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16. Abstract

Twenty bridge decks are being observed to determine the behavior and probable service lives of concrete bridge decks with waterproofing systems where the free chloride-ion content was two or more lbs per cu yd at the top mat of reinforcement when the waterproofing was constructed. Fifteen of the decks had 40 percent or more of the top mat reinforcement actively corroding according to copper-copper sulphate half-cell measurements. The other five decks had 5 percent to 40 percent of the top mat of reinforcement actively corroding.

Initial postconstruction survey results show that the waterproofing system used gives good initial protection from moisture penetration from the surface, and that 83 percent of the study decks contain delaminations. Nearly all delaminations found after construction were small in size and tended to be located within the same area as delaminations found during preconstruction surveys. Corrosion rates tended to decrease after the waterproofing system had been completed.

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State of Illinois
DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

RESULTS OF BRIDGE DECK CONDITION SURVEYS AND CORROSION RATE DETERMINATION

by

J. E. LaCroix

Interim Report

IHR-306

Bridge Deck Condition Survey

A Research Project Conducted by
Illinois Department of Transportation
in cooperation with
U. S. Department of Transportation
Federal Highway Administration

June 1979

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

RESULTS OF BRIDGE DECK CONDITION SURVEYS AND CORROSION RATE DETERMINATION

INTRODUCTION

The rehabilitation of prematurely deteriorated portland cement concrete bridge decks which contain concrete having high chloride-ion contents at the top mat of reinforcement is a serious problem facing many highway engineers and administrators. The major deterioration consists of delamination and subsequent spalling caused by the electrochemical corrosion of the reinforcing steel.

In many states, bridge deck rehabilitation includes repair of spalled and delaminated areas, then sealing the surface of the contaminated but sound concrete to prevent the penetration of moisture and oxygen, two necessary elements in electrochemical corrosion of the reinforcing steel. It is argued, however, that partial restoration would not result in permanent protection because corrosion will continue due to the presence of moisture and oxygen that is believed to penetrate the concrete deck from the underside in sufficient quantities to continue the corrosion process. It is believed, therefore, that the only way to assure permanent protection is to remove otherwise sound concrete in a potentially destructive environment, then prevent intrusion of deicing salts.

The objective of this experimental study is to determine the behavior and probable service life of concrete bridge deck-interlayer membrane-asphalt overlay systems where the chloride-ion content at the top mat of reinforcing steel equals or exceeds the 2.0 lbs Cl^-/yd^2 threshold level at the time the interlayer membrane and asphalt overlay are constructed.

Twenty portland cement concrete bridge decks were selected for this study based upon chloride content and corrosion activity in the top mat of reinforcement prior to rehabilitation. Fifteen of the decks have 40 percent or more at the top mat reinforcement actively corroding (Category I) and the other five decks have less than 40 percent of the top mat actively corroding (Category II) according to copper-copper sulfate (CSE) electrode measurements.

The two categories are similar to the first two of three suggested by Clear (1) who grouped decks, based upon potential surveys, into three categories:

(1) 40 percent or more potentials greater than 0.35 volts CSE

(2) 5 percent to 40 percent potentials greater than 0.35 volts CSE

(3) less than 5 percent potentials greater than 0.35 volts CSE

Work by others (1,2) shows strong evidence that corrosion of reinforcing steel is active when the potentials are greater than 0.35 volts CSE; therefore, throughout this report voltage potentials greater than 0.35 volts CSE are considered to indicate active corrosion of the reinforcing steel.

Membrane performances will be evaluated using data obtained from surface condition surveys, from delamination surveys of subsurface conditions, from electrical resistivity of membrane-pavement systems (ANSI/ASTM D3633-77), and from readings taken from pairs of conductive strips placed between the membrane and PCC deck surface across the traffic lanes at the points of deadload contraflexure. Conductive strips were placed at points of deadload contraflexure because the first cracks in the overlay and leaking of the membrane, should it occur, will happen at those points first. Resistivity readings are used to evaluate permeability of the waterproofing. Rebar corrosion will be monitored using the polarization resistance methods, both two-electrode and three-electrode systems, and using commercially available Magna Corrosometer® Probes.

DESCRIPTION OF DECKS SELECTED FOR STUDY

Bridge decks selected for study were suggested by the IDOT Highway District offices and were either under contract or scheduled for a specific letting. Rideover visual surveys were made and tentative categories were established using cracking, spalling, and surface appearance as criteria. Twenty-four decks were scheduled for preconstruction surveys, from which 20 decks were scheduled for study. Survey results follow this section. The structures are located in three highway districts. Waterproofings were constructed by four different contractors.

