LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON

Final Report

State Planning and Research Project Number 5288

by

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16. Abstract

This final report presents information collected by ODOT personnel from bridge deck overlays constructed in Oregon between 1989 and 1995. Decks were placed on a variety of existing bridge types prepared using hydrodemolition, milling, and diamond grinding followed by sand, water or air blasting. Both latex and microsilica overlays were placed under a variety of environmental conditions. The study investigated causal relationships between construction and environmental factors and deck cracking and delamination and, where warranted, recommends procedures to minimize these distresses.

Statistical analyses of available environmental and construction information from several overlays constructed between 1989 and 1993 failed to clearly establish the cause(s) of delamination or cracking. Petrographic studies of cores taken from these decks appear to show increased microcracking in substrates prepared with milling compared to those prepared with hydrodemolition. Diamond ground substrates were not included in this phase of the study. This analyses supports increased use of hydrodemolition over milling.

In an effort to establish the casual relationships, detailed environmental and material property data were collected during construction on five bridges in 1995. Statistical analyses of data provides information on the range of environmental conditions under which bridge deck may be placed, however, little cracking or delamination was noted in any of the five bridges. Thus, the cause(s) were not identified

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

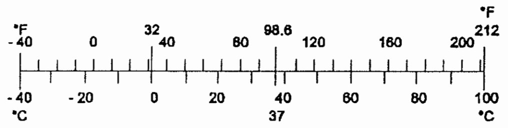
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F



* SI is the symbol for the International System of Measurement

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DISCLAIMER

LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON

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1.0 INTRODUCTION

The deterioration of concrete pavements and bridge decks is a major concern for most transportation agencies. Media attention on the decayed infrastructure has helped some agencies gain public support for their rehabilitation projects. Bridge deck rehabilitation is one area receiving increased national attention.

It had been estimated that FHWA should be required to spend about 50 billion dollars to rehabilitate 40 percent of all bridges in the United States (*Strategic Highway Research Program 1992*). Although only a portion of these moneys will be spent on the decks, the public often judges the quality of the bridge rehabilitation by the quality of the new surface.

Agencies and the public want to minimize user inconvenience and maintenance costs. These items are generally minimized when the overlay is tightly bonded to a sound substrate and little or no surface cracking is present. Engineers recognize that the presence of surface cracks and delamination generally signal reduced service life and increased maintenance costs (*Krauss and Rogalla 1996*). The purpose of this study is to investigate factors that may influence the development of bond at the interface and affect surface cracking.

1.1 BACKGROUND

Bridge deck deterioration appears inevitable and is attributable to the environment and traffic density and loading. This deterioration affects the service life and maintenance costs of the bridge as well as user safety and convenience. The presence of surface spalling and cracking indicate deck deterioration and may signal corrosion of the underlying reinforcing steel. However, well-defined relationships between crack width (at the surface) and concrete or steel deterioration are not well established (*Krauss and Rogalla 1996*).

Some agencies (e.g., Oregon DOT) are using latex or microsilica modified concrete to rehabilitate bridge decks. These materials have improved properties over conventional portland cement concrete, particularly lower permeability. Latex-modified concrete (LMC) was the most common deck overlay material in the 1980s (*Ramakrishnan 1992*). Microsilica modified concrete (MC) has begun to replace LMC, in part, due to the relative ease of placement. Both these materials generally perform well, however, distresses are sometimes reported shortly after construction.

1.2 PURPOSE

This report identifies construction techniques, materials, and environmental conditions that may be related to early-age distresses in LMC and MC bridge deck overlays. Where appropriate, recommendations are made for changes to specifications.

1.3 SCOPE

This project focuses on bridge deck performance in Oregon. Data collection was based on an extensive literature review (*Lundy and Sujjavanich 1994*). Bridge design elements (i.e., girder type, size, and spacing) have been specifically excluded from the investigation. The initial literature review was supplemented using a recently completed NCHRP report (*Krauss and Rogalla 1996*).

2.0 CAUSES OF EARLY AGE DISTRESS

It is virtually impossible to identify a single cause of early-age cracking or delamination in LMC and MC overlays. Krauss and Rogalla ranked factors affecting early cracking in bridge decks. Table 2.1 shows the relative importance of each factor, discussed in detail in their report. When bridge design factors are excluded, early age distress is most likely related to a combination of factors including the environment, construction procedures, and materials. Each of these factors are considered below.

2.1 ENVIRONMENT

High evaporation rates and ambient temperatures contribute to early-age bridge deck distress. Under early-age conditions when concrete strength is low, high rates of evaporation may result in plastic shrinkage cracking. Cracking may also result when large temperature differentials between the concrete temperature and the minimum air temperature occur shortly after placement, before the concrete has gained sufficient strength.

Krauss and Rogalla report a significant trend toward increasing 28-day design strengths of concrete used in bridge decks. In addition, they report that even lower water to cement ratios (w/c ratio) are often specified to protect against corrosion of reinforcing steel. Data collected in Oregon (see Table 3.3) shows that Oregon Department of Transportation (ODOT) mixes have w/c ratios of 0.24 to 0.35. The low w/c ratios increase the mix sensitivity to environmental conditions, in part, due to the relative lack of available bleed water.

A relationship has been widely used to estimate the evaporation rate based on a combination of wind, air and concrete temperatures and humidity (*Cope 1987; Lerch 1957*). For overlays having high surface to volume ratios, this factor has been reported as the single most significant contributor to early age cracking (*Cope 1987; Ramakrishnan 1992*). A low rate of evaporation (see Figure 2.1), i.e., less than 0.75 kg/m^2/hr (0.15 lb/ft^2/hr), is normally recommended. However, Kuhlman suggested a lower rate of less than 0.5 kg/m^2/hr (0.1 lb/ft^2/hr) to minimize plastic shrinkage cracking in mixes containing silica.

