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Effects of Curing On Bridge-Deck Concrete Shrinkage Cracking

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EFFECTS OF CURING ON BRIDGE-DECK CONCRETE SHRINKAGE CRACKING

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ABSTRACT

This report describes performance of concrete overlays placed on concrete bridge decks before and after issuance of NYSDOT Engineering Instruction 86-24, which mandated discontinuance of monomolecular film and specified desirable rates of moisture evaporation from the newly poured plastic concrete during the curing period. It required rapid placement of wet burlap as needed to retard rapid evaporation of moisture, and prohibited concrete placement when a maximum evaporation rate might be exceeded. For field evaluation, 18 bridges were randomly selected, 9 built before and 9 after the change of policy. All were single-span with high-density concrete deck overlays. Cracking was surveyed, and information collected and reviewed on condition of the bridge decks at the time of concrete placement. Statistical analysis indicated that subsequent incidence of cracking did not differ significantly between the two groups of deck overlays.

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APPENDIX: Engineering Instruction 86-24: "Structural Slab Concrete and Overlays Curing Procedures

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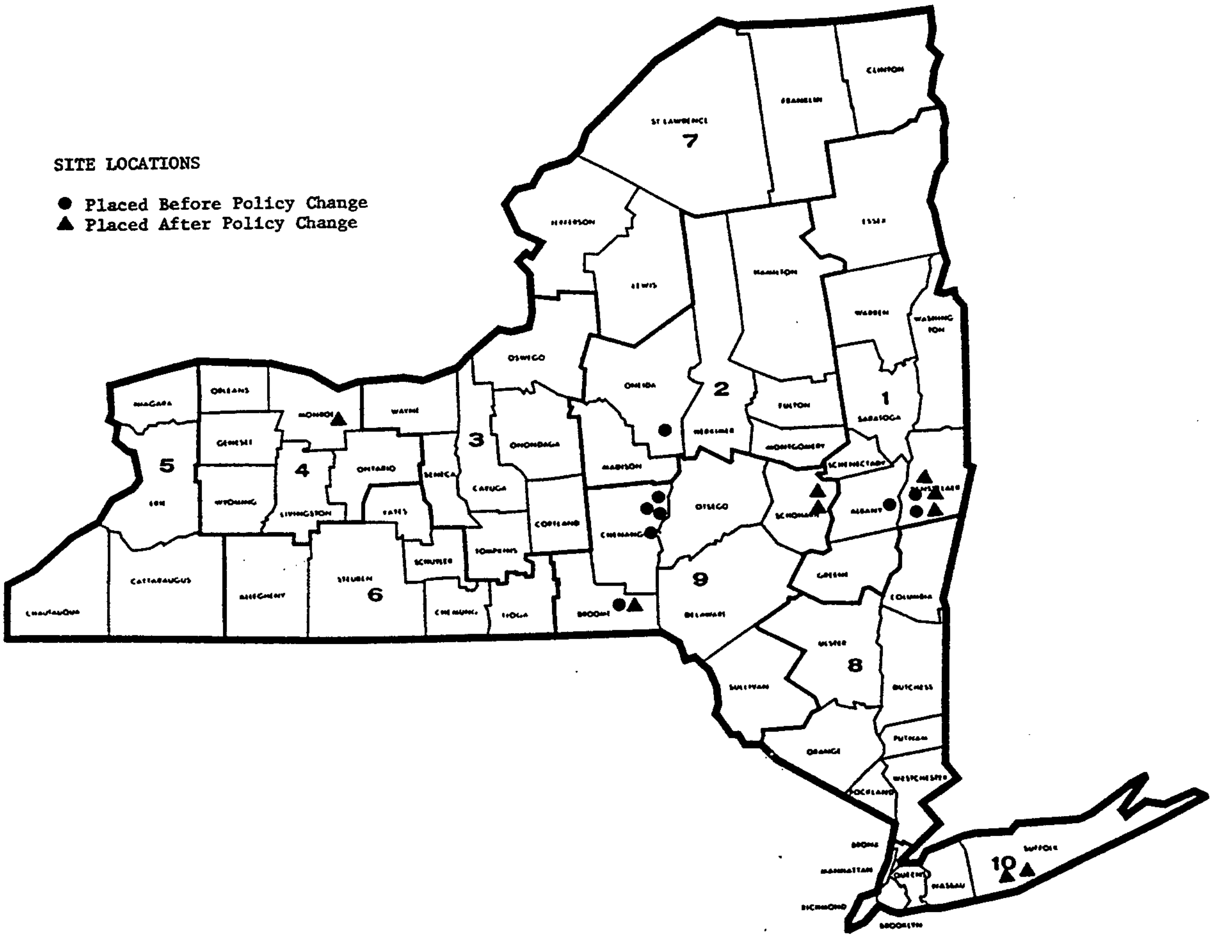
Figure 1. Locations of surveyed bridge decks.



