LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON

Interim Report

SPR Project Number 5288

Oregon Department of Transportation

LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON

Interim Report

SPR Project Number 5288

by

James R. Lundy

and

Suvimol Sujjavanich

Department of Civil Engineering
Oregon State University
Corvallis, OR 97331

Prepared for
Oregon Department of Transportation
Salem, OR 97310

and

Federal Highway Administration
Washington, D.C. 20560

January 1995

Technical Report Documentation Page

1. Report No. FHWA-OR-RD-95-06	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON Interim Report		5. Report Date August 1994 6. Performing Organization Code
7. Author(s) James R. Lundy and Suvimol Sujjavanich		8. Performing Organization Report No.
9. Performing Organization Name and Address Oregon State University Department of Civil Engineering Corvallis, Oregon 97331-2302		10. Work Unit No. (TRAIS) 11. Contract or Grant No. SPR #5288
12. Sponsoring Agency Name and Address Research Unit Engineering Services Section Oregon Dept. of Transportation 2950 State Street Salem, Oregon 97310	U.S. Dept. of Transportation Federal Highway Administration Washington, D. C. 20590	13. Type of Report and Period Covered Interim Report 1992-1993 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This interim report presents information collected from 24 bridge deck overlays constructed in Oregon between 1989 and 1993. Decks were placed on a variety of existing structures using hydroblasting, milling and diamond grinding surface preparation. All decks were latex or microsilica modified concrete.

Some decks experienced premature cracking and/or delamination. The objective of this study is to determine the possible cause(s) of these distresses and recommended procedures to correct the problem.

Statistical analyses of available environmental and construction information failed to clearly establish the causes of early cracking or delamination. Petrographic studies did show more microcracking was present in the substrate when milling was used compared to hydrodemolition.

17. Key Words	18. Distribution Statement
Latex modified concrete, microsilica concrete, overlays, bridge decks	Available through the Oregon Department of Transportation Research Unit

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

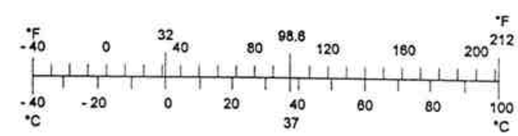
SI* (MODERN METRIC) CONVERSION FACTORS

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.				
		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

(4-7-94 jbp)

ACKNOWLEDGEMENTS

The authors would like to acknowledge the efforts of the Technical Advisory Committee. The assistance of Keith Johnston and Fred Lucht of Oregon Department of Transportation was invaluable. Also, the considerable talents of Mr. Tom Patty of Erlin, Hime Associates are gratefully acknowledged. The outstanding skills of Laurie Dockendorf are greatly appreciated.

DISCLAIMER

This document is disseminated under the sponsorship of the Oregon Department of Transportation in the interest of information exchange. The State of Oregon assumes no liability for its content or use thereof.

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policies of the Oregon Department of Transportation.

The State of Oregon does not endorse products or manufacturers. Trademarks or manufacturer's names appear herein only because they are essential to the object of this document.

This report does not constitute a standard, specification, or regulation.

This page intentionally left blank.

LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON
Interim Report

TABLE OF CONTENTS

LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON
Interim Report

LIST OF FIGURES

LATEX AND MICROSILICA MODIFIED CONCRETE BRIDGE DECK OVERLAYS IN OREGON
Interim Report

LIST OF TABLES

1.0 INTRODUCTION

The deterioration of concrete in pavements and bridge decks is a major concern for most transportation agencies. Increased focus by the media on the decayed infrastructure in the United States has helped agencies gain public support for many projects. Rehabilitation of bridge decks is one area receiving increased attention nationwide.

It has been estimated that FHWA will spend about 50 billion dollars to rehabilitate 40 percent of all bridges in the United States [*1*]. Although only a portion of these monies 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. 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

Deterioration of existing bridge decks is manifest in surface spalling and has been related to the contamination of the concrete and corrosion of the reinforcing steel. There are many factors which contribute to this deterioration such as the quality of concrete and workmanship, environment, cracking, chemical admixtures used, and the increased traffic. In addition, most existing bridges have no protection system to prevent salt infiltration. The accumulation of intruded salts through the pore structure of concrete will initiate and certainly exacerbates steel corrosion. This will be followed by additional cracking, spalling, or delamination of concrete from the increased volume of the corroded steel [*2*]. These factors reduce the service lives of concrete pavements and bridge decks.

Good performing repair materials and cost-effective application of these materials serve two purposes. First, effective materials and efficient techniques reduce public inconvenience and, therefore, user costs. Second, materials which reduce the bridge deck permeability provide a protection system against chloride and sulfate infiltration. Normally, the effectiveness of a bridge deck overlay is judged by many factors such as impermeability and durability. Although used extensively in the past, normal concrete has often been replaced by lower permeability microsilica and latex-modified materials.

Currently, latex-modified concrete (LMC) is widely accepted as a practical repair material for bridge deck overlays due to its low permeability and good bond with the substrate deck. Other properties such as tensile, flexural, and impact strength, and chemical and abrasion resistances, are also improved over portland cement concrete (PCC) [*3-5*]. Compared to the other repair materials such as PCC overlays, deck coating, and surface sealer, LMC overlays have been shown to be cost-effective with service lives of about 15 to 20 years [*4,6,7*]. Placement techniques are similar to the conventional concrete which further enhances the use of LMC.

Latex-modified concrete is a mixture of normal portland cement concrete and latex. The latex is typically included in the form of colloidal suspension polymer in water. The polymer latex suspension in water, usually a milky-white fluid, contains small, spherical, copolymer particles about 0.05 to 1.0 μm in diameter. After proper curing time under appropriate conditions, the polymer latex will coalesce to form a polymer film. The continuous film formed on the surface will act as a barrier to help maintain internal moisture and will benefit the curing stage. The film also forms a continuous matrix throughout the cement gel which bridges some capillary pores and microcracks. This results in concrete property improvements such as decreased permeability, increased durability, bonding, ductility, strength, and toughness [*5*]. In addition, LMC provides a workable concrete since the emulsion lubricates the fresh mix and the workability of fresh concrete at low water to cementitious material (w/c) ratios is notably improved [*5*].

Typical LMC mixes contain about 5 to 10 percent latex solid and have w/c ratios of about 0.30 to 0.40. Since most commercial latexes are in emulsion form, the total calculated water in mix must include the water in the latex emulsion [*8*]. In some cases, antifoaming or air detraining admixtures may be necessary to control air contents in the mixture [*5*]. Special equipment such as mobile mixers are used for quality production.

As a result of the environmental concerns of the 1970s, a new mineral admixture became available. Silica fume (microsilica), formerly discharged to the atmosphere, joined fly ash as a concrete admixture. When properly proportioned, silica fume improves the properties of both fresh and harden concrete. These properties are cohesiveness, compressive and bond strength, lower permeability and increased resistance to abrasion, cavitation, frost and chemical attack. The initial performance investigations from laboratories and cost studies from many states reported that microsilica concrete (MC) was a suitable alternative overlay material [*9,10*].

MC is manufactured by adding 3 to 21 percent silica fume to PCC. For example, for steel corrosion protection improvement, 3.8 to 10 percent of silica fume is sufficient [*11*].

Silica fume, a by-product of the silicon or ferrosilicon alloy industry, are very fine particles. The diameter is about one-hundredth of cement particle size. The product from the reaction of the silica fume and cement during hydration fills the pores in normal cement paste and reduces the volume of large pores. This results in void system modification and improvement of concrete properties [*12*].

A high-range water reducer is commonly used in the mix to counteract the increased water demand associated with the addition of this ultra-fine material. In some cases, where freeze-thaw resistance is required, an increase in the amount of air entraining agent used is needed to compensate for the effect of this material [*13*]. Although some agencies and researchers report that MC shows a tendency to develop plastic shrinkage cracking, most report that proper curing can reduce this problem [*13*].

Microsilica concrete can be effectively produced and transported by normally available equipment such as ready-mix trucks [*12,13*]. The use of common equipment generally results in lower costs compared to LMC which requires mobile mixers [*12*]. For example, the material costs of a MC bridge in Washington was about 65 percent of LMC material cost [*12*]. Obviously, the cost depends on several factors such as the percent of added silica fume and the furnished quantity. No definitive statement regarding cost can be made [*14*].

Despite several successful projects using both LMC and MC overlays, there are many documents [*3,9,15-17*] which report problems with these two materials in bridge deck overlays. Cracks and delamination (debonding) are the most typical distresses reported [*3,9,15-17*], especially for thin (≤ 2 in. (50 mm)) overlays. These distresses reduce the effectiveness of the overlay to prevent the intrusion of harmful chemicals. Therefore the increased cost of LMC and MC overlays may not be justified. Often, cracks and delamination occur shortly after placement [*10,15,18*]. Other minor distresses such as freeze and thaw scaling, extensive wear and reduced skid resistance have also been reported [*14,15,18*].

In summary, at present LMC is accepted as an effective material for use in bridge deck overlays in the United States and MC shows promise as an alternative material. Providing cracking and delamination can be avoided, both materials have improved properties over conventional concrete which should result in increased bridge deck lives. However, to minimize cracking and delamination, further study of the influencing factors and possible solutions are needed.

The conventional procedure for working with LMC and MC bridge deck overlays is similar and can be classified into four steps:

1) **Surface Preparation**. Following the repair of deteriorated areas in the existing deck and substrate, the surface is scarified to a minimum depth of 1/4 in. (6 mm) to ensure all unsound and contaminated concrete is removed [*7,14,15*]. Several methods are used including scabblers, jackhammers, shotblasters, milling machines, and hydroblasting (hydrodemolition). Some states (Michigan, Illinois, and Maryland) report hydroblasting to be the most effective [*15*]. In addition to saving labor and reducing noise and dust, this method does not damage existing sound concrete and prepares the surface for overlay in one pass. However, the production rate is much lower than mechanical scarification. Following scarification, air or sandblasting is used to

remove any laitances [*9,14*]. Checks for unsoundness or delamination of the existing deck are usually conducted using a chain drag or other suitable methods as the work progresses.

The clean, prepared surface is wetted prior to overlay placement. Soaking, commonly for 24 hours, is used to ensure a saturated condition [*11*]. A bonding material is normally placed before the overlay to provide a better bond between overlay and substrate concrete [*18*]. For LMC overlays placed under normal conditions, some states require a 1 hour prewetting with a slurry of sand, cement, and latex mixture or a latex emulsion on the prepared deck prior to overlay placement [*19*]. Other states limit the prewetting period to 20 minutes to avoid setting of the bonding agent. Some MC projects (i.e., Ohio) used grout containing 7.5 to 15 percent silica fume [*11,14*]. However, some studies report that primer application is unnecessary for LMC and MC overlays. The researchers believe that these materials provide satisfactory bond strength as a result of the superior properties of the LMC and MC-modified concretes [*5,9*].

2) **Mixing**. Component materials are accurately proportioned and thoroughly mixed with proper equipment. For LMC, a mobile mixer is commonly used. Mobile mixers are required to avoid long mix times which generate high air contents due to the foaming action of the latex emulsion [*19*]. For MC, either central plant batching and ready-mix truck transport or mobile mixers may be used. This overlay material is used with high-range water reducers (super-plasticizer) to eliminate workability problems.

3) **Placing**. Normally, the mixtures are discharged directly to the placing area. Sometimes other equipment such as buggies, buckets, or pumps are needed in restricted space areas [*20*]. Proper finishing must be completed before the overlay surface begins to dry. This is especially important for LMC overlays. In hot, dry, and windy conditions LMC should be placed before the bonding grout is dry, to prevent the slurry from acting as a bond breaker.

4) **Curing**. Curing of each type of overlay is different due to the characteristics of the material. LMC needs a minimum 24-hour wet cure to reduce plastic shrinkage [*7,21*]. However Babei [*18*], Lafraugh [*15*], and Kuhlmann [*2*] reported that prolonging the wet cure to 48 hours provides a stronger material with smaller cracks and lower permeability. After the wet cure, air cure is required to develop the continuous latex film. Early surface cracking is often traceable to exposure to hot, dry, and windy conditions [*5*]. As with normal PCC, shrinkage cracking can be minimized by following standard practices for hot weather concreting [*15*].

LMC has been proportioned using ASTM Type I, II, and III portland cements. For LMC using Type I cement, the overlay should be cured a total of three days before opening to traffic. However, for LMC using Type III cement, Sprinkel [*19*] and Kuhlmann [*20*] reported cure times of only one day before opening for service on Virginia and Delaware projects.

Microsilica concrete relies, in part, on pozzolanic activity for material strength gain. This reaction generally occurs more slowly than the cement hydration reaction and benefits from a wet cure. Several methods have been tried to achieve the goal of pozzolanic strength gain. Some organizations, such as Washington DOT [*12*] and Ohio DOT [*14*], use a wet cure method of moist burlap covered with polyethylene sheets for two days. Except for Washington DOT, the polyethylene is removed after 42 hours and the wet burlap resoaked for an additional six hours. This is followed by a dry cure for two days. Another curing method Ohio DOT used is wet cure with burlap and polyethylene sheet for three days [*12*]. Virginia DOT [*9*] tried two different methods. The first used wet burlap and polyethylene sheeting for one day prior to the application of curing compound. The second method applied curing compound immediately after texturing without any wet curing. Typical practice for New York State DOT is a one day wet cure with wet burlap and polyethylene sheeting followed by three more days curing under polyethylene sheets [*10*]. However, Luther [*11*] recommended continuing the wet burlap cure for at least three days for the best results.

1.2 OBJECTIVES

From the discussion, it is obvious that the construction of LMC/MC overlays is quite complicated. The performance of the overlay can be impacted by a variety of factors including deck preparation, material quality, curing, placement techniques, bridge condition, and environmental conditions. The objective of this study is to examine existing bridge decks to determine if the relative influence of these factors can be determined.

1.3 SCOPE

By design, this project is limited to observations gathered from existing bridge decks in Oregon. Considerable information was gathered from construction diaries and other subjective project information. Wherever possible, quantitative data were used. However, the bulk of the information is observational.

This page intentionally left blank.

2.0 DECK PREPARATION

The Oregon Department of Transportation (ODOT) has allowed decks to be prepared for overlay using a variety of techniques. To date, milling, grinding, and hydrodemolition have been used. Milling and hydrodemolition have been used most widely.

2.1 PREPARATION TECHNIQUES

All of the procedures have as their main purpose, the development of a sound substrate to which the overlay will bond. Milling and grinding prepare the substrate through the removal of a specified thickness (i.e., 1/4 in. (6 mm)). Localized removal of unsound concrete is often necessary. Normally, pneumatic pavement breakers or chipping hammers are used to remove unsound concrete.

In contrast, hydrodemolition equipment is designed to remove all unsound concrete in a single pass without resorting to localized hand work. The success of this procedure relies on the skill of the operator and the quality of the equipment.

Each type of deck preparation has advantages and disadvantages. Only the development of microcracking in the existing deck for two preparation methods is examined herein. This was carried out through petrographic analysis of cores.

