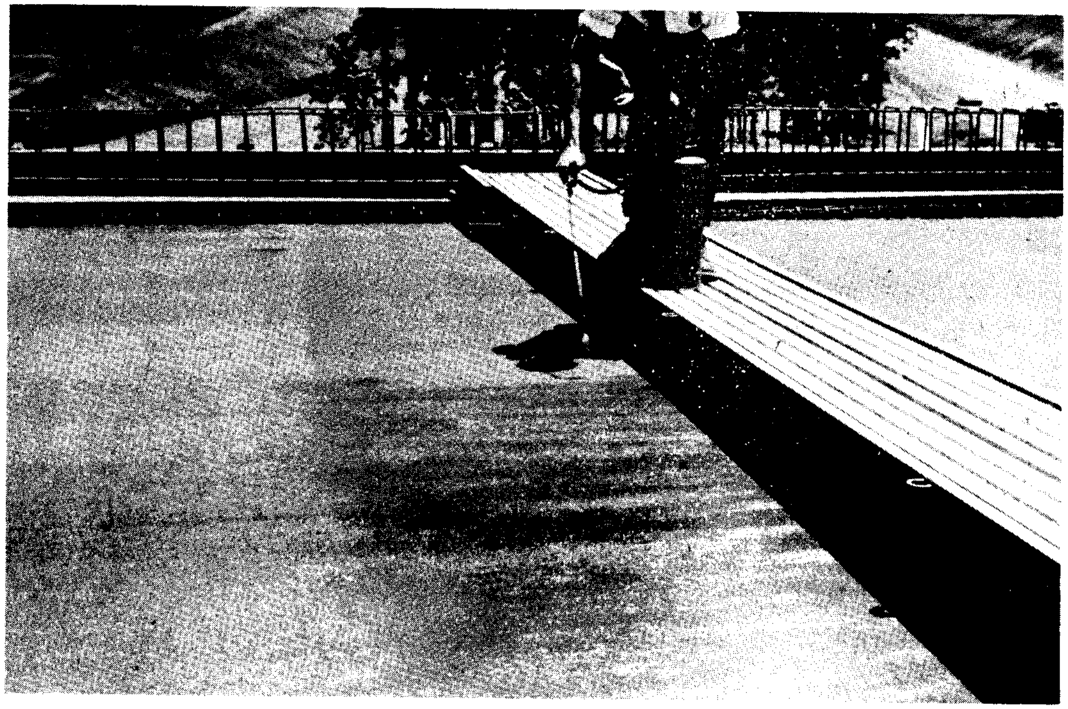


Figure 7. Application of curing. (Actually application of CRS on Span 3 of B 648.)

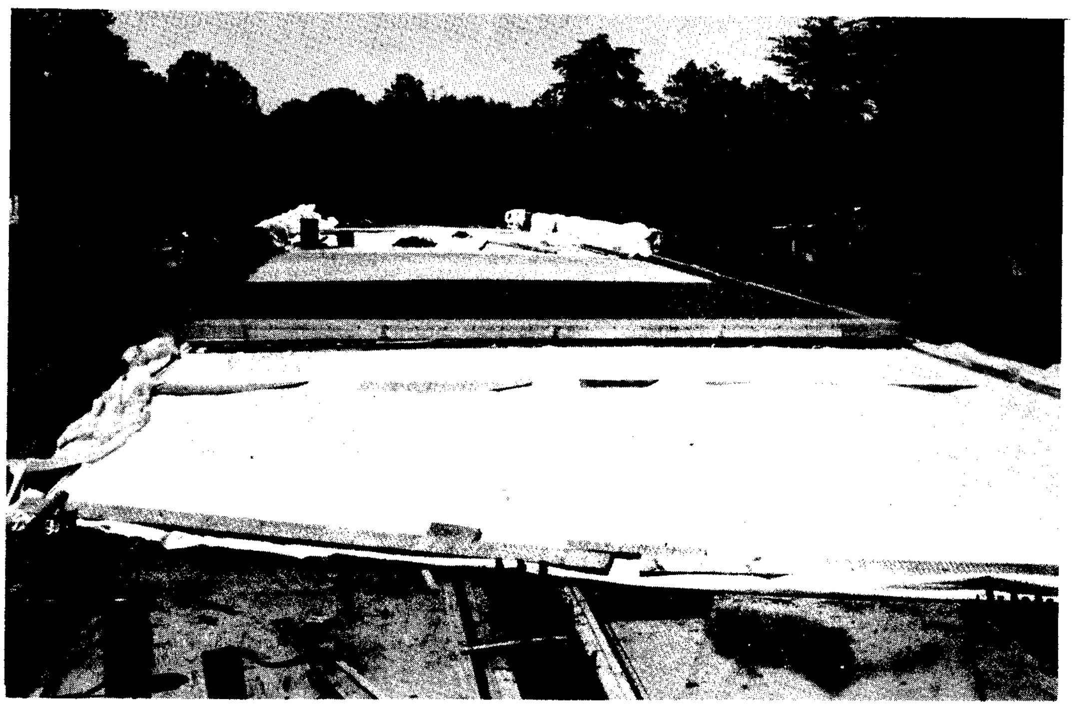


Figure 8. View of Span 3 of B 648 showing three types of curing: foreground WPS; middle, CRS; and distance LMS.

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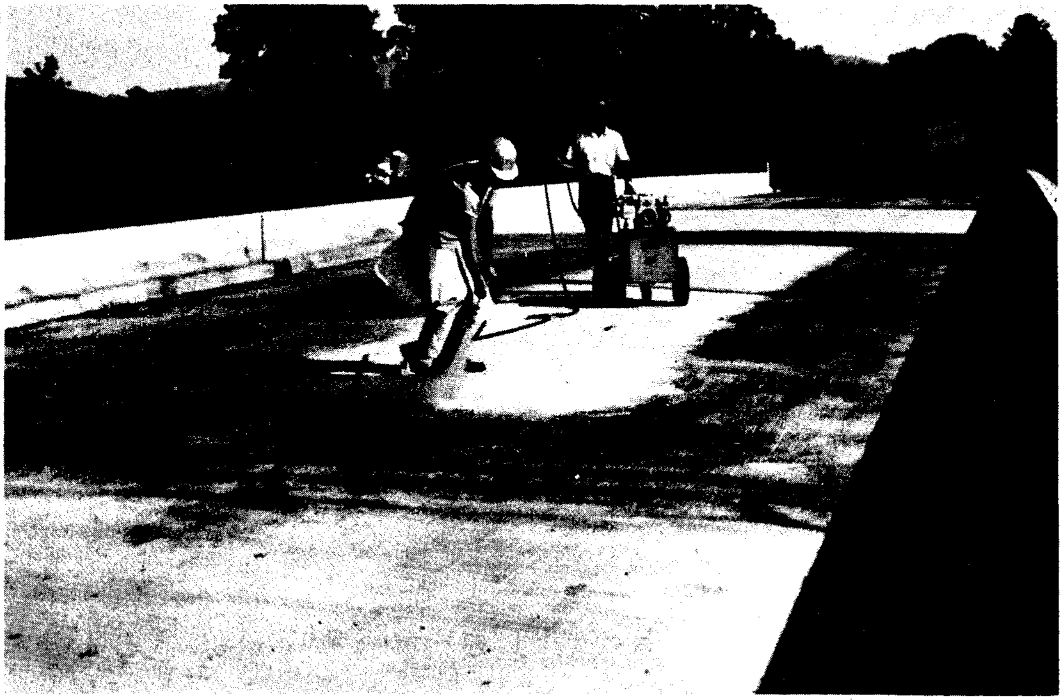

Figure 9. LOT treatment on Span 3 of B 648. In the foreground is CRS panel. The LOT is being applied to Panel 1, cured with LMS, with no additional treatment to remove the LMS.

Testing Procedures

The sampling and testing area was located close to the deck, as was shown in Figure 2. Twenty-nine samples were taken, one to represent each of the test combinations shown in Figure 1. The number of samples taken per day was either two or thre Acceptance sampling was conducted on each truckload as described earlier. It should b noted that the acceptance sampling was always from the last portion of the first 3/4 yd^3 discharged, while the research samples were from randomly selected bucket loads and thus represented various portions of the sampled truckload.

From each sample the following tests were made:

Slump (ASTM C 143)

Air Content — Pressure Method (ASTM C 231)

Unit Weight (ASTM C 138)

Mixture Temperature

Stiffening Rate (ASTM C 403)

Compressive Strength (ASTM C 31)

Resistance to Freezing and Thawing (ASTM C 290)
(Using a 2% NaCl solution)

Moisture Loss (Weight change of 19.5 cm x 19.5 cm x 5 cm specimens)

In addition to the tests on the concrete, periodic measurements of temperature, humidity and wind velocity were made to aid in estimating evaporation rates and drying potential.

Observations were also made of the progress and timing of the various construction operations previously described. The data from observations of the placing and finishing operations described in Figures 2 - 8 are summarized in Table IV. These observations are also presented graphically in Figure 10. From these data it is seen that the operations controlled by the contractor — i.e., depositing, screeding, etc. — were less variable than those operations for which the constraints were imposed by some characteristic of the concrete. The most variable operations were delivery and texturing.

In view of the inherent variability of bridge construction processes the data in Table IV reflect systematic construction procedures among the three structures. Although no comparable published values are available, the coefficients of variation, which generally range between 20 and 30, are believed to represent excellent control.

TABLE IV

TIMING OF VARIOUS CONSTRUCTION OPERATIONS RECKONED FROM THE TIME OF BATCHING
(Values in Hours)

	Delivery	Depositing		Screeding		Finishing		Texturing		Curing	
	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish	Start	Finish
B648											
39 Truckloads											
Average,	0.56	0.70	0.95	1.18	1.34	1.49	1.67	2.27	2.76		4.44*
Coef. of Variation,	32	23	20	14	26	21	21	49	42		25
Maximum	1.22	1.22	1.50	1.63	1.98	2.05	2.25	5.13	6.20		7.28*
Minimum	0.36	0.52	0.62	0.80	1.08	0.93	1.05	1.13	1.18		2.78
B651											
Truckloads											
Average,	0.68	0.78	1.05	1.29	1.49	1.73	1.81	2.95	3.09		4.69
Coef. of Variation,	34	21	18	30	28	27	26	28	26		24
Maximum	1.83	1.17	1.43	2.23	2.50	2.82	2.92	4.53	4.78		7.53
Minimum	0.42	0.53	0.63	0.67	0.87	0.90	1.00	1.37	1.45		2.33
B652											
Truckloads											
Average,	0.67	0.85	1.08	1.38	1.57	2.20	2.34	3.88	4.02	5.10	5.91
Coef. of Variation,	39	21	16	26	24	18	16	30	28	17	25
Maximum	1.72	1.37	1.55	2.13	2.32	3.07	3.22	7.00	7.22	7.88	8.72
Minimum	0.42	0.58	0.80	0.70	0.82	1.17	1.37	1.87	1.93	3.01	3.25
Total											
Truckloads											
Average,	0.63	0.78	1.03	1.29	1.47	1.85	1.97	3.22	3.38		5.06
Coef. of Variation,	35	21	18	26	26	22	20	31	30		25
Maximum	1.83	1.37	1.55	2.23	2.50	3.07	3.22	7.00	7.22		8.72
Minimum	0.36	0.52	0.62	0.67	0.82	0.90	1.00	1.13	1.18		2.33

*Excludes one case in which polyethylene was not applied until the morning following placement. This was due to high humidity and "soft" surface.

