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DEPARTMENT OF TRANSPORTATION
Bureau of Materials and Physical Research

Bridge Deck Condition Survey

by

J. E. LaCroix

Final Report

IHR-306

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

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16. Abstract
Performance of 20 chloride-contaminated, partially restored, waterproofed bridge decks was evaluated for three years. Annually, surface conditions were mapped, extent and location of delaminated areas were determined, waterproofing permeability was measured, and attempts were made to determine the rate of corrosion.

Insufficient service life performance data were available to determine if sealing surface of partially restored chloride-contaminated decks will affect the rate of deterioration. Voids or blisters were found in the waterproofing system. Delaminations could not be distinguished from blisters. Results of corrosion measurements were inconclusive. The waterproofing membrane prevented penetration of surface moisture.

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BRIDGE DECK CONDITION SURVEY

INTRODUCTION

Purpose

This study was started to obtain sufficient data for use in evaluating the economic benefits of waterproofing chloride-contaminated concrete bridge decks. Its initial objective was to determine the behavior and probable service lives of concrete bridge deck-interlayer membrane-asphalt overlay systems where chloride-ion contents of the bridge decks are over 2.0 pounds per cubic yard of concrete at the level of top reinforcing steel at the time the interlayer membrane and asphalt overlays are constructed.

Background

Illinois bridge deck rehabilitation procedure, as in many other states, consists mainly of repair and replacement of spalled and delaminated concrete, then waterproofing the decks with an interlayer membrane, adding a sand-asphalt cushion and topping the system with a dense-graded bituminous concrete wearing course. All sound concrete remains in place regardless of chloride content.

Delaminations and subsequent spalling are the symptoms of the problem of corrosion of the top mat of reinforcement. The corrosion process begins with the migration of moisture laden with free chloride ions, usually from deicing salts, to the reinforcement. With the presence of sufficient oxygen, corrosion cells are formed. As the corrosion process continues, the volume of corrosion products becomes greater than the volume of parent metal. The volume change creates forces greater than can be withstood by the concrete. Horizontal cracks or delaminations are formed. The cracks eventually reach the surface and pieces of concrete, or spalls, are broken out.

Information available at the study inception suggests that partial restoration will extend service life, but little hard data were available for use in evaluating the benefits of partial restoration versus total restoration. Some sources suggest that waterproofing is an effective barrier to penetration of sufficient moisture and oxygen to continue the corrosion process. Others believe that although the surface may be waterproofed, sufficient moisture and oxygen will penetrate the deck from the underside and the corrosion process will continue.

In the 1970's, FHWA was leaning toward a policy of reduced financial participation for bridge deck rehabilitation programs unless specifications called for the removal of all deck concrete with chloride content exceeding the 2.0 lbs. Cl^-/yd^3 of concrete threshold level. Early investigations show that most of Illinois' decks are chloride-contaminated and more than half of the total number of PCC bridge decks in service contain more than 2.0 lbs. Cl^-/yd^3 of concrete.

This report contains the results and evaluations of data collected during a 5-year study of waterproofed bridge decks. Deck restoration consisted mainly of partial-depth patching of spalled and delaminated areas. Sound concrete remained in place, even though it may have been chloride-contaminated. Deck restoration and waterproofing were completed in accordance with Illinois' prevailing standards and specifications. No new or unique specifications or changes were included for research purposes. The work described in this report was conducted under Illinois Highway Research Project IHR-306, "Bridge Deck Condition Survey."

Scope

Twenty decks were to be surveyed annually. Surveys included visual inspections and mapping surface conditions, determining the extent and location of delaminated areas, making photographic records of surface conditions, determining corroding areas and chloride contents during the bare-deck surveys, and determining waterproofing permeability. Attempts were to be made to determine the rate of corrosion of the top mat rebars. Service life data were to be used to evaluate the economic benefits of the partial restoration waterproofing procedure.

Conclusions

Study decks were in service 2 to 3 years at the close of the study. Insufficient service life performance data were generated to determine if sealing the surface of concrete decks containing chloride in excess of the corrosion threshold will control future deterioration. Without accurate service life data, economic analysis can only be based upon conjecture. The original goals of the study could not be attained.

Recommendations

It is recommended that another 5 to 7 years of study be undertaken to continue the data collection and analysis phase of the original study. Seven to 10 years' service life may be sufficient to develop estimates of performance trends.