2.2 PETROGRAPHIC ANALYSIS

Petrographic analysis of 8 cores was conducted by Mr. T.S. 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 bridges. The bridge substrates had been prepared using either milling or hydrodemolition. Much of the information contained in this section was taken from reports submitted by Erlin, Hime Associates [*26*]. Other details can be found in Appendix A.

Cores were taken from bridges with both MC and LMC overlays located throughout the state as shown in Table 2.1. Photos of each of the cores are shown in Figure 2.1. Figures 2.2, 2.3, and 2.4 show close-up photos of the interface of Cores 4, 10, and 11, respectively. Figures 2.5 to 2.8 show higher magnification photographs of Cores 17 and 19. Patty [*26*] reported the following with regard to the cores.

Table 2.1. LMC and MC core locations.

Core ID	Bridge	Surface Preparation	Overlay Type (LMC/MC)
4 5	Santiam O'Flow No. 4 I-5; MP 240.42; Br. No. 8124	Hydroblasting	MC
10 11	Holiday St. Exit Ramp I-84; MP D-1.32 Left; Br. No. 7036	Milling	MC
14 17	O'xing Neil Creek Rd Southbound I-5; MP 10.34; Br. No. 9184	Milling	MC
19 20	Colestin Bridge Southbound I-5; MP 4.61; Br. No. 9260A	Milling	MC

The underlying original concrete in Cores 4 and 5 contained a siliceous gravel, top size 1 1/4 in. (32 mm), and a natural siliceous sand. The overlay mix had a much smaller graded siliceous pea gravel, top size 3/8 in. (10 mm). The paste in the original deck concrete was lighter in color than the overlay and had an estimated 5 to 5 1/2 bags of cement per cubic yard, with no fly ash, and a water/cement ratio estimated at 0.45. The mix was air-entrained and had an air content estimated at 7 to 8 percent. In comparison, the darker colored overlay mix was estimated to have 6 bags of cement with about 1 to 1 1/2 bags of fly ash. The paste in the overlay had an estimated water/cement ratio of 0.40 and about 6 percent entrained air.

The interface or contact between the overlay and original concrete was characterized as being irregular, with about 1/4 to 3/8 in. (6 to 10 mm) of relief, and a zone of chalky, soft paste on top of the irregular surface. The paste within the light-colored contact zone contained fly ash, indicating that it was associated with the overlay mix at time of placement. Phenolphthalein applied to freshly broken surfaces did not indicate that the soft chalky material was carbonated. Some discontinuous shrinkage cracks were noted within the soft chalky zone but, when the samples were broken in the laboratory, bond strength along the contact appeared good. When Cores 4 and 5 were broken in the laboratory, other cut and polished sections showed the overlay to be well bonded to the original concrete. The surface region of the original deck concrete was free of microcracking in the paste as well as the aggregate particles in contact with the interface surface. Additional details of the petrographic examination are summarized in the attached Study Sheets contained in Appendix A.

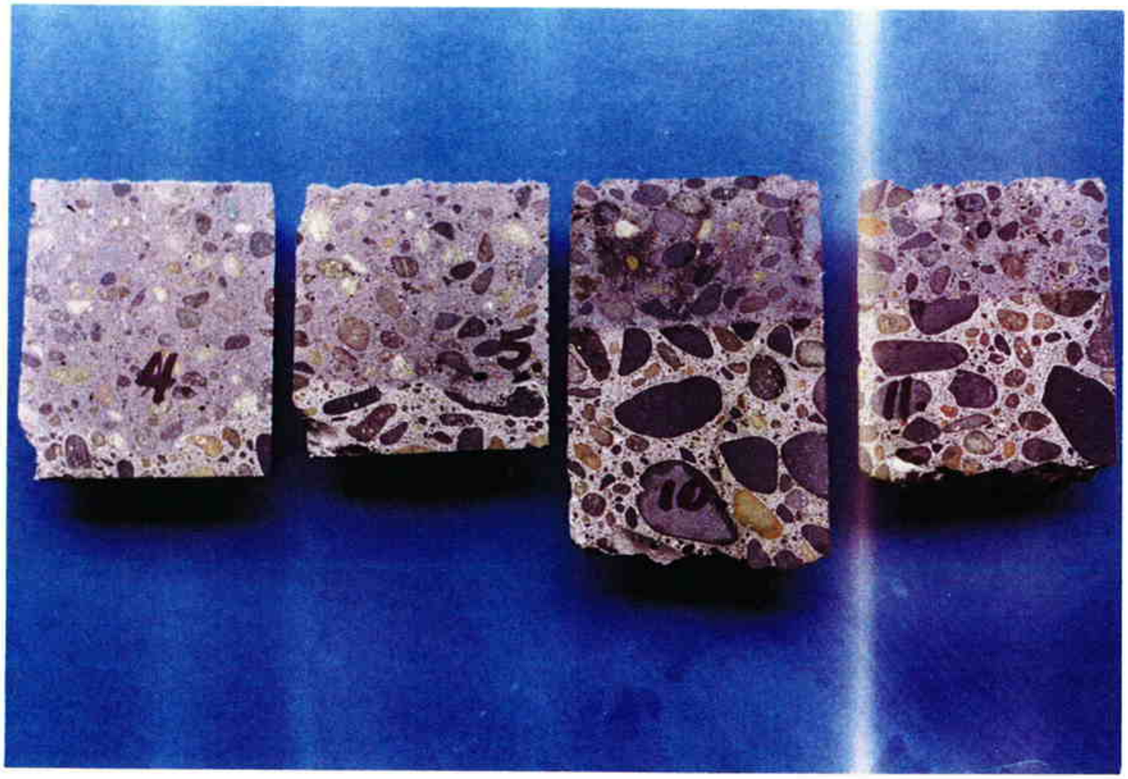


Figure 2.1a. Cores 4, 5, 10, and 11 Cut and Polished for Examination.

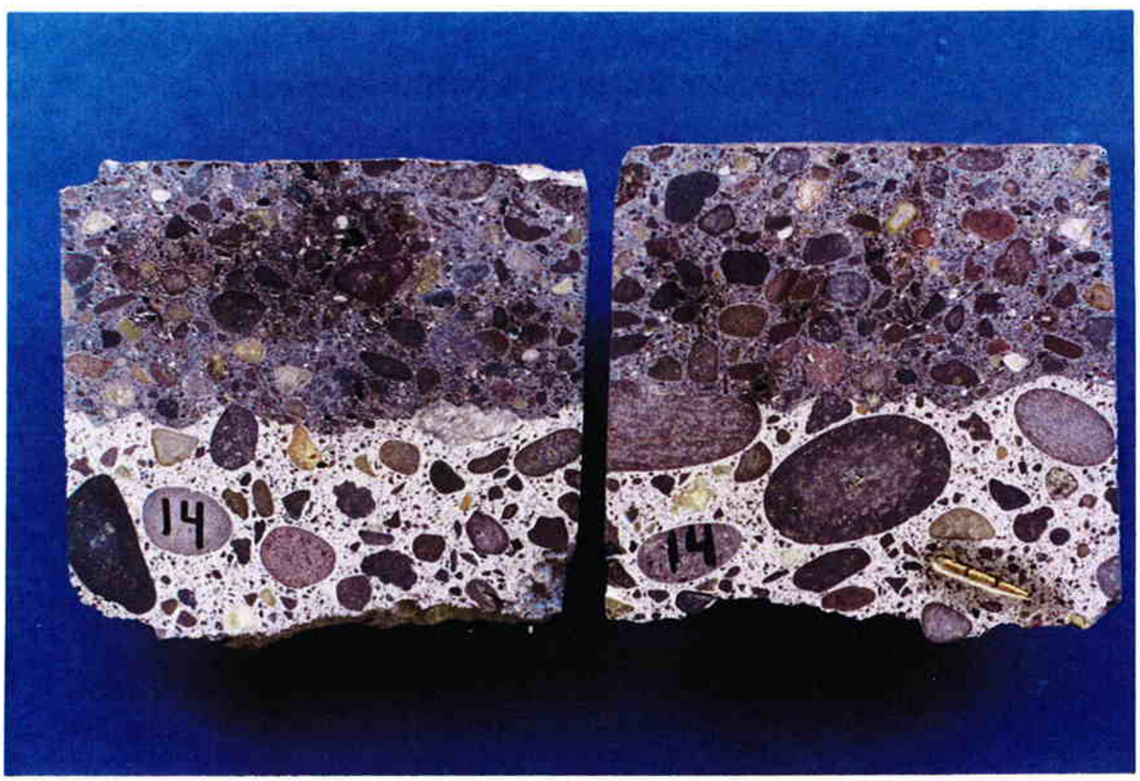


Figure 2.1b. Cut and Polished Section of Core 14.

This page intentionally left blank.

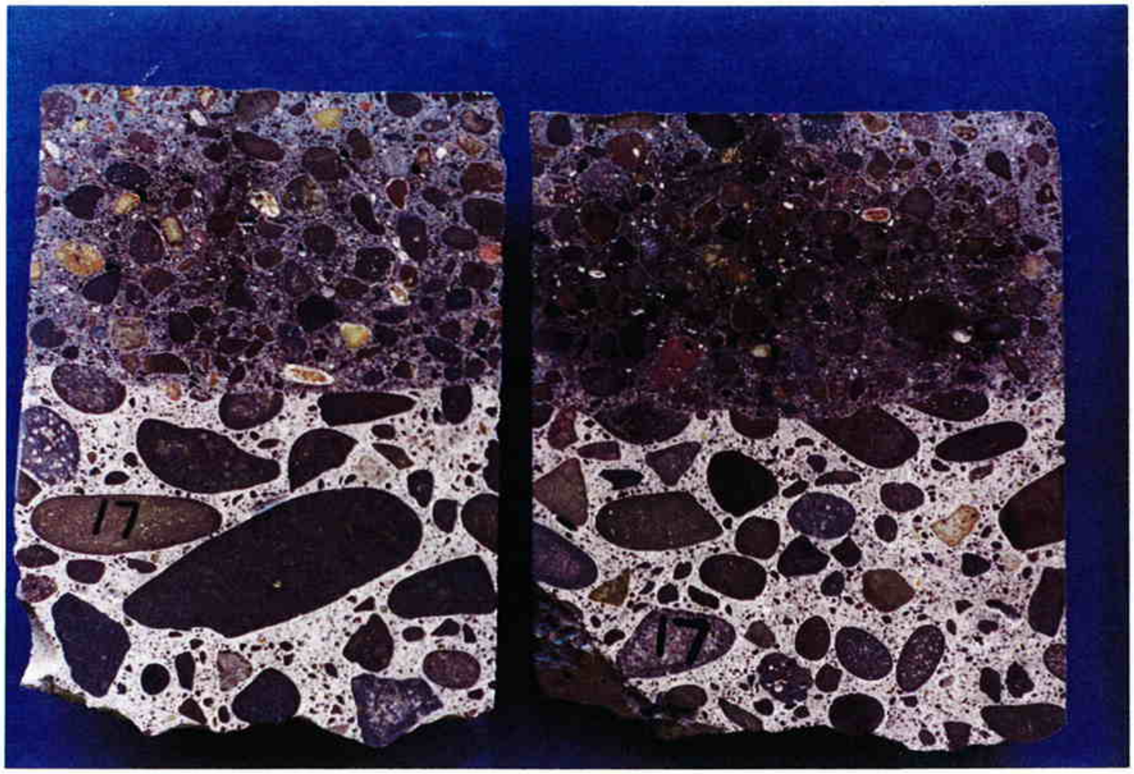


Figure 2.1c. Cut and Polished Section of Core 17.

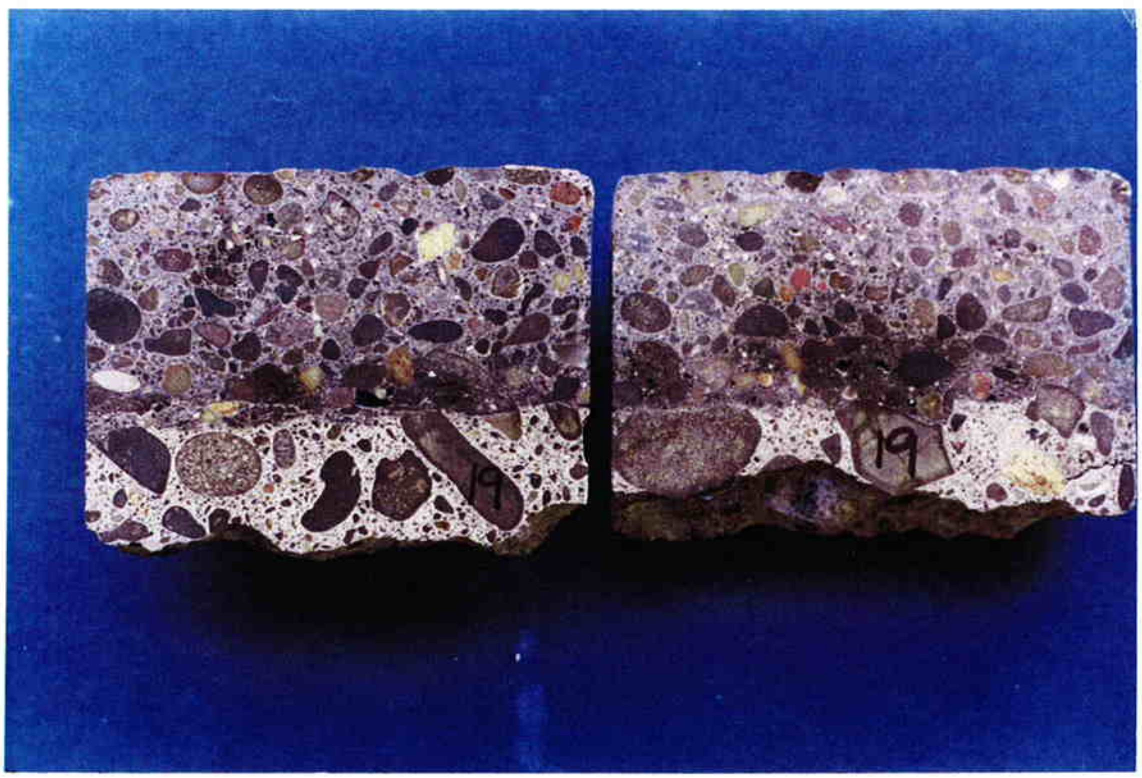


Figure 2.1d. Cut and Polished Section of Core 19.

This page intentionally left blank.

Figure 2.1e. Cut and Polished Section of Core 20.