Located near the cities of Morton, Bloomington-Normal, and Urbana-Champaign, 14 of the decks are on FAI 74, and 2 decks each are located on FAI 55, FAI 57, and FAI 55-74 (Figure 1). There are dual structures at each location. All structures were constructed in accordance with prevailing standards and specifications. Through the remainder of the report, the structures will be referred to by number as follows:

District	Location	Direction of Traffic Structure Number
4	FAI 74 over FAS 496 NE of Morton	EB 090-0019, WB 090-0020
4	FAI 74 over Mud Creek, five miles west of Ill. 117 Interchange	EB 090-0023, WB 090-0024
3	FAI 55 over US 51, N of Normal	NB 057-0024, SB 057-0025
3	FAI 55-74 over US 150, W of Bloomington	NB 057-0018, SB 057-0019
5	FAI 74 over FAI 57, NW of Champaign	EB 010-0018, WB 010-0019
5	FAI 57 over Ill. 10, W of Champaign	NB 010-0009, SB 010-0010
5	FAI 74 over Saline Drainage Ditch, 10 miles E of Urbana	EB 010-0028, WB 010-0027
5	FAI 74 over Salt Fork Creek, 11 miles E of Urbana	EB 010-0029, WB 010-0030
5	FAI 74 over C&EI RR, 15 miles E of Urbana	EB 010-0031, WB 010-0032
5	FAI 74 over Stony Creek, 24 miles E of Urbana	EB 010-001, WB 010-0002

The waterproofing membrane system used on each deck is as shown in Figure 2 and consists of a penetrating primer, a built-up coal tar pitch emulsion membrane with two plies of coated glass fabric, and a 1/2-inch hot-mix sand-asphalt protection layer. Prior to placement, spalled and delaminated areas were repaired