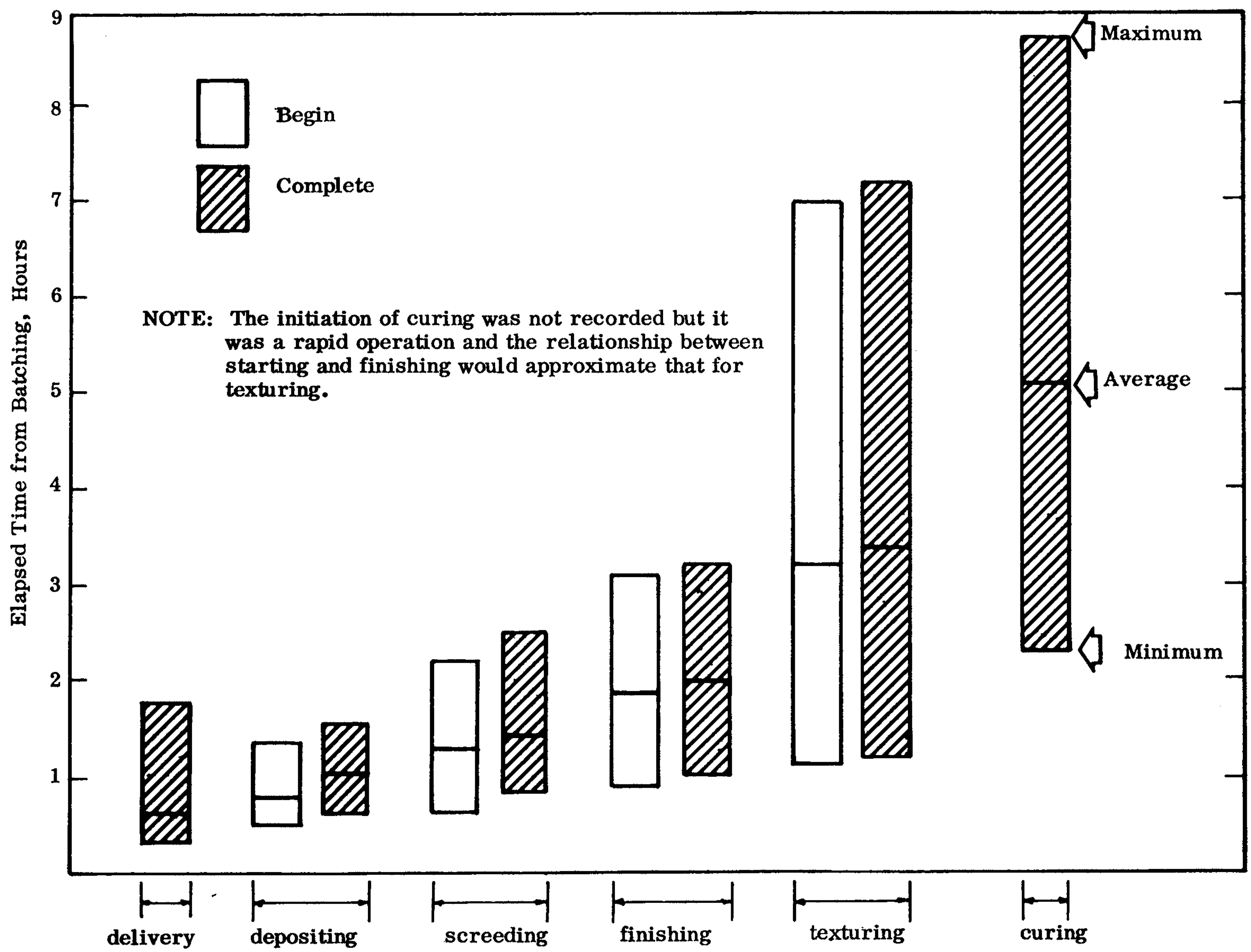

Figure 10. Elapsed time between batching of the concrete and the performance of the various construction operations.

Fresh Concrete Characteristics

The three bridges, comprising eleven slabs, required 114 truckloads of concrete. From these, 29 research samples were taken and data from acceptance sampling, previously described, were available from all truckloads. All loads presented during the job met the specified requirements for slump and air content. The overall control of the concrete, as reflected by the lack of rejections, was good. Because the inspectors used various test methods (i.e., slump vs. Kelly Ball and pressure vs. Chace) interchangeably, direct correlations among all data from the acceptance and research testing are not meaningful. Comparison of the data, however, shows the research test results to be representative of the concrete properties. The values for the important properties are given in Table V.

TABLE V

MEASURED AND CALCULATED PROPERTIES OF FRESH CONCRETE
BASED UPON 29 SAMPLES

	Slump, in.	Air Content, %	Yield, % of Theoretical	Water-Cement Ratio, gal/sk.	Cement Factor, sk/cyd	Difference* between Mixture Temperature and Air Temperature °F
Average	3.8	6.3	99.2	4.86	6.81	+10.6
Maximum	4.7	9.7	102.1	4.94	6.91	+24
Minimum	2.8	5.1	97.9	4.78	6.73	-4
Standard Deviation	0.23	0.91	0.85	0.05	0.06	+8.3

*Concrete Temperature greater than Air Temperature is considered positive.

The maximum air content of 9.7 percent was the only value measured during the project that fell outside of specified limits. The acceptance sample result for this load was 7.5 percent as measured with the Chace indicator. The difference very likely reflects a within batch variation. The next highest air content recorded for the randomly drawn samples was 7.2 percent, which reflects the fact that the 9.7 percent value was unusual.

The results presented in Table V suggest that properties of the concrete among the various slabs were sufficiently uniform so that their influence on the performance of the various curing and/or protective materials can be considered constant.

The most disturbing results were the concrete temperatures which, while below the specified maximum of 90°F, hovered very near this limit and were consistently higher than the air temperature. This situation compounds the detrimental influence of adverse atmospheric conditions causing excessive evaporation and attendant finishing difficulties. The contractor was aware of this situation and was able to moderate its influence by careful attention to his finishing operation. This is discussed later.

Determination of the stiffening rate by ASTM C 403 is essentially a laboratory procedure. The results are influenced not only by materials variability, but also by atmospheric conditions. The data for initial and final set (500 psi and 4,000 psi penetration resistance) are given in Table VI.

TABLE VI

STIFFENING RATES AS MEASURED BY ASTM C 403 ON 29 SAMPLES

	Initial Set, hrs. (500 psi)	Final Set, hrs. (4,000 psi)
Average	6.1	7.3
Standard Deviation	1.2	1.5
Maximum	9.2	11.2
Minimum	4.2	4.9

Because the setting time of concrete is influenced by several variables the comparatively large variations shown in Table VI are not surprising. Such large variations emphasize the difficulties accompanying any effort to control construction operations based upon "fixed time" criteria which do not take into account the interaction of materials and environmental factors. A large portion of the variation is attributable to the combined effects of initial mixture temperatures and the average curing temperatures prior to initial set, as is shown in Figure 11. In this plot high mixture and curing temperatures tend to be associated with earlier set. The variations in setting times were not directly correlatable with differences in finishing characteristics but previous studies and data presented later suggest that they were reflected in the times for applying the curing media.

The preceding test results are indicative of the general quality level of the concrete. The remaining test results and observations will be presented during the discussion of the various curing materials.

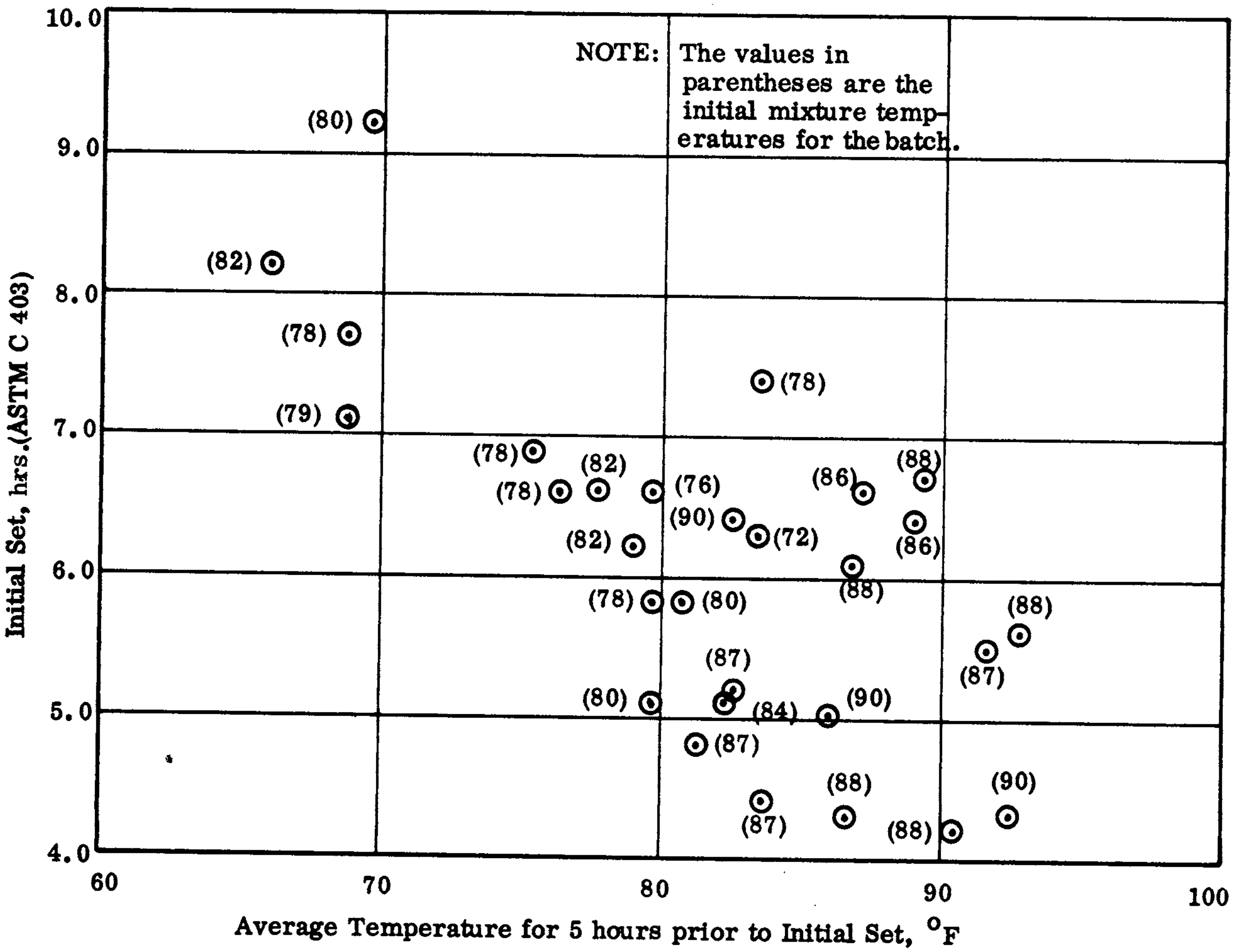

Figure 11. Initial set (500 psi resistance by ASTM C 403) vs. the average air temperature for 5 hours prior to initial set.

Atmospheric Conditions

During each placement, hourly measurements of air temperature, relative humidity, and wind velocity were made at locations representative of the concreting area. These data permitted calculation of evaporation rates by the procedures described by Lerch (1957) and subsequently published by the Portland Cement Association (1968). The air temperature and computed evaporation rates are plotted in Figure 12 for each of the eleven placement days. The air temperatures were lower during the placements on B 648 than on B 651 and B 652. The evaporation rates were below the value of 0.10 lb./ft.^{2}/hr. on all spans except Span 3 of B 648 and Span 1 of B 651. The effects of this excessive evaporation were strongly felt on B 648 and are discussed in detail later in this report.