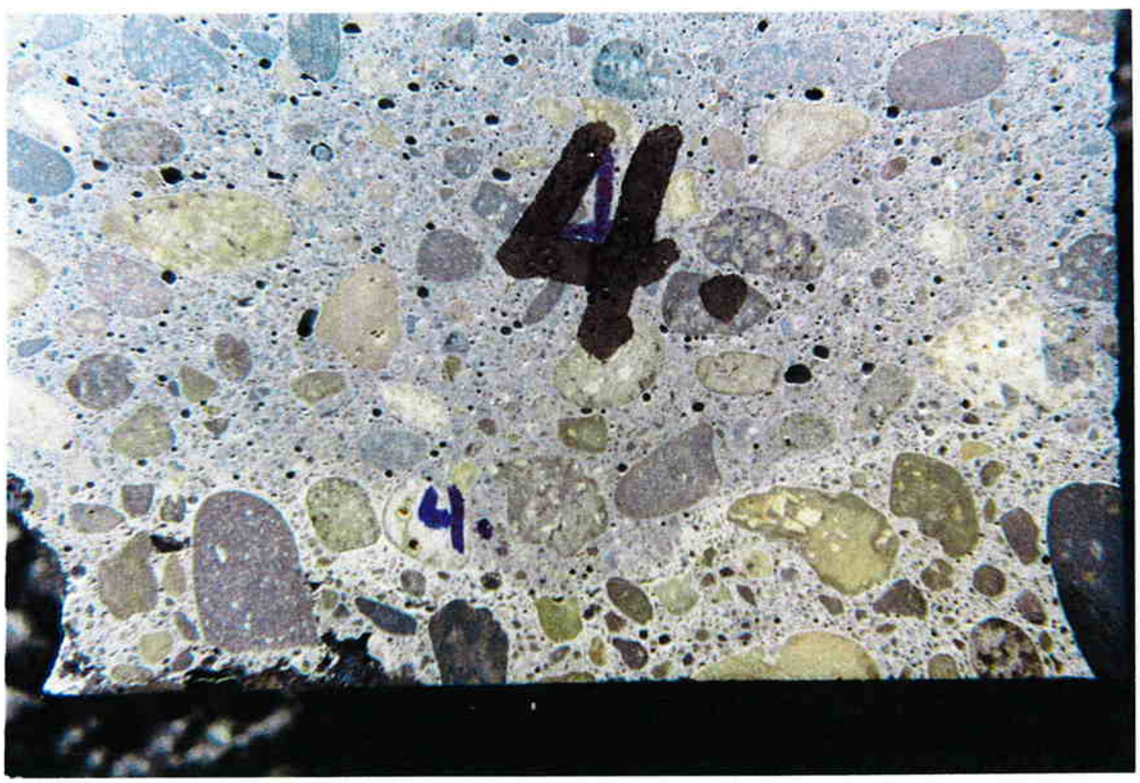


Figure 2.2. Close-Up View of Core 4 Showing the Overlay (Dark Concrete) in Contact with the Original Bridge Deck Concrete (Lighter Colored). Note fairly irregular contact surface. (Magnification about 2X.)

This page intentionally left blank.

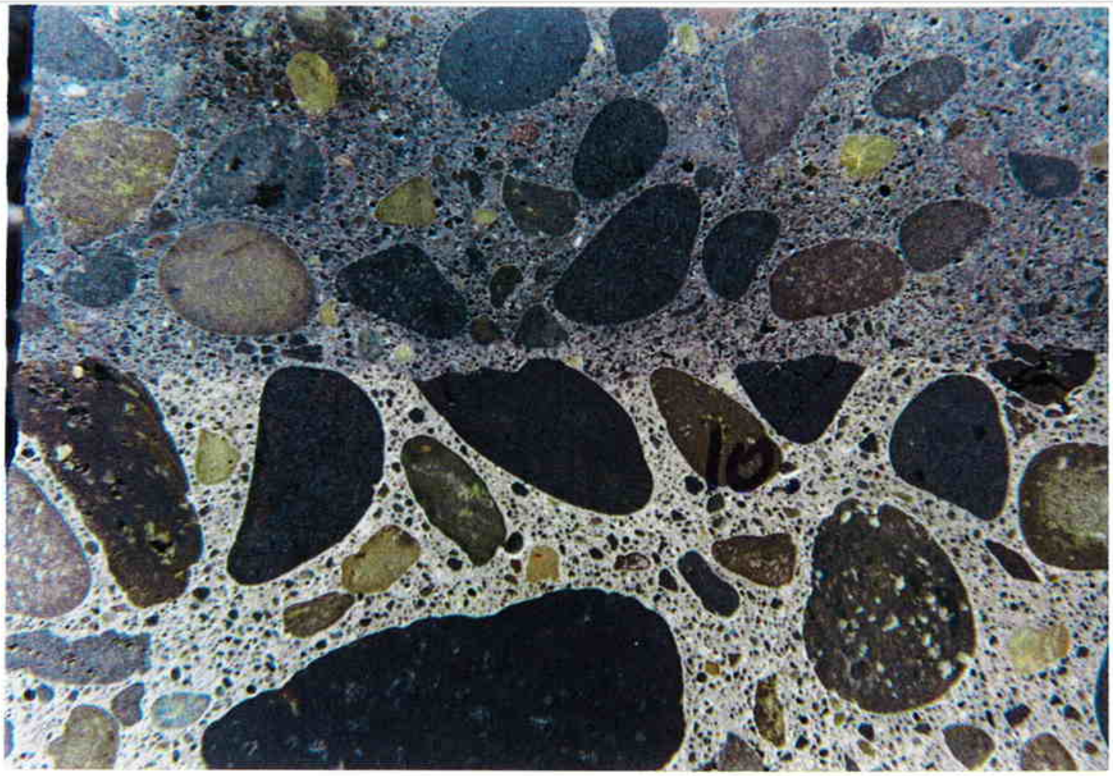


Figure 2.3. Close-Up of Core 10 Showing Interface Surface Between Overlay (Dark) Concrete and Original Deck Concrete (Lighter Colored).

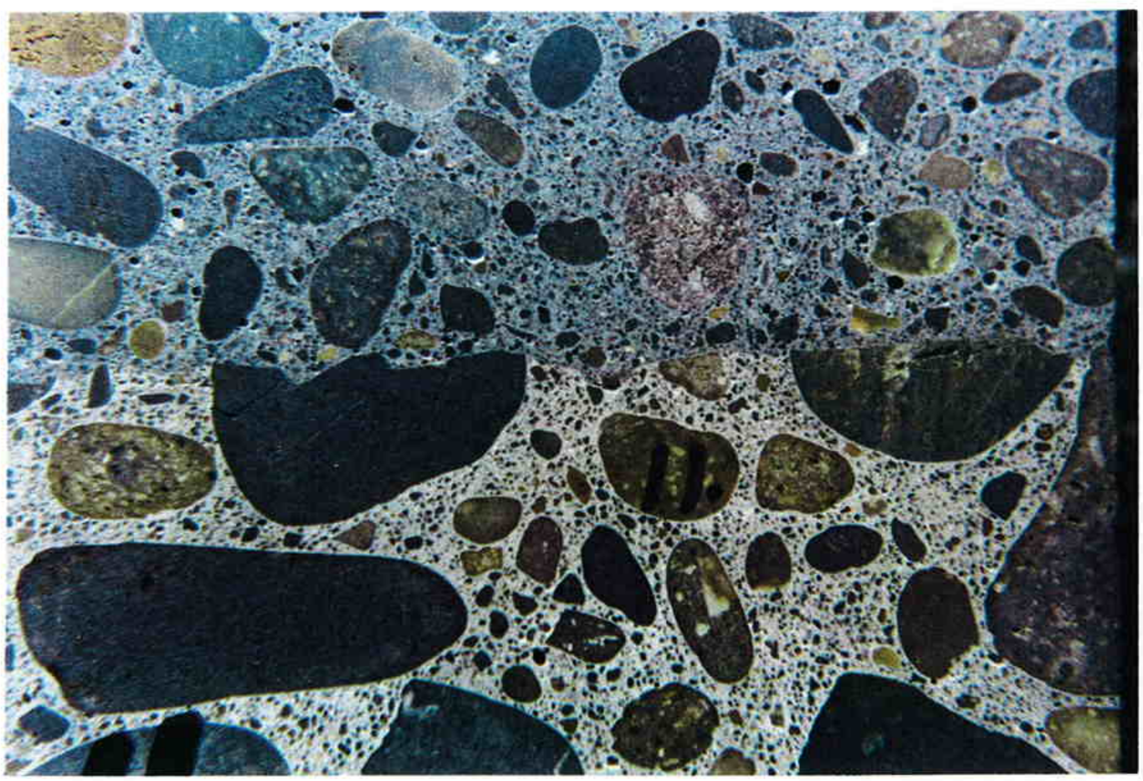


Figure 2.4. Close-Up of Core 11 Showing Interface Surface Between Overlay and Original Concrete.

This page intentionally left blank.

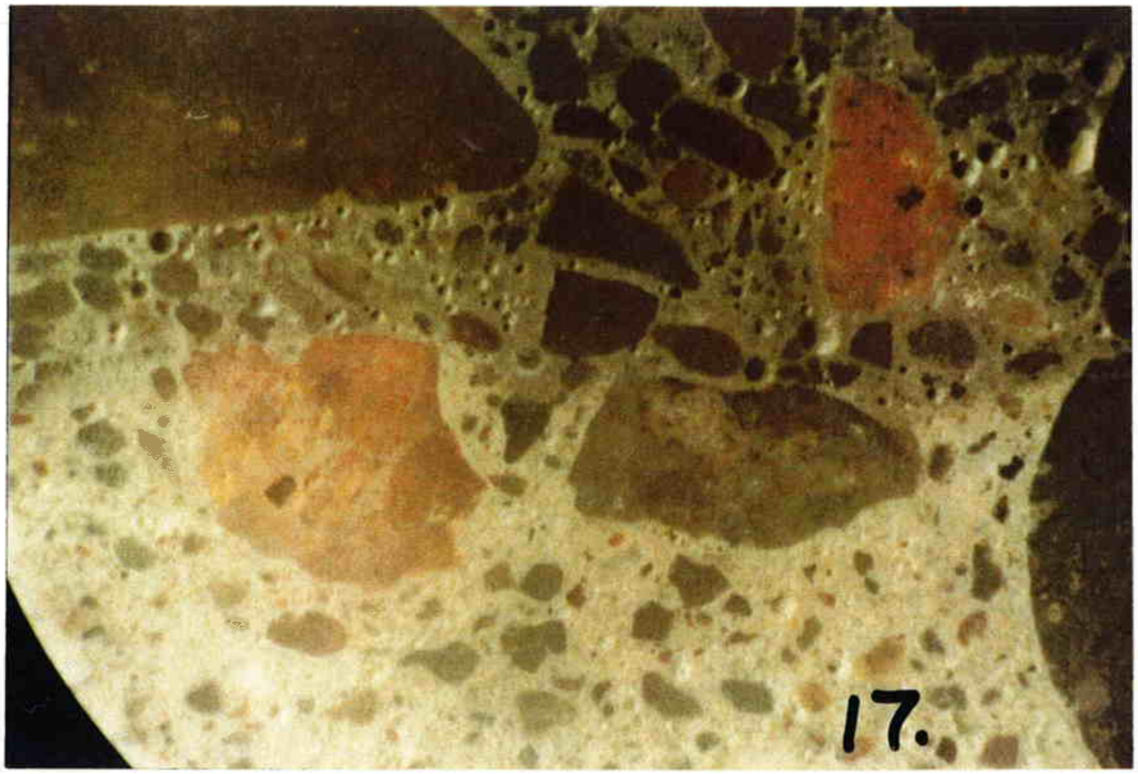


Figure 2.5. Close-Up View of Interface Surface Between Overlay and Original Concrete of Core 17. (Magnification about 10X.)

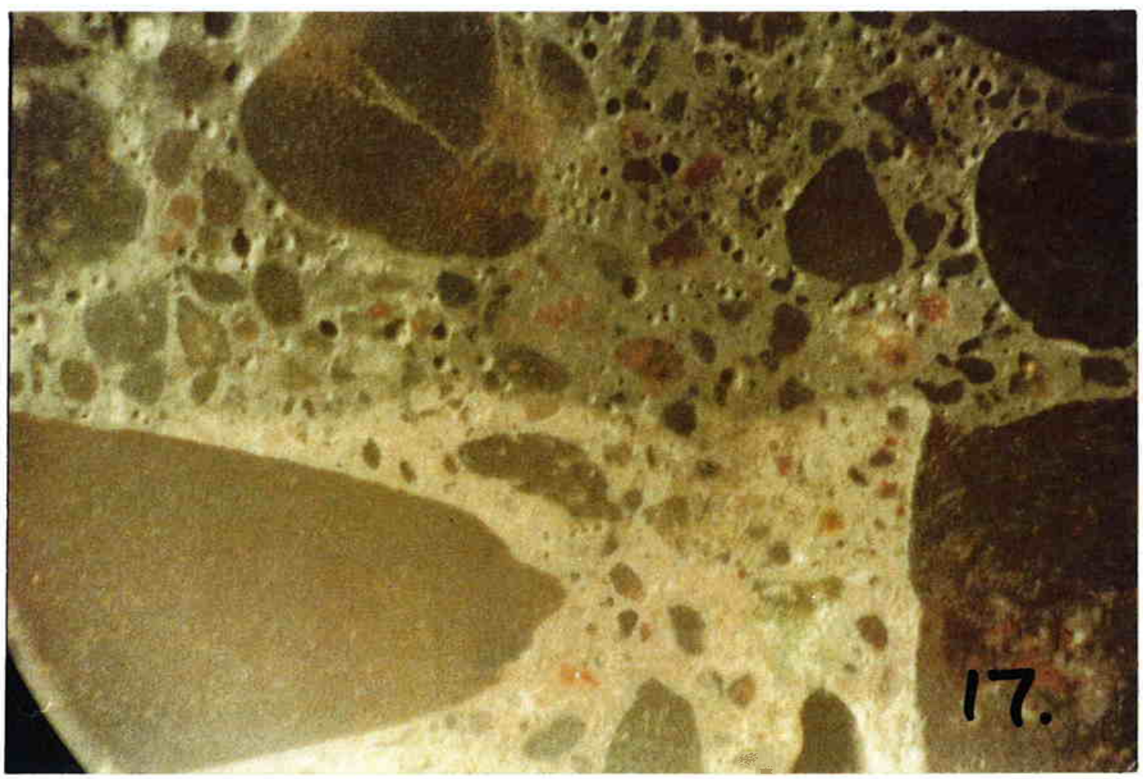


Figure 2.6. Close-Up of Core 17 Showing Contact Surface Between Overlay and Original Concrete. (Magnification about 10X.)

This page intentionally left blank.