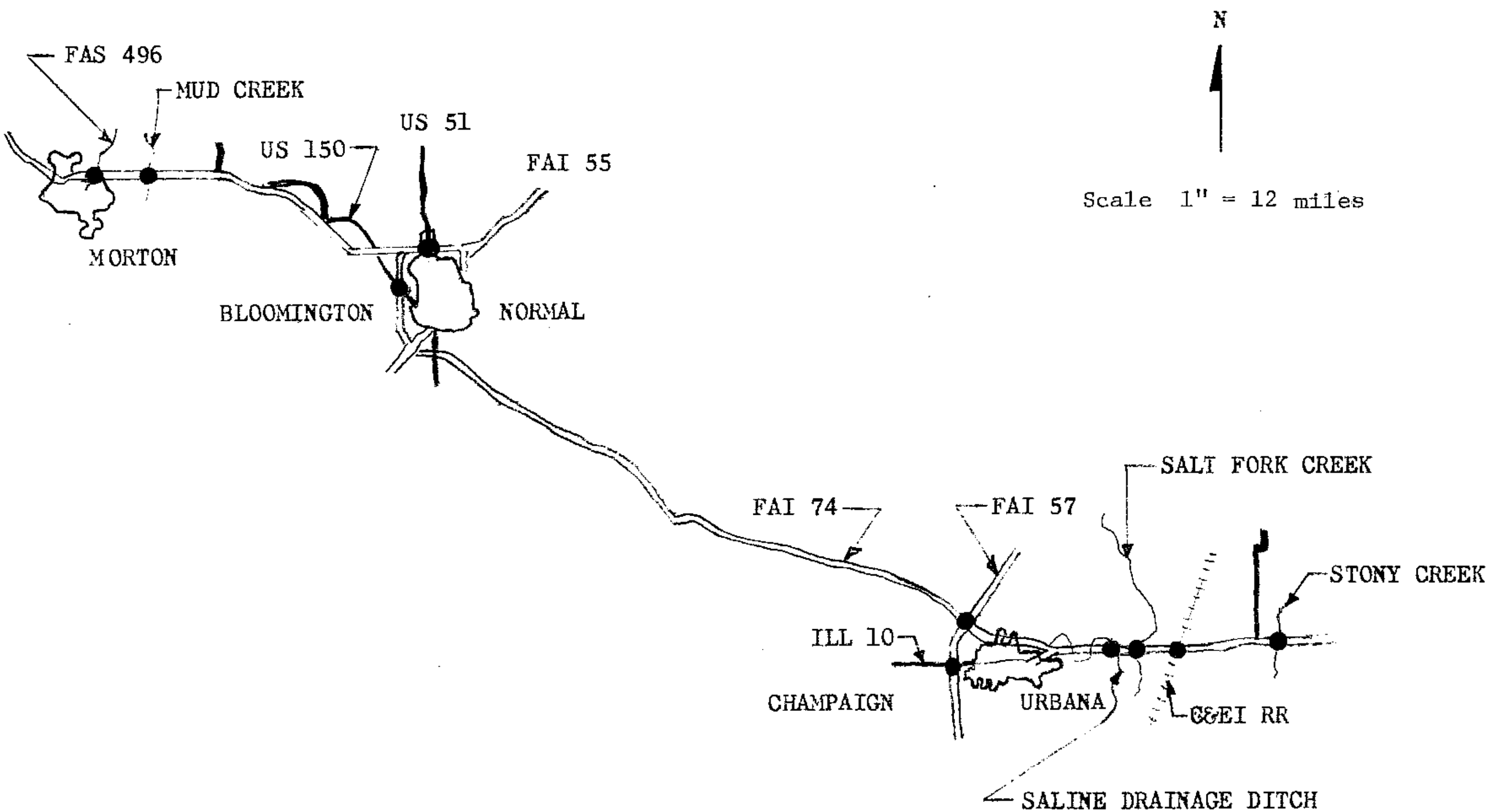


Figure 1. Location Map.

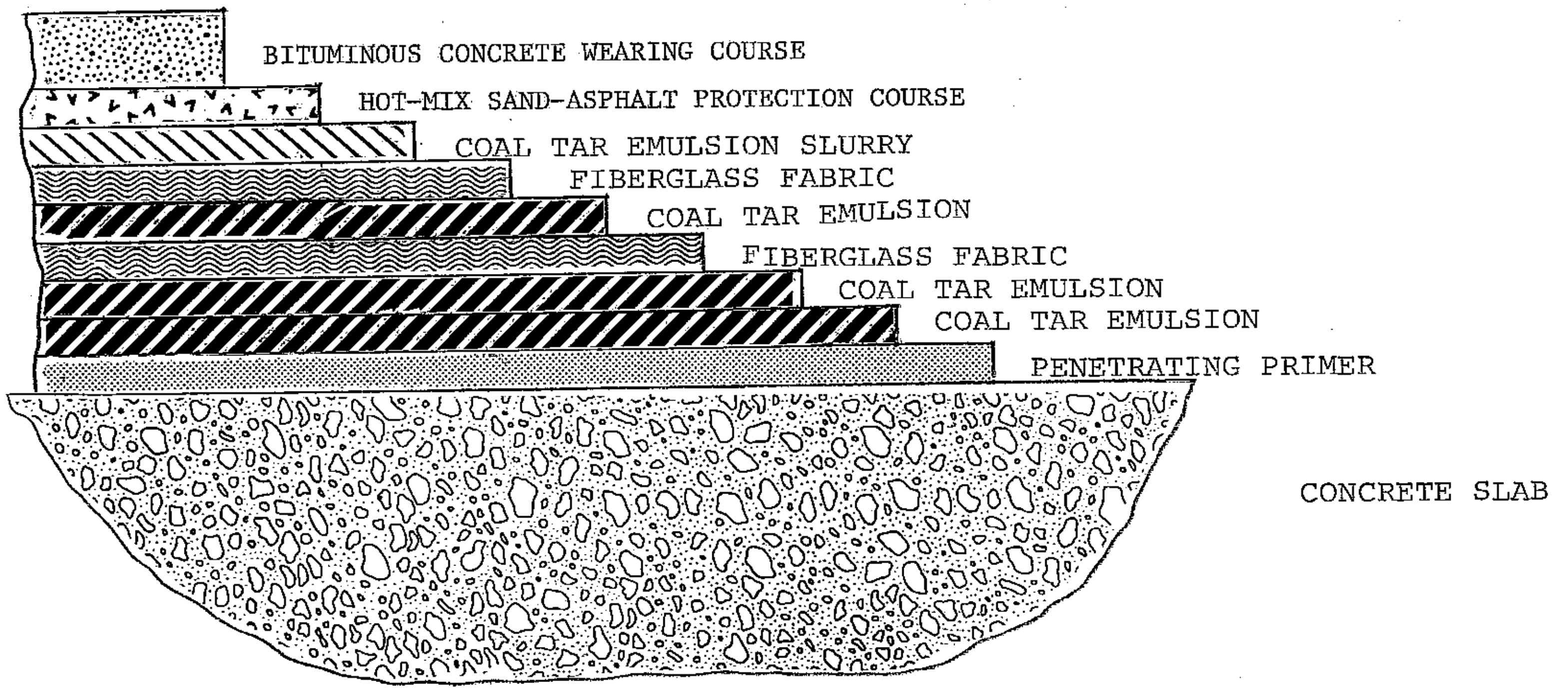


Figure 2. Waterproofing System.

in accordance with present deck-slab repair provisions. On eight decks in District 5, structures 010-0001, 2, 27, 28, 29, 30, 31, and 32, a cement slurry was used to fill the excessive number of aggregate popouts on each surface. The wearing surface is a 1 1/4- to 1 1/2-inch thick dense-graded bituminous concrete mixture.