The combination of wind, temperature and solar radiation affects bridge temperatures. A high temperature difference between the deck and fresh concrete is recognized as another contributor to cracking and delamination (*LaFraugh and Zinserline 1987*). Delamination of concrete overlays placed on concrete pavements has been attributed to "flash" setting of the fresh concrete as it contacted the hot base slab (*Lundy 1990*). LaFraugh suggests thermal shock between the base concrete and overlay contributes to cracking, however, no details are available (*LaFraugh and Zinserline 1987*). Several agencies reported that placing decks at night can significantly reduce deck cracking and afternoon placements are most likely to crack (*Portland Cement*

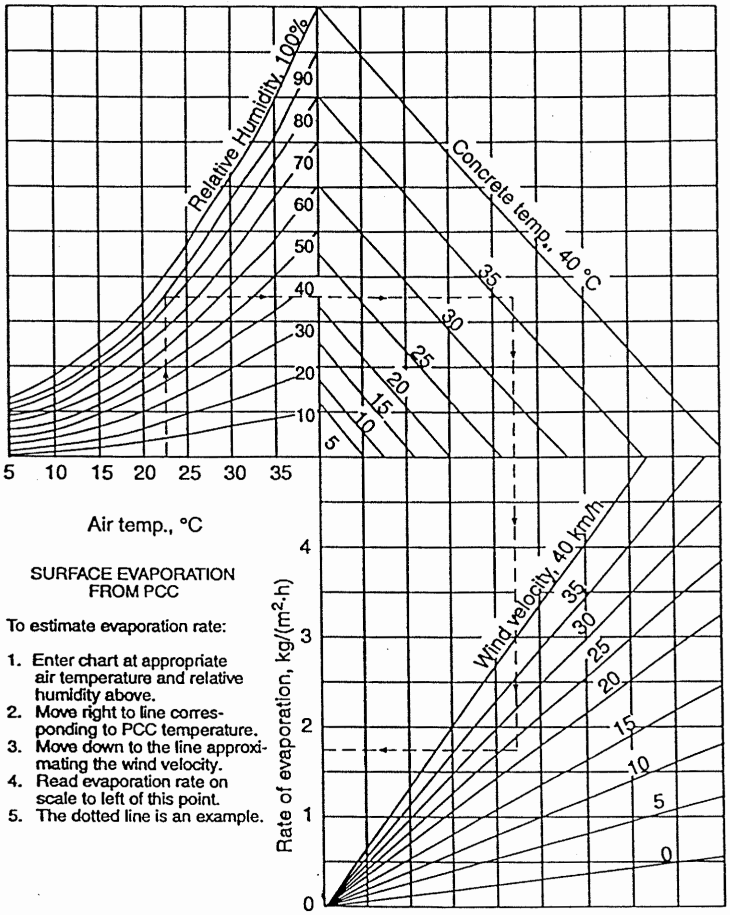
Association 1970; Purvis 1989). Temperature differentials between the surface (top or bottom) and the center of the bridge deck also may induce sufficient stress in the curing overlay to cause cracking or delamination (*Thepchatri, Johnson and Matlock 1977*).

Table 2.1 Factors affecting early cracking in bridge decks (*Krauss and Rogalla 1996*)

Factors	**Effect**			
	Major	**Moderate**	**Minor**	**None**
Design				
Restraint	✓			
Continuous/simple span		✓		
Deck thickness		✓		
Girder size		✓		
Girder type		✓		
Alignment of top and bottom reinforcement bars		✓		
Form type			✓	
Concrete cover			✓	
Girder spacing			✓	
Quantity of reinforcement			✓	
Reinforcement bar sizes			✓	
Dead load deflections during casting			✓	
Stud spacing			✓	
Span length			✓	
Bar type-epoxy coated			✓	
Skew			✓	
Traffic volume				✓
Frequency of traffic-induced vibrations				✓
Materials				
Modulus of elasticity	✓			
Creep	✓			
Heat of hydration	✓			
Aggregate type	✓			
Cement content and type	✓			
Coefficient of thermal expansion		✓		
Paste volume - free shrinkage		✓		
Water cement ratio		✓		
Shrinkage-compensating cement		✓		
Silica fume admixture		✓		
Early compressive strength			✓	
High range water reducing admixtures			✓	
Accelerating admixtures			✓	
Retarding admixtures			✓	
Aggregate size			✓	
Diffusivity			✓	
Poisson's ratio			✓	
Fly ash				✓
Air content				✓
Slump (within typical ranges)				✓
Water content				✓
Construction				
Weather	✓			
Time of casting	✓			
Curing period and method		✓		
Finishing procedures		✓		
Vibration of fresh concrete			✓	
Pour length and sequence			✓	
Reinforcement ties				✓
Construction loads				✓
Traffic-induced vibrations				✓
Revolutions in concrete truck				✓

The magnitude of these differentials can be estimated if the solar radiation, shade temperatures, and wind velocities can be determined for a given site (*Cope 1987; Emerson 1973; Thepchatri, Johnson, and Matlock 1977*). The daily temperature variation must be known to predict this temperature effect. In the daytime, particularly during summer, bridges normally have greater heat gain than loss and rising temperatures result. This pattern reverses and bridge temperatures drop at night. Minimum temperatures generally occur before sunrise and increase to maximum in midafternoon. Sujjavanich (*1996*) used these data to estimate the temperature induced stresses in a bridge deck overlay at ages between 12 and 48 hours.