I. INTRODUCTION

A. Background

In the past, bridge-deck concrete deterioration due to shrinkage cracking has been a problem in New York State. These cracks allow water, deicing chemicals, and other harmful materials to penetrate and pass through the deck, leading to corrosion delamination, and spalling. Shrinkage cracks are induced by loss of water, and form when the evaporation rate exceeds the rate at which bleed water rises to the concrete surface (1). The evaporation rate at the concrete surface is high when concrete and air temperatures are high, humidity is low, and wind velocity is high. When concrete is being placed during adverse conditions, it is important to take necessary precautions to ensure that the incidence of plastic shrinkage cracking is significantly reduced.

In the early 1980s, the Materials Bureau changed the curing specifications and hot-and cold-weather provisions for structural concrete as directed by NYSDOT's Structural Concrete Committee. On May 2, 1983, the standard specifications were revised to eliminate use of white-pigmented sprayed-on curing compounds and to require use of wet-burlap. The change also added certain provisions for placement of concrete during hot and cold weather.

On May 23, 1986, the Department issued more stringent procedures in Engineering Instruction 86-24 (see Appendix) to reduce plastic shrinkage cracking in structural slab concrete and concrete overlays. The EI restated the elimination of monomolecular film as a retardant, and required rapid placement of wet burlap should certain evaporation rates be exceeded. A combination of air and concrete temperatures, humidity, and wind velocity is used to set a theoretical optimum water evaporation rate. The purpose of the study reported here was to examine the effectiveness of the new curing procedures issued in EI 86-24.

B. Investigation

1. Selection of Test Sites

The decks surveyed in this study were simple-span, high-density concrete overlays, selected from a list of 90 bridges supplied by the Bridge Inventory Unit. A total of 18 bridges were randomly selected (Fig. 1), 9 placed in 1984-85 and 9 in 1988-89, before and after issuance of EI 86-24. All had sawed-groove surfaces, as shown in Figure 2. On two-lane spans carrying two-way

Table 1. Summary of bridge decks surveyed.

BIN	Site	Over/Under	Grid Section	AADT
PLACED BEFORE CHANGE OF CURING POLICY				
Rensselaer County (Region 1)				
1038550SB	1A*	150/Moordener Kill	1	920
1038550NB	1B*	150/Moordener Kill	2	920
1092792EB	2A*	I-90/VanHoesen Rd	3	8,884
1092791WB	2B*	I-90/VanHoesen Rd	4	8,884
Albany County (Region 1)				
1092282EB	3A	7/I-787	5	20,064
1092281WB	3B*	7/I-787	6	20,064
Oneida County (Region 2)				
1051441EB	4A	5S/Pitcher St	7	14,187
1051441WB	4B	5S/Pitcher St	8	14,187
Broome County (Region 9)				
1063189SB	5A	201/17	9	25,677
1063189NB	5B	201/17	10	25,677
Chenango County (Region 9)				
1094912EB	6A*	I-88/41	11	4,575
1094911WB	6B*	I-88/41	12	4,575
1053480EB	7A	23/Canasawacta Cr	13	826
1053480WB	7B	23/Canasawacta Cr	14	826
1094982EB	8A*	I-88/206	15	4,273
1094981WB	8B*	I-88/206	16	4,273
1094931EB	9A*	I-88/Ives Hill Rd	17	4,575
1094932WB	9B*	I-88/Ives Hill Rd	18	4,575
PLACED AFTER CHANGE OF CURING POLICY				
Rensselaer County (Region 1)				
1092660SB	1C	Elliot Rd/I-90	1	1,200
1092660NB	1D	Elliot Rd/I-90	2	1,200
1092642EB	2C*	I-90/151	3	15,124
1092641WB	2D*	I-90/151	4	15,124
1092622EB	3C*	I-90/43	5	15,124
1092621WB	3D*	I-90/43	6	15,124
Monroe County (Region 4)				
1048800SB	4C	Culver Ave/I-490	7	13,200
1048800NB	4D	Culver Ave/I-490	8	13,200
Broome County (Region 9)				
1054791EB	5C	17/Cocoanut Cr	9	12,319
1054792WB	5D	17/Cocoanut Cr	10	12,319
Schoharie County (Region 9)				
1053520SB	6C*	30/Schoharie Cr	11	3,306
1053520NB	6D*	30/Schoharie Cr	12	3,306
1053510SB	7C*	30/Schoharie Cr	13	3,306
1053510NB	7D*	30/Schoharie Cr	14	3,306
Suffolk County (Region 10)				
1056119EB	8C	27/Howells Rd	15	71,665
1056129WB	8D	27/Howells Rd	16	71,665
1064039EB	9C	27/Udall Rd	17	63,272
1064039WB	9D	27/Udall Rd	18	63,272