FIELD TEST PROGRAM

Deck Selection

Twenty decks were selected for full-time study on the basis of corrosion activity in the top mat of reinforcement prior to rehabilitation. Fifteen of the decks have 40 percent or more of the top mat reinforcement actively corroding (Category I), and the other 5 decks have less than 40 percent of the top mat actively corroding (Category II) according to copper-copper sulphate electrode (CSE) measurements.

Ride-over inspections were made initially to rate the surface condition of about 150 portland cement concrete bridge decks located throughout the state. These decks were either under contract for rehabilitation or were scheduled for a specific letting. Surface condition was rated based upon the estimated amounts of patching, spalling, and cracking. Few patches, spalls, and cracks suggested little corrosion, or Category II, while many patches, spalls, and cracks suggested much corrosion, therefore Category I. Finding Category II decks was a major problem.

From the group, 25 decks were scheduled for preconstruction surveys, from which 20 were selected for full-time study. The 20 decks include 8 on structures over water and 12 dry-land structures. Four of the dry-land structures are included in 2 full cloverleaf interchanges. The structures are incorporated in FAI 55, FAI 57, and FAI 74 (Figure 1). There are dual structures at each location. All

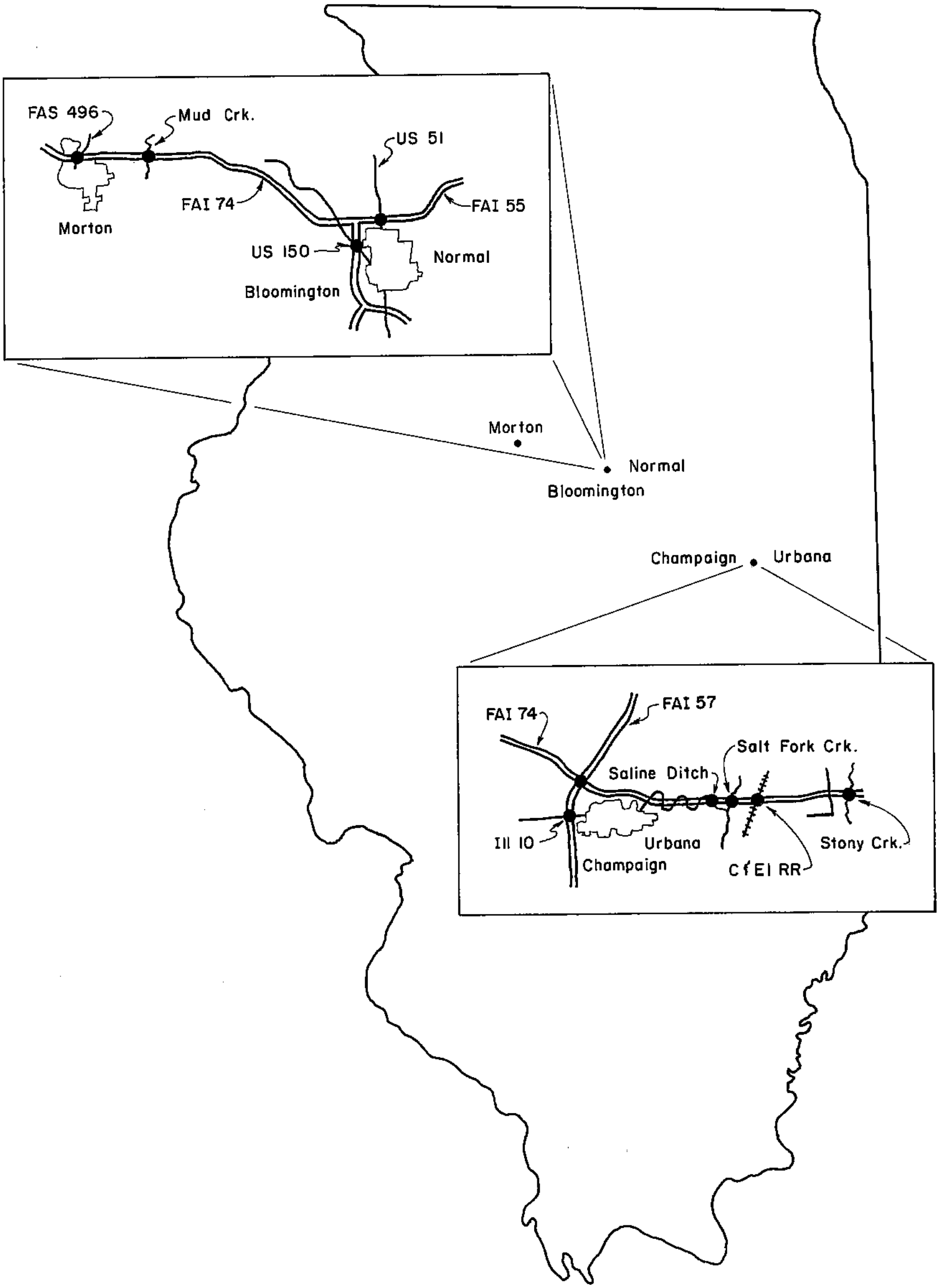


Figure 1. Deck locations

structures were constructed in accordance with prevailing standards and specifications. Structure numbers to be used through the remainder of the report are as follows:

Illinois Highway District	Structure Location	Direction of Traffic and Structure Number
4	FAI 74 over FAS 496 NE of Morton	EB 90-0019, WB 90-0020
4	FAI 74 over Mud Creek, 5 mi. W of Ill. 17 Interchange	EB 90-0023, WB 90-0024
3	FAI 55 over US 51, N of Normal	NB 57-0024, SB 57-0025
3	FAI 55-74 over US 150 W of Bloomington	NB 57-0018, SB 57-0019
5	FAI 74 over FAI 57, NW of Champaign	EB 10-0018, WB 10-0019
5	FAI 57 over Ill. 10, W of Champaign	NB 10-0009, SB 10-0010
5	FAI 74 over Saline Drainage Ditch, 10 miles E of Urbana	EB 10-0023, WB 10-0027
5	FAI 74 over Salt Fork Creek, 11 miles E of Urbana	EB 10-0029, WB 10-0030
5	FAI 74 over C&EI RR, 15 miles E of Urbana	EB 10-0031, WB 10-0032
5	FAI 74 over Stony Creek, 24 miles E of Urbana	EB 10-0001, WB 10-0002

Half-Cell Survey and Chloride Determinations