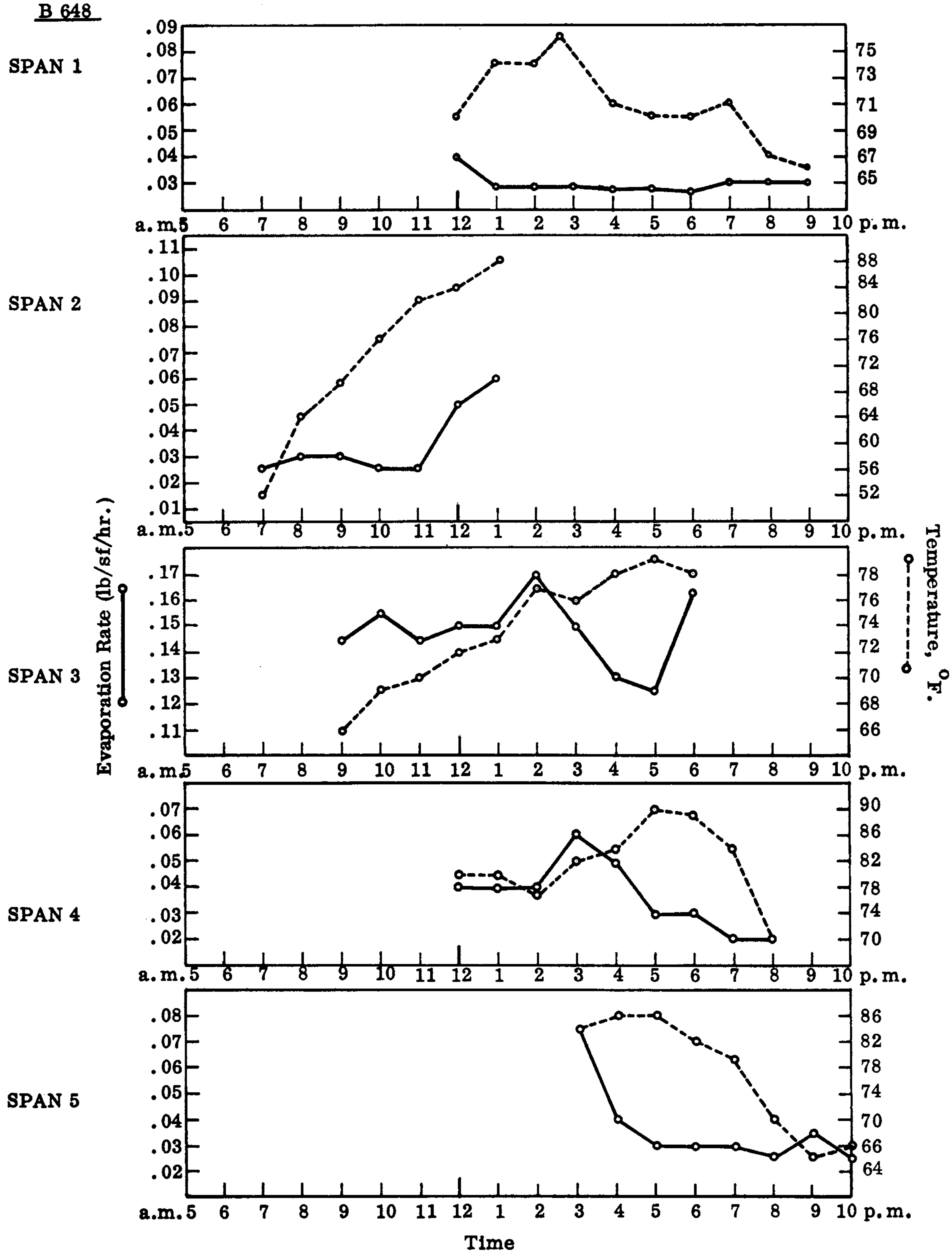

Figure 12. Air temperatures and computed evaporation rates for each placement day

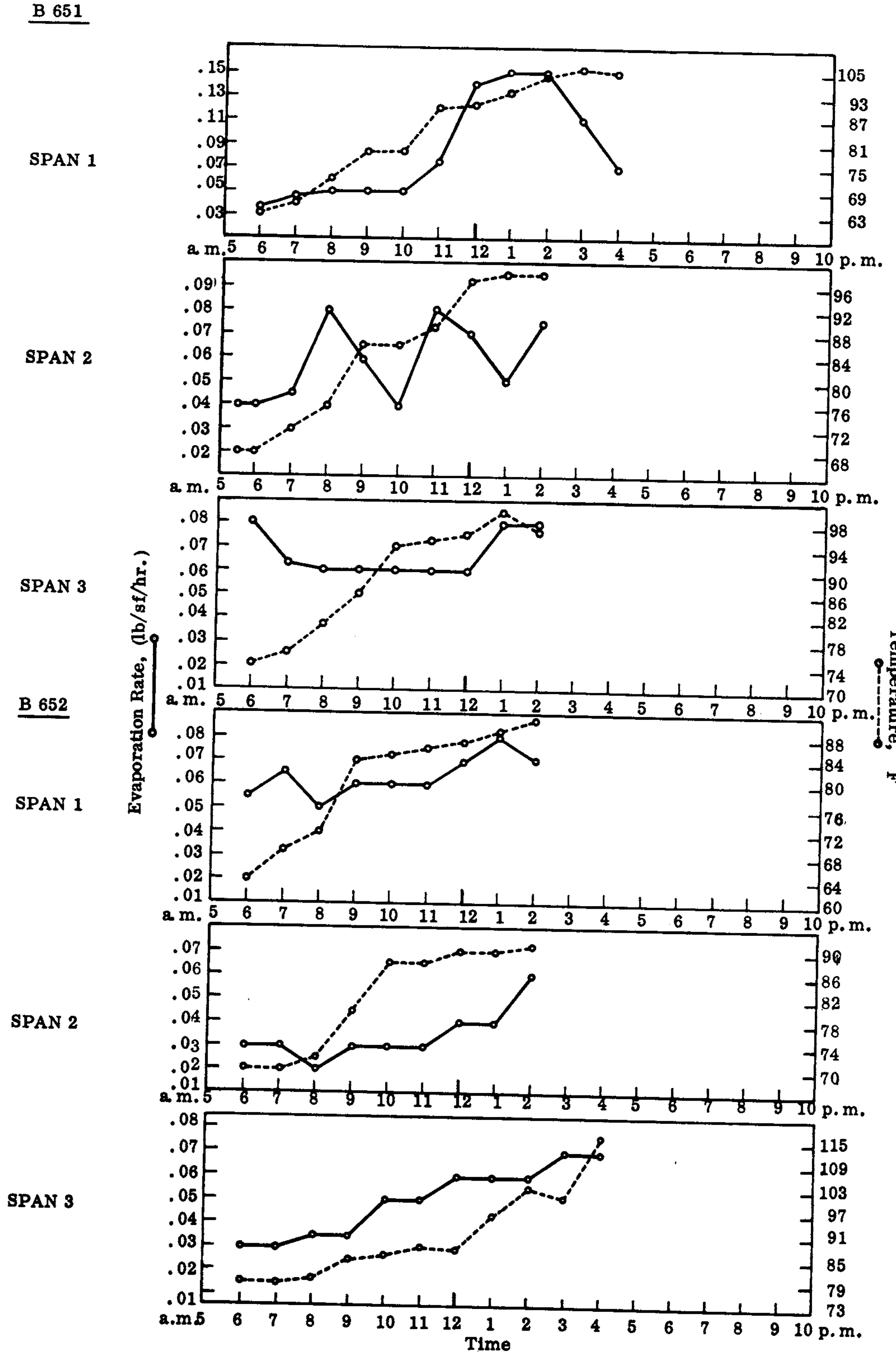

Figure 12. (Continued)

The PCA report (1968) states "There is no way to predict with certainty when plastic shrinkage cracking will occur. When the rate of evaporation is as high as 0.2 to 0.3 lb. per square foot per hour, precautionary measures are almost mandatory. Cracking is possible if the rate of evaporation exceeds 0.1 lb. per square foot per hour."

Performance of Various Curing and Protective Treatments

The distribution of the conditions identified in Table I and shown in Figure 1 is summarized in Table VII.

TABLE VII

DISTRIBUTION OF TEST CONDITIONS

Condition	Material	B 648	B 651, 652	Total
1	LMS	1	3	4
2	WPS	1	1	2
3	LMS + LOT	4	6	10
4	WPS + LOT	3	3	6
5	MEF + LMS + LOT	1	1	2
6	MEF + WPS + LOT	2	1	3
7	MEF + LMS	Not Used		
7A	MEF + WPS	0	1	1
8	CRS	1	0	1

Conditions 3 and 4, currently acceptable under Virginia Department of Highways Specifications, were used on ten and six locations, respectively. The LOT was omitted on four panels previously cured with LMS and for two on which the curing was with WPS. On five of the remaining panels, the MEF was used prior to curing. The remaining panel was cured with CRS. The decision to include only one of the originally planned CRS panels was based on the performance of the material, as will be subsequently discussed. The characteristics of the curing materials were given earlier in Table II.

The average differences between the times of application of the several curing materials and initial set are shown in Table VIII. The average delays between texturing and curing are also shown.

TABLE VIII

RELATIONSHIP AMONG TIMES FOR CURING, TEXTURING AND INITIAL SET

Curing Material	Difference between Times of Application of Curing and Initial Set (positive values indicate before initial set), hours			Difference between Texturing and Initial Set (positive values indicate before initial set), hours
	Average	Maximum	Minimum	Average
Polyethylene (WPS)	+0.50*	+3.4	-2.3*	+1.91
Membrane (LMS)	+1.28	+5.2	-0.5	+1.07
Chlorinated Rubber (CRS)	+3.4	—	—	+1.5

*Excludes one case in which polyethylene was not applied until the morning following placement. This was due to high humidity and "soft" surface.

The LMS was applied about forty minutes earlier than the WPS, reckoned on either initial set or completion of texturing. This differential is less than that observed in an earlier study which involved numerous contractors (Hilton, Newlon and Shelburne — 1965).

The LMS was applied until complete coverage as judged visually by the contractor's and Department's inspection personnel was obtained. The measured coverage rates for the 16 panels cured with LMS are shown in Table IX along with that for the single panel cured with CRS.

TABLE IX

MEASURED COVERAGE OF SPRAYED CURING MATERIALS

Material	Number of Panels	Coverage Rate (ft^2/gal)		
		Average	Maximum	Minimum
LMS	16	585	911	251
CRS	1	319	—	—

In spite of the fact that the coverage was judged adequate by visual standards, the coverage rates measured were significantly lower than those specified. The rates measured on the first two panels were 708 and 911 ft^2/gal. Since it was agreed by project personnel that the specified rate could not be obtained, a target rate of 400 ft^2/gal. was adopted for the remaining panels. The appearance of this level of curing is seen in Figure 8, which shows Span 3 of B 648 on which the coverage rate was 392 ft^2/gal. When it was ultimately decided, for reasons discussed later, to omit the CRS on the mainline structures, two panels on B 652 were cured with LMS applied to obvious excess. These two panels were designated as "heavy" in Figure 1. Despite this extra effort the measured rate on these two panels was 251 ft^2/gal.

The necessary coverage rate is a function of a number of factors. Among the more important are (1) characteristics of the curing compound, (2) texture of the surface and (3) orientation of the surface (i.e. vertical or horizontal). A coverage rate of 200 $ft.^2$/gal. is commonly specified and is the rate required in the ASTM moisture retention test. The Bureau of Reclamation (1966) specifies a maximum coverage rate of 150 ft^2/gal. for reasonably smooth surfaces and a smaller coverage rate for rougher surfaces. It further states that the coverage rate should be established "as necessary to obtain an even, white, continuous membrane".

It would appear that the texture imparted by the burlap used on these bridges would require about the same or slightly more compound than would the conventional laboratory specimens. On the other hand, moisture retention is roughly proportional to the solids content and the significantly higher solids content required to meet the restrictive Virginia Department of Highways' requirements described earlier would provide better coverage per unit volume than would a lower solids content. For example, if a material with a unit moisture loss of 0.050 gm/cm^2, which meets AASHO requirements, gives satisfactory coverage at a rate of 200 $ft.^2$/gal., then it would seem that for equivalent curing, one with a loss of .010 gm/cm^2, such as that used in this project, could be applied at a lower rate. Whether the proper rate would be reduced to one-fifth is a matter of conjecture but the proper rate would probably be of the order obtained in this study; i.e. 600 $ft.^2$/gal. The results of a recently published study (Carrier and Cady — 1970) suggest that application at one-half rate (i.e. 50 $ft.^2$/gal.) or double rate (i.e. 400 $ft.^2$/gal.) of a membrane with a loss of 0.026 gm/cm^2 maintains approximately the same relative humidity as when the membrane is applied at the normal rate. These findings do not condone poor curing practices but indicate that it is the first increment of curing that is critical.