*Cored.

Figure 2. Sawed-grooved deck surface, with cracks highlighted.

Figure 3. Typical hairline crack.

traffic two test sections were selected -- one in each direction -- and on one-way two-lane spans one test section was selected, all in the driving lane, in the direction of traffic, and away from skewed joints. The decks are listed in Table 1.

2. Methods of Evaluation

In each section, a 4 by 10 m grid was laid out in 1 m^2 increments. In most cases, cracking was not readily visible, and water was sprayed on the surface to enhance crack visibility. As it evaporated, the cracks stood out and were outlined in yellow crayon before they dried and disappeared (Fig. 2). Crack length was measured in centimeters and then totaled and recorded separately for each square meter. Only random pattern cracks were documented, ignoring those considered to be stress-related.

Ten of the 18 bridges were chosen for coring, with at least two specimens removed from each test section. Each core was visually examined to determine the type and depth of cracking. In addition to this visual rating, cores were sent to the Materials Bureau lab for shear strength testing at the bonded interface between new and old concrete, 48-hour moisture absorption, concrete unit weight, and rapid determination of chloride permeability.

II. RESULTS

A. Crack Survey

The 18 sites included 36 grid sections for evaluation. Crack length was totaled for each 40 m^2 grid, resulting in 18 observations each for groups placed before and after issuance of the Engineering Instruction changing curing practice (Table 2). The 18-site sample size for each group was sufficient to detect any substantial reduction (over 50 percent) in cracking rate, with 80-percent probability if such a reduction had actually occurred. Cracking on deck overlays placed before the change averaged 0 to 655 cm/m^2, and those place after ranged from 2.8 to 598.8 cm/m^2. Compliance of these samples to a normal distribution was verified, and a number of statistical tests were used to determine if a decrease in average cracking could be detected. Sample statistics are summarized in Table 3. The tests conducted showed no statistically significant difference in average cracking between the two groups at the 95-percent confidence level.

B. Visual and Lab Tests of Cores

A total of 26 cores were taken. Each was examined and assigned a visual rating from 1 to 3 -- 1 denotes a hairline crack not easily visible, 2 one more clearly visible, and 3 an obvious wide

Table 2. Summary of deck cracking.

Site	Grid Section	Cracking, cm/40 m^2	Site	Grid Section	Cracking Cracking, cm/40 m^2
Placed Before Change of Curing Policy			Placed After Change of Curing Policy		
1A	1	24,525	1C	1	814
1B	2	21,430	1D	2	900
2A	3	26,200	2C	3	9,750
2B	4	20,130	2D	4	16,780
3A	5	12,560	3C	5	10,690
3B	6	11,520	3D	6	12,140
4A	7	10,830	4C	7	7,855
4B	8	2,450	4D	8	7,040
5A	9	1,090	5C	9	3,010
5B	10	850	5D	10	110
6A	11	280	6C	11	23,950
6B	12	780	6D	12	10,150
7A	13	135	7C	13	19,270
7B	14	0	7D	14	20,290
8A	15	12,410	8C	15	18,840
8B	16	12,080	8D	16	18,650
9A	17	4,820	9C	17	20,600
9B	18	2,530	9D	18	20,500

Table 3. Summary of sample statistics.

Statistic*	Before Policy Change	After Policy Change	Combined
Sample Size	18	18	36
Mean Cracking	228.6	307.3	268
Standard Deviation	226.3	196.1	212
Minimum	0.0	2.8	0
Maximum	665.0	598.8	655

*Cracking measured in centimeters per square meter.