COLLECTION AND SUMMARIZATION OF FIELD DATA

Preconstruction

Field surveys were made on each deck at least twice prior to rehabilitation, with three exceptions--the dual structures on FAI 55 spanning US 51 (Structure Nos. 057-0024 and 057-0025), will have been surveyed at least four times prior to rehabilitation, and the eastbound FAI 74 structure spanning FAS 496 (Structure No. 090-0019) was surveyed once after patching had been completed.

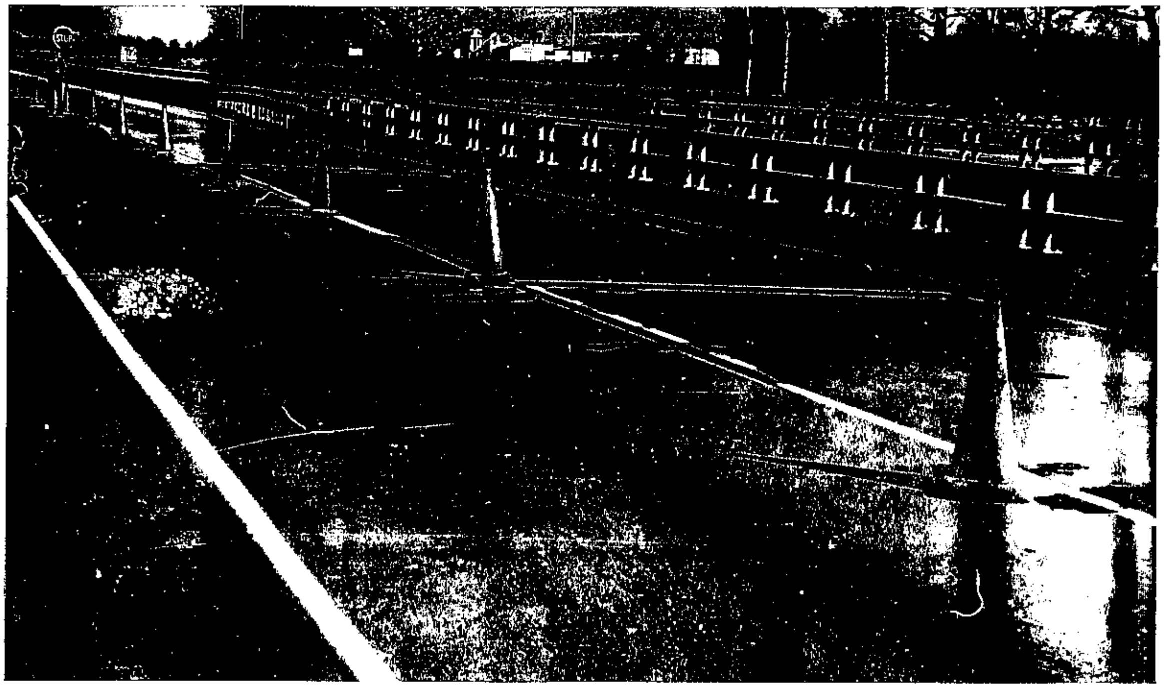
The field survey consisted of mapping the surface condition, making copper-sulfate electrode (CSE) half-cell measurements on a 4-foot grid, detecting delaminations using an S.I.E. Delamtect, determining chloride contents in areas where half-cell readings were less than 0.35 volts CSE, and some steel-depth measurements. Results of the most recent prior-to-rehabilitation survey are shown in Table 1. Views of typical Category II and Category I study decks are shown in Figure 3a and 3b, respectively.

In Table 1, percent area equal to or greater than 0.35 V CSE represents the area of active corrosion. The percent area equal to or greater than 2 lbs Cl^- less than 0.35 V CSE column represents that area of the deck where the top mat of reinforcement probably was not actively corroding but where the chloride contamination equaled or exceeded the 2 lb Cl^-/cu yd threshold level (1). The percent area contaminated is the sum of columns 3 and 4 and represents the deck area contaminated with 2 lbs or more of Cl^-/cu yd of concrete. Percent area