To measure moisture loss, the weight losses of specimens 19.5 cm x 19.5 cm x 5 cm were determined. The specimens, shown in Figure 13, were treated at the same time as the area of the slab from which the sample was taken. Although the timing of application of the various materials closely matched that for the structures, the control of the application was judged visually and thus was more approximate. From each sample two specimens were tested. In 24 of the 28 cases, the weight losses of the duplicate specimens agreed within 10 percent. For each combination of curing materials the weight loss data are presented in Table X. The average values of the 4 samples for which the variation between duplicate specimens exceeded 10 percent were included in the analyses because the values were close to the values from the remaining samples and had no influence on the magnitude of the result. The data are presented graphically in Figure 14.

Figure 13. View of specimens used in measurement of moisture loss. Also shown are the instrument for measuring relative humidity and the penetrometer used in ASTM C 403.

TABLE X

MOISTURE LOSS IN $gms/cm.^2$ OF CONCRETE CURED WITH VARIOUS MATERIALS

Condition	Material	Occurrences	Screed to Cure		Cure to 24 hrs.		Cure to 48 hrs.	
			Average	Coefficient of Variation	Average	Coefficient of Variation	Average	Coefficient of Variation
1, 3	LMS	14	0.106	52	.031	79	.043	80
2, 4	WPS	7	0.188	18	.054	57	.072	35
5	MEF + LMS	2	0.073	44	.045	100	.049	86
6, 7A	MEF + WPS	4	0.90	11	.038	80	.134	53
8	CRS	1	0.20	—	.028	—	.041	—

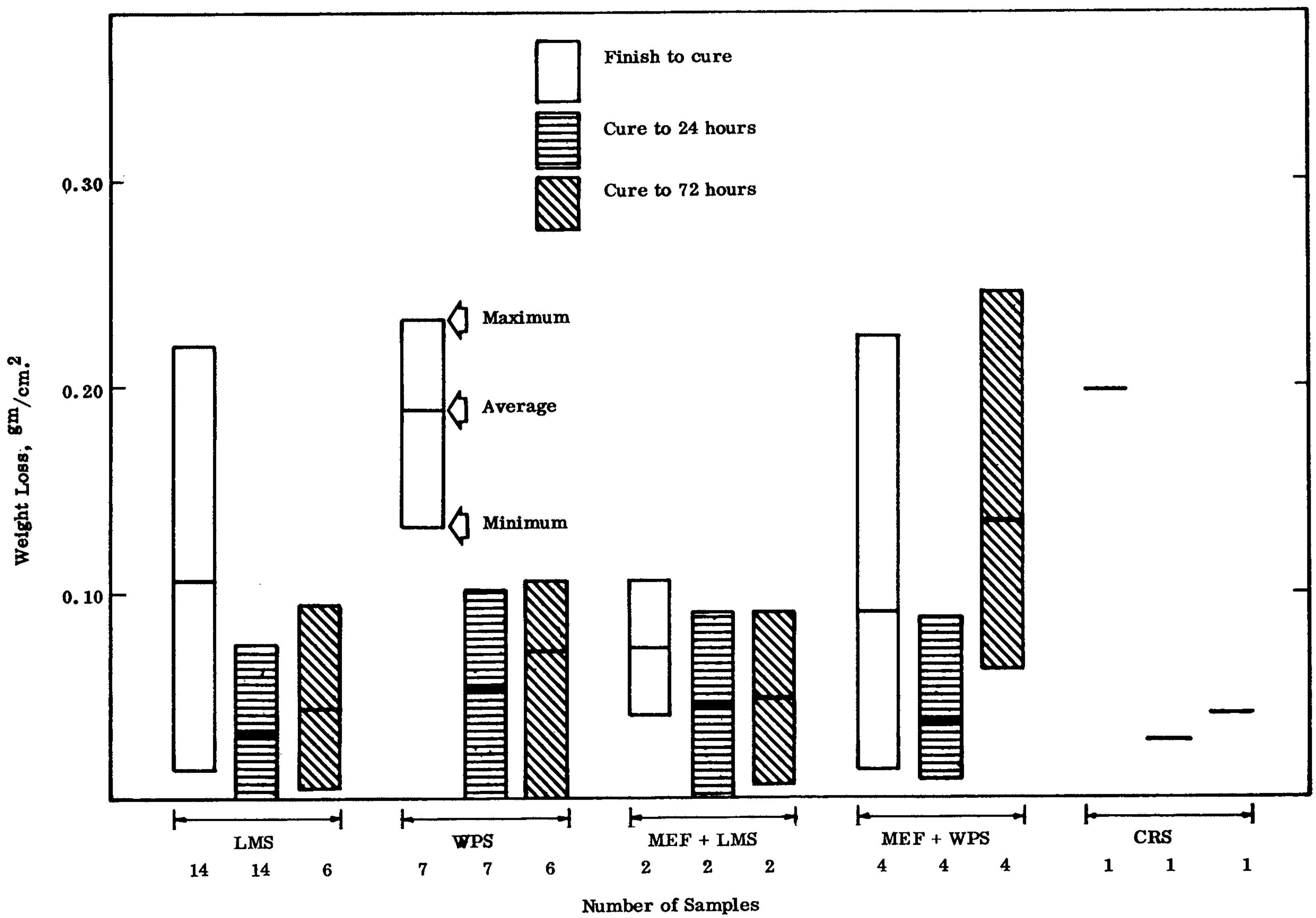

Figure 14. Moisture losses of concretes variously cured.

Because of the variability of the process, the test method, and the comparatively limited number of samples, the results should only be considered as suggestive. The measured losses after application of curing are of the proper order of magnitude. It is apparent that the average losses during the period preceding application of curing were significantly larger than those which occurred after the curing materials were applied. The differences in losses between concretes cured with LMS and WPS are not significant. The differences in weight loss between the concretes are believed to reflect the longer time of exposure to evaporation resulting from the delay in application of WPS as compared with LMS.

Behavior of Chlorinated Rubber

Even though the performance of the chlorinated rubber curing compound included in the preliminary evaluations reported in Part I had not been good, three panels, one on each structure, were proposed for this project. The decision to include these materials was based upon published reports of satisfactory performance in other areas. (Holland — 1967, Ryell and Chojnacki — 1969). Because of uncertainties regarding its effect on skid resistance it was decided to place the material on B 648 and let its inclusion on B 651 and B 652 be contingent upon the results of skid testing and other observations on B 648. For reasons discussed below, the CRS was placed only on B 648.

The CRS used was that designated as #8 in Part I of this report. Its performance while poor, was among the better of three of the six materials evaluated. The significant characteristics of the materials from laboratory testing are given in Table XI and compared with the data for the field sample given earlier in Table II.

TABLE XI

CHARACTERISTICS OF CRS

Sample	Moisture Loss, AASHO T 155 (Va. Modification) Average of 3 specimens, gm/in^2 gm/cm^2		Solids Content, %
	24 hours	72 hours	
Laboratory Evaluation (Part I)	0.078 (.012)	0.115 (.017)	31.2
Field Sample	0.080 (.012)	0.121 (.019)	—

Chlorinated rubber curing compounds are generally formulated to meet the requirements of the federal specifications, which limit the moisture loss to 0.039 gm/cm^2. The federal requirement can usually be met at a solids content of 20 - 25 percent. To meet the more restrictive Virginia Department of Highways' requirements, a higher solids content, approximately 30 - 32 percent, was necessary.

The application of CRS was made in the center panel (No. 2) of Span 3 on B 648. Panel 1 received LMS and Panel 3 WPS, with subsequent treatments of linseed oil as previously described.

Reference to Figure 12 will show that the atmospheric conditions during the placement of Span 3 were the most severe encountered during the project. The computed evaporation rate ranged between 0.15 and 0.17 during the time of placement. This was primarily the result of winds blowing from west to east at speeds ranging between 5 - 10 mph combined with a relative humidity of about 30 percent. The maximum air temperature during placement was 71°F. The maximum for the day was 80°F. The temperature of the concrete as delivered was about 10° F higher than that of the air temperature, which aggravated the evaporation potential. The severe conditions were recognized by the contractor, who made a special effort to speed up the various operations.

Although the severe atmospheric conditions undoubtedly influenced the performance of the CRS the same circumstances existed for the other curing materials and thus the slab offered an excellent comparison under adverse conditions when curing is most critical.

The CRS was applied by the manufacturer using two separate passes of a hand sprayer as was shown in Figure 7. It was noted that the material dried quickly and formed a tenacious glossy membrane within 15 minutes after application.

On the day after placement, the development of "blisters" was noted throughout the panel cured with CRS. These blisters ranged in diameter from 1/8 inch to 1$\frac{1}{2}$ inches. They were most prevalent in the center of the panel. There were some in the first third of the panel, i.e. the first concrete placed, but none in the last third. Fine cracking and crazing were evident throughout the panel cured with CRS. These conditions are shown in Figures 15 and 16. As a reference for future condition surveys the areas showing cracking and/or blisters are shown in Appendix B. The cracking was also noted but in a greatly reduced amount in the panel cured with LMS. There was no blistering in the LMS panel.

Close examination of the blisters disclosed that most of the larger ones were associated with a "pinhole" as seen in Figure 16. Adhering to the underside of the blister was a thin film of mortar. The blistered area generally appeared "whitish" as compared with the unaffected area that has the normal "yellow-green" appearance. It is believed that the whitish cast signified a microscopic separation between the CRS film and the underlying concrete.

Figure 15. View of panel cured with chlorinated rubber showing surface cracking, blisters and whitish areas.

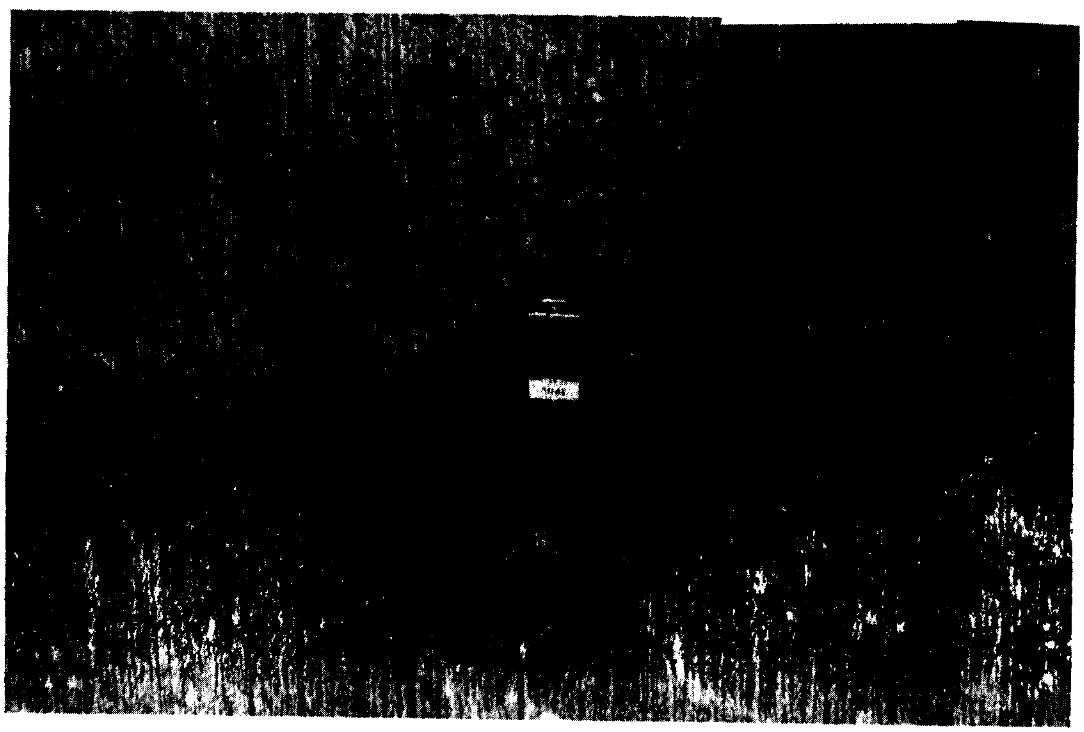

Figure 16. Close-up of two blisters showing "pinhole" in center. Long dimension of book is $4\frac{3}{4}$ inches.

Such blistering has not been previously reported. Limited attempts to reproduce the phenomenon in the laboratory were unsuccessful. Although no conclusive explanation can be given for the phenomenon the most likely cause is that the blisters were formed by pressure from bleed water after the formation of the tenacious film. The severe drying conditions resulting in a rapid drying of the surface and dictated the need for application of the curing materials.