Table 4. Summary of field observations.

Core	Site	Visual Rating*	Depth, cm Overlay	Depth, cm Crack
Placed Before Change of Curing Policy				
1	1A	3	5.08	5.08
2	1B	3	6.35	6.35
3	2A	3	6.35	6.35
4	2B	3	6.35	6.35
5	3B	1	6.35	2.50
6	3B	1	5.72	1.50
7	6A	1	6.35	2.50
8	6A	1	6.00	2.20
9	6A	1	6.35	2.00
10	6B	2	6.35	2.20
11	8A	2	6.35	6.00
12	8A	2	6.35	6.00
13	8A	2	6.35	2.20
14	8B	2	6.35	3.50
15	9A	3	5.08	2.50
16	9B	3	5.72	5.72
Placed After Change of Curing Policy				
17	2C	3	7.62	2.00
18	2D	2	6.35	2.20
19	3C	1	6.35	2.00
20	3D	2	6.35	1.50
21	6C	1	6.35	2.00
22	6D	1	5.08	5.08
23	6D	1	6.35	6.35
24	6D	1	5.72	5.72
25	7C	1	6.35	2.50
26	7D	2	5.72	1.50

*1 = hairline crack, not easily visible.
2 = crack more easily visible.
3 = obvious wide crack.

crack. A typical hairline crack is shown in Figure 3. Visual ratings and crack depths are summarized in Table 4. Cores taken on the deck overlays placed before and after the policy change had average crack depths of 3.93 and 3.09 cm, respectively. Most cracks were hairline and due to shrinkage. About 30 percent of the cores had cracks extending the full overlay depth in both groups of decks. Wider, more visible cracks (rating of 3) were found for 37 percent of decks in the "before" period, versus 10 percent in the "after" period. At the 95-percent confidence level, however, this difference was not statistically significant.

The Materials Bureau lab tested the cores, using NYSDOT Test Method 501-10P for concrete unit weight, NYSDOT Method 501-14F for concrete percent absorption, NYSDOT Method 502-6E for shear strength of bonded concrete, and ASTM Standard Test Method C 1202-91 for electrical indication of concrete's ability to resist chloride ion penetration, with the results summarized in Table 5. Cracking rate was not found to be correlated with any of the characteristics measured -- i.e, unit weight, 48-hour absorption, unit shear, or chloride penetration.

C. Climatological Data

Concrete and air temperatures were compiled from cylinder test reports obtained from the Materials Bureau. Humidity and wind velocity were taken from regional monthly summary reports from the National Climatic Data Center. Evaporation rates were calculated from the nomograph chart shown in the Appendix. Table 6 summarizes temperatures, humidities, wind velocities, and evaporation rates. In most cases, moisture evaporation involved less than 0.73 $kg/m^2/hr$, with only two overlays having higher rates that required rapid placement of wet burlap -- within 5 minutes of pouring concrete. A number of factors were considered in correlating the cracking rates, including these variables:

- A binary variable indicating whether placement occurred before or after issuance of the Engineering Instruction.
- Annual average daily traffic.
- Year, month, and starting time of placement (hour of the day).
- Conditions during placement, including air temperature, concrete temperature, wind velocity, relative humidity, and evaporation rate.

Cracking rates were not strongly correlated with any of these factors. It thus was not possible to obtain a useful model to explain or predict the cracking rate using these variables.

Table 5. Summary of laboratory test results.

Core	Site	Unit Shear MPa	Weight, kg/m³	48-hr Absorption, %	Chloride Penetration, C
Placed Before Change of Curing Policy					
1	1A	--	2162.7	5.6	--
2	1B	4.54	2243.6	4.9	3230
3	2A	4.59	2275.6	4.8	2466
4	2B	2.57	2211.5	5.2	--
5	3A	4.92	2291.7	4.7	2820
6	3B	--	2227.6	3.0	2704
9	6A	4.06	2163.5	5.0	4528
10	6B	6.32	2243.6	4.5	2699
13	8A	--	2291.7	3.7	1750
14	8B	--	2291.7	4.0	1662
15	9A	0.66	2115.4	5.5	6491
16	9B	--	2227.6	4.4	--
Placed After Change of Curing Policy					
17	2C	2.79	2307.7	4.7	4397
18	2D	3.61	2291.7	4.6	3323
19	3C	2.13	2291.7	4.4	3731
20	3D	3.19	2243.6	4.8	4364
21	6C	--	2227.6	5.5	3624
22	6D	2.39	2227.6	5.3	2718
25	7C	--	2163.5	6.1	5535
26	7D	--	2275.6	5.0	3205

Table 6. Summary of climatological data.