TABLE 1. PRIOR-TO-REHABILITATION SURVEY RESULTS

Illinois Highway District	Structure Number	Year Const.	% Area ≧ 0.35 V CSE	% Area ≧ 2#Cl < 0.35 V CSE	% Area Contaminated	% Area Delaminated	Deck Lgth. (ft)	Date of Survey
			FHWA CATEGORY II					
4	090-0024	1960	29	28	57	0.5	130	4/07/77
3	057-0018	1965	30	28	58	3.3	440	5/10/77
5	010-0032	1959	30	42	72	2.2	170	4/12/78
3	057-0019	1965	36	32	68	3.0	440	4/26/77
5	010-0002	1960	38	37	75	3.8	152	4/12/78
			FHWA CATEGORY I					
5	010-0009	1964	41	24	65	2.1	300	3/24/77
4	090-0020	1960	42	35	77	10.0	126	4/07/77
3	057-0024	1964	43	34	77	2.0	209	4/21/78
5	010-0010	1964	43	57	100	0.8	300	3/24/77
4	090-0023	1960	44	34	78	4.2	130	4/07/77
5	010-0028	1958	44	42	86	4.2	164	4/11/78
3	057-0025	1964	50	40	90	2.8	209	4/21/78
5	010-0031	1959	58	8	66	8.2	170	4/12/78
5	010-0018	1964	61	8	69	13.0	210	3/25/77
5	010-0027	1958	64	22	86	9.1	164	4/12/78
5	010-0001	1960	70	24	94	10.5	152	4/12/78
5	010-0029	1958	82	11	93	14.4	160	4/11/78
5	010-0030	1958	82	12	94	10.8	160	4/11/78
5	010-0019	1964	87	5	92	17.0	210	3/24/77
4	090-0019	1960	93 1/	-	93+	.2 1/	126	4/06/77

1/ Patching completed late fall 1976; survey made early spring 1977.



a). Typical Category II deck.

b). Typical Category I deck.

Figure 3. Photographs of typical Category I and Category II decks.

delaminated is derived from data collected from 1-foot-wide longitudinal strips on 2-foot center-to-center transverse increments, and equals the area of delamination in the 1-foot-wide strips divided by the total area in the 1-foot strips (not total deck area) times 100.

Results of the preconstruction survey show that the actively corroding area on the Category II decks is very near the upper limit (40 percent for the category (Table 1). The results also show that more than 50 percent of the surface area of each Category II deck is contaminated with chloride contents greater than the corrosion threshold.

Visual observations indicate that the amount of surface distress, mostly spalling and patching, was considerably less on the Category II decks than on most of the Category I decks (Figure 3a and 3b). In three instances, adjacent structures were in different categories.

Postconstruction

Upon completion of the rehabilitation, delamination measurements were ta the surface condition was mapped, and the waterproofing effectiveness of the interlayer membrane was evaluated by making resistance readings on the copper strips and resistivity readings through the membrane at 36 points on 4-foot grid patterns around the copper strips.

Preconstruction and postconstruction delamination surveys are made over the same defined trace locations. Traces are longitudinal measurements made on a 2-foot center-to-center transverse spacing. The first center is located 1 foot from the outside curb and the last center is located in the traffic lane 1 foot from the interface of the traffic lane and passing lane. By design, in each trace the Delamtect measures two 3-inch-wide strips separated by 6 inches. This type of survey covers 50 percent of the total surface area from the centerline between lanes to the right curb on each deck.

Permanent records are made by hot stylus pen on a two-channel strip chart. The presence or absence of delamination is shown on the chart. Solid concrete is represented by a relatively smooth line near the base line. Delaminations are indicated by pen excursions above the base line. The length of strip chart for successive passes varies slightly, but are sufficiently accurate for use in determining growth of total delaminated area from time to time.

Results of the initial postconstruction survey show that delaminations were found on 15 of the 18 completed decks (Table 2). On two of the decks the delamination found after rehabilitation nearly equaled that found before. The same two decks contained the least delamination of any prior to rehabilitation. It can also be seen that the 3 decks where no delaminations were found after rehabilitation were among the group containing the most delamination prior to rehabilitation.

The delaminations found after construction tend toward being located within the same same area as delaminations found during the preconstruction surveys. With few exceptions, individual delaminations found after rehabilitation were small in size, i. e., 1 foot or less in longitudinal distance (mostly 6 inches), and mostly on one recording channel, rarely on both channels and very few on two adjacent traces.

The initial tests for permeability show that the waterproofing system used is effective in preventing penetration of water from the surface, although there were some doubtful areas on five of the decks according to ASTM D3633-77 results (Table 2). Resistivity readings through the membranes show that, on all decks but five, the values were greater than .5 Megohms, indicating good protection. On the remaining five decks, the readings indicate that 94 to 97 percent of the surface area has good protection, with the protection on the remaining 3 to 6 percent being considered doubtful because the resistivity readings ranged