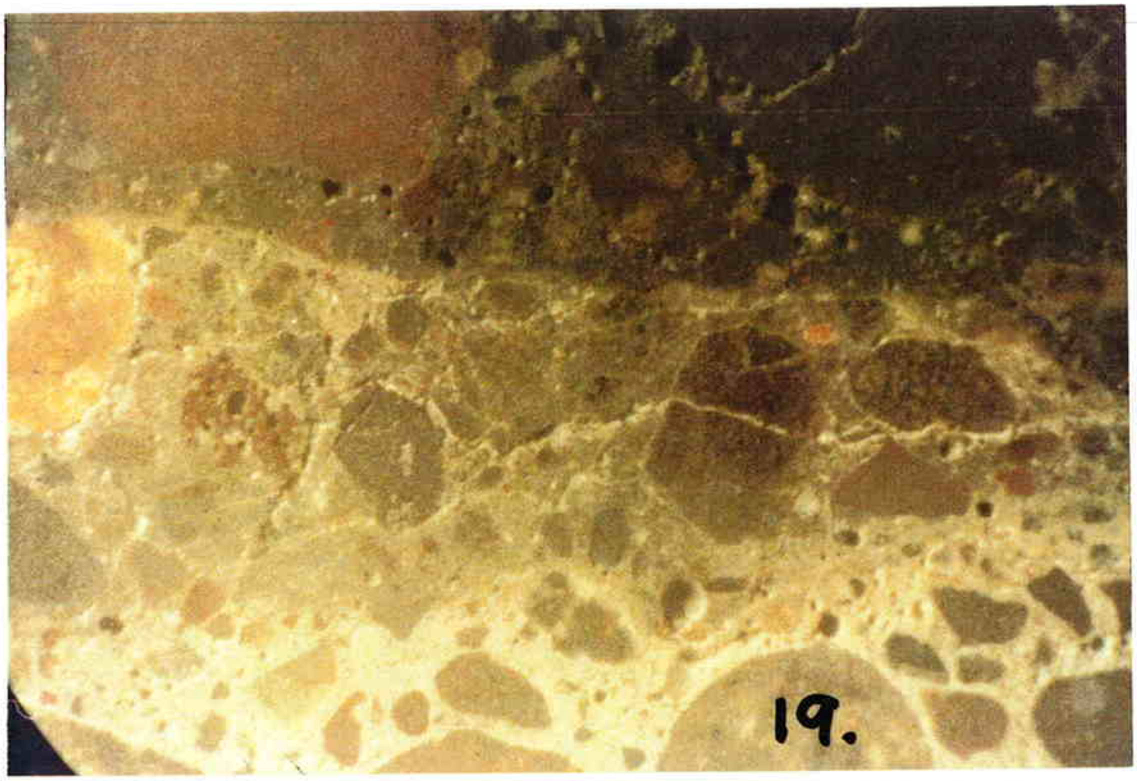


Figure 2.7. Close-Up View of Fracture Zone Associated with the Interface Between the Overlay and Original Concrete Observed in Core 19. (Magnification about 10X.)

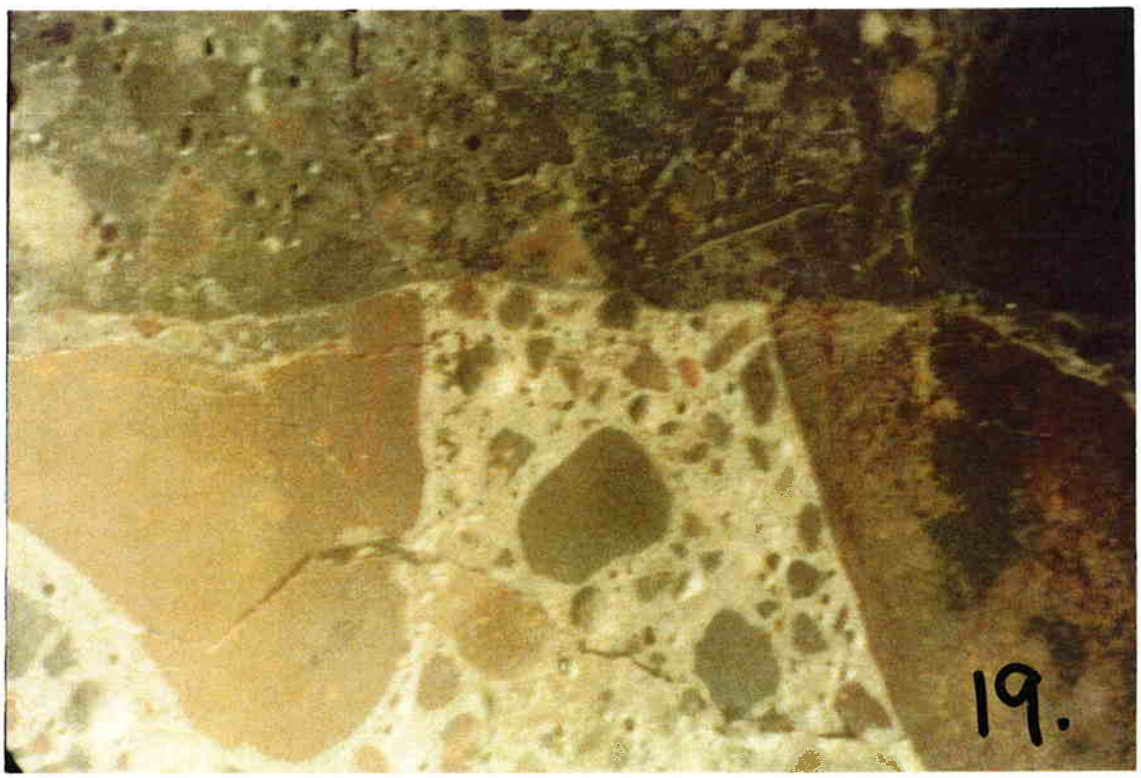


Figure 2.8. Another View of Core 19 Showing Fracturing Associated with the Contact Surface Between the Overlay and Original Concrete. (Magnification about 10X.)

Cores 10 and 11 exhibited a darker colored overlay mix with a depth of 1 5/8 to 2 in. (41 to 50 mm). The coarse aggregates were well-rounded siliceous gravels; however, the top size noted for the overlay mix was 3/8 to 1/2 in. (10 to 13 mm), compared to 1 1/4 in. (32 mm) for the original concrete. The paste in the original concrete contained an estimated 5 1/2 bags of cement per cubic yard and showed features which suggested a water/cement ratio of about 0.45. No fly ash was observed and the air void system was rather poorly entrained and had an air content estimated at 3 to 4 percent. The darker overlay mix in both cores showed a moderately high cement content estimated at 7 to 7 1/2 bags per cubic yard with no fly ash. Optical features of the hydration products indicated a water/cement ratio estimated at 0.38 to 0.40.

The interface in Cores 10 and 11 was relatively even with a relief no greater than about 1/8 in. (3 mm). The interface or contact surface was clean and uniform in color. The bond strength between the overlay and the original concrete appeared high. However, the samples showed a significant number of microcracks in the paste and fractures within the aggregate in contact with the interface surface. One section of Core 11, when broken in the laboratory, showed some preference to fracturing horizontally within the original concrete 1/8 to 1/4 in. (3 to 6 mm) below the interface surface; however, the bond at the interface appeared excellent.

The overlay mix represented in Cores 4, 5, 10, and 11 contained a well-rounded siliceous gravel with a nominal top size of 3/8 in. (10 mm). The gravel was composed of dark felsitic igneous rocks such as rhyolite and trachyte. The fine aggregate was a natural siliceous sand composed essentially of quartz, feldspar, and rhyolite-type rock fragments. Although some types of rhyolite are known to be potentially alkali reactive, evidence of alkali-silica reaction producers was not detected in the overlay mixes.

The overlay mix in Cores 14, 17, 19, and 20 was significantly darker than the original mixes. Optical studies indicated the overlay contained cement estimated at 6 to 6 1/2 bags per cubic yard, compared to 5 to 5 1/2 bags of cement per cubic yard for the original mixes. No fly ash mineral admixture was detected in any of the mixes for these cores.

The overlay mix generally had water/cement levels estimated at 0.40, compared to 0.45 to 0.48 for estimated water/cement ratios in the original concrete.

Observed air void systems in the overlay mixes consisted of well-developed, spherical air voids and estimated in the 5.5 to 6.5 percent range except for Core 19. The overlay mix for Core 19 was non-air-entrained, and had an estimated air content of only 1 to 2 percent. The air contents in the original concrete mixes generally were in the 5 to 6 percent range.

The interface zone of contact between the overlay and original concrete in Cores 14 and 17 (seen in Figures 2.3 and 2.4) was clean, smoothly undulating with a maximum relief of 1/8 to 1/4 in. (3 to 6 mm) Many of the coarse aggregates in contact with the interface appeared to have been shotblasted or sandblasted; others were smooth and rounded. No significant fracturing of the original concrete was found in Cores 14 and 17. Photomicrographs illustrated in Figures 2.7 and 2.8 show the condition of the contact zone in Core 17.

Traces of alkali-silica gel were observed in the original underlying concrete portion of Cores 19 and 20. The interface zone between the overlay and original concrete in Core 19 exhibited significant fracturing of the original concrete and within the coarse aggregate particles adjacent to the contact surface.

However, Core 20 did not show severe cracking. Minor fractures were observed, but they were not as pronounced as observed in Core 19. The photomicrographs illustrate the microfracturing subparallel to the contact surface within the original concrete. As observed in all the cores, the overlay concrete did not exhibit fracturing parallel to the interface. Evidence of partially removed overlay concrete superimposed with newer overlay mix was detected in Core 19.

Mr. Patty concluded the following:

1) The surface preparation procedure used on the original bridge deck represented by Cores 4 and 5 resulted in a relatively irregular surface with up to about 3/8 in. (10 mm) of relief. The procedure used in preparing the bridge deck surface represented by Cores 10 and 11 resulted in less relief but significant microcracking in the paste and fracturing of the aggregates just below the interface. The thin, light-colored chalky layer of paste above the interface contact in Cores 4 and 5 exhibited discontinuous microcracks; however, the bond quality or strength in all of the bridge deck overlays represented by these cores appeared high.

2) Based on the observations in the study, Cores 4 and 5 are assumed to represent hydrodemolition procedures and Cores 10 and 11 represent rotomilling methods of concrete removal.

3) The surface preparation used on the bridge decks represented by Cores 14, 17, and 20 removed original concrete with minimal "damage" which might influence long-term performance. However, Core 19 showed evidence that a previous overlay had been partially removed and superimposed with a more recent overlay. The partially removed overlay was severely fractured during its removal procedure. In addition, the original concrete observed in Core 19 had significant fracturing parallel to the contact interface. This observed fracturing could potentially affect long-term performance of the overlay represented by this core.

This page intentionally left blank.

3.0 DECK PERFORMANCE

Latex-modified and microsilica-modified bridge deck overlays generally perform very well. Occasionally distresses are noted shortly after the overlay is placed, often even before the bridge is reopened to traffic. These distresses, shrinkage cracking and delamination, are often attributed to construction problems and may be controllable through specification or inspection. This section examines other states' experience and reports the results of an investigation of several Oregon bridge deck overlays.

3.1 BACKGROUND

The experience of agencies using LMC is discussed first. Missouri, Kentucky, Washington, and Virginia DOTs reported satisfactory performance.

3.1.1 LMC

3.1.1.1 Missouri

The Missouri Department of Transportation investigated 24 LMC and seven latex-modified mortar (LMM) bridge deck overlay projects constructed between 1979 and 1981 [*22*]. These projects were surveyed after approximately five years of service. Most of these projects are located in areas where deicing salts are widely used. Common distress problems were delamination and cracking.

Both random and transverse cracking were reported; however, little longitudinal cracking was noted. The cracks, which ranged from moderate to severe, covered about 20 percent of total deck area. Some cracks penetrated through the overlay and into the deck substrate. Interestingly, it was reported that no correlation between the depth of the crack and the width of the crack at the surface was found. From statistical analyses, new bridge decks showed significantly less surface cracking, compared to rehabilitated bridge decks. In addition, LMC showed a lower percentage of cracks than LMM.

Debonding was found on only 0.57 percent of the total bridge deck area. The extent and severity of the delamination were not considered a serious problem. However, the inspection reported an increase in delamination of 35 percent in one initially non-debonded new deck.

Corrosion testing using copper-copper sulfate half cells was conducted on the bridges. Approximately 90 percent showed low voltage potential readings (more positive than -0.20 volt). This indicates that the LMC and LMM provides an effective protection system against chloride intrusion for at least 5 years. Since the performance of these LMC overlays is satisfactory, Missouri DOT recommended the use of LMC for bridge deck overlays. They suggest a minimum thickness of 1 3/4 in. (44 mm).

3.1.1.2 Kentucky

The Kentucky DOT [*17*] reported on the performance of both new and rehabilitated bridge deck overlays using two brands of latex in 1987.

Thirty-eight LMC bridge deck overlays using DOW latex, were placed on new and existing bridges. The existing bridges were closed to traffic during construction. An additional 10 existing bridges were open to traffic during construction. Post-construction surveys showed only five bridges were rated as poor due to spalling and delamination.

A second type of latex (Reichhold) was used on 49 overlays; most placements were on in-service bridges. Five of the 49 bridges were rated from fair to poor. In addition, after six years of use, four of six inspected bridges showed serious deterioration even though the first year performance of all the bridges was rated as excellent. Since most of the bridges are old (average 25 years) the presence of delamination might be related to the underlying deck deterioration [*17*].

Every bridge in this study showed the specific crack patterns which indicate that deck flexure and thermal changes may have contributed to deterioration.

3.1.1.3 Washington

Washington DOT investigated the performance of six bridges with LMC overlays in 1986 [*18*]. Most of them were less than five years old at the time of inspection. The superstructures of five bridges were prestressed or reinforced concrete continuous structures while the other was a 16-span prestressed bridge. Surveys were conducted on each bridge to determine extent of salt contamination. Salt contamination ranged from 0 to 83 percent of the total area. The after-overlay surveys showed no freeze and thaw scaling.

The test results showed that the 1 1/2 in. (38 mm) LMC overlays effectively retarded steel corrosion, although they were not impermeable to chloride intrusion. This observation was confirmed by reports from many states such as Indiana, Ohio, and Minnesota [*3*]. Surface deposited chloride could significantly penetrate only the upper

1/2 in. (13 mm) with chloride content decreasing with depth. Chlorides in the lower level of the overlay migrate from the existing contaminated deck. Only 4 percent of total deck area showed corrosion-induced deterioration and no spalling was found.

Various degrees of cracking were found in these bridges. Cracking of as much as 35 to 40 percent of deck area were found in some bridges. These cracks might develop from the shallow cracks of only 3/8 to 3/4 in. (10 to 20 mm) deep, propagating through the overlay thickness and in some cases into the substrate deck during the service life. Researchers believe this propagation is attributable to flexure of the deck under the service load and was aggravated by environmental effects and shrinkage.

Debonding was not a serious problem in this study, with only 0.05 percent of deck area delaminated. Debonding was reported immediately after curing on one bridge. From his study, Babei [*18*] believed that cracking might relate to delamination, but cracking was not the direct cause of delamination. Also, he concluded that the LMC overlays might last 25 years given good performance during the first 5 years. However, researchers recommended maintenance to maintain skid resistance, especially in the wheel tracks.