The water reducing admixture would, of course, delay the set of the underlying concrete with concomitant continuation of bleeding. Thus cracking would be evident in the surface, but sealing of the surface would restrict escape of bleeding water to a degree dependent upon the integrity of the film. The absence of blisters in the panel cured with LMS would be consistent with a slower development of the film and the ability to pass pressure from water vapor.

The time intervals between curing and initial set were previously shown in Table VIII. The intervals for Span 3 were: LMS = + 3.9 hrs., CRS = + 3.4 hrs., and WPS = + 3.4 hrs. Comparison with Table VIII shows that this was the most rapid application of WPS during the whole project; an action dictated by the severe conditions and likely responsible for the absence of surface cracking in the WPS panel. It is also of interest to note that each of the curing materials was applied at about the same stage of hydration. It is very likely that use of the monomolecular film, as described later, would have been beneficial to the performance of all of the curing media on this span.

Although the mechanism which led to the difficulties observed cannot be precisely identified, it is evident that even at the relatively light coverage rate (319 $ft.^2$/gal. as compared with the recommended 200 $ft.^2$/gal.) a relatively thick tenacious film of material remained on the surface. This is discussed later in connection with the results from the measurements of skid resistance.

Monomolecular Film MEF

In Part I of this report the use of the monomolecular film during the interval between finishing and curing was shown to have some beneficial effect on the scale resistance of the concrete specimens. This was attributed to the fact that the specimens were fabricated under circumstances intended to simulate a drying condition such as that encountered during placement of Span 3 on B 648.

As shown in Figure 1, the monomolecular film was used on six preselected panels; four prior to curing with WPS and two before LMS. Reference to Figure 12 will show that in only one of the six panels (Panel 3 of Span 1 on B 651) were severe drying conditions encountered. In this case a direct comparison of moisture loss is not valid because, as is shown in Table XII, the evaporation rate was much higher for Panel 3 and there was considerable delay in the application of the WPS. In fact, reference to Table XII shows that the application on Panel 3 was the latest application of the WPS for the entire project.

The benefit of the MEF is still suggested by the fact that the moisture losses on Panel 1 and Panel 2 would have been larger for equal evaporation rates and application times. Reference to Figure 14 shows that the average moisture loss for the panels which received MEF is lower than for panels cured by the same materials but without MEF. The improvement for WPS is greater than for LMS, which reflects the longer delay in application of WPS.

In addition to these quantitative indications from measurements of moisture loss, several qualitative observations are significant. During the project the finishers noted the improvement to "finishibility" and texturing resulting from the reduced rapid drying of the surface and the retention of a "live" surface. Several times they requested permission to apply it to panels for which it was not scheduled and, based on the experiences with the deck slabs, they requested and were granted permission to use it on certain slope protection placements.

TABLE XII

EVAPORATION RATES AND MOISTURE LOSSES ON SPAN 1 OF B 651

Panel	Material	Interval between Application of Cure and Initial Set*	Average Evaporation Rate 5 hr. Prior to Initial Set	Moisture Loss, gm/cm^2
1	WPS	+0.8	.07	0.217
2	WPS	+0.5	.07	0.154
3	MEF + WPS	-2.3	.13	0.224

*Positive values indicate curing before initial set.

During the placement of Span 5 on B 648, there was a delay of about one hour between arrival of the second and third trucks. Concern was expressed as to the possible formation of a cold joint. After about one-half hour, the surface of the leading edge of the concrete in place was sprayed with MEF and when the next truck arrived the surface was "live". The contractor's personnel expressed the view that such would not normally have been the case.

While the MEF displayed the obvious advantages described above, several cautions were also suggested. Because the MEF is nine-tenths water, care must be exercised to control the amount applied, since the recommended amount (200 - 500 $ft.^2$/gal.) seems very small. The use of MEF must not be taken as a license to spray water.

On several of the days when MEF was used the evaporation potentials were low. These conditions, coupled with the use of a water reducing and retarding admixture that promoted bleeding, delayed the texturing operation. It was observed that the sheen from bleeding for slabs sprayed with the MEF was generally uniform whereas the appearance of bleeding on non-sprayed slabs was "spotty". Thus the general use of MEF would not be justified but it is an excellent product for severe or emergency conditions. Based upon this and other experiences, the Virginia Department of Highways issued on April 14, 1970 a memorandum to its District Engineers permitting the use of MEF. A copy of the memorandum is included as Appendix C.

Linseed Oil Treatments

The surfaces of all spans of B 648 were treated with linseed oil on August 25, 1969, when the ages of the slabs ranged between 2 and 3 months. Application was made to B 651 and B 652 on September 10, 1969, when the ages of the slabs ranged between $2\frac{1}{2}$ and $3\frac{1}{2}$ months. The treatment was applied to the sections designated LOT in Figure 1, using the equipment that was shown in Figure 9. The application was made in two coats approximately one hour apart. The intended total rate of coverage was 0.040 gal/sq. yd. The first coat was completely dry before application of the second coat. Drying conditions were excellent as noted in Table XIII. Adjacent panels were treated at the same time even though they were on different spans. The coverage rates and atmospheric conditions are summarized in Table XIII. These coverage rates are all within 10 percent of the target value. Although not considered a part of this experiment, the parapet walls adjacent to the panels were also treated. The curing on all of the parapets had been accomplished with WPS.

TABLE XIII

COVERAGE RATES IN gallons/$_{yd.}$^{2} FOR LINSEED OIL TREATMENTS

Location	1st Coat	2nd Coat	Total	Atmospheric Conditions
B 648 Span 1, Panels 1 & 2 and Span 2, Panel 3	.024	.020	.044	Air Temp. 75° - 80° F R.H. 45% wind — calm
Span 2, Panel 1 & Span 3, Panel 3	.021	.016	.037	
Span 3, Panel 1 & Span 4, Panel 1	.021	.019	.040	
Span 4, Panel 3 & Span 4, 5, Panels 1 & 2	.020	.017	.037	
B 651 Span 1, Panels 2 & 3	.024	.015	.039	Air Temp. 72° - 80° F R.H. 40% wind — 5-10 mph
Span 2, Panels 1 & 2	.024	.014	.038	
Span 3, Panels 2 and 3	.024	.015	.039	
B 652 Span 1, Panels 2 & 3	.024	.015	.039	
Span 2, Panel 2	.024	.016	.040	
Span 3, Panel 1	.024	.014	.038	
Span 3, Panel 3	.024	.014	.038	

The appearance of B 648 immediately after treatment is shown in Figure 17. The more uniform appearance of the panel cured with LMS as compared with that cured with WPS is apparent. This condition had been noted also in the laboratory evaluation (Newlon — 1970).

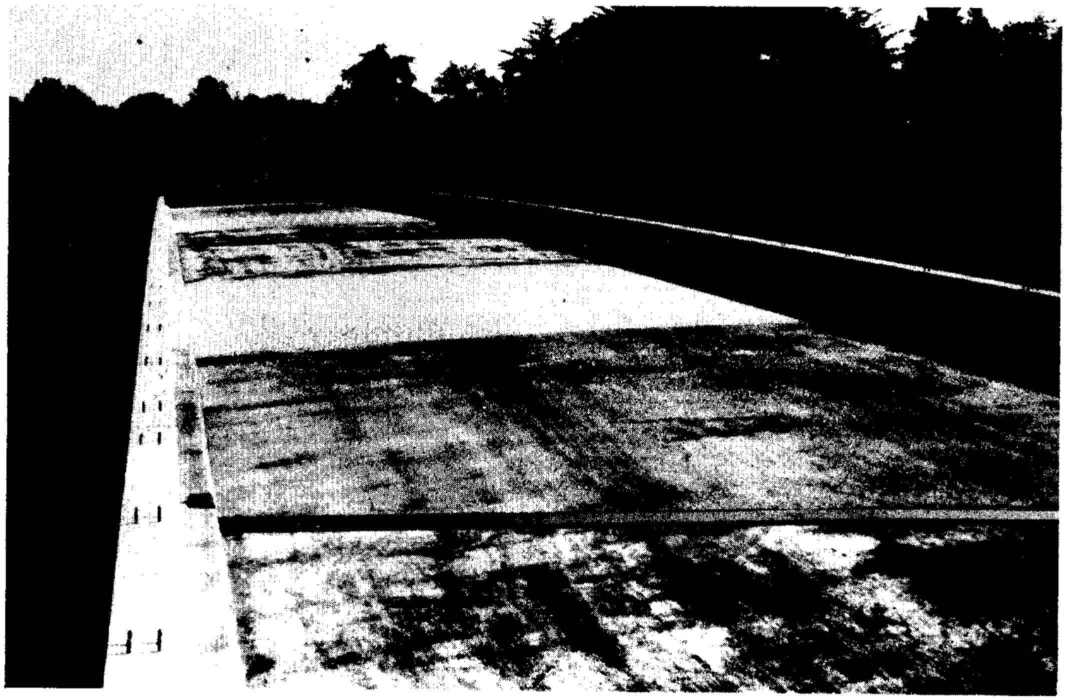

Figure 17. View of B 648 after application of the LOT. In immediate foreground is Panel 1 of Span 1. The first full span is Span 2 and the panel just beyond the joint is Panel 3. (Refer to Figure 1.)

PROPERTIES OF THE HARDENED CONCRETE

From each sample three 6" x 12" cylinders were made for compressive strength tests in accordance with ASTM C 31 and three 3" x 4" x 16" beams were made for determination of resistance to freezing and thawing in accordance with ASTM C 290. All of these specimens were cured and/or treated at the same time as the panel that they represented. They were stored in the field near the structure. Although the shortcomings of field curing were recognized, it was hoped that the strength results would provide some guidance as to the relative merits of the several materials. The strength results are given in Table XIV. The cylinders cured under standard conditions were those taken by the job inspection personnel. One set of two cylinders was taken to represent each span.

TABLE XIV

STRENGTH RESULTS

Condition	Number of Tests*	Compressive Strength, psi	
		Average	Standard Deviation
Std. Moist Cure — 14 days	11	4412	391
Field Cure (sprayed) — 7 days	16**	3640	416
— 28 days	16	4660	553
Field Cure (covered) — 7 days	13**	3550	526
— 28 days	13	4640	428

*One test is average of two cylinders.

One test is a single cylinder

As noted earlier, the high concrete temperatures on B 651 and B 652 which accompanied the high air temperatures did influence placement and these are reflected in slightly lower strengths for the high temperature placements. The average strengths after 14 days of moist curing for cylinders from B 648, B 651 and B 652 were 4633, 4005, and 4449 psi, respectively.

The strength differences shown in Table XIV are not significant. As would be expected, the variability as measured by the standard deviation is larger for the field cured cylinders than for standard moist curing.

From each sample, three 3" x 4" x 16" beams were cast for exposure to laboratory freezing and thawing tests in accordance with ASTM Designation C 290 except that the solution surrounding the specimens was a 2% NaCl solution instead of water. The specimens were stored near the structure and cured and treated like the panel which they represented. The exposure was scheduled to begin approximately at the onset of freezing weather. At the time of exposure, the age of the concretes varied between five and six months and the LOT had been in place for 90 or 75 days, depending upon which bridges the specimens represented.

Because of loss of specimens by vandalism and breakage from construction operations during the long field storage only about one-half of the specimens were available for testing. Because of the long delay between construction and the scheduled beginning of testing and because the number of spaces in the freezer coincided with the number of test panels, it was decided to test one randomly selected beam for each condition. Using this procedure, each combination was represented by from 1 to 9 specimens.

The beams were exposed to rapid freezing and thawing in a 2% solution of NaCl using procedures described in detail in Part I of this report (Newlon — 1970). The weight loss and relative durability factor were computed as described in ASTM C 290. The degree of scaling of the top surface was estimated using a weighted average reflecting the area affected and the severity of scaling. This procedure was also described in detail in Part I. The results of these tests are given in Table XV.