TABLE 2. POSTCONSTRUCTION SURVEY RESULTS

Structure Number	% Area Delaminated: Before Construction	% Area Delaminated: After Construction	Resistivity: Copper Strips [1/]	Resistivity: Sponges [5/]
090-0024	0.5	0.4	G	G
057-0018	3.3	0.1	G	G
010-0032	2.2	0.3	G	G
057-0019	3.0	0.5	G	G
010-0002	3.8	2.8	G	D(5.6)
010-0009	2.1	0.6	G[2/]	G
090-0020	10.0	1.1	G	G
057-0024	2.0	Rehabilitation Not Yet Completed (1978)		
010-0010	0.8	0.3	G[2/]	D(2.7)
090-0023	4.2	0.1	G	G
010-0028	4.2	0.4	3/	G
057-0025	2.8	Rehabilitation Not Yet Completed (1978)		
010-0031	8.2	0.8	G	G
010-0018	13.0	0	G	D(4.3)
010-0027	9.1	1.1	G[4/]	D(2.7)
010-0001	10.5	0	G	D(5.6)
010-0029	14.4	0.3	G	G
010-0030	10.8	0.7	G	G
010-0019	17.0	0	G	G
019-0019	*	0.2	G	G

* No before construction survey.

1/ G = Good Protection, resistance between pairs measured greater than 10 K ohms.

2/ Strips in passing lane.

3/ None installed.

4/ Strips between primer and first coat of coal tar emulsion.

5/ G = Good Protection, readings greater than .5 MEGOHMS.
D(—) = Doubtful (Estimated % Area Affected), readings .1 to .5 MEGOHMS.
NG(—) = No Good (Estimated % Area Affected), readings less than 1 MEGOHMS.

from .1 to .5 Megohms. There were no decks in the study upon which the initial surveys show the waterproofing protection to be no good (readings less than .1 Megohms). Resistance readings on the pairs of copper strips were all greater than 10 K ohms, indicating good protection according to the standards used on this study.

As was expected, the initial condition survey shows no cracks, spalls, or failures on any of the new deck surfaces.

Corrosion Rate Data

An attempt is being made to monitor corrosion activity in four of the study decks. Corrosometer probes purchased from MATCOR, Inc., and the two- and three-element polarization resistance techniques, are being used to estimate the rate of activity.

The corrosometer probe (trade name for electrical resistance probes) model PR-CPBD-13 is a 50-mil thick 13-inch long piece of mild steel. Ten inches of the element are exposed to the corrosive environment and are called the measuring element. Three inches of the probe are encapsulated in epoxy to protect it from corrosion and are called the reference element. Probes are installed near to but not touching the top mat of reinforcement and are electrically connected to the rebars except when making measurements. As the measuring element corrodes, the resistance ratio between the measuring element and the reference element increases. Readings are made with a Model CK-3 Portable Corrosometer® on which a digital dial indicates micro inches of metal loss. (3,4)

The electrochemical polarization theory for the polarization resistance experiments is discussed by Stern and Geary. (5) In both the two- and three-element installations, three 6-inch specimens were electrically isolated in the top mat of reinforcement as described by Lankard et al. (6) In the three-element installation a zink bar is added above one test specimen as a reference electrode. An adjustable DC voltage power supply inputs the polarizing potential. Electrical measurements are made with a Simpson 360 digital volt-ohm-milliameter.

The installations are in parallel structures No. 057-0018 and No. 057-0019 on FAI 55-74 spanning US 150 west of Bloomington, and in parallel structures No. 010-0029 and No. 010-0030 on FAI 74 spanning Salt Fork Creek east of Urbana. The Bloomington installations were made in September of 1977 and the Salt Fork Creek installations were made in July 1978.

The polarization resistance experiments were installed simultaneously with and in close proximity to the corrosometer probes. In two locations, the corrosometer probe is about two feet from the polarization experiment (010-0029 west end and 010-0030 east end). At three locations, the probes and polarization experiments are separated by 6 feet (010-0029 east end and 010-0030 west end, and 057-0019). At the remaining location (057-0018), there is a 12-foot separation. Typical installations are shown in Figure 4.

All probes and polarization resistance experiments were installed in the traffic lane near the ends (between 3 and 16 feet) of the structures so that the attached cables could be dropped through drain holes. By placing the experiments in these locations, readings can be taken at any time from a safe position beneath the deck without the need of costly traffic protection.

Construction scheduling on the two contracts differed somewhat. On structures 010-0029 and 010-0030, all construction was completed during the 1978 season, first on the passing lanes and then the traffic lanes. Less than one month passed between installation of the corrosion monitoring devices and placement of the bituminous wearing course. However, on structures 057-0018 and 057-0019, the traffic lanes were completed first, about one month after the instruments were installed. Work began on the passing lanes, but winter set in before all work could be completed. The passing lanes were overlaid with a

a). Structure No. 057-0019.

b). Structure No. 010-0024 West End.