FIGURE 00540-1 SURFACE EVAPORATION FROM CONCRETE ¹



SURFACE EVAPORATION
FROM PCC

To estimate evaporation rate:

1. Enter chart at appropriate air temperature and relative humidity above.
2. Move right to line corresponding to PCC temperature.
3. Move down to the line approximating the wind velocity.
4. Read evaporation rate on scale to left of this point.
5. The dotted line is an example.

¹ Based on Figure 2.1.5 from ACI booklet "Hot Weather Concreting" (ACI 305R-77).

Figure 2.1 Nomograph relating air temperature, relative humidity, concrete temperature, and wind speed to evaporation rate (*Lerch 1957*).

2.2 CONSTRUCTION PROCEDURE

The quality of the overlay is sensitive to construction process. As indicated in Table 2.1, a variety of construction-related activities may influence the development of cracking in overlays. Krauss and Rogalla (*1996*) point out that environmental conditions at the time of placement (discussed above) are perhaps the most important construction factors. Furthermore, they report that proper and timely curing will prevent plastic shrinkage cracking. Different substrate preparation techniques (i.e., milling or shot blasting) may result in different bond strengths and therefore different cracking or delamination performance (*Lundy 1990*).

Petrographic analyses of the cored samples from some Oregon projects indicated a clear difference in the amount of cracking present in the substrate (*Lundy and Sujjavanich 1994*). Hydrodemolition appears to provide a substrate surface with fewer microcracks, compared to milling. A clear relationship between surface preparation type and cracking or delamination could not be established in that study.

Traffic loadings are not normally of concern at early ages on the overlaid deck since only loads from construction activities are applied directly to the bridge overlay. However, it is rarely possible to close the bridge to traffic in the adjacent lanes. This may affect the overlay performance particularly when high traffic volume conditions combine with heavy truck traffic. This effect has been reported (*Ramakrishnan 1992; Sprinkel 1992; Ohama, Kwammen and Kamil 1990*), although not verified and has been considered a statistically insignificant factor by one researcher (*Guant and Sutton 1987*). Other studies indicated a possible effect from this factor (*Cope 1987; Ohama, Kwammen and Kamil 1990; Bishara 1979; Manning 1981*).

The bridge type is reported to influence the presence of cracking in bridge decks (*Cope 1987; Krauss and Rogalla 1996*). More flexible structures, such as steel structures, have more reported cracking (*Sprinkel 1992; Bishara 1979*). Continuous span structures are more susceptible to cracking than simple-span structures (*Krauss and Rogalla 1996*). Krauss and Rogalla also report that the use of epoxy-coated bars has probably increased the number and width of deck cracks.

The presence of substrate distress from the uncorrected structural deficiencies may cause cracks later or at early ages when tensile strength is low. The deck movement caused by the deflection or temperature change may result in reflective cracking through overlay thickness (*Bishara 1979, Sujjavanich 1996*).

2.3 MATERIALS

Several concrete material properties are thought to affect the susceptibility of bridge deck concrete to cracking. The use of LMC and MC results in lower permeability, but also increases certain undesirable properties as well. For example, Krauss and Rogalla recommend low early strength and modulus of elasticity reduce the cracking tendency of mixes. They suggest the use of low amounts of low heat of hydration cements with good quality, low shrinkage aggregates (*Krauss and Rogalla 1996*).

At early ages, the plastic and drying shrinkage rates can have a significant impact on cracking of LMC and MC (*LaFraugh and Zinserling 1987*). Considerable evidence shows that random cracks usually occur in the first 24 hours following placement and may extend to 19 mm (0.75 in) deep (*ODOT 1996, coring logbook*). The most frequently reported circumstances in which this occurs are under construction conditions of high w/c ratio mixture, high air temperature (>29 °C (84 °F)), and high wind velocity (*Bishara 1979*).

2.3.1 PLASTIC SHRINKAGE

Plastic shrinkage occurs during the time when concrete is still plastic and the evaporation rate is higher than the bleeding rate. Capillary menisci at the air-water interface penetrate into the concrete matrix (*Chandra and Ohama 1994*), tensile capillary pressure develops and plastic shrinkage cracking is a consequence. This action may occur in response to several individual conditions or a combination of these conditions, especially high air temperature, high concrete temperature, low humidity, and high wind velocity.

Low bleeding is normal for both LMC and MC. If curing protection is not sufficient at very early ages, plastic shrinkage cracking is likely to occur. Under dry ambient conditions, the cracks commonly appear in the first 24 hours (*LaFraugh and Zinserling 1987; Sprinkel 1992*). However no plastic shrinkage prediction models exist for either microsilica or latex modified concrete. Furthermore, no standard test method is available. Shrinkage has been measured at early ages using embeddable strain gauges (*Ohama 1995*).

2.3.2 DRYING SHRINKAGE

Moisture loss to the environment after the concrete is hardened causes drying shrinkage in concrete. LMC shrinkage is reportedly lower than conventional concrete due to the presence of the latex (see Figure 2.2) (*Ramakrishnan 1992*). However, it may be either larger or smaller, depending on latex type and latex to cement ratio (*Jonasson 1982*). Microsilica concrete typically reaches higher temperatures during early hydration, which causes higher thermal stress in the overlay. Researchers found that some high strength silica modified mixes undergo intense shrinkage at early ages without the normal initial swelling commonly noted in conventional concrete (*Paillere, Buil and Serrano 1989*).

Drying shrinkage cracks result from the continued loss of moisture in concrete after initial hydration. Although drying shrinkage occurs throughout the life on concrete, asymptotically approaching an ultimate value, the bulk of this shrinkage occurs within two years (*Bishara 1979*). Little data is available for MC, however the LMC shrinkage rate at early ages (first two weeks or three weeks after construction) is higher than normal concrete (*Bishara 1979; Public Works 1988, Vol. 119, No. 2*). Oregon DOT noted additional cracking during the first year following construction on an LMC deck (*ODOT 1996, construction logbook*). Normally this type of crack is finer and deeper than plastic shrinkage cracking (*ODOT 1996,coring logbook; ODOT 1996, construction logbook*).