Site	Temperature, °C		Humidity, %	Wind Velocity, km/h	Evaporation Rate, kg/m²/hr
	Concrete	Air			
Placed Before Change of Curing Policy					
1A	23	19	54	19	0.59
1B	29	25	48	21	1.07
2A	27	27	60	13	0.64
2B	22	17	70	13	0.73
3A	18	24	60	18	0.64
3B	24	29	43	24	0.49
4A	16	13	72	0	0.10
4B	13	9	47	24	0.39
5A	29	32	43	11	0.64
5B	29	16	57	18	1.17
6A	21	12	87	15	0.39
6B	21	13	75	16	0.64
7A	22	14	44	13	0.69
7B	26	26	47	11	0.49
8A	19	10	83	11	0.34
8B	24	19	81	13	0.44
9A	17	7	49	13	0.39
9B	21	12	83	18	0.49
Placed After Change of Curing Policy					
1C	17	9	59	21	0.49
1D	14	11	90	3	0.15
2C	28	20	71	0	0.15
2D	25	19	76	16	0.64
3C	29	27	84	0	0.15
3D	24	17	95	0	0.10
4C	19	15	53	16	0.73
4D	26	21	74	16	0.59
5C	20	21	45	23	0.54
5D	14	16	67	15	0.39
6C	21	11	100	0	0.10
6D	29	19	90	6	0.39
7C	26	17	76	8	0.44
7D	23	16	59	8	0.34
8C	23	16	79	16	0.59
8D	24	16	78	18	0.68
9C	13	7	70	16	0.39
9D	11	6	70	19	0.24

III. CONCLUSIONS AND RECOMMENDATIONS

Evaluation of the crack surveys and core test data for the 18 sites resulted in these findings:

1. Cracking on deck overlays placed before the curing policy changes averaged from 0 to 655 cm/m^2, and those placed after the change from 2.8 to 598.8 cm/m^2. The crack survey showed no statistically significant difference in average cracking between the two groups at the 95-percent confidence level.

2. Cores taken from overlays placed before and after the policy changes had average crack depths of 3.93 and 3.09 cm, respectively. Most cracks were hairline and resulted from shrinkage.

3. Cracking rate was not found to correlate with any of the characteristics measured -- unit shear, weight, 48-hr absorption, or chloride penetration.

4. Cracking rates were not strongly correlated with any of these factors: AADT, time of placement (hour of day), or conditions during placement (air or concrete temperature, wind velocity, relative humidity, or evaporation rate).

Overlay construction practices should be studied more thoroughly to clarify the effects of changes in curing policy on incidence of shrinkage cracking. In the study reported here, most decks experienced the allowable evaporation rate of 0.73 kg/m^2/hr and did not require any special curing as required by EI 86-24.

ACKNOWLEDGMENTS

This project was conducted under general supervision of Dr. Robert J. Perry, Director of Transportation Research and Development, under direction of Dr. Wes Yang, Engineering Research Specialist II, and Luis Julian Bendaña, Engineering Research Specialist I. Richard D. Wright, Principal Engineering Technician, assisted in the field performance surveys. Statistical analysis was performed by Dr. Deniz Sandhu, Engineering Research Specialist II. Special thanks are extended to the Materials Bureau, Bridge Data Services Unit, Region 9 Materials personnel, and Transportation Maintenance Residencies in Regions 1 and 9 -- their assistance was essential in conducting the investigations for this study.

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REFERENCE

1. Babaei, K., And Hawkins, N.M. Evaluation of Bridge Deck Protective Strategies. Report 297, National Cooperative Highway Research Program, Transportation Research Board, September 1987.