3.1.1.4 Virginia

In 1990, the Virginia DOT reported on the performance of 14 LMC bridge deck overlays, age ranging from 2 to 20 years [*6*]. The test results which included permeability, chloride content, bond and compressive strength, and general visual inspection showed satisfactory performance. The overlays effectively retarded increasing chloride ion content at the rebars which directly related to steel corrosion.

Numerous cracks were found in four of the 14 bridges. Wide plastic shrinkage cracks were the majority of cracks in two bridges while on the other two, many random hairline cracks from drying shrinkage were noted. A few cracks were believed to be caused from drying shrinkage, bridge movement and reflection from the deck substrate. Delamination was not reported in this study.

3.1.2 MC

In the past few years, interest in MC as an alternative overlay material has dramatically increased. Several states have conducted experimental projects. The experiences of Ohio, Virginia, Washington, Kentucky, New York, Tennessee, Michigan, Maine, Illinois, and Oregon are presented.

3.1.2.1 Ohio

The overlay placed on Ohio Bridge ASD-511 in 1984 is believed to be the first MC overlay in the United States [*10*]. This overlay was constructed to a minimum depth of 1 1/2 in.(38 mm), using conventional placing procedures with mortar from the concrete used as bond grouting. The non-air-entrained mixture contained 15.5 percent fume. When reported in 1988, surveys conducted at one week and one year showed the overlay to be performing well. Laboratory results from the rapid freezing and thawing test (ASTM C666) were poor. However, an inspection following the first winter reported only two cracks 16 in. (410 mm) long and 1 1/4 in. (32 mm) deep. No delamination was found.

In 1987, an air-entrained MC overlay was placed with 15 percent silica fume and cement-sand bonding grout [*10*]. A 3-month inspection reported no cracks. Laboratory petrographic analyses of the air void system and rapid freeze and thaw test results were both satisfactory. From data analyses and field observations of the same projects, Bunke [*14*] reported the possible tendency for MC overlays to crack when placed in variable thickness. He also suggested the percentage of silica fume could be reduced to 10 percent without adversely affecting permeability. The satisfactory performance resulted in Ohio planning to extend the use of MC overlays [*10*].

3.1.2.2 Virginia

In 1987, Virginia DOT overlaid a 46-year-old bridge with MC containing 7 to 10 percent silica fume [*9*]. The minimum overlay thickness was 1 1/4 in. One month after construction, the investigation showed satisfactory performance. Previous laboratory tests showed acceptable results could be achieved from MC containing 5 percent silica fume. The amount of silica fume was increased from 7 to 10 percent in the field to counter the effect of field variation. Ozyildirim [*9*] reported satisfactory results of strength characteristics, durability, and observed distresses. Nearly crack-free performance was observed, with only one 1 ft. (300 mm) long crack found extending through the overlay thickness. Delaminations which occurred along the longitudinal joint were believed to be associated with poor consolidation from an immersion-type vibrator. It is expected that VDOT will continue MC overlay projects in the future [*10*].

3.1.2.3 Washington

In Washington, a concrete-box-girder-type bridge was overlaid with air-entrained MC containing 9 percent silica fume to determine the feasibility of using MC overlays. The existing bridge deck had a chloride content exceeding 2 lb/cy (1 kg/m^3) over 64 percent of the deck area indicating the likelihood of rebar corrosion. A small area of delamination in the existing deck was noted. A 1 1/2 in. (38 mm) overlay was placed in 1988. As reported in 1989 [*12*], the deck was in good condition with no surface flaws.

Washington DOT also reported laboratory tests on LMC and MC. The results indicated comparable permeabilities for both materials. The MC had higher compressive strength than LMC. Although the average bond strength of microsilica concrete was lower, it was acceptable. MC had satisfactory skid resistant and rapid chloride permeability results comparable to LMC.

3.1.2.4 Kentucky

Kentucky DOT overlaid microsilica concrete on a three-span bridge (Bridge No.1120-44) in 1985. This MC overlay contained 15.5 percent silica fume, and used standard placing procedures with mortar from the concrete as a bonding grout. Four months after placement, an inspection reported no increase in cracking beyond some plastic shrinkage cracks noted shortly after placement. These cracks were attributed to delays in applying the curing protection. The 9-month inspection of this bridge discovered some increased cracking. The 2-year inspection also noted additional cracking but no delamination or spalling. In addition, the researcher reported that the overlay resisted chloride intrusion [*10*].

3.1.2.5 New York.

New York DOT initiated a laboratory study in 1984 to determine if MC was a suitable alternative overlay material [*10*]. Mixtures containing 13.9 percent silica fume and no air entrainment showed satisfactory property improvement and high potential as an alternative overlay material. In 1985, several experimental MC overlay projects were constructed using both a truck mixer and a mobile mixer. Placement followed conventional procedures using vibrating and roller screeds. Some plastic shrinkage cracks were found when a roller screed was used. The researcher also reported good workability with no ravelling and spalling associated with saw-cut grooves.

A later project placed in 1986 used nearly the same mix proportions. In this project, plastic shrinkage cracking was reduced by adjusting working schedule arrangements including evening placement, properly adjusting equipment, increasing consolidation and using a higher percentage of fine material. An inspection in 1987 showed a variety of surface distresses. Even within the same project, there was evidence of an unblemished surface in one lane and reflective cracks in another lane. Despite these defects, New York DOT concluded that MC is a viable alternative overlay material.

3.1.2.6 Tennessee

Tennessee placed their first MC overlay on a bridge across Obey River in 1986. This 4 in. (100 mm) overlay used 11.2 percent silica fume. The mix showed good workability and acceptable finishability, although the concrete was rather sticky. Standard batching, truck-mixed concrete, and a wet burlap cure were used. A 10-day inspection reported transverse cracks at about 5 ft. (2 m) intervals. A subsequent inspection at 6 months reported no changes. Good performance and high strength gain at early ages led Tennessee DOT to accept MC in high early strength applications for overlays. They scheduled this material for use on several later projects [*10*].

3.1.2.7 Michigan

Michigan DOT studied microsilica concrete containing 10 percent silica fume in the laboratory in 1985. Results showed that MC could be used as an alternative to LMC for bridge deck overlays. In 1986, two MC overlay projects were placed with a nominal thickness of 2 in. (50 mm) and full depth repairs in some areas. This project used conventional placement procedures, cement-sand bonding grout, and a roller screed. Both projects had acceptable workability for the fresh concrete and no plastic shrinkage cracks were reported. However, a few tight cracks forming rectangles were reported within two weeks regardless of the thickness of the overlay. Drying shrinkage at six months after construction was slightly higher than for previous LMC overlays. The rapid chloride permeability test results were lower than those of LMC but both were in the very low range. These successes have prompted Michigan DOT to plan additional laboratory studies and experimental MC projects [*10*].

3.1.2.8 Maine

The Maine DOT began investigating MC as a wearing surface on bridge decks in 1986. Two experimental bridges deck overlay projects were constructed in 1986. The overlays were 2 in. (50 mm) thick with 7.2 percent silica fume. Conventional placement procedures were used with a cement-sand bonding grout. Curing included 7 days of wet burlap followed by a 2-day dry cure before opening to traffic. These projects were reported free of cracks and delamination. Another project (3 in. (80 mm) thickness) was placed in the same manner in 1987 but no follow-up study was reported [*10*].

3.1.2.9 Illinois

Illinois placed two MC experimental overlays containing 11.1 percent silica fume in 1987. A modified bonding agent containing 15 percent silica fume was used prior to placement of the 3 in. thick overlays [*10*]. One project used a 4-day wet cure consisting of wet burlap and plastic sheets, while the other used a curing compound. Three months after placement the first project reported a few transverse cracks. There was no inspection report of the second project.

Another project was overlaid in 1987, using 11.2 percent silica fume concrete of various thicknesses from 1.5 to 4 in. (40 to 100 mm). The project was successful and no distress was noted.

3.1.2.10 Oregon

Seven MC overlays placed in 1989 were inspected one year after construction. Only two distresses, cracking and delamination, were reported [*23*]. Very fine cracking was found on all bridges in a random pattern, interconnecting to form a map pattern in some areas. These cracks occurred principally during the first few weeks after placement. A similar pattern of distress has been noted in LMC projects. Drying shrinkage was identified as the probable cause.

Delamination was noted near joints or cracks in a few cases. Most of them were found between the overlay and deck substrate during the first year. Size and location of the delaminations were found to relate to the overlay performance [*23*]. For example, it was hypothesized that liquids could seep through the cracks or joints and accumulate in the adjacent delamination. This results in increasing delamination and reduced overlay performance.

Several other states such as Wisconsin, Pennsylvania, Indiana, and Vermont also use MC. Many experimental projects were placed and the researchers reported success of the projects, but detailed performance data are not available [*10*].

3.1.3 SUMMARY

The overlay performance reports of several states can be summarized as follows.

1) Both materials, LMC and MC, perform well as an effective protection system when properly constructed and maintained, prolonging the service life of bridge decks about 15 to 20 years.

2) Cracking, especially random and transverse cracks, and delamination are the most commonly reported distresses. Cracking of the overlay increases the gross permeability of the overlay, thereby reducing the protection of reinforcing steel. Early cracking appears to be related to plastic and drying shrinkage. Although initially shallow, these cracks often propagate through the overlay. Additional cracking may develop or be aggravated due to flexural stresses from live loads or reflective cracking from the deck substrate.

3) Delamination is often reported; however, normally little area is affected. Debonding is not considered as serious a problem as cracking. Poor surface preparation and continued rebar corrosion are believed to be the main causes.

4) LMC is reported to be more sensitive to quality control, experienced workmanship, and working conditions than MC or normal PCC.

5) For MC, the deck chloride contamination was found to be unrelated to the development of surface flaws. However, since MC has been studied for only a few years, the available data reflect only early age performance. Follow-up studies are needed.

3.2 DATA COLLECTION

Information was collected on 13 bridge rehabilitation contracts in Oregon 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.

3.2.1 AVAILABLE DATA

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

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 report.

Formal memoranda and handwritten notes from telephone communications.

3.2.2 DATABASE DEVELOPMENT

From several criteria including simplicity, capability, efficiency, and DOT preference, the relational database, Paradox 4.0 was chosen to manage the data in tabular form. In addition to the capability to efficiently store, edit, search, sort, graph, and report, the simplicity of this database allows the user to easily update the database [27,28].

For easy organizing and manipulating, the data are grouped and stored in 10 different table forms. These consist of one key table and nine supporting tables. The tables are described in detail below. A summary of the input is shown in Table 3.1.

The key table "Project" which contains project ID, mix ID, and sample ID, was developed to identify and link the other data tables. Project ID is composed of three parts: xxxxx-yyyy-zz. These parts indicate contract number (xxxxx), bridge number (yyyy), and event (zz), respectively. The last part (event) distinguishes events which occurred on different dates under the same contract. For example, project ID 10972-6886-02 indicates an event (placement) for bridge 6886 in contract 10972. A subsequent placement would have another event number. By linking this project ID with the appropriate tables, the other information can be found. This coding system allows tracking of data.

Mix and sample ID are set according to the document number of the mix and sample data report for easy tracking and checking. These ID are the key link to other tables.

Table 3.1. Summary of data storage.

Table Name	Structure	Field Name	Field Type
Project	1	IDPROJECT	A30
	2	DATE	D
	3	CONTRACT #	A15
	4	BRIDGE #	A18
	5	IDMIX	A10
	6	IDSAMPLE	A20
General	1	CONTRACT #	A15
	2	BRIDGE #	A18
	3	COMPL.DATE	D8
	4	HIGHWAY	A80
	5	SPAN #	A4
	6	BEGIN MILEPOST	N
	7	END MILEPOST	N
	8	REGION #	A5
	9	BRIDGE TYPE	A50
	10	BRIDGE AGE YRS	N
	11	ADT	N
	12	% TRUCK	N
Aggregate	1	CONTRACT #	A15
	2	3/4 IN (COARSE)	N
	3	1/2 IN (COARSE)	N
	4	3/8 IN (COARSE)	N
	5	1/4 IN (COARSE)	N
	6	# 4 (COARSE)	N
	7	# 10 (COARSE)	N
	8	# 40 (COARSE)	N
	9	ELONG.%	N
	10	3/8 IN (SAND)	N
	11	1/4 IN (SAND)	N
	12	# 4 (SAND)	N
	13	# 8 (SAND)	N
	14	# 16 (SAND)	N
	15	# 30 (SAND)	N
	16	# 50 (SAND)	N
	17	# 100 (SAND)	N
	18	# 200 (SAND)	N
	19	ORG.PLATE #	N
	20	SAND EQUIV.	A8
	21	FINENESS FACTOR	N
	22	SAND SOURCE	A20
	23	AGGREGATE SOURCE	A20

Table 3.1. **Summary of data storage (continued).**

Table Name	Structure	Field Name	Field Type
Haul	1	IDPROJECT	A30
	2	BATCH TIME i	A10
	3	PLACEMENT TIME i	A12
	4	HAUL TIME i	A10
	5	CONC.TEMP.i	A8
	6	SURFACE TEMP. i	A8
	7	SLUMP i	A8
	8	AIR i	A8
Preparation	1	CONTRACT #	A15
	2	BRIDGE #	A18
	3	INITIAL PREP.TECH.	A50
	4	FINAL PREP.TECH.	A50
	5	BONDING AGENT USED	A25
	6	COMMENT 1	A80
	7	COMMENT 2	A80
Mix	1	IDMIX	A10
	2	MIX DESIGN	A2
	3	CEMENT (lbs)	N
	4	WATER (lbs)	N
	5	LATEX MIX (lbs)	A12
	6	SLURRY MC (lbs)	A12
	7	DRY MC (lbs)	A12
	8	W/C RATIO	A12
	9	CONC.TEMP	A12
	10	SLUMP (in.)	A12
	11	% AIR	A12
	12	FINE (lbs)	N
	13	COARSE (lbs)	N
	14	LATEX/MC TYPE	A20
	15	LATEX/MC MANU.'R	A25
	16	FLYASH TYPE	A15
	17	FLYASH (lbs)	N
	18	CONCRETE SUPPLIER	A25
	19	OTHER ADMIX.	A25
	20	OTHER ADMIX.TYPE I	A14
	21	OTHER ADMIX.TYPEII	A14
	22	OTHER ADMIXTYPEIII	A14
	23	OTHER ADMIX.DESIGN	A14
	24	ADMIX.TYPE IDESIGN	A14
	25	ADMIX.TYPEIIDESIGN	A14
	26	ADMIX.TYPEIII DESIGN	A14
Contract	1	BRIDGE #	A18
	2	CONTRACTOR NAME	A18
	3	BRIDGE TYPE	A12
	4	BOND STRENGTH	N
	5	NOTE	A50