In conventional concrete, several empirical equations have been proposed to predict shrinkage with time, particularly drying shrinkage (*Mindess and Young 1981; Bishara, Rose and Youssef 1978*). The relationships are normally defined as functions of curing time, relative humidity, shrinkage-half-time, or ultimate shrinkage.

Bishara proposed an empirical model to predict shrinkage of LMC after the first 24 hours (*Sujjavanich 1996*). This expression agreed well with his test data in which approximately 95 percent of total shrinkage at the early age occurred within the first two months.

LMC:

$$\varepsilon_{sh} = 817 \times 10^{-6} \times \left[\frac{t}{5.13 + t} \right] \tag{2-1}$$

Where ε_{sh} = shrinkage strain at time t
t = time, days

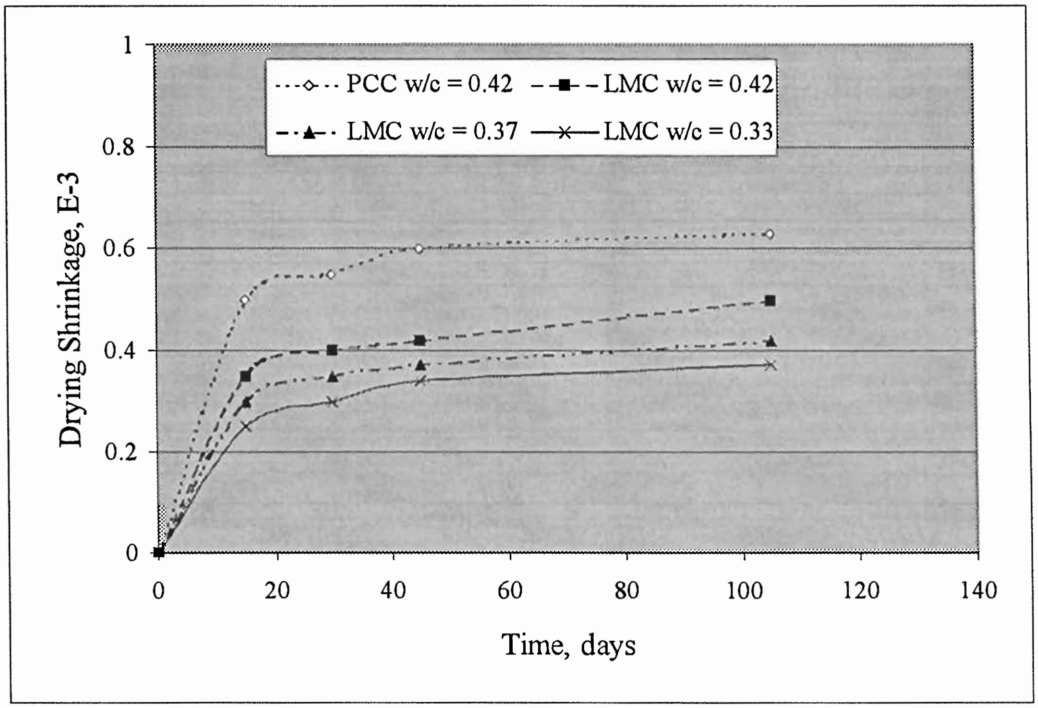


Figure 2.2 Comparison of drying shrinkage performance between LMC and conventional concrete (*Ramakrishnan 1992*).

Krauss and Rogalla proposed a restrained concrete ring test to judge the cracking tendency on concrete mixtures. This test allows various mixes to be compared on a relative basis. Details of the procedure can be found in Krauss and Rogalla's report.

Although not specifically classified as drying shrinkage, some researchers have identified differential shrinkage between the overlay and substrate as a possible cause of cracking and delamination (*Babei and Hawkins 1990; Public Works 1988, Vol. 119, No. 2*). Differential movement may cause cracking particularly in the first two to three weeks when the shrinkage rate is high. One study identified this differential movement as a primary cause of cracking in the overlay (*Cope 1987*). Occasionally, tight map cracking is reported during the first several months after construction. This might be caused by differential shrinkage and deck creep. The Interstate 182 project in Washington is an example of this cracking pattern (*ODOT 1996, coring logbook*).

3.0 RESEARCH RESULTS

Information was gathered in four areas to determine the causes of early-age delamination and cracking in LMC and MC overlays:

- Construction information from thirteen Oregon bridge deck overlay jobs were examined. Data were collected from construction diaries, weather records and condition surveys.

- Cores were taken from several bridge overlay projects in which different surface preparation techniques (hydrodemolition and milling) were used to prepare the substrate. These cores were evaluated using methodology described in ASTM C856, “Petrographic Examination of Hardened Concrete.”

- Twenty-three additional cores were extracted from three bridges to determine the depth of cracking and the correlation between reinforcing steel and cracking.

- Detailed construction monitoring was conducted on five bridges constructed in 1995. Environmental conditions at the time of placement, material properties, and early-age distress were recorded and evaluated.

The activities are described in detail below.

3.1 ANALYSIS OF CONSTRUCTION RECORDS

Information was collected on thirteen bridge rehabilitation contracts constructed between 1989 and 1992. The data were used to investigate correlations between various factors and the development of distress. The data are described below.

The construction reports of 13 selected LMC or MC bridge deck overlay contracts in Oregon were examined. These consist of 24 bridges of three structural types and varying age. The following data sources were available.

- Summary sheets prepared by ODOT personnel.

- Narrative reports from ODOT project personnel.

- Laboratory reports on concrete mix designs and material properties.