TABLE XV

AVERAGES ($\bar{X}$) AND COEFFICIENTS OF VARIATION (V) FOR DATA FROM ACCELERATED FREEZING AND THAWING TESTS OF SAMPLES OBTAINED FROM THE FIELD PROJECT

Material	Avg. and Coeff. of Variation	Number of Samples	Weight Change, % 119 cycles	Weight Change, % 362 cycles	Scale Rating 119 cycles	Scale Rating 362 cycles	Relative Durability Factor 362 cycles
WPS	$\bar{X}$	3	-0.58	-4.27	0.97	1.06	92.4
	V		56	25	88	81	2.7
WPS + LOT	$\bar{X}$	6	+0.96	-0.20	0.10	0.73	96.9
	V		33	650	0	83	11.9
MEF + WPS + LOT	$\bar{X}$	4	+0.91	-0.50	0.10	0.93	108.1
	V		21	175	0	69	11.3
LMS	$\bar{X}$	4	-0.60	-3.88	1.2	1.6	105.9
	V		139	35	67	0.1	15.3
LMS + LOT	$\bar{X}$	9	+0.92	-0.67	0.25	1.0	99.2
	V		52	192	187	51	18.4
MEF + LMS + LOT	$\bar{X}$	2	+0.52	-0.61	0.07	0.95	89.8
	V		106	8	50	112	7.9
CRS	$\bar{X}$	1	0	-2.98	0.20	1.50	92.9
	V		—	—	—	—	—

The weight loss is based upon the weight of the specimen at the time of exposure in the laboratory test. Although the degree of saturation of the specimens is unknown the length of field exposure should have been sufficient for equilibrium to have been achieved except as influenced by the surface treatment. Weight losses are shown for 119 and 362 cycles (the termination of testing) because these ages offer comparisons with the laboratory results presented in Part I of this report. Considering the fact that the single specimens were used to represent different batches of field cured concrete the agreement of the results as measured by the coefficients of variation is very good and is of the same order as that reported for the laboratory studies in Part I.

The specimens with LOT showed significantly lower weight losses at 119 and 362 cycles than comparably cured concretes which did not receive this treatment. The remaining combinations are represented by comparatively few specimens. The single CRS treated specimen showed a loss approaching that of the specimens without LOT.

The scaling ratings provide the same general indications as do the weight losses. The uniformly high relative durability factors reflect the high air contents, which offer protection from internal cracking caused by freezing. The results agree well with those for comparable specimens and combinations evaluated in the laboratory phase reported in Part I.

DECK PERFORMANCE

Skid Resistance

Results presented in Part I of this report reflected a possible reduction in skid resistance for surfaces with moderate textures treated with CRS. Because these results were obtained on comparatively small laboratory specimens with the British Portable Tester, they were subject to considerable uncertainty.

On July 17, 1969, when the age of the spans ranged between 37 and 56 days, skid tests were conducted on B 648 using the Council skid testing trailer, which conforms to the requirements of ASTM Designation E274-65 T. Five tests were performed on each panel in the northbound and southbound lanes. The results of these tests are given in Table XVI along with similar data obtained in September 1970 after approximately one year of traffic. The data were obtained at a trailer speed of 30 mph and converted to predicted stopping distances for a car stopping from 40 mph on the basis of unpublished correlations developed at the Research Council. Data obtained from B 651 and B 652 prior to opening to traffic were obtained in September 1970 and are shown in Table XVII. At that time the decks had been exposed to construction traffic only for approximately one year. The initial tests on B 648 were conducted prior to the application of the LOT. The initial tests on B 651 and B 652 were conducted approximately one year after the linseed oil application. The influence of the LOT on skid resistance has been studied by Runkle (1969).

It can be seen from Tables XVI and XVII that with the exception of the initial tests of the CRS, all of the skid numbers were above the value of 40 considered necessary by the Virginia Department of Highways. The number for the panel treated with CRS was about 25% below those of the adjacent panels. There is some difference among spans on B 648 (higher values on Spans 4 and 5), which suggests differences in texturing. Factors affecting these differences were not reflected in the data collected.

Based upon the reduction in skid resistance on B 648 attributable to the CRS, it was decided to omit it from the mainline bridges (B 651 and B 652).

To explore this further, a section of concrete pavement in a rest area on the southbound lane of Rt. I-85 north of McKenney was selected for curing with the same chlorinated rubber sealer as used on B 648. The area (3,000 ft.^{2}) was placed and cured on June 11, 1969. The section was in the truck lane between Stations 22 + 38.50 and 23 + 88.50. No "blistering" of the surface was observed. The weather conditions were not severe as was the case during placement of Span 3 on B 648. The air temperature range was 64° F to 84°F with partly cloudy skies. The concrete did not

TABLE XVI

SKID RESISTANCE FOR B 648

Section	Material	Predicted Skid Numbers for Car Stopping from 40 mph			
		Prior to Traffic		After 1 Year of Traffic	
		NBL	SBL	NBL	SBL
Span 1, Panel 1	MEF + WPS + (LOT)*	50	50	40	46
Span 1, Panel 2	MEF + WPS + (LOT)*	51	50	46	48
Span 2, Panel 3	LMS + (LOT)*	50	50	48	47
Span 2, Panel 2	WPS	48	50	47	47
Span 2, Panel 1	WPS + (LOT)*	48	50	46	48
Span 3, Panel 1	LMS + (LOT)*	48	46	46	44
Span 3, Panel 2	CRS	38	38	44	42
Span 2, Panel 3	WPS + (LOT)*	54	50	43	44
Span 4, Panel 1	LMS + (LOT)*	56	57	47	42
Span 4, Panel 2	LMS	57	54	45	44
Span 4, Panel 3	WPS + (LOT)*	56	54	44	44
Span 5, Panel 1	MEF + LMS + (LOT)*	54	54	46	41
Span 5, Panel 2	LMS + (LOT)*	52	54	45	42

	Number of Tests	Skid Number Prior to Traffic	Number of Tests	After 1 Year
Avg. WPS	8	51	2	47
Avg. LMS	10	52	2	44
Avg. CRS	2	38	2	43
Avg. MEF + LMS	2	54	0	—
Avg. MEF + WPS	4	50	0	—
Avg. WPS + LOT	-	—	6	45
Avg. LMS + LOT	—	—	8	45
Avg. MEF + LMS + LOT	—	—	2	44
Avg. MEF + WPS + LOT	—	—	4	45

*LOT not in place for testing prior to traffic.

TABLE XVII

SKID RESISTANCE FOR B 651 AND B 652

Section	Material	Predicted Skid Numbers for Car Stopping from 40 mph Prior to Traffic Age = 1 Year	
		Traffic Lane	Passing Lane
B 651			
Span 1, Panel 3	MEF + WPS + LOT	42	45
Span 1, Panel 2	WPS + LOT	41	44
Span 1, Panel 1	WPS	42	46
Span 2, Panel 2	LMS + LOT	42	46
Span 2, Panel 1	WPS + LOT	44	48
Span 3, Panel 1	LMS	42	47
Span 3, Panel 2	LMS + LOT	41	48
Span 3, Panel 3	MEF + LMS + LOT	40	46
B 652			
Span 1, Panel 3	LMS + LOT	44	42
Span 1, Panel 2	WPS + LOT	44	42
Span 1, Panel 1	MEF + WPS	46	43
Span 2, Panel 2	LMS + LOT	44	43
Span 2, Panel 1	LMS	44	44
Span 3, Panel 1	LMS + LOT	44	44
Span 3, Panel 2	LMS (heavy)	44	42
Span 3, Panel 3	LMS (heavy) + LOT	44	44

	Number of Tests	Skid Number
Avg. WPS	2	44
Avg. LMS	6	47
Avg. WPS + LOT	6	44
Avg. LMS + LOT	12	48
Avg. MEF + WPS + LOT	2	44
Avg. MEF + LMS + LOT	2	43
Avg. MEF + WPS	2	44

contain a water reducing retarder and so the conditions postulated as responsible for the "blistering" did not exist. On July 18, 1969, when the concrete was 37 days old, skid tests were run on the section cured with CRS and the adjacent section cured with LMS. The predicted skid number for both sections was 49. Thus the use of CRS in this case had no influence on the skid resistance. Inspection of the surface disclosed the absence of the very tenacious film formed on B 648. Again, it is believed that the lower potential for bleeding of the pavement concrete contributed to the formation by the CRS of a film having different characteristics from that formed on B 648.

After one year all of the panels on all of the three bridges exhibit essentially the same skid resistance. The higher skid number for the panel cured with CRS reflects the removal under traffic of the CRS film as described later in the presentation of results from condition surveys. The skid numbers measured in 1970 are all lower than reflecting abrasion from traffic. While B 651 and B 652 had not been opened to traffic, they had been subjected to heavy truck traffic during paving of adjacent roadways.

In several cases predicted skid numbers near 40 were recorded. Visual observations and comparisons with other surfaces suggest that the surface should indicate higher values, but confirmation will depend upon stopping distance tests made with a car. These will be reported in the future along with results from condition surveys.

Condition Surveys

Condition surveys were made on all structures in September 1969 and again in September 1970. In the initial surveys, at which time the decks had been exposed to essentially no traffic, the only significant performance characteristic was the very fine surface cracking in the center panel of Span 3 on B 648, which was described earlier and which is shown in Appendix C. After moderate traffic, the cracking was beginning to be obscured by traffic, dust, etc. and was visible only upon close inspectio

At the time of the 1970 survey, B 648 had been open to traffic for about one year B 651 and B 652 were scheduled to be opened to traffic in three weeks and had been subjected to construction traffic for about one year. On B 648 there was some very light scaling in the gutter areas of Panels 2 and 3 of Span 2. These areas appeared to be the result of removal of laitance in the areas hand finished after removal of screed rails. In Span 3 of B 648, light scaling is evident over most of Panel 2 which was cured with CRS. This scaling appears to be the result of removal of the CRS and the upper surface of the concrete. Scaling is spotty, but covers about fifty percent of the surface. The southernmost one-third of the panel is less affected than the remaining portion. No defects were observed on the portions of Span 3 cured with WPS and LMS.

The only defects noted on B 651 and B 652 were transverse cracks over each pier in the negative moment areas. There are five to seven cracks at each pier and their widths vary from very fine to moderate. These cracks apparently formed under construction traffic during paving of the adjacent roadway segments.

OBSERVATIONS AND CONCLUSIONS

Because the goal of this project was to evaluate the influence on durability of the several curing and protective materials, this report is basically an installation report against which subsequent performance can be judged. Some of the results accumulated during construction suggest observations and conclusions which are listed below:

1. The operations of the contractor were efficient as reflected in the lack of rejections of concrete, the low coefficients of variation, and the timing of his various operations. The uniformity achieved will greatly reduce the influence of the concrete on the behavior of the performance of the curing and protective treatments.

2. The uniformly satisfactory air contents indicate a good probability of good performance of the deck surfaces.

3. The results of laboratory freezing and thawing tests of concrete specimens made during construction and cured, treated and stored in the field, agreed well with and confirmed the results of similar tests reported in Part I of this report. Specimens treated with linseed oil showed reduced scaling and weight loss as compared to those without the treatment and those cured with chlorinated rubber.

4. Coverage rates of sprayed curing materials were lower than those specified. It is probable that materials meeting the more restrictive requirements of the Virginia Department of Highways need not be applied at the rates of 150 - 200 $ft.^2/gal.$ commonly specified for materials meeting AASHO requirements.

5. Polyethylene coverings were applied later than the sprayed curing materials. The average difference was about 45 minutes.

6. Linseed oil coverage rates were very close to the target value of 0.040 $gal/yd.^2$ At this coverage rate, the presence of the linseed oil is barely discernible after a month or two.

7. The performance of the chlorinated rubber was unsatisfactory. It developed a very tenacious film which blistered and reduced skid resistance by about 25 percent. It is believed that the bleeding characteristics of the concrete, which contained a water reducing-set retarding admixture, and the severe atmospheric conditions significantly contributed to this behavior; however, these are always present in bridge decks built under Virginia Department of Highways Specifications during the summer when curing requirements are most critical. The conditions did not develop in supplementary tests on a rest area using paving concrete.

646 8. Desirable benefits of the monomolecular film in extending time available for finishing and for use in emergency situations was qualitatively confirmed. The reduced moisture loss prior to application of curing was also verified although the observed test panels were comparatively few.