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APPENDIX

ENGINEERING INSTRUCTION 86-24
"Structural Slab Concrete and Overlay Curing Procedures"

TO:	**ENGINEERING INSTRUCTION** NEW YORK STATE DEPARTMENT OF TRANSPORTATION
	SUBJECT: STRUCTURAL SLAB CONCRETE AND OVERLAY CURING PROCEDURES Subject Code: 7.27-1-555; 578; 584
Distribution: 31 [X] Main Office 33 [X] Regions 34 [X] Special	Code: E.I. 86-24
APPROVED: [signature] Deputy Chief Engineer (Structures)	Date: May 23, 1986 Supersedes:

Along with the increased workload over the past few years, problems associated with placing new bridge deck concrete have increased significantly. Problematic conditions such as surface tearing, openness, cracking and poor microtexture, are traceable to specific weather conditions.

When certain weather factors (relative humdity and wind speed) interact in just the right manner with the concrete placement temperature, the bleed water evaporation rate increases dramatically. This accelerated water loss is directly related to the conditions noted earlier. In order to alleviate the effects of rapid evaporation a special note (attached) has been prepared.

This note requires rapid placement of wet burlap should certain evaporation rates be predicted and prohibits concrete placement entirely should a specific maximum evaporation rate be predicted.

The requirements of this note will affect the following pay items:

555.0401	578.01	584.01
555.0402		584.11
555.0403		
555.0404		
555.0405		

It has also been established that the use of monomolecular film to retard evaporation rates has not been successful. This note also eliminates the use of monomolecular film.

This instruction takes effect with the letting of July 17, 1986 (Ammendment deadline June 27). Changes to contracts being processed are to be made by ammendment if feasible.

For ongoing contracts, construction engineers are encouraged to point out to contractors the advantages of placing wet burlap more quickly if conditions are such that the evaporation rate will be between 0.15 lbs/s.f./hr and 0.25 lbs/s.f./hr. Placement of structural sidewalk, slab, overlay, or curb concrete should be discouraged completely if the evaporation rate will meet, or exceed, 0.25 lbs/s.f./hr.

HC 157a (4/73)

Subsection 578-3J. Second paragraph, after the first sentence, add the following:

"The allowable time period for wet burlap covering shall not exceed five(5) minutes if the theoretical evaporation rate is expected to reach, or exceed, 0.15 lbs./s.f. of exposed surface. This rate shall be calculated by the contractor in accordance with the requirements of subsection 555-3.09C using TABLE 555-3. The contractor shall supply all instruments necessary to make the required calculations. All instruments shall be certified by an independent laboratory, approved by the Engineer, as being in good working order, and as having been calibrated within the twelve months immediately prior to use. The contractor's measurements and calculations shall be subject to the Engineer's approval."

Page 5-97

At the bottom of the page delete the last line "C. Monomolecular Film." in its entirety.

Page 5-98

Beginning at the 1st line at the top of the page, change "D" to "C", in the 5th line change "E" to "D", in the 6th line change "F" to "E" and in the 7th line change "G" to "F".

Page 5-107

Under 584-3.12 Hot Weather Provisions, A. High Density Concrete, delete 1., in its entirety, and replace with the following:

1. The requirements of subsection 555.304A shall apply except no concrete shall be placed below 50°F. The time limitations for the placement of wet burlap, as required by subsection 555-3.09C, shall also apply.

Page 5-107

Under 584-3.12 Hot Weather Provisions, B. Latex Modified Concrete, delete 1., in its entirety, and replace with:

1. The provisions of §584-3.12A shall apply.

STRUCTURAL CONCRETE

Please make the following changes to the Standard Specifications of January 2, 1985:

Subsection 555-3.04A. First paragraph, sixth line. Insert the following between "shall apply". and "All foreign...: "No structural slab, sidewalk, or curb concrete shall be placed if the combination of ambient air temperature, relative humidity, wind speed, and plastic concrete temperature, all combine such that a surface moisture evaporation rate is theoretically equal to, or greater than, 0.25 lbs./s.f. of exposed surface. It shall be the contractor's responsibility to determine this rate. (Refer to subsection 555-3.09C, and TABLE 555-3)."