- Construction data including actual mix proportions and fresh mix properties such as slump, air content, and concrete temperature.

- General daily reports.

- Formal memoranda and handwritten notes from telephone communications.

- Condition surveys of the completed bridge deck.

The available data were not sufficiently detailed, particularly in the following areas.

- An inconsistent format was found on most projects.

- Inconsistent data collection and ambiguous data reporting were common.

- There was significant variation in the quality and quantity of data collected within and between projects.

- Most condition survey results were reported qualitatively in a manner that did not allow specific distress to be located or quantitatively described.

These limitations presented significant problems when attempting to determine the relationships between deterioration and construction procedures. Detailed descriptions of the analyses and evaluation are contained in Reference 4.

In summary, the evaluation failed to clearly identify any statistically valid cause of early-age cracking or delamination in LMC or MC bridge deck overlays. However, examination of the data suggests that milled surfaces are more likely to delaminate than surfaces prepared using hydrodemolition.

3.2 PETROGRAPHIC EVALUATION OF BRIDGE DECK CORES

Petrographic analyses of eight cores were conducted by Mr. Tom Patty of Erlin, Hime Associates (a division of Wiss, Janney, Elstner Associates, Inc.) in Austin, Texas. Cores were examined using the methods given in ASTM C856 "Practice for Petrographic Examination of Hardened Concrete." Two cores were taken from each of four bridge decks constructed using either LMC or MC as shown in Table 3.1. The following is a summary of Mr. Patty's findings. Details may be found in "Latex and Microsilica Modified Concrete Bridge Deck Overlays in Oregon: Interim Report" (*Lundy and Sujjavanich 1994*).

Table 3.1 LMC and MC core descriptions.

Core ID	Bridge ID	Surface Preparation	Overlay Type
4 5	Santiam Overflow No. 4 Interstate 5, MP 240.42, Bridge No. 8124	Hydrodemolition	MC
10 11	Holiday St. Exit Ramp, Interstate84, MP D-1.32 Left, Bridge No. 7036	Milling	MC
14 17	Overcrossing Neil Creek Road, Southbound, Interstate 5, MP 10.34: Bridge No. 9184	Milling	MC
19 20	Colestin Bridge Southbound, Interstate 5, MP 4.61, Bridge No. 9260A	Milling	LMC

The milling technique used on the Holiday Street exit ramp (Bridge No. 7036) produced significant microcracking in the paste and aggregates of the substrate in contrast to surface produced on the hydrodemolition substrate. Cores 14, 17, and 20 showed very little damage. However, Core 19 had significant cracking parallel to the interface.

The relative small number of cores examined precludes making definitive statements regarding the extent of microcracking resulting from milling compared to hydrodemolition. However, there is some evidence that hydrodemolition reduces the likelihood of this potentially damaging form of cracking.

3.3 CRACK EVALUATION

Oregon Department of Transportation personnel obtained 23 cores from three bridge deck overlays. All cores were taken at locations in which surface cracks were visible. The cores were examined to determine the thickness of the overlay and the depth of cracking. Detailed descriptions of each core are included in the Appendix (Table A.1). The results of the evaluation are summarized in Figure 3.1.

ODOT personnel used a pachometer to avoid reinforcing steel. Nevertheless, steel was encountered in approximately 1/3 of the cores (8 of 23). Cracking in these cores extended through the entire overlay thickness in most cases (Cores 15 to 23). Similar results have been reported for new, full-depth bridge decks by Krauss and Rogalla based on surveys of transportation agencies.

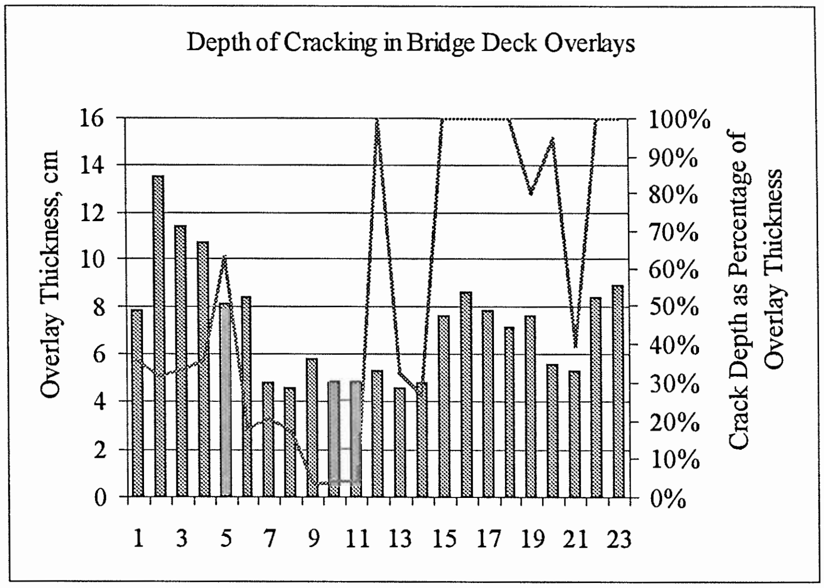


Figure 3.1 Bridge deck overlay core evaluation.

In contrast, cracking in cores located away from reinforcing steel was significantly shallower. The crack width at the overlay surface was also noticeably narrower.

3.4 DETAILED DATA COLLECTION ANALYSIS

The placements of overlays on five bridges were carefully monitored by Oregon DOT personnel. The information shown in Table 3.2 was collected for each placement. It was hoped that this information could be correlated with appearance of deck cracking thus identifying material properties or placement environments to be avoided. Essentially no cracking was noted in any of the five bridges in the first 12 months following placement.

This excellent result precludes identifying specific problem environments. However, the results do display the range of environments under which overlays can be successfully placed. A summary is shown in Table 3.3. The entire data set is included as Appendix A.