Figure 4. Photographs of typical corrosion monitoring installations.

hot-mix bituminous concrete for the winter, and the remaining work was completed during the next summer and late fall. The corrosion monitoring devices were in place for 12 to 14 months prior to completing the entire waterproofing. In structures 057-0018 and 057-0019, corrosometer probes were installed in backfill with chloride content the same as in the original concrete surrounding the steel, while in the other structures the probes were installed at higher chloride contents than that of the original environments as follows:

Structure Number and Probe Location	Probe Designation	Backfill Cl^-		Original Cl^-	
		PPM	lbs/yd^3	PPM	lbs/yd^3
057-0018, North End, Center of Lane	CP(2)	516	2	516	2
010-0029, West End, Center of Lane	CP(4)	1000	4	558	2
057-0019, North End, Outer Wheelpath	CP(7)	1737	7	1737	7
010-0030, West End, Outer Wheelpath	CP(10)	2500	10	1792	7
010-0030, East End, Outer Wheelpath	CP(15)	3750	15	838	3
010-0029, East End, Center of Lane	CP(20)	5000	20	942	4

The 4 probes in structures 010-0029 and 010-0030 were installed at higher Cl^- contents than the surrounding environments to determine the effect of increased Cl^- contents on corrosion rate. Corrosometer probe corrosion rates in mils per year are determined using measurements made with a Magna CK-3 Portable Corrosometer® and the Magna equation for corrosion rate:

$$CR = \frac{\Delta \text{ Reading}}{\Delta \text{ Time (Days)}} \times 9.125$$

Where: Δ Reading = the difference in dial readings.

Δ Time = time elapsed between readings in days.

All polarization resistance electrodes were isolated in areas of the top mat of transverse reinforcement where the CSE potentials indicated active corrosion as follows:

Structure No. and Location	Avg. CSE Potential Volts
057-0018 - North End	.36
010-0029 - West End	.41
057-0019 - North End	.35
010-0030 - West End	.39
010-0030 - East End	.44
010-0029 - East End	.42

Rebars were located using a James® Electronics Model C-4952 R Meter. The contractors severed the bars and cut grooves in the deck for the lead wires. Once the bars were cut, 1 1/2-inch-diameter holes were drilled in the concrete to the surface of each bar so that electrical connections could be made. To complete the connections, small-diameter holes were drilled in the rebars, and the stripped end of an otherwise completely insulated lead wire was inserted in the hole and connected to the rebar by forcing a tapered brass pin into the hole. The lead wires were cut to length and placed in the grooves. Insulating gaskets were installed wherever the bars were severed to electrically isolate them. All holes and saw cuts were filled with commercially available crack sealer and mortar. In the three-element installations, a 1/4- x 1/4-inch zinc bar, the length of the severed rebar, was installed in a 1-inch slot, 1/8 to 1/4 inch above the rebar. The slot was backfilled with slurry consisting of 85 percent plaster, 10 percent bentonite, and 5 percent zinc sulfate. For the polarization resistance measurements, corrosion rate in mils per year (CR) is proportional to the slope of the current-potential curve (6).

$$CR = K \frac{\Delta i}{\Delta E}$$

Where: K = 0.012, based upon electrochemical constants and coefficients for steel in concrete

Δi = current density, microamps per sq. cm.

ΔE = polarizing potential, volts

The polarizing potential is applied to the system in a square wave function.

Results of corrosometer probe measurements made on CP(2) and CP(7), along with results from the two-element polarization resistance (2EPR) installations, are shown in Table 3. In the table, corrosion rate is expressed in units of mils per year. Age, in months, represents the time difference between date of test and date of installation, to the nearest month.

As can be seen in Table 3, the corrosion rate predicted by the 2EPR installation in structure 057-0018 has not varied significantly since installation. Corrosion rates shown for the other three installations show a marked decrease, then tend to stabilize. On each structure, the corrosion rate predicted by corrosometer probes for the 10th and 14th month is about 10 times greater in magnitude, on the average, than that predicted by the 2EPR experiment. Comparison of all results shows that the corrosometer probe predicts higher rates than polarization resistance.

The magnitude of difference in corrosion rate estimates obtained using the two devices cannot be explained. Some of the initial differences result from installation procedure. Polarization resistance elements should stabilize very quickly because they are practically undisturbed during installation; therefore, the corrosion activity and measurements should stabilize quickly. In contrast, when installing corrosometer probes, the reinforcement is jarred considerably during the removal of concrete cover and, when exposed, the reinforcement is partially cleaned of rust. Salt is added to the backfill mortar in an effort to reproduce the original concrete environment. As a result, the corrosometer probes require a longer period of time to stabilize.