9. Difficulties with finishing were associated with days when the computed evaporation rates exceeded 0.10 lb./$ft.^2$/hr.

10. High mixture temperatures combined with high air temperatures were reflected in a measurable reduction of compressive strengths and acceleration of setting.

RECOMMENDATIONS

1. The currently specified curing procedures for concrete bridge decks followed by linseed oil treatments continue to be the most satisfactory of the several alternatives practically available for improved durability.

2. Application of the linseed oil treatments following curing with a white pigmented resin based compound of the type specified by the Virginia Department of Highways was once again shown to be satisfactory.

3. Procedures for utilization of the monomolecular film should be initiated so that it can be available in situations where it is needed. These include (1) days with high evaporation potential, (2) delayed application of curing, and (3) equipment breakdowns. Specification of its use for all decks is not desirable.

4. Unless penetration can be demonstrated, no further consideration should be given to materials designed to cure and protect in a single application since the two functions are mutually exclusive (i.e., one requires keeping water in while the other requires keeping it out) and they should be thought of as two separate operations.

ACKNOWLEDGEMENTS

A field study requires the cooperation of numerous elements of the Department and the construction industry. Appreciation is expressed to the Department's Construction Division for assistance in planning and preparing special provisions for the project and to the Materials Division for special tests and evaluations. The cooperation of the personnel of the Louisa Residency in coordinating the work with the contractor was invaluable, particularly that of B. D. Conklin, Project Inspector.

Special appreciation is expressed to Thomas M. Nunnally, the contractor, who went beyond the requirements of the special provisions to cooperate with the research personnel. Several manufacturers made curing materials available for testing and the project.

The testing was supervised by C. E. Giannini, Materials Technician, and the observation of the construction activities and the major portion of the data reduction were made by R. A. Parrish and H. E. Harrison, Highway Engineer Trainees, who were assigned to the Council for the summer during which the field work was completed.

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APPENDICES

0064-002-102,B647,B648,B650,
B651,B652
I-64-2(55)93

APPENDIX A

SPECIAL PROVISIONS FOR THE ESTABLISHMENT OF TEST SECTIONS TO BE USED IN THE EVALUATION OF SEVERAL TYPES OF CURING AND PROTECTIVE MATERIALS

6-1-68

Description - This work shall consist of the application of several types of curing and protective materials on concrete surfaces of the superstructures for bridge structures B648, B651 and B652 in accordance with these specifications. The various surfaces included in the test sections are as follows: Top of deck slabs, top and face of wheel guards, sidewalks and safety walks and top and inside face of parapet walls.

Curing and protection materials shall be applied to the bridge superstructures within the boundaries of the test sections shown on the attached drawing, unless otherwise directed by the Engineer.

Materials, Rates of Application and Materials to be Furnished by the Department and those to be Furnished by the Contractor -

(a) White Polyethylene Sheeting (WPS) - White polyethylene sheeting shall conform to the requirements of Section 223.04 of the 1966 Specifications. This material shall be furnished by the Contractor.

(b) Liquid Membrane Seal (LMS) - Liquid membrane seal shall conform to the requirements of Section 223.05 of the 1966 Specifications and shall be applied in reasonably close conformity to the rate of one (1) gallon per 150 square feet of surface area. This material shall be furnished by the Contractor.

(c) Linseed Oil Treatment (LOT) - Linseed oil treatment shall conform to the following requirements:

1. Linseed Oil - Linseed oil shall conform to the requirements of AASHO Designation M126 except that it shall be of a type especially formulated for the protection of concrete.
2. Thinner - Thinner shall be mineral spirits conforming to the requirements of AASHO Designation M128.

Linseed oil treatment shall be applied in accordance with the provisions of Section 540.04 of Supplemental Specifications for Section 540. This material shall be furnished by the Contractor.

(d) Monomolecular Evaporation Film (MEF) - Monomolecular Evaporation Film is a material which is sprayed on fresh concrete, using a low-pressure garden-type sprayer. It is used to reduce the evaporation which occurs during the period between the final pass of the screed and the texturing operation. Monomolecular evaporation film shall be applied in reasonably close conformity to the rate specified by the Engineer. This material will be furnished by the Department.

(e) Chlorinated Rubber Sealant (CRS) - Chlorinated rubber sealant is a combination curing compound and protective coating. The material is sprayed on concrete immediately following the texturing operation, using a low-pressure garden-type sprayer. Chlorinated rubber sealant shall be applied in reasonably close conformity to the rate specified by the Engineer. This material will be furnished by the Department.

(?) Epoxy Membrane Compound (EMC) - Epoxy membrane compound is a combination curing com and protective coating. The material is sprayed on the fresh concrete immediately following the texturing operation and the disappearance of the heavy water sheen. low-pressure garden-type sprayer is used to apply the material. Epoxy membrane compound shall be applied in reasonably close conformity to the rate specified by t Engineer. This material will be furnished by the Department.

Cooperation of the Contractor - The Contractor shall cooperate fully with the Engineer the establishment of the test sections. The Contractor shall keep the Engineer informe of the dates on which it is anticipated that a deck slab placement or the application c linseed oil is to occur giving at least 12 hours of prior notification. Further, the Contractor is advised that a Research Engineer and one or more Research Technicians wil be present during the deck slab placements and application of linseed oil for the purpc of evaluating climatic conditions at the time of the placement and to perform more frec (than usual) tests on the fresh concrete as well as a determination of the actual appli rates obtained for the curing and protection materials. (Note: The additional testing mentioned herein will not serve to establish the acceptance or rejection of the concret but will be used to establish the basis for future evaluation of the relative performar of the curing and protective materials. It is not anticipated that such tests and observations will interrupt or delay the Contractor to any appreciable extent.)

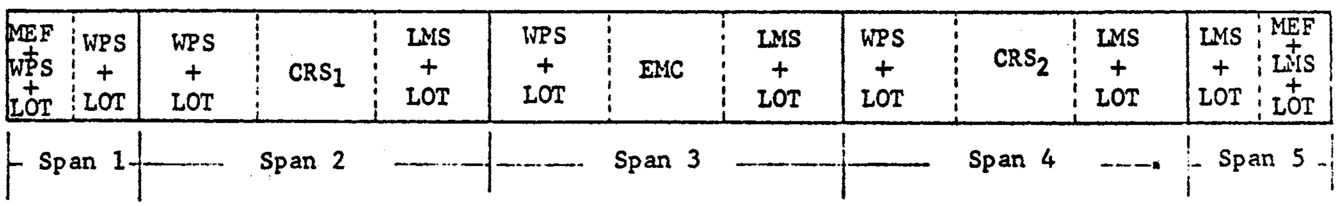
The Contractor shall assist the Engineer in delineating the boundaries of each tes section using narrow-width painted lines. The paint will be furnished by the Departmer

Method of Measurement and Basis of Payment - This work will not be measured for payment The cost of the application and the materials which the Contractor is to furnish shall included in other appropriate pay items in the contract.

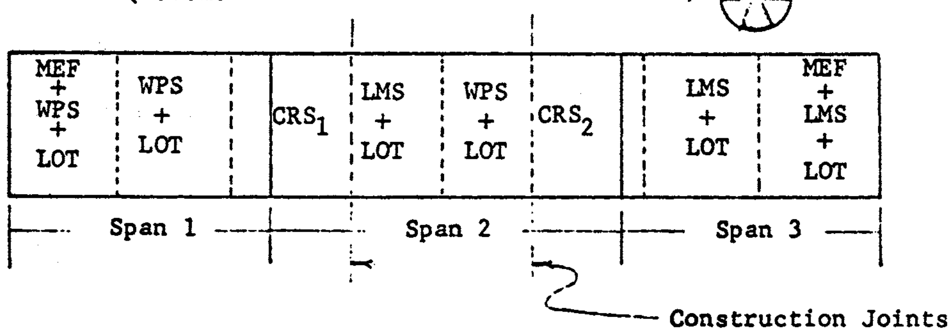
FIGURE A-1

TEST SECTIONS
FOR
EVALUATION OF CONCRETE CURING AND PROTECTION MATERIALS
0064-002-102, B647, B648, B650, B651, B652
I-64-2(55)93

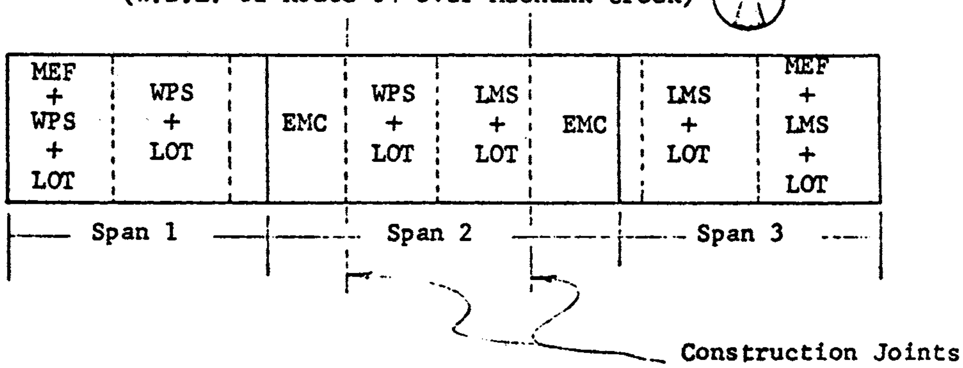
Structure B648
(Route 744 over Route 64)



Structure B651
(E.B.L. of Route 64 over Mechunk Creek)



Structure B652
(W.B.L. of Route 64 over Mechunk Creek)



(WPS) - White Polyethylene Sheeting
(LMS) - Liquid Membrane Seal
(LOT) - Linseed Oil Treatment
(MEF) - Monomolecular Evaporation Film
(CRS) - Chlorinated Rubber Sealant
(EMC) - Epoxy Membrane Compound

NOTES RECONCILING FINAL LAYOUTS (FIGURE 1) WITH THOSE PROPOSED IN THE WORK PLAN (FIGURE A-1)

B 648

Span 1. In Panel 1, MEF was applied by mistake.

Span 2. Panels 1 and 3 were interchanged for the convenience of the contractor. In Panel 2, WPS was substituted for CRS when the number of CRS panels was reduced.

Span 3. EMC was eliminated because of poor performance in outdoor evaluations (Appendix of Part I). CRS was substituted.

Span 4. Panels 1 and 3 were interchanged for the convenience of the contractor. In Panel 2 LMS was substituted for eliminated CRS to balance Span 2.

Span 5. Panels 1 and 2 were interchanged for the convenience of the contractor.

B 651

Span 1. In Panel 1, CRS was replaced with WPS as in Span 2 of B 648.

Span 3. In Panel 1, CRS was replaced with LMS as in Span 4 of B 648.

B 652

Span 1. In Span 1 MEF + WPS was substituted for the eliminated EMC. In Panel 3 LMS + LOT was substituted for MEF + WPS + LOT to balance Panel 2.

Span 2. In Panel 2 LMS was substituted for WPS and for comparison the LOT was omitted on Panel 1.

Span 3. In Panel 1, LMS + LOT was substituted for eliminated EMC. For reasons discussed in the report, the LOT was eliminated in Panel 2 and the MEF in Panel 3. The application rates for LMS were increased.