Clearly, bridge deck overlays can be placed over a wide range of environmental conditions without developing early age cracks. Although distress survey information is only available for the first year following construction, it appears that the low w/c ratios and high cement contents used by ODOT have not adversely affected the deck overlays.

The evaporation rates were calculated for each combination of recorded conditions using the nomograph shown in Figure 2.1. The average evaporation rate (0.20 $kg/m^2/hr$) is low compared to the commonly recommended value of 0.75 $kg/m^2/hr$ (0.15 $lb/ft^2/hr$). This may account for the relative lack of cracking evident at early ages in these bridge deck overlays.

Table 3.2 Data Collection On Five Oregon Bridges

Project ID	Placement Environment	Concrete Tests
• Contract number	• Air temperature	• Unit weight
• Bridge number	• Deck temperature	• Slump
• Project name	• Concrete temperature	• Air content
• Deck preparation	• Relative humidity	• Cement content
• Lane direction	• Wind speed	• w/c ratio
• Curing technique	• Time from batching to placement	• Compressive strength, 7-day
		• Bond strength

Table 3.3 Summary Of Data Collected On Oregon Bridge Deck Overlay Projects

Data Item	Count	Mean	Standard Deviation	Maximum Value	Minimum Value
Air Temperature, °C (°F)	120	17.1 (62.8)	5.5 (10.4)	30.0 (86)	7.2 (45)
Deck Temperature, °C (°F)	120	19.1 (66.4)	4.3 (7.7)	31.7 (89)	10 (50)
Concrete Temperature, °C (°F)	120	23.3 (74.0)	2.6 (4.6)	29.4 (85)	17.7 (64)
Relative Humidity, %	120	61.5	26.9	100	17
Wind Speed, kph (mph)	120	1.3 (0.8)	1.8 (1.1)	8.1 (5.0)	0 (0)
Evaporation Rate, $kg/m^2/hr$ ($lb/ft^2/hr$)	120	0.20 (0.04)	0.10 (0.02)	0.05 (0.01)	0.65 (0.13)
Time (batching to placement), minutes	120	45.8	30.3	117	3
Unit weight, kg/m^3 (lb/ft^3)	27	2,320 (143.0)	40 (2.4)	2,420 (149.2)	2,280 (140.7)
Slump, mm (in.)	21	137 (5.4)	38 (1.5)	191 (7.5)	76 (3)
Air content, %	27	4.8	1.0	7.8	3.8
Cement content, kg (lb)	14	300 (662)	12.7 (28)	340 (750)	293 (647)
w/c ratio	25	0.30	0.05	0.35	0.24
Compressive strength, 7-day, Mpa (psi)	21	38.9 (5644)	5.7 (830)	59.4 (8620)	32.9 (4780)
Bond strength, Mpa (psi)	28	1.5 (216)	0.3 (43)	1.9 (283)	1.1 (153)

4.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the information gathered and evaluated in this study, the following conclusions and recommendations appear warranted.

4.1 CONCLUSIONS

1. Petrographic analysis of cores from four bridges shows there may be differences between milled and hydrodemolition prepared decks. There appears to be an increased chance of microcracking when milling is used to prepare the deck compared to decks prepared using hydrodemolition.

2. Although a single cause or sets of causes for early age delamination and cracking could not be statistically determined, it appears that milled decks tend to display more cracking than decks prepared using hydrodemolition. Contractor experience plays a significant role in successful bridge deck placement, regardless of the deck preparation technique used.

3. Nationally reported increases in deck cracking is attributable to a variety of causes, however trends toward increasing strengths and lower w/c ratios appear to play a significant role.

4. Plastic shrinkage cracking can be reduced by adhering to the recommended 0.75 $kg/m^2/hr$ (0.15 $lb/ft^2/hr$) evaporation rate limit, placing only under cool conditions (night, if necessary) and insuring proper curing. Fortunately, under many Oregon weather conditions the evaporation rate limits are easily met.

4.2 RECOMMENDATIONS

1. If further investigations of bridge deck performance are to be undertaken, then records should be kept in a consistent format.

2. Distress survey data should be taken so that type, severity, and extent of each distress is clearly identified with the appropriate location on the bridge.

3. The restrained specimen test described by Krauss and Rogalla should be used whenever the relative cracking potential of various mixes are being considered.

4. Hydrodemolition should be used rather than milling to prepare the existing deck surface to receive the overlay unless alternate milling techniques can be identified that do not cause microcracking. Insufficient information was available to judge the performance of diamond grinding.