Although a legion of unanswered questions surround the corrosion rate measurements, the results for the 10th to 14th month show a decrease in corrosion

TABLE 3. CORROSION RATES STRUCTURES NO. 057-0018 AND 057-0019

		STRUCTURE 057-0018		STRUCTURE 057-0019	
Date of Test	Age Months	2EPR	CP(2)	2EPR	CP(7)
		Mils/year		Mils/year	
11/4/77	2	.06	11.7	.06	3.7
1/5/78	4	.06	5.7	.06	2.3
4/25/78	7	.06	3.0	.06	0.9
7/28/78	10	.07	0.5	.06	0.1
9/5/78	12	.07	0.6	.07	0.4
10/6/78	13	.07	1.6	.03	0.5
11/3/78	14	.07	0.6	.03	0.4

TABLE 4. CORROSION RATES STRUCTURES NO. 010-0029 AND 010-0030

		010-0029 West End		010-0030 West End		010-0030 East End		010-0029 East End	
Date of Test	Age Months	3EPR	CP(4)	3EPR	CP(10)	3EPR	CP(15)	3EPR	CP(20)
		Mils/year		Mils/year		Mils/year		Mils/year	
9/6/78	2	.01	0.8	.01	1.7	.01	0.6	.01	2.5
10/5/78	3	.05	1.6	.04	2.4	.01	1.1	.13	3.6
11/2/78	4	.01	1.2	.01	1.8	.01	0.7	.05	2.7
		2EPR		2EPR		2EPR		2EPR	
10/5/78	3	.35		.29		.27		.03	
11/2/78	4	.32		.24		.34		.03	

2EPR - Two-Element Polarization Resistance
3EPR - Three-Element Polarization Resistance
CP( ) - Corrosometer Probe (Designation Number Indicates Chloride Concentration in lbs Cl^-/cu yd conc.)

rate that coincides with completion of the entire waterproofing. Future measurements should show how or if the corrosion rate changes with time.

Results of measurements made on the newer corrosion monitoring installations are shown in Table 4. A decrease in CP rates and the 2EPR rates is anticipated. The lack of activity in the 3EPR installation cannot be explained.

DISCUSSION

Delaminations were detected in 15 of 18 completed decks during the initial post-construction survey. The delaminations were small in size and tend to be located within the same area as those found before construction, but because of variations in the length of Delamtect strip chart, the exact location of the delaminations cannot be pinpointed. It is not known when the delaminations measured through the new bituminous surfaces were formed. Many possibilities exist, including but not necessarily limited to:

(1) The delaminations developed after the rehabilitation was completed and are extensions of original delaminations which were repaired during rehabilitiation.

(2) The delaminations formed in newly patched areas or are anomalies in the new patches.

(3) The delaminations were missed during construction.

Future delamination surveys and visual observations will be useful in monitoring delamination growth rate, if any, and in establishing time to failure, i.e., spalling which will develop through the interlayer membrane overlay system. The first spalls should develop from delaminations located in the wheel tracks.

Differences in corrosion rates are to be expected. The chemical corrosion reaction rate varies, depending upon the concentration of the various essential elements and the quantities of elements vary throughout the deck. Temperature fluctuations influence the rate of metal corrosion. Electrochemical corrosion activity has been shown to cease entirely when the temperature remained below the freezing point of water for several days prior to making measurements.

Results of measurements made with two different measuring systems show decreases in corrosion rates after the interlayer membrane waterproofing systems had been completed. The data do not explain the magnitude of difference between types of measuring devices. With time the magnitude of difference in results predicted by the two measuring systems may decrease to a much lower level.

Additional corrosion monitoring installations will be made in the 2 decks which have not been waterproofed. The 2EPR, 3EPR and split-bar 2EPR installation will be made. No corrosometer probes will be installed. It is anticipated that several of each type installation will be made on each deck.

REFERENCES

1. Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair," Report FHWA-RD-74-5 Interim Report, Federal Highway Administration, February 1974.

2. Stratfull, R. F., Jurkovich, W. J., and Spellman, D. L. "Corrosion Testing of Bridge Decks," Transportation Research Record 539, 1975, pp. 50-59.

3. Instruction Manual, Model CK-3 Portable Corrosometer®, Magna Corporation.

4. Keldsen, John T., "Measuring Steel-in-Concrete Corrosion with an Electrical Resistance Probe," Corrosion /78, NACE, March 6-10, 1978, pp. 123/1 - 123/6.

5. Stern, M., and Geary, A. L., "Electrochemical Polarization," Journal of the Electrochemical Society, Vol. 104, No. 1 January 1957.

6. Lankard, D. R., Slater, J. E., Hedden, W. A., and Miesz, D. E., "Final report on Neutralization of Chloride in Concrete," Battelle, Columbus Laboratories, Sept. 30, 1975, pp. 130-136.