Addendum No. 1

Page 20

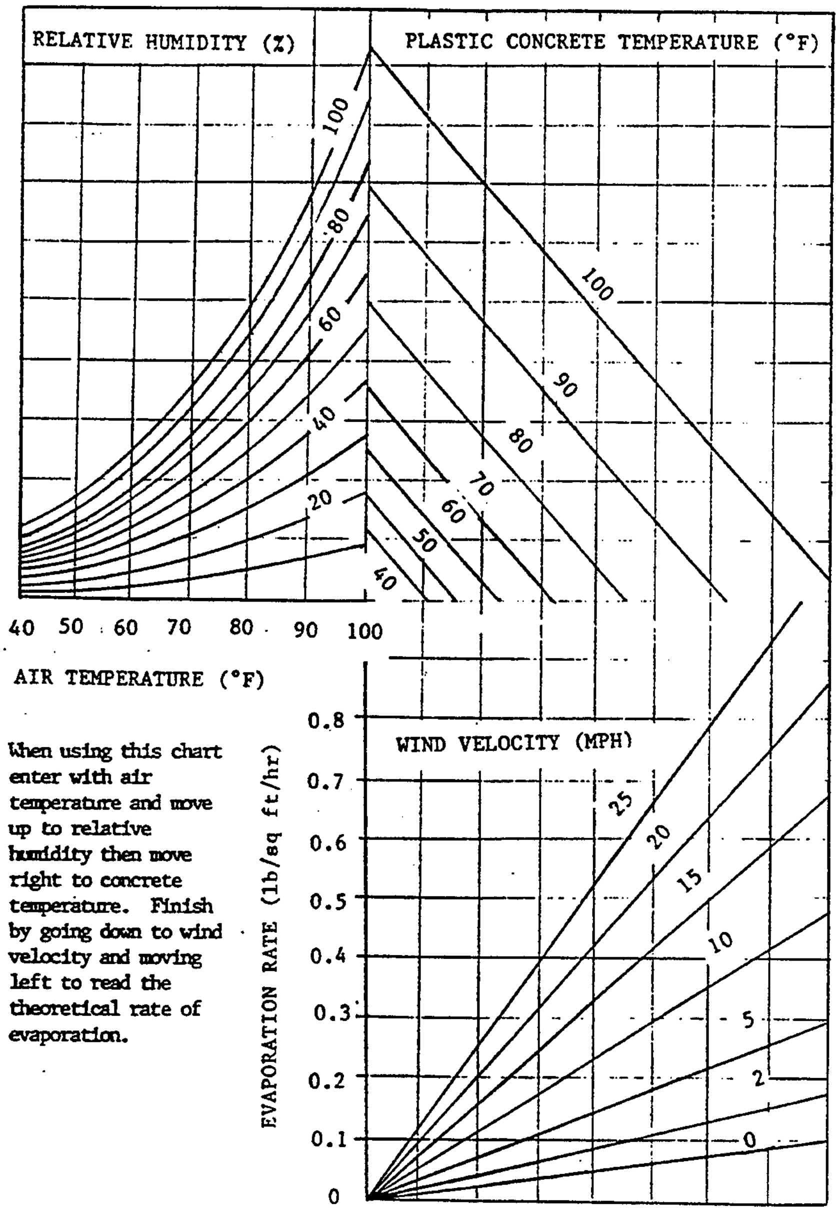
Subsection 555-3.09C. Second paragraph, first sentence. Add the following: "...the requirements of 555-3.09A, except that the allowable time period for wet burlap covering shall not exceed five (5) minutes if the theoretical evaporation rate is expected to reach, or exceed, 0.15 lbs./s.f. of exposed surface. This rate shall be calculated by the contractor using TABLE 555-3. The measurements for air temperature, relative humidity, and wind speed shall be taken as near as possible to the final placement of the concrete. Concrete temperature shall be taken from the sample used for slump and air content tests. These measurements and calculations shall be performed at least once per hour, beginning with the initial concrete placement. If, in the Engineer's opinion, significant changes occur in atmospheric conditions, additional measurements and calculations by the contractor will be required. The contractor shall supply all instruments necessary to make the required calculations. All instruments shall be certified by an independent laboratory, approved by the Engineer, as being in good working order, and as having been calibrated within the twelve months immediately prior to use. The contractor's measurements and calculations shall be subject to the Engineer's approval."

Page 5-85

Subsection 578-3I. Add the following as the second paragraph:

"No overlay concrete shall be placed if the combination of ambient air temperature, relative humidity, wind speed, and plastic concrete temperature, all combine such that a surface moisture evaporation rate is theoretically equal to, or greater than, 0.25 lbs./s.f. of exposed surface. It shall be the contractor's responsibility to determine this rate. The requirements of subsection 555-3.09C, and TABLE 555-3 shall apply."

TABLE 555-3



When using this chart enter with air temperature and move up to relative humidity then move right to concrete temperature. Finish by going down to wind velocity and moving left to read the theoretical rate of evaporation.