5. An evaporation limit of 0.75 kg/m^2/hr (0.15 lb/ft^2/hr) should be implemented.

6. ODOT should consider contractor experience and performance when awarding deck overlay contracts.

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APPENDIX A

DATA SUMMARY

Table A.1 Bridge Deck Core Log Summary

Location			Crack Type	Overlay Thickness, cm	Crack Depth, cm	Crack Depth as percentage of overlay thickness	Comments
Bridge number	Direction	Core Location, all distances in meters					
8302	WB	9.1 from 2nd deck joint	Transverse	7.8	2.8	35%	No crack visible in substrate
	EB	32	Transverse	8.6	8.6	100%	Reinforcing steel present
	EB	18.3	Transverse	7.8	7.8	100%	Reinforcing steel present
	WB	42.7 from 2nd deck joint11.5 from west end of bridge, 5.2 from rail	Transverse	13.5	4.3	32%	No crack visible in substrate
	WB	30.5 from 2nd deck joint	Transverse	8.9	8.9	100%	No crack visible in substrate
	WB	3.0 from east end	Forked	11.4	3.8	33%	New section of bridge; not overlay
	WB	9.1	Transverse	10.7	3.8	36%	New section of bridge; not overlay
	WB	18.2 from 1st deck joint, 4.6 from rail	Transverse	8.1	5.1	63%	No crack visible in substrate
	WB	7.6 from 1st deck joint, 4.6 from rail	Transverse	8.4	1.5	18%	No crack visible in substrate
	EB	30.5	Transverse	7.1	7.1	100%	Reinforcing steel present
	EB	Right lane, 15.2 from West end, 4.6 from rail	Transverse	7.6	6.1	80%	Reinforcing steel present
8094A	NB	4.6 from South end, 3.0 from rail	Transverse	8.4	8.4	100%	Transverse steel present, sample split on reinforcing
	NB	10.7 from south end, 5.2 from rail	Transverse	4.8	1.0	21%	Very tight surface crack
	NB	12.2 from south end, 4.3 from rail	Transverse	4.6	0.8	17%	Very tight surface crack
	SB	53.3 from North end, 4.6 from rail	Transverse	5.8	0.2	4%	Very tight surface crack
	SB	39.6 from North end, 4.6 from rail	Longitudinal	4.8	0.2	5%	Very tight surface crack
	SB	19.8 from North end, 4.3 from rail	Transverse	4.8	0.2	11%	Very tight surface crack
	SB	57.9 from North end, 0.3 north of deck joint, 4.6 from rail	Longitudinal	5.3	5.3	100%	Tight surface crack
8498	WB	4.6 west of 2nd joint, 1.5 from curb	Transverse	4.6	1.5	33%	Very tight surface crack
	WB	3.0 west of 1st joint	Transverse	4.8	1.3	26%	Very tight surface crack
	EB	1.5 from end, 6.1 from rail	Forked	7.6	7.6	100%	Tight surface crack
	EB	1.8 east of 2nd joint, 1.2 from curb	Longitudinal	5.6	5.3	100%	Reinforcing steel noted
	EB	1.2 east of 2nd joint	Transverse	5.3	2.1	100%	Reinforcing steel noted

Table A. 2 Data Collected From Bridge Deck Placements In 1995

Identification	Lane	Pour No	Air Temp °F	Deck Temp °F	Mix Temp °F	Rel. Hmd. %	Wind Spd. mph	Time min.	Core Str, psi	Unit Wt lbs/ cu ft	Slump, in.	Air, %	Cement Content lb	w/c Ratio	7-day Comp. Str, psi	Bond Str, psi
Bridge No. 9215	EB	1	61	68	80	73	2	90			3	4				283
	EB	1	63	75	85	71	5	90			3	4				283
Coquille River Bridge	EB	2	60	74	74	78	4	44		142	6.5	5.1	653.3	0.3	5530	
	EB	2	63	74	74	71	2	44		142	6.5	5.1	653.3	0.3	5530	
Hydrodemolition	EB	3	58	60	73	78	2	85								243
	EB	3	58	70	74	77	2	85								243
	EB	3	59	72	75	76	2	85								243
	EB	3	59	72	75	77	2	85								243
	EB	4	57	62	73	80	0	41								
	EB	4	58	62	73	86	1	41								
	EB	4	58	62	73	92	0	41								
	WB	1	48	50	73	95	0	117								153
	WB	1	48	50	73	99	0	117								153
	WB	1	48	50	73	100	0	117								153
	WB	2	46	53	71	94	0	76		144	5.75	3.8	659.9	0.3	5900	180
	WB	2	47	50	71	95	0	76		144	5.75	3.8	659.9	0.3	5900	180
	WB	3	45	51	65	100	0	77								217
	WB	3	46	53	65	99	0	77								217
	WB	4	45	55	70	100	0	42								165
Bridge No. 9216	WB	4	45	65	75	100	0	42								165
	EB	1	52	64	78	96	0	70		142	4	4.5	646.7	0.33		
	EB	1	53	66	80	91	0	70		142	4	4.5	646.7	0.33		
Coquille River Bridge	EB	1	54	66	72	90	0	70		142	4	4.5	646.7	0.33		
	EB	2	55	63	73	87	0	105		142	5	4	646.7	0.35	5400	
Hydrodemolition	EB	2	55	63	78	86	2	105		142	5	4	646.7	0.35	5400	
	EB	2	63	64	78	67	1	105		142	5	4	646.7	0.35	5400	
	EB	2	63	64	78	74	1	105		142	5	4	646.7	0.35	5400	
	EB	3	62	70	76	68	1	69								
	EB	3	70	70	76	62	1	69								
	EB	3	74	71	76	50	2	69								

Table A. 2 Data Collected From Bridge Deck Placements In 1995 (Continued)

Identification	Lane	Pour No	Air Temp °F	Deck Temp °F	Mix Temp °F	Rel. Hmd. %	Wind Spd. mph	Time min.	Core Str, psi	Unit Wt lbs/ cu ft	Slump, in.	Air, %	Cement Content lb	w/c Ratio	7-day Comp. Str, psi	Bond Str, psi
Hydrodemolition (cont.)	EB	4	75	71	78	45	1	61								
	EB	4	76	78	79	42	0	61								
	EB	4	77	79	80	41	3	61								
	WB	1	51	59	75	93	0	76								
	WB	1	51	60	73	91	0	76								
	WB	1	52	59	73	86	0	76								
	WB	2	48	62	75	94	0	107			7.5	5		0.31	5410	254
	WB	2	49	58	75	94	0	107			7.5	5		0.31	5410	254
	WB	2	49	63	73	92	0	107			7.5	5		0.31	5410	254
	WB	2	50	55	73	86	0	107			7.5	5		0.31	5410	254
	WB	3	52	58	73	82	1	49								
	WB	3	53	58	72	81	1	49								
	WB	3	54	58	72	74	3	49								
	WB	3	57	58	72	71	0	49								
	WB	4	65	63	72	61	1	86								247
	WB	4	66	68	75	54	1	86								247
	WB	4	70	73	75	50	1	86								247
Bridge No. 2208	WB	5	75	73	75	45	1	48								
	WB	5	75	74	83	45	0	48								
	NB	1	76	68	79	34	1	43								
Clackmas River Bridge, Estacada	NB	1	79	70	79	30	2	43								
	NB	2	80	78	79	32	4	30		141	7.25	6	684	0.33	5060	
Diamond Grinding	NB	2	80	80	79	30	2	30		141	7.25	6	684	0.33	5060	
	NB	3	83	89	79	30	3	36								
	NB	3	85	78	79	32	3	36								
	NB	4	81	85	79	29	5	32								
	NB	5	84	80	83	29	2	18								
	NB	5	86	85	79	30	3	18								
	SB	1	53	60	79	94	2	41								