Table 3.1. **Summary of data storage (continued).**

Table Name	Structure	Field Name	Field Type
Construction	1	IDPROJECT	A30
	2	DATE OF POUR	D
	3	QTY PLACED CUYD	A10
	4	CURING TECHNIQUE I	A25
	5	DURATION (HRS) I	N
	6	CURING TECHNIQUEII	A25
	7	DURATION (HRS) II	N
	8	AVG.COMP.ST.(psi)	A12
	9	AVG.BOND.ST.(psi)	A12
	10	DELAM.SURVEY METH.	A25
	11	DELAM.SURVEY RESUL	A25
	12	CRACK.SURVEY RESUL	A30
	13	COMMENT (i)	A80
	14	COMMENT (ii)	A80
	15	COMMENT (iii)	A80
	16	COMMENT (iv)	A80
	17	COMMENT (v)	A80
	18	MEMO	M240
Sample	1	IDSAMPLE	A20
	2	CEMENT	N
	3	WATER	N
	4	LATEX	N
	5	MICROSILICA	N
	6	W/C RATIO	N
	7	CONC.TEMP.	N
	8	SLUMP	N
	9	% AIR	N
	10	SAND	N
	11	COARSE	N
	12	COMP.ST.	N
	13	LATEX/MC TYPE	A20
	14	LATEX/MC MANU.'R	A25
	15	FLYASH TYPE	A15
	16	FLYASH lbs	N
	17	SUPPLIER	A25
	18	OTHER ADMIXTURES	A25
	19	ACTUAL ADMIX I	A14
	20	ACTUAL ADMIX II	A14
	21	ACTUAL ADMIX III	A14
	22	COMMENT (i)	A80
	23	COMMENT (ii)	A80
	24	COMMENT (iii)	A80
	25	COMMENT (iv)	A80
	26	COMMENT (v)	A80

Table 3.1. **Summary of data storage (continued).**

Table Name	Structure	Field Name	Field Type
Weather	1	IDPROJECT	A30
	2	LOCATION	A30
	3	FROM STATION	A12
	4	TO STATION	A12
	5	DIRECTION	A12
	6	START DATE START	D
	7	TIME	A6
	8	START AIR TEMP	N
	9	START WIND VEL.	A10
	10	END DATE	D
	11	END TIME	A6
	12	END AIR TEMP.	N
	13	END WIND VEL.	A10
	14	PRECIP.AT SITE	A10
	15	WEATHER	A10
	16	TEMP.RANGE	A10
	17	WIND RANGE	A10
	18	HUMIDITY RANGE	A10
	19	NEAREST WEATH.STA.	A18
	20	APPR.DIST.TO SITE	A10
	21	STA.MIN.TEMP.	N
	22	STA.MAX.TEMP.	N
	23	STA.PRECIP.(ins)	A15
	24	STA.HUMIDITY	N
	25	STA.WIND VEL.	N
	26	STA.EVAP.AMT.(ins)	N
	27	COMMENTS	A80

In addition to the Project table, nine supporting tables are set up to provide additional detail. Data are grouped in General, Aggregate, Haul, Preparation, Mix, Contract, Construction, Sample, and Weather.

General provides the contract number, bridge name, location, type of bridge, age, and traffic condition.

Aggregate provides information about the properties of the aggregate used such as gradation, organic impurities, sand equivalent, source, supplier, etc.

Haul provides hauling information such as batch time, placing time, deck temperature, and concrete properties for each placement.

Preparation provides information about surface preparation activities such as the type of initial and final preparation.

Mix provides the information about the mix design used in each project such as cement content, water, coarse and fine aggregate, w/c, admixtures used, and supplier. Four admixtures are classified as:

other admix. type 0 indicates air-entraining agent.
other admix. type I indicates water reducing agent.
other admix. type II indicates water reducing agent.
other admix. type III indicates any other admixture.

Contract provides information about the contractor for each project.

Construction provides construction information such as placement date and quantity, curing techniques and duration, average compressive and bond strengths for concrete placed on that day, method and result of delamination/cracking survey and comments, if any.

Sample provides information about each concrete sample, e.g., date of placement, actual mix proportions, cement, water, w/c, aggregate, LMC/MC, amount and supplier of admixtures, slump, percent air content, and concrete temperature.

Weather provides information about the environmental conditions including location, direction of placement, start/end date and time, start/end air temperature and wind velocity, weather, temperature range, humidity range, and information from the nearest weather station.

The entire data set is included as Appendix B of this report.

3.3 DATA ANALYSIS

After examining the data, it appeared that the available construction data were not sufficiently detailed. Specific deficiencies are as follows:

1) Inconsistent format was found in most projects.

2) Data are significantly scattered. Inconsistent data collection and ambiguous reported data are typical. Several placements were not clearly reported.

3) Wide variation in quality and quantity of data collection. Some projects provided the collected data in greater amount and detail, while some provided only limited information.

4) Most deterioration survey results are reported qualitatively in a manner that did not allow specific distresses to be located precisely.

These limitations present significant problems when attempting to determine the relationships between deterioration and construction procedures. Nevertheless, analyses were conducted as described below.

From 13 selected projects, 24 bridges were analyzed. Among these, eight bridges (33 percent) are aged between 20 to 30 years, nine bridges (37.5 percent) are aged between 30 to 40 years and two bridges (8 percent) are over 40 years. Only one bridge (4 percent) was less than 20 years. No data are available for four bridges (16 percent).

Most, 16 of 24 bridges (66 percent) are classified either as reinforced concrete deck girder (RCDG) or RCDG/partly steel. Five bridges (21 percent) are reinforced concrete box girder (RCBG) and for three bridges (13 percent) data are not available. The majority of the studied bridges, 18 bridges (75 percent) are LMC overlaid, five bridges (21 percent) are MC overlaid and one bridge (4 percent) is fiber-latex-modified concrete overlaid.

When classified by first surface preparation technique, 14 bridges (58 percent) used milling, four bridges (17 percent) used diamond grinding, three bridges (12.5 percent) used hydroblasting, and three bridges (12.5 percent) had no data available.

When classified by deterioration performance, four bridges (17 percent) show delamination, 12 bridges (50 percent) show no delamination, and for eight bridges (33 percent) data are not available or are unclear. Among all bridges, nine (37.5 percent) show signs of cracking, four (17 percent) show no sign of cracking, and 11 (46 percent) had no data available or the available data were not clear.

When classified by mechanical properties, none had an average compressive strength at 7 days less than the requirement of 3300 psi (23 000 kPa). However, a few individual tests for some bridges had lower strength than 3300 psi. Compared to compressive strength, average bond strength of these bridges shows the wider variation and 17 percent of the data are unclear or not available.

These data are summarized in Appendix B.

3.4 STATISTICAL EVALUATION

Two statistical software packages, STATGRAPHIC 5.1 and SAS 6.04, are used as the analysis tools to evaluate overlay performance [*29*]. Three major questions of interest are addressed:

1) **Is there any evidence which indicates a relationship between delamination and surface preparation technique?**

Since the available delamination data for each bridge is qualitative, with little or no reporting of the area of delamination, the response can only be characterized as delaminated or not delaminated for each bridge. Logistic regression analysis (LRA) is considered a proper tool [*30*] for this analysis. Three preparation techniques: milling, hydrodemolition, and diamond grinding are classified as indicator variables. However, when considering the segregation of the available data (Table 3.2) no statistically valid conclusions can be drawn. The majority of data fall in category 1 (milled), only a few fall in categories 2 and 3. Additional data that fill the table cells would be required for this question to be answered with statistical certainty.

Table 3.2. Relationship of surface preparation to delamination.

Delamination Present	Milled (1)	Hydroblast (2)	Diamond Grind (3)
0 (yes)	3	0	1
1 (no)	8	3	0

Preliminary examination of these limited data suggest that deck preparation using hydroblasting is less likely to cause delamination compared to milling.

2) **Is there any relationship between crack development and environmental conditions?**

Temperature, wind, and humidity are expected to influence crack development. These data are reported in project diaries within a range and the values are mostly unavailable. Therefore, these data are classified in an ordinal scale and considered as indicator variables.

Another variable which has a high tendency to relate to crack performance is temperature difference between the existing deck and the placed mix. Temperature difference often results in differential volume change and may raise the risk of cracking [*31*]. Since the deck temperature data are not reported for most bridges, the available data from three bridges was used to estimate the relationship between deck and air temperature.

$$\text{Deck temperature (°F)} = 18 + 0.72 \times \text{(air temperature °F)}$$

The difference between the calculated deck temperature and the mix temperature of the two groups, cracked and uncracked, is analyzed to determine whether there is a difference in means between these two groups. From analysis of variance (ANOVA), there is no evidence of a difference in this parameter between cracked and uncracked overlays (p-value = 0.15).

As with the delamination data, most of the crack information is qualitative and the exact locations on a bridge are not available. Crack performance of each bridge can only be categorized as cracked or uncracked. Therefore, the logistic linear regression approach is used as an analysis tool. However, due to limited information on actual location, the crack development factor cannot be clearly associated with a specific set of environmental conditions. The available data segregate into a few environmental categories as shown in Table 3.3.

There are significant gaps in the data and statistically valid conclusions could not be drawn.

3) **Are there any construction factors that explain bridge deck overlay performance?**

Several factors are expected to relate to overlay performance such as construction and curing techniques. Only limited information was available on these factors, making statistical analysis difficult. Both LMC and MC overlay performance are sensitive to contractor experience. Bond strength, which reflects workmanship and preparation technique, was used as a surrogate variable for contractor experience. Since LMC and MC materials are different, the data are analyzed separately.

Table 3.3. Number of deck placements for which environmental data are available.

Relative Humidity Range	Temperature Range											
	2			3			4			5		
	Wind Range			Wind Range			Wind Range			Wind Range		
	W1	W2	W3	W1	W2	W3	W1	W2	W3	W1	W2	W3
1												
2		5			20			1				
3	1	2		1	3			2				
4	2	7			1	1						

KEY:

Humidity	**Temperature**	**Wind**
1 = Dry	1 = less than 32°F (0°C)	W1 = Still
2 = Low	2 = 32 to 50°F (0 to 10°C)	W2 = Low
3 = Medium	3 = 50 to 70°F (10 to 20°C)	W3 = Medium
4 = Humid	4 = 70 to 85°F (20 to 29°C)	W4 = High
	5 = greater than 85°F (29°C)	

Due to the characteristic of the available data, the Levene Method [*32*] was chosen to test the equality of variance of bond strength as affected by contractor. This method is suitable for unequal sample size and asymmetric distribution [*33*].

The analysis suggests that contractor performance might be a significant factor, especially for LMC overlays. Most of the variability in bond strength of LMC is attributable to differences between contractors (p-value < 0.001). For MC, statistical analysis of the available data does not suggest a difference in variation between contractors.

Means of bond strength between contractors are different for both LMC and MC (p-value= 0.000 and 0.0016 for LMC and MC, respectively). When considering the effect of preparation technique on bond strength, there is some indication that the techniques might affect bond strength for LMC overlays (p-value = 0.0349). While for MC overlay, the results from the available data does not indicate the difference in means due to different preparation techniques.

However, mechanical properties such as bond strength are affected by many factors, for example age [*34*] and form of microsilica used [*35*]. Therefore, based on the available observational data, these confounding factors may affect the statistical results for analysis of difference in means.

This page intentionally left blank.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Based on the information gathered in this study the following conclusions can be drawn.

1) Analysis by Erlin, Hime Associates of cores from four bridges shows there may be differences between milled and hydroblasted decks.

2) Based on the limited data in this study, more microcracking of the existing deck was found when milling was used than when hydrodemolition was used.

3) All cores taken from Oregon bridge decks were intact and the overlay-deck bond was sufficient.

4) Studies from other states show cracking and delamination may be attributed to construction practice, surface preparation, and/or environmental conditions.

4.2 RESEARCH RECOMMENDATIONS

To further investigate the factors that may contribute to premature cracking and delamination for 1994 bridge deck overlays, the following recommendations are warranted:

1) Construction records should be kept in a consistent format. Preparation technique, timing of construction progress from start of mixing to curing, complete details of mix and field tests, method and time of curing, and environmental conditions should be included.

2) Location of each pour should be reported as well as the location of bond tests and cracks or delamination.

3) The deterioration survey report should be in a quantitative format which includes specific location and area information.

4.3 IMPLEMENTATION RECOMMENDATION

1) Rotomilling should not be allowed for bridge deck preparation.

This page intentionally left blank.

5.0 REFERENCES

1. Andrzeij Nowak, Bridge Evaluation, Repair and Rehabilitation, *NATO ASI Series*, Vol. 187, London, 1990.

2. Jack J. Fontana and John Bartholomew, Use of Concrete Polymer Material in the Transportation Industry, *Application of Polymer Concrete: ACI Publication SP-69,* Detroit, 1981.

3. L.A. Kuhlmann, Performance History of Latex Modified Concrete Overlay, *Application of Polymer Concrete: ACI Publication SP-69,* Detroit, 1981.

4. John. A. Manson, Overview of Current Research on Polymer Concrete: Material and Future Needs, *Application of Polymer Concrete: ACI Publication SP-69*, Detroit, 1981.

5. Dennis L. Bean and Tony B. Husband, Latex Admixture for Portland Cement Concrete and Mortar, *Technical Report REMR-CS.3*, Missouri, 1986.

6. Michael M. Sprinkel, Twenty-Year Performance of Latex-Modified Concrete Overlay, *Virginia Department of Transportation Report No. 920883*, Washington, DC, 1992.

7. Soroushian Parviz and Tlili Atef, Latex Modification Effects on Mechanisms of Microcrack Propagation in Concrete Material, *Transportation Research Record 1301*, Washington, DC.

8. G.C. Hoff, L.N. Godwin, Alan D. Buck, Tony B. Husbands, Katharine Mather, and Kenneth L. Saucier, Chemical Polymer and Fiber Additive for Low Maintenance Highway, *NOYES Data Corp.*, ed. by G.C. Hoff, New Jersey, 1977.

9. C. Ozyildirim, Experimental Installation of a Concrete Bridge Deck Overlay Containing Silica Fume, *Transportation Research Record 1204*, Washington, DC, 1988.

10. Mark D. Luther, Silica-Fume (Microsilica Concrete) in Bridge in the United States, *Transportation Research Record 1204*, Washington, DC, 1988.

11. Mark D. Luther, High-Performance Silica Fume (Microsilica)-Modified Continuous Repair Material, *Transportation Research Record 1284*, Washington, DC.

12. Tom H. Roper and Edward H. Henry, Jr., Burlington Northern Railroad Overcrossing Bridge, Micro Silica Modified Concrete Overlay, *Washington State Department of Transportation FHWA Report No.5/718W WA-RD-164.1*, Washington, 1989.

13. C. Ozyildirim, Investigation of Concrete Containing Condensed Silica-Fume, *FHWA Report No. VHTRC-86-R25,* 1986.

14. Dennis Bunke, ODOT Experience with Silica-Fume Concrete, *Transportation Research Record 1204*, Washington, DC, 1988.