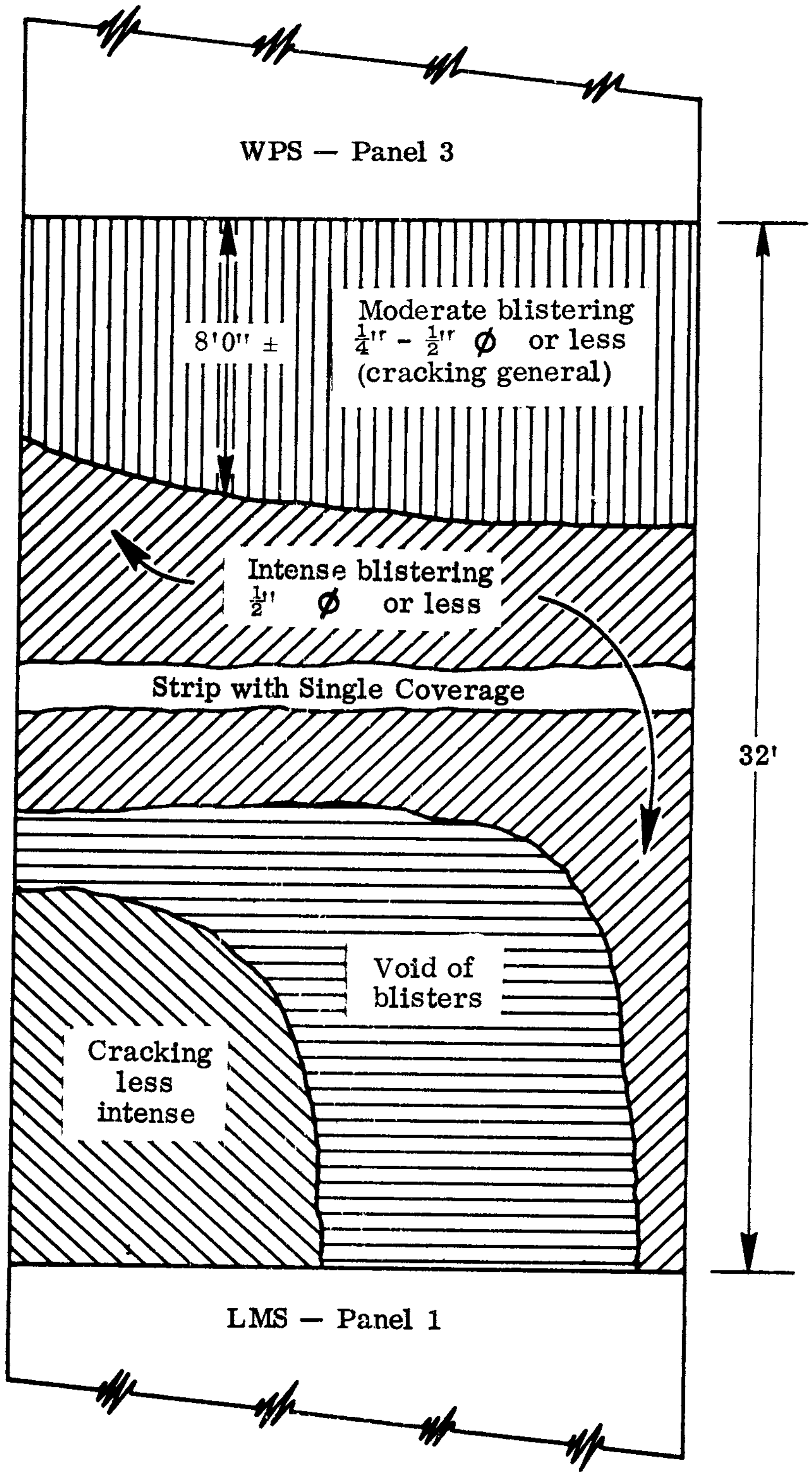


Figure B-1. Appearance of Panel 2, Span 3, B 648, Prior to traffic

APPENDIX C

COMMONWEALTH OF VIRGINIA

DEPARTMENT OF HIGHWAYS
RICHMOND, VA. 23219

April 14, 1970

W. S. SCOTT
HWAY CONSTRUCTION ENGINEER

Portland Cement Concrete - Use of Monomolecular Film for Retarding Evaporation of Water from Fresh Concrete

Memorandum
to - DISTRICT ENGINEERS

Attached herewith are copies of Form CF-le published by Master Builders concerning their product "Confilm" to be distributed to your Resident, Bridge and Materials Engineers. "Confilm" is a material applied to fresh concrete immediately behind the pass of the screed to retard the evaporation of water from the concrete until the next operation can be performed on the surface (texturing for example).

The performance of this product has been examined by Mr. Howard H. Newlon, Assistant State Research Engineer, both in the laboratory and in the field. No detrimental affects have been discovered from the use of the material when used as recommended by the manufacturer. The film is quite strong but completely disappears with a subsequent pass of the screed or the texturing operation. The Bridge Contractor who applied this material in an experimental project on several structures on I-64, east of Charlottesville, was very pleased with its performance and requested permission for more extensive use to assist in combating the crusting that occurs during rapid drying weather conditions.

The Department would certainly benefit from any product or procedure which does in fact result in the reduction of evaporation, the primary cause for drying shrinkage cracks. Such cracking is a major problem in bridge deck construction, particularly on days on which the wind, temperature, humidity, or combination of these are such that rapid drying of the surface occurs.

This office offers no objection to the approval of requests from Contractors to use "Confilm" this summer on a project-by-project basis of approval. The material is relatively inexpensive and the quantities used are small. It should be emphasized that the material is diluted with nine parts of water. It is only necessary to apply a very light fog because the material spreads itself over the surface by contact with bleed water. The use of the spray should not be interpreted as permission to apply free water to the surface. While the material

- more -

District Engineers
April 14, 1970
Page 2

can be reapplied as often as necessary (between various operations), heavy applications are not necessary and are not to be permitted.

Please see that a record is kept of the bridge decks on which the monomolecular film is used and a report filed at the end of the 1970 summer construction season concerning the observed performance. If the results are as favorable on a larger scale as they have been to date, we will seriously consider requiring the use of the material whenever drying conditions are encountered during bridge deck construction.

We are advising the Virginia Road Builders Association and Master Builders of our interest in obtaining a wider base of experience with this product.

W. S. Scott
W. S. Scott
Construction Engineer

/jc
cc- Mr. J. V. Clarke
Mr. A. K. Hunsberger
Mr. K. E. Ellison
Mr. J. N. Clary
Mr. J. M. Wray, Jr.
Mr. J. H. Dillard
Resident Engineers
Bridge Engineers
Materials Engineers
Bureau of Public Roads

MASTER BUILDERS

CONFILM

Finishing Aid for Concrete Flatwork Under Drying Conditions

purpose of CONFILM:

CONFILM is an aid to producing high quality concrete flatwork. It retards rapid evaporation of water, normalizes the surface condition of the slab, and permits better adherence to finishing schedules. This renders it especially useful under drying conditions, including hot weather and work in heated interiors during cold weather.

action of CONFILM*:

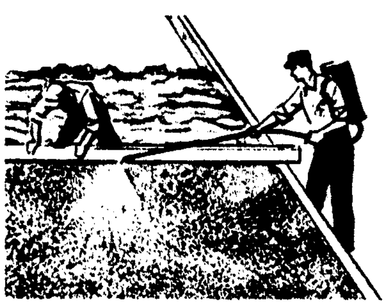
CONFILM sprayed over the surface of fresh concrete immediately after screeding forms a monomolecular film that usually lasts as long as the concrete remains plastic, despite succeeding floating and trowelling operations. This protective shield effects a number of important actions.

CONFILM reduces evaporation of surface moisture about 80% in wind and about 40% in sunlight. It has no effect on the cement hydration process. Concrete strength (early and ultimate), abrasion resistance and durability are not altered except for the improvement in over-all quality resulting from control of rapid evaporation.

CONFILM reduces evaporation only while concrete is in its plastic state. It is not a substitute for early curing of the hardened concrete nor does it alter the effectiveness of membrane-type curing compounds.

When CONFILM is used, there is a marked absence of white efflorescence on the concrete surface. The trace of CONFILM residue on hardened concrete does not impair bonding or alter appearance.

advantages of CONFILM:



The following are some important advantages typical of CONFILM application:

1. Concrete finishes easier and better when CONFILM is used. It eliminates or reduces crusting, stickiness, and underlying sponginess which often results in uneveness and poor surface texture. The surface closes better under the trowel.

2. Reduction and in many instances elimination of plastic shrinkage cracking and wind crusting of the surface of flatwork. CONFILM supplements the recommended practices for hot weather concreting. The use of cooled aggregates and mixing water, erection of sunshades, and placing concrete during the cooler times of the day are helpful practices in combating the ill effects of rapid evaporation. Under some conditions CONFILM alone will provide the necessary safeguard.

(CONFILM does not eliminate the problem of plastic cracking caused by placing concrete on a hot, highly absorbent base which rapidly withdraws moisture from the underside of the slab. This condition is usually corrected by use of plastic sheeting over the base or by cooling and saturating the base just prior to placing the concrete.)

3. Concrete with lower slump and lower unit water content can be used for flatwork since CONFILM virtually eliminates the need to add extra mixing water to compensate for rapid evaporation during finishing.

4. Use of air-entrained concrete as required for durability and workability is encouraged whereas air entrainment otherwise might be avoided because it increases susceptibility of the concrete to crusting and stickiness under drying conditions.

*A detailed technical discussion of the action of monomolecular films, typified by CONFILM, is contained in the Journal of the American Concrete Institute, Volume 62, pp. 977-985.

ACI Committee 302 on 'Recommended Practice for Concrete Floor and Slab Construction' suggests the use of monomolecular films as a helpful measure to prevent rapid drying of fresh concrete.

advantages: *(continued)*

5. Under rapid drying conditions, the amount of surface handled per finisher is increased because the surface remains plastic and finishable for a longer time. Work can proceed, whereas without CONFILM it might be postponed to avoid finishing problems.

(The quality of workmanship is improved with possible reduction in over-all cost. Timing of the various finishing operations is less critical when CONFILM is used.)

where to use:

CONFILM is effective, beneficial and compatible with the following finishing operations:

- air-entrained and non-air-entrained concretes
- normal, retarded and accelerated setting concretes
- metallic and non-metallic aggregate dry shake applications
- surface retardants for exposed aggregate finishes
- natural and colored concrete finishes
- burnished hard trowel finishes and non-slip swirled trowel or wood float finishes
- hand finishing and machine finishing
- highway, residential, commercial, institutional and industrial flatwork
- membrane-type curing compounds, plastic sheeting, water-proof paper or ponding
- tilt-up, lift-slab, precast concretes

where not to use:

CONFILM may not be required under conditions of high humidity and/or low ambient temperatures, or on concrete that bleeds excessively.

application of CONFILM:

CONFILM is applied with an ordinary garden-type tank sprayer or with the equipment used for application of membrane-type curing compounds.

- Agitate CONFILM in the factory container. Then dilute one part by volume with nine parts of water and again agitate the solution.
- Pump the spray tank to operating pressure and adjust the nozzle to obtain a fine spray mist.
- Early application of CONFILM is very important. Apply immediately after screeding.
- Spray surface lightly and uniformly. Agitate the CONFILM solution prior to each application. Repressure the tank as needed. Avoid having the nozzle too close to the fresh concrete or the pressure too high, which could disrupt the concrete surface – use a fine mist.
- Proceed with bull-floating or darbying; CONFILM is spread by these operations. Under severe drying conditions, additional applications of CONFILM should be made after each work operation including bull-floating or darbying, wood floating, flat trowelling and raised trowelling.

precautions:

1. CONFILM may not be needed under conditions of high humidity and/or low ambient temperatures, or on concrete that bleeds excessively.

2. Agitate CONFILM before diluting and agitate again prior to each application.

3. Early application of CONFILM is important.

4. Apply uniformly to develop a continuous, unbroken film on the surface.

5. Under severe drying conditions repeated applications of CONFILM should be made following each work operation.

6. Concrete treated with CONFILM, like any other concrete, must be cured. CONFILM is not a curing agent.

estimating data:

coverage – one gallon of CONFILM is mixed with nine gallons of water to make 10 gallons of sprayable solution which covers 2000 to 5000 square feet of fresh concrete with a single application. If more than one application of CONFILM is made, such as under adverse drying conditions, the area of concrete treated per gallon or solution is reduced accordingly.

packaging – CONFILM is packaged in 1, 5 and 55 U.S. gallon pails and drums, and 1 and 5 Imperial gallon pails.

suggested specifications:

Immediately after the screeding of concrete flatwork (floors, pavements, driveways, etc.) the surface shall be sprayed with Master Builders CONFILM to reduce rapid evaporation of water. The Manufacturer's application procedure and precautions shall be strictly observed.

MASTER BUILDERS

CLEVELAND, OHIO 44118 • TORONTO 15, ONTARIO

Products for Improving Concrete

Printed in U.S.A.

Form CF-1f