Table A. 2 Data Collected From Bridge Deck Placements In 1995 (Continued)

Identification	Lane	Pour No	Air Temp °F	Deck Temp °F	Mix Temp °F	Rel. Hmd. %	Wind Spd. mph	Time min.	Core Str, psi	Unit Wt lbs/ cu ft	Slump, in.	Air, %	Cement Content lb	w/c Ratio	7-day Comp. Str, psi	Bond Str, psi
	SB	1	54	61	78	92	0	41								
	SB	2	57	61	64	83	0	44	7225							
	SB	2	57	61	78	86	0	44	7225							
Bridge No. 1617	SB	3	67	64	72	61	0	29	8710							
	SB	4	70	65	72	59	0	27		149	4.5	4.2	748	0.24	8620	
	SB	5	74	68	72	51	0	22	7500							
Clackmas River Bridge, Oregon City	NB	1	71	73	69	59	0	30								
	NB	3	69	67	80	59	1	35								
Diamond Grinding	NB	4	68	67	75	61	1	19								
	NB	5	69	68	75	61	1	16								
	NB	6	66	66	75	68	1	14		143	4.75	7.8		0.27	6720	212
	NB	7	64	66	75	73	1	22								253
	NB	8	62	66	75	77	1	16								
	NB	9	58	66	75	91	1	10								
	NB	10	68	73	85	54	0	28								
	NB	11	71	73	83	55	0	23	7230							
	NB	12	67	70	83	58	0	13		149	4.5	4.2		0.24		184
	NB	13	66	70	83	56	0	29								
	NB	14	66	70	75	54	0	26								
	NB	14	66	71	83	56	0	26								
	NB	15	66	70	75	54	0	13	6650							
	NB	16	60	65	75	67	0	12								
	NB	17	62	65	75	61	0	19								
	NB	18	55	66	75	79	0	30								
	NB	18	56	65	75	74	0	30								
	NB	19	55	66	75	79	0	9								
	NB	20	56	66	72	80	0	13								204

Table A. 2 Data Collected From Bridge Deck Placements In 1995 (Continued)

Identification	Lane	Pour No	Air Temp °F	Deck Temp °F	Mix Temp °F	Rel. Hmd. %	Wind Spd. mph	Time min.	Core Str, psi	Unit Wt lbs/ cu ft	Slump, in.	Air, %	Cement Content lb	w/c Ratio	7-day Comp. Str, psi	Bond Str, psi
Bridge No. 1617	NB	21	57	66	72	80	0	6								
	NB	22	54	66	72	78	0	5								
	NB	23	52	66	72	83	0	3								
Clackmas River Bridge, Oregon City	SB	1	64	55	72	22	0	26								
	SB	2	62	60	67	25	1	34								
Diamond Grinding	SB	2	67	62	67	22	1	34								
	SB	3	72	64	67	23	0	27								
	SB	4	72	70	67	20	1	19		143	7.25	5		0.31	6370	
	SB	5	72	72	67	19	0	18								
	SB	6	70	70	66	20	0	20								
	SB	7	73	70	66	22	1	21								
	SB	8	76	68	66	18	2	22								
	SB	9	75	77	70	17	3	22								
	SB	10	78	76	70	17	0	18								
	SB	11	78	76	70	17	0									
	SB	12	78	74	70	19	0	23								
	SB	13	72	76	70	18	0	15								
	SB	14	73	78	70	17	0	17		146	5.75	4		0.32	5990	

Table A. 2 Data Collected From Bridge Deck Placements In 1995 (Continued)

Identification	Lane	Pour No	Air Temp °F	Deck Temp °F	Mix Temp °F	Rel. Hmd. %	Wind Spd. mph	Time min.	Core Str, psi	Unit Wt lbs/ cu ft	Slump, in.	Air, %	Cement Content lb	w/c Ratio	7-day Comp. Str, psi	Bond Str, psi
Bridge No. 7657	SB	15	75	76	69	19	0	14								
	SB	16	72	71	69	17	0	9								
	SB	17	72	71	69	17	0	8								
MP 27.1 - Woodburn NCL	SB	18	72	71	69	17	0	7								
	SB	1	60	67	77	86	3	38								
Milling	SB	1	64	65	78	78	1	38								
	SB	2	58	62	77	91	1	33		141	3.5	5.4		0.3	4780	160
	SB	2	62	65	77	83	1	33		141	3.5	5.4		0.3	4780	160
	SB	3	58	62	73	96	1	37								
	SB	3	58	65	73	93	0	37								
	SB	4	53	58	68	39	2	38								
	SB	4	56	58	69	33	2	38								
	SB	5	52	59	68	36	1	36								
	SB	5	52	59	68	43	0	36								
	SB	6	52	59	68	41	0	33								
	SB	7	52	57	69	42	0	21		141	4.5	6.7		0.34	5040	