15. R.W. La Fraugh and M.H. Zinserling, Concrete Overlay for Bridge, *FHWA Report No. WA-RD-93.1*, Washington, 1987.

16. Alfred G. Bishara, Latex Modified Concrete Bridge Deck Overlays: Field Performance Analysis. *Report No. FHWA/OH/79/004*, Ohio, October 1979.

17. James H. Havens, Theodore Hopwood and E.E. Courtney, Bridge Decks and Overlays, *Kentucky Transportation Research Program*, Lexington, 1987.

18. Babaei Khossrow and M. Neil Hawkins, Performance of Bridge Deck Concrete Overlay. *Extending the Life of Bridge: ASTM STP1100,* Philadelphia, 1990.

19. D.G. Walters, Styrene-Butadiene Latex Modified Concrete (S-B LMC) Bridge Deck Overlay, *Proceedings*, International Congress on Polymers in Concrete, September 1991, San Francisco, CA.

20. L.A. Kuhlmann, Using Styrene-Butadiene Latex in Concrete Overlay, *Transportation Research Record 1204*, Washington, DC, 1988.

21. L.A. Kuhlmann, Cracks in Latex Modified Concrete Overlay: How They Get There, How Serious They are and What to do About Them, *Transportation Research Record 1301*, Washington, DC.

22. Missouri Cooperative Highway Research Program, Performance of Latex Modified and Low Slump Concrete Overlay on Bridge Deck, *Report No. PB 85-104131*, Missouri, 1985.

23. Bo Miller, Microsilica Modified Concrete for Bridge Deck Overlays, *First Year Interim Report: FHWA Experimental Features OR 89-03A,89-03B,89-03C*, Oregon, 1991.

24. A Report Card, Latex Modified Concrete Deck Overlays, *Public Works*, Vol. 119, No. 2, February 1988.

25. David Manning, Effect of Traffic-Induced Vibration on Bridge Deck Repairs, *Transportation Research Board Executive Committee Research Report*, Washington, 1981.

26. T.S. Patty, "Interim Reports Nos. 1 and 2, Petrographic Studies of ODOT Bridge Deck Cores," December 1993 and March 1994, Erlin, Hime Associates.

27. Simpson Alan, *Mastering Paradox 4.0 for DOS*, Publisher Sybex, San Francisco, 1992.

28. *Paradox 4.0: User's Guide*, Borland International, CA, 1992.

29. *SAS/STAT: User's Guide Release 6.04*, SAS Institute Inc., NC, 1991.

30. Fred Ramsey and Dan Schafer, *The Statistical Sleuth: An Intermediate Course in Statistical Method*, Oregon State University, Corvallis, OR, 1991.

31. Margaret Jackson, "Durability of Bridge Decks: TRC 9210," Arkansas State Highway and Transportation Department, 1992.

32. Kuehl, *Statistical Principles of Research Design and Analysis*.

33. Morton B. Brown and Alan B. Forsythe, "Robust Tests for the Equality of Variances," *Journal of the American Statistical Association*, Vol.69, no.346, June 1974.

34. L.A. Kuhlman, Styrene-Butadiene Latex Modified Concrete: The Ideal Concrete Repair Material, Concrete International, October 1990.

35. M.D. Cohen and J. Olex, "Silica Fume in PCC: The Effects of Form on Engineering Performance," Concrete International: Design & Construction, vol. 11, September 1989.

This page intentionally left blank.

Appendix A

PETROGRAPHIC DETAILS OF CORES EXAMINED BY ERLIN, HIME ASSOCIATES

Information contained herein was taken from Reference 26

STUDY SHEET

The concrete submitted for study was examined using methods of petrographic microscopy as outlined in ASTM C856. A detailed description is as follows:

CORE 4

Specimen

Length:	5 3/4 in. (includes 3 1/2 in. overlay).
Diameter:	4 in.
Top:	Deeply broom finished.
Bottom:	Broken-off surface in original concrete.
Reinforcement:	#4 and #5 rebars in original concrete.
Remarks:	Reportedly core taken through bridge deck overlay into older deck concrete. Location, type of structure and condition unknown.

Aggregate (Original concrete)

Coarse:	Well-rounded siliceous gravel composite of felsitic igneous rocks such as rhyolite and basalt. Gradation, distribution, and soundness appeared normal. Top size 1 1/4 in.(1)
Fine (Sand):	Natural siliceous sand composed mainly of quartz, feldspar, and felsitic rock fragments.

Paste (Original concrete)

Color:	Medium gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.45.(3)
Solid Additives:	None observed.(2)
Air Void System:	Entrained, estimated at 7 1/2 to 8 percent.(4)

Remarks

(1) Overlay concrete composed of similar aggregate types; however, the nominal top size was 3/8 in.

(2) The overlay concrete contained an estimated 6 bags of cement with about 1 1/2 bags of fly ash per cubic yard.

(3) The water/cement ratio for the overlay concrete was estimated at 0.40.

(4) Estimated at 6 percent for the overlay mix.

STUDY SHEET

CORE 5

Specimen

Length:	6 in.
Diameter:	4 in.
Top:	Heavy broom finish.
Bottom:	Broken surface.
Reinforcement:	#4 and #5 rebars in located near bottom.
Remarks:	Core taken through a 3 in. overlay into original concrete.

Aggregate (Original concrete)

Coarse:	Well-rounded siliceous gravel, same as described in Core 4. Top size 1 1/4 in.(1)
Fine (Sand):	Natural siliceous sand, similar in composition as identified in Core 4.

Paste (Original concrete)

Color:	Medium gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.45.(3)
Solid Additives:	None observed.(2)
Air Void System:	Entrained, estimated at 7 to 7 1/2 percent.(4)

Remarks

(1) Overlay mix contained siliceous pea gravel, top size 3/8 in.

(2) Overlay mix was estimated at 6 bags of cement per cubic yard with a fly ash admixture estimated at 1 to 1 1/2 bags.

(3) Estimated at 0.40 for the overlay mix.

(4) Estimated at 6 percent for the overlay mix.

STUDY SHEET

CORE 10

Specimen

Length:	5 1/2 in.
Diameter:	4 in.
Top:	Milled or ground surface which partially obscured the tined surface of the overlay.
Bottom:	Broken surface within the original concrete deck.
Reinforcement:	None observed.
Remarks:	Core taken through a 2 1/8 in. thick concrete overlay into original concrete deck.

Aggregate (Original concrete)

Coarse:	Well-rounded siliceous gravel composed mainly of rhyolite, trachyte, and basalt-type igneous rocks, top size 1 1/4 in. Gradation distribution and soundness appeared normal.(1)
Fine (Sand):	Natural siliceous sand composed mainly of quartz, feldspar, and dark felsitic rock fragments.

Paste (Original concrete)

Color:	Medium gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 1/2 bags.(2)
Water/Cement Ratio:	Estimated at 0.45.(3)
Solid Additives:	None observed.
Air Void System:	Entrained, estimated at 3 to 4 percent.(4)

Remarks

(1) Overlay mix contained siliceous pea gravel, top size 3/8 in.
(2) Overlay mix contained an estimated 7 to 7 1/2 bags.
(3) Overlay mix estimated at 0.38 to 0.40.
(4) Overlay mix estimated at 6 1/2 to 7 1/2 percent.

STUDY SHEET

CORE 11

Specimen

Length:	4 in. (1 3/4 in. overlay).
Diameter:	4 in.
Top:	Deeply tined but well worn by traffic, polished sand grains.
Bottom:	Broken surface in the original concrete deck.
Reinforcement:	None observed.
Remarks:	Core taken through a 1 3/4 in. thick concrete overlay into original concrete.

Aggregate (Original concrete)

Coarse:	Well-rounded siliceous gravel, similar in composition and size as described for Core 10.(1)
Fine (Sand):	Natural siliceous sand, same as described for Core 10.

Paste (Original concrete)

Color:	Medium gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 1/2 bags.(2)
Water/Cement Ratio:	Estimated at 0.45.(3)
Solid Additives:	None observed.
Air Void System:	Poorly entrained, estimated at 3 to 4 percent.(4)

Remarks

(1) Overlay mix had 1/2 in. pea gravel coarse aggregate.
(2) Overlay mix with 7 to 7 1/2 bags.
(3) Overlay mix estimated at 0.38.
(4) Overlay mix estimated at 5 to 6 percent.

STUDY SHEET

The concrete submitted for study was examined using methods of petrographic microscopy as outlined in ASTM C856. A detailed description is as follows:

CORE 14

Specimen

Length:	3 1/2 in. (includes 1 7/8 in. overlay).
Diameter:	4 in.
Top:	Smoothly polished by traffic, aggregates exposed and polished.
Bottom:	Broken-off surface in original concrete.
Reinforcement:	None observed.
Remarks:	Type of structure and location not identified. Core taken through overlay into original concrete.

Aggregate (Original concrete)

Coarse:	Well-rounded siliceous gravel composed of rhyolite and basalt. Gradation, distribution, and soundness appeared normal. Top size 1 in.(1)
Fine (Sand):	Natural siliceous sand composed mainly of quartz, feldspar, and felsitic igneous rock fragments.

Paste (Original concrete)

Color:	Creamy gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.48.(3)
Solid Additives:	None observed.
Air Void System:	Entrained, estimated at 5 to 5 1/2 percent.(4)
Secondary Deposits:	Significant number of voids with varying amounts of ettringite as clumps and linings.(5)

Remarks

(1) Overlay concrete composed of similar aggregate types; however, the nominal top size was 3/8 in.

(2) Overlay concrete contained an estimated 6 to 6 1/2 bags per cubic yard with no fly ash observed.

(3) Water/cement ratio for the overlay was estimated at 0.40.

(4) Air content estimated at 6 percent for the overlay.

(5) Ettringite as infrequent traces in some voids in overlay.

STUDY SHEET

CORE 17

Specimen

Length:	4 3/4 in. (includes 2 1/4 in. overlay).
Diameter:	4 in.
Top:	Smoothly worn by traffic, aggregates exposed and polished.
Bottom:	Broken surface in original concrete.
Reinforcement:	None observed.
Remarks:	Core taken through overlay into original concrete. Type of structure and location not indicated.

Aggregate

Coarse:	Well-rounded siliceous gravel, similar in composition as identified in Core 14. Top size 1 in.(1)
Fine (Sand):	Natural siliceous sand, similar in composition as identified in Core 14.

Paste (Original concrete)

Color:	Creamy gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.48.(3)
Solid Additives:	None observed.
Air Void System:	Entrained, estimated at 6 percent.(4)
Secondary Deposits:	Ettringite observed in clumps and linings in voids.(5)

Remarks

(1) Nominal top size in overlay was 3/8 in.
(2) Overlay contained an estimated 6 to 6 1/2 bags per cubic yard with no fly ash.
(3) Overlay concrete estimated to have 0.40 water/cement ratio.
(4) Overlay concrete had entrained air estimated at 6 to 7 percent.
(5) Traces of ettringite in voids.

STUDY SHEET

CORE 19

Specimen

Length:	2 3/4 in. (includes 1 3/4 in. overlay).
Diameter:	4 in.
Top:	Traffic worn and polished surface, aggregate exposed.
Bottom:	Broken surface into original concrete.
Reinforcement:	Imprint of #4 rebar at bottom surface of original concrete.
Remarks:	Type of structure or location not indicated. Cracks associated with corrosion products and alkali-silica reaction deposits adjacent to rebar in original concrete. Evidence of previously placed overlay incompletely removed. Extensive fracturing of original concrete adjacent to interface contact.

Aggregate

Coarse:	Siliceous gravel composed mainly of rhyolite and trachyte-related igneous rocks. Top size 1 in.(1)
Fine (Sand):	Natural siliceous sand.

Paste (Original concrete)

Color:	Light gray.
Hardness:	Moderately firm.
Luster:	Dull to semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.48.(3)
Solid Additives:	None observed.
Air Void System:	Entrained, estimated at 5 percent.(4)
Secondary Deposits:	Corrosion products (rust) and alkali-silica gel associated with crack adjacent to rebar.(5)

Remarks

(1) Overlay mix with top size 3/8 in.
(2) Overlay mix estimated at 6 to 6 1/2 bags.
(3) Overlay mix estimated at 0.40.
(4) Overlay mix non-air-entrained, estimated at 1 to 2 percent.
(5) None observed in overlay.

STUDY SHEET

CORE 20

Specimen

Length:	3 1/4 in. (includes 2 in. overlay).
Diameter:	4 in.
Top:	Traffic worn surface, exposed aggregates.
Bottom:	Broken surface in original concrete.
Reinforcement:	None observed.
Remarks:	Core taken through overlay into original concrete. Some fracturing of old concrete paste and aggregates associated with the interface surface.

Aggregate (Original concrete)

Coarse:	Siliceous gravel similar to that described for Core 17.(1)
Fine (Sand):	Natural siliceous sand similar to that described for Core 17.

Paste (Original concrete)

Color:	Light gray.
Hardness:	Firm.
Luster:	Semi-vitreous.
Texture:	Fine-grained.
Cement Content:	Estimated at 5 to 5 1/2 bags per cubic yard.(2)
Water/Cement Ratio:	Estimated at 0.48.(3)
Solid Additives:	None observed.
Air Void System:	Entrained, estimated at 6 percent.(4)
Secondary Deposits:	Several coarse aggregates associated with alkali gel reactions.(5)

Remarks

(1) Overlay mix with top size 3/8 in.
(2) Overlay mix estimated at 6 to 7 bags per cubic yard.
(3) Overlay concrete water/cement ratio estimated at 0.38 to 0.40.
(4) Overlay air content estimated at 6 to 6 1/2 percent.
(5) None observed in overlay.

Appendix B

DATA COLLECTED ON OREGON BRIDGES

Table B.1. Bridge detail in the studied projects.

Bridge No.	Bridge Name	Highway	Type	Age,yrs
7036B	Holladay Street Off Ramp	Pacific & Columbia River	RCDG	36
7040A	Grand Avenue On Ramp	Pacific & Columbia River	RCDG	37
8498 (WB)	Meacham Overcrossing of UPRR	Old Oregon Trail	RCDG	31
9712B	U'xing Lester Ave.	East Portland Freeway	RCBG	18
8882A	O'xing Columbia Blvd.: Delta Park-Marquam Bridge	Pacific Highway	RCDG, Partly StDkGir	28
8883A	U'xing Hwy1: Delta Park-Marquam Bridge	Pacific Highway	RCDG, Partly StDkGir	28
1377A	U'xing N&S Hwy1	Pacific Highway - I-5	RCDG, Steel-- Northbound Structure	70
7333C	Oregon-Washington State Line	Pacific Highway - I-5	RCDG, Steel-- Southbound Structure	40
7374A	North Santiam-Little North Fork Road	North Santiam Highway	RCDG	40
1229A	Mackenzie River (Hayden Bridge)	FAS A464 (Marcola Road)	StDkGir	26
17151	Buldock Slough-S. Baker Int. (E.B.S. Campbell)	Old Oregon Trail	RCDG, RCBG	*
9515C	Campbell St. Int. O'xing Ep Hwy 12	Old Oregon Trail	RCDG, RCBG	20
9516A	S. Baker Int.	Old Oregon Trail	RCBG	21
8195C	W. Marquam & N. Tigard Int. - Hood St. Pacific Highway	Pacific Highway	RCDG	32
8203C	W. Marquam & N. Tigard Int. - 26th Ave. O/P Pacific Highway	Pacific Highway	RCDG	32
6886	O'xing Hwy 442 (Chiloquin): Dalles-California: Forge Rd (East & West Half)	Dalles-California Highway	RCDG	45
8302E	Encina Int. O'xing Hwy 66 & UPRR	Old Oregon Trail	RCDG, Partly StDkGir	28
8302W	Encina Int. O'xing Hwy 66 & UPRR	Old Oregon Trail	RCDG, Partly StDkGir	28
8018A	I-5: Jump-off Joe Creek - North Grants Pass Section (Louis Creek Bridge)	Pacific Highway	RCDG	35

*No data available
RCDG - Reinforced Concrete Deck Girder
RCBG - Reinforced Concrete Box Girder

Table B.1. Bridge detail in the studied projects (continued).

Bridge No.	Bridge Name	Highway	Type	Age,yrs
8019A	I-5: Jumpoff Joe Creek - North Grants Pass Section (Merling Hill Bridge)	Pacific Highway	RCBG	35
8093A	I-5: Jumpoff Joe Creek - North Grants Pass Section (Jumpoff Joe Creek Underxing Bridge)	Pacific Highway	RCDG	34
8094A	I-5: Jumpoff Joe Creek - North Grants Pass Section (Jumpoff Joe Creek Bridge)	Pacific Highway	RCDG	35
7794-A-B	NB O'xing of SB Hwy 51: I-5	Pacific Highway	RCBG	22
7794-B-B	SB O'xing of SB Hwy 51	Pacific Highway	RCBG	22

Table B.2. Preparation technique used on each bridge.

Bridge No.	Initial Preparation Technique	Final Preparation Technique	Bonding Agent
7036B	Class I: mill	Pressure wash; some sandblasting	
7040A	*	*	
8498 (W.B.)	Rotormilling, Class I and some Class II near it.	Dry sandblast and washing	
9712B	*	Sandblast	
8882A	Class I by milling	Sweeping & hydroblasting & sandblasting	
8883A	Classes I & II by milling	Hand scrabbling & hydroblasting/pressure washing	
1337A	Rotormilled 1-6 in of ac wearing surface	Classes II & III; and washing	Silkadum 32 HI-MOD (span 3)
7333C	Rotormilled 1-6 in of ac wearing surface	Classes I & II	
7374A	*	Sandblast	
1229A	Class I; Class II: milling	Hydroblast	Dow latex emulsion
17151	Classes I & II (diamond grinding)	*	
9515C	Classes I & II (milling & diamond grinding)	Power wash	
9516A	Classes I & II (diamond grinding)	*	
8195C	Classes I & II: milling, hand chipping then diamond grinding	Sandblast; washing	
8203C	Class I & some Class II: milling then diamond grinding	Sandblast & washing	
6886	Class I (east), Classes I & II (west): diamond grinding	Sandblast	
8302E	Class I, Class II: waterblasting	Waterblast (3000 psi - 3 times for cleaning)	
8302W	Class I, Class II, Class III (diamond grinding)	Sandblasting	
8018A	Rotormilling; diamond grinding; wood waste removal	Pressure sand/waterblast	Latex slurry

*No available data

Table B.2. Preparation technique used on each bridge (continued).

Bridge No.	Initial Preparation Technique	Final Preparation Technique	Bonding Agent
8019A	Rotormilling; diamond grinding; wood waste removal	Pressure sand/waterblast	Latex slurry
8093B	Rotormilling; diamond grinding; wood waste removal	Pressure sand/waterblast	Latex slurry
8094A	Rotormilling; diamond grinding; wood waste removal	Pressure sand/waterblast	Latex slurry
7794-A-B	Hydroblasting Class I & II	Pressure wash Class I	
7794-B-B	Hydroblasting Classes I & II (20-30 ksi)	Pressure wash Class I (2-5 ksi)	

Table B.3. Bridge overlay type and properties.

Bridge No.	Type	Avg. St., Psi (kPa)	Avg. Slump, in. (mm)	Avg. Air, %
1229A	Fiber LMC	3962 (27 320)	4.4 (110)	4.6
1377A	LMC	4147 (28 590)	4.7 (120)	4.6
17151	LMC	4545 (31 340)	6.0 (150)	4.3
6886	LMC	4680 (32 270)	3.1 (79)	3.7
7036B	MC	5282 (36 420)	5.8 (150)	4.6
7040A	MC	6280 (43 300)	9.2 (230)	4.2
7333C	LMC	5041 (34 760)	5.0 (130)	5.0
7374A	LMC	4310 (29 720)	4.5 (110)	3.5
7794-A-B	MC	5435 (37 470)	6.0 (150)	5.9
7794-B-B	MC	7000 (48 270)	4.5 (110)	4.6
8018A	LMC	4806 (33 140)	5.6 (140)	4.9
8019A	LMC	4806 (33 140)	5.6 (140)	4.9
8093B	LMC	6180 (42 610)	5.0 (130)	4.5
8094A	LMC	4337 (29 900)	6.5 (170)	4.0
8195C	LMC	4755 (32 790)	5.8 (150)	4.0
8203C	LMC	4740 (32 680)	9.0 (230)	3.5
8302E	LMC	5712 (39 380)	3.5 (89)	4.4
8302W	LMC	3780 (26 060)	4.9 (120)	3.7
8498 (W.B.)	MC	5470 (37 720)	6.7 (170)	6.9
8882A	LMC	4283 (29 530)	4.9 (120)	3.7
8883A	LMC	4272 (29 460)	4.2 (110)	3.8
9515C	LMC	4405 (30 370)	6.1 (150)	4.7
9516A	LMC	4134 (28 500)	4.9 (120)	4.1
9712B	LMC	5135 (35 410)	2.8 (71)	4.6

Table B.4. Distress survey results.

Bridge No.	Avg. Bond Strength psi, (kPa)	Remark	Delamination	Cracking
1229A	169 (1 170)	0 of 4 fail	No	No
1377A	132 (910)	11 of 87 fail	No	Yes
17151	***		*	*
6886	210 (1 450)	1 or 4 fail	*	*
7036B	127 (876)	7 of 9 fail	Yes	Yes
7040A	*		*	Yes
7333C	205 (1 410)	0 of 21 fail	No	No
7374A	232 (1 600)	0 of 2 fail	No	*
7794-A-B	156 (1 140)	0 of 7 fail	No	*
7794-B-B	156 (1 140)	0 of 7 fail	No	*
8018A	264 (1 820)	2 of 9 fail	No	No
8019A	159 (1 100)	0 of 2 fail	No	Yes
8093B	278 (1 920)	1 of 2 fail	No	No
8094A	167 (1 150)	0 of 8 fail	Yes	Yes
8195C	214 (1 480)	0 of 4 fail	No	*
8203C	208 (1 430)	0 of 2 fail	No	*
8302E	325 (2 240)	0 of 6 fail	No	*
8302W	240 (1 650)	1 of 6 fail	Yes	Yes
8498 (W.B.)	202 (1 390)	0 of 9 fail	Yes	Yes
8882A	454 (3 130)	0 of 10 fail	**	**
8883A	409 (2 820)	0 of 13 fail	**	**
9515C	***		*	Yes
9516A	***		*	Yes
9712B	140 (965)	0 of 2 fail	No	*

Notes:
- * No available data
- ** Unclear information
- *** Reported bond strength of 99.3 to 333.4 psi (685 to 2299 kPa) for bridges 17151, 9515C, 9516A but not specified by bridge

Table B.5. Environmental condition and crack survey result.

ID Project	Weather	Temp. Range	Wind Range	Humidity Range	Temp. Diff., °F	Cracking
10708-7036B-1	*	*	*	*	4.9	Yes
10708-7036B-2	*	*	*	*	*	Yes
10708-7040A-1	*	*	*	*	9.8	Yes
10717-8498-1	3	3	2	*	12.1	Yes
10717-8498-2	3	3	3	*	7.9	Yes
10717-8498-3	*	*	*	*	9.1	Yes
10718-9712B-1	2	4	2	2	7.3	
10767-8882A-1	3	3	3	4	14.6	**
10767-8882A-2	2-3	3	3	3	*	
10767-8882A-3	2	3	2	2	16.2	**
10767-8882A-4	2	3	2	2-3	*	**
10767-8882A-5	2	4	2	2	2.9	**
10767-8882A-6	3	2	2	3	6.8	**
10767-8882A-7	3	2	2	4	8.8	**
10767-8882A-8	*	*	*	*	2.5	**
10767-8883A-1	3	3	2	3	*	
10767-8883A-2	2	3	2	3	*	
10767-8883A-3	2	3	2	2	*	
10767-8883A-4	3	3	2	2	6.0	
10767-8883A-5	1	5	2	1	10.0	
10767-8883A-6	1	4	2	2	12.1	
10767-8883A-7	1	3	2	2	17.2	
10767-8883A-8	3	3	2	3	10.0	
10767-8883A-9	2	3	2	2	6.3	
10767-8883A-10	3	2	2	2	12.0	

* No available data

** Unclear data

Table B.5. Environmental condition and crack survey result (continued).

ID Project	Weather	Temp. Range	Wind Range	Humidity Range	Temp. Diff.,°F	Cracking
10768-1377A-1	1	3	2	2	5.7	No
10768-1377A-2	2	3	1-2	3	1.6	*
10768-1377A-3	2	3	2	3	8.4	No
10768-1377A-4	2	3	2	2	9.2	No
10768-1377A-5	2	3	2	2	3.0	Yes
10768-1377A-6	2	3	2	2	9.3	No
10768-1377A-7	2	3	2	2	7.0	*
10768-1377A-8	2	3	2	2	6.6	Yes
10768-1377A-9	2	3	2	2	10.5	Yes
10768-1377A-10	2	3	2	2	2.9	No
10768-1377A-11	3	3	2	3	4.4	No
10768-1377A-12	2	3	1	3	6.1	No
10768-1377A-13	2	2-3	1-2	3	7.3	No
10768-1377A-14	3	2-3	2	3	13.6	No
10768-1377A-15	2	2-3	2	2	0.9	No
10768-1377A-16	*	3	2	2	2.4	No
10768-1377A-17	2-3	2	2	4	6.9	No
10768-1377A-18	1-3	3	2	2	7.1	No
10768-1377A-19	3	3	2	2	1.7	No
10768-1377A-20	3-4	3	2	2	2.7	No
10768-1377A-21	1-3	2-3	2	3	6.5	No
10768-1377A-22	2	2-3	2	2	0.2	No
10768-1377A-23	2	2	2	4	8.0	No
10768-1377A-24	2	2	2	4	1.3	No
10768-1377A-25	1	2-3	2	4	2.7	No
10768-7333C-1	4	3	2	4	4.5	No
10768-7333C-2	3-4	3	3	4	9.2	No
10768-7333C-3	4	2-3	2	4	12.7	No
10768-7333C-4	4	2-3	2	4	8.9	No
10768-7333C-5	4	2-3	1-2	4	6.5	No
10768-7333C-6	2	2	1	4	9.0	No
10768-7333C-7	1	3	2	2	4.2	No
10768-7333C-8	2	2-3	2	4	9.6	No
10768-7333C-10	1	2-3	2	2	5.6	No

Table B.5. Environmental condition and crack survey result (continued).

ID Project	Weather	Temp. Range	Wind Range	Humidity Range	Temp. Diff.,°F	Cracking
10768-7333C-11	3	3	2	2	6.8	No
10768-7333C-13	2-3	3	2	2	6.0	No
10768-7333C-14	3	3	2	3	6.3	No
10768-7333C-15	2-3	3	2	2	3.4	No
10768-7333C-16	2-3	3	2	2	7.6	No
10768-7333C-17	3-4	3	*	2-3	0.2	No
10768-7333C-18	*	*	*	*	1.1	No
10768-7333C-19	3	2	*	2	6.9	No
10768-7333C-20	3	2	2	2	9.6	No
10777-7374A-1	4	3	3	3	2.1	*
10875-1229A-1	*	3	*	*	3.9	No
10930-17151-1	2	2-3	2	2-3	*	*
10930-17151-2	3	2-3	1-2	1	9.8	*
10930-9515C-1	2	3	2	3	*	Yes
10930-9515C-2	3	2-3	2	1	*	*
10930-9516A-1	1	3	2	3	*	Yes
10930-9516A-2	2-3	2-3	2	2-3	*	Yes
10930-9516A-3	2	2-3	1	1	12.7	*
10930-9516A-4	3	3	2	1	5.3	*
10952-8195C-1	1-3	4	2	3	2.3	*
10952-8195C-2	2	3	2	2	5.5	*
10952-8195C-3	2	3	2	2	0.2	*
10952-8195C-4	*	*	*	*	4.7	*
10952-8203C	3-4-5	3	2	2	10.5	*
10972-6886-1	2	2-3-4	2	2	17.5	*
10972-6886-2	2-3	2-3-4	2	2	23.3	*
11018-8302E-1	3	3	2	1	2.8	*
11018-8302E-2	2	3-4	1	1	9.5	*
11018-8302E-3	2	3	2	2	2.3	*
11018-8302W-1	1-2-3	2-3-4	1-2	1	*	Yes
11018-8302W-2	*	*	*	*	0.1	Yes
11018-8302W-3	*	*	*	*	*	Yes

Table B.5. Environmental condition and crack survey result (continued).

ID Project	Weather	Temp. Range	Wind Range	Humidity Range	Temp. Diff.,°F	Cracking
11065-8018A-1	2	2	2	2	5.1	No
11065-8018A-2	3	4	2	2	6.3	No
11065-8018A-3	2	3	2	2	*	No
11065-8019A-1	1	3	2	2	19.4	Yes
11065-8093B-1	2	3	2	2	20.5	No
11065-8094A-1	2	3	2	2	5.3	Yes
11065-8094A-2	2	3	2	2	5.5	No
11065-8094A-3	1	4	2	3	17.2	Yes
11065-8094A-4	1	4	2	3	18.0	No
11120-7794AB-1	*	*	*	*	12.3	*
11120-7794AB-2	2-3	3	2	2	8.7	*
11120-7794AB-3	1	3	2	2	13.1	*
11120-7794BB-1	*	2-3	2	3-4	13.1	*

KEY:

Humidity	Temperature	Wind	Weather
1 = Dry	1 = less than 32°F (0°C)	1 = Still	1 = Clear
2 = Low	2 = 32 to 50°F (0 to 10°C)	2 = Low	2 = Fair
3 = Medium	3 = 50 to 70°F (10 to 20°C)	3 = Medium	3 = Cloudy
4 = Humid	4 = 70 to 85°F (20 to 29°C)	4 = High	4 = Shower
	5 = greater than 85°F (29°C)		5 = Rain
			6 = Snow