Corrosion of reinforcing steel was measured using a copper-copper sulphate half-cell. Measurements were made on a 4-foot grid in the shoulder, acceleration lane (if present), and traffic lane of each deck. Areas with readings greater than 0.35 volts more negative than the half-cell were considered to be actively corroding. The negative sign is not shown in the data (Figure 2). Electrical hookups were always arranged so that the voltmeter readings were positive numbers.

Concrete dust samples were obtained for chloride analysis from areas where the half-cell measurements were less than 0.35 volts. Sample locations were selected randomly from undelaminated, noncorroding areas. Ten samples were taken on each deck greater than 300 feet in length. Five samples were collected from each deck less than 300 feet in length. (Four decks were greater than 300 feet; 16 decks were 210 feet or less.) Concrete dust samples were taken from 1½-inch-diameter holes drilled to about the top of the top mat reinforcement.

Results of the preconstruction surveys are included in Table 1. The "% Area ≥ 0.35V CSE" column is the area of active corrosion. The column "% Area ≥ 2# Cl$^-$ 0.35V CSE" is the deck area not actively corroding but contaminated beyond the chloride threshold level. The "% Area Contaminated" column is the summation of the two previous columns and represents an estimate of the deck area containing a minimum of 2 lbs. Cl$^-$/yd^3 of concrete.

As can be seen in Table 1, every structure has more than 50% of the deck concrete chloride contaminated to a level exceeding the threshold level. If the 1974 FHWA guidelines had been followed, the <u>entire</u> surface to the top mat would have had to be removed from <u>every</u> deck, which on most structures, because of economics, would have required complete deck removal.

NB I-55 OVER US 51
Structure No. 57-0024
SECTION 57-4HB-4

SOUTH END

9																		
8																		
7																		
6	.33	.33	.35	.36	.35	.31	.40	.43	.41	.29								
5	.32	.25	.20	.32	.54	.28	.27	.33	.33	.39	.22	.21	.21	.22	.22	.27	.27	.22
4	.39	.25	.20	.36	.31	.28	.32	.39	.28	.42	.23	.20	.16	.20	.20	.29	.44	.29
3	.27	.25	.25	.32	.30	.28	.29	.35	.29	.42	.25	.27	.23	.23	.24	.36	.42	.27
2	.32	.23	.21	.23	.24	.30	.29	.29	.29	.28	.31	.31	.24	.27	.29	.33	.31	.27
1	.30	.19	.31	.39	.23	.39	.33	.38	.31	.40	.33	.50	.31	.28	.24	.22	.27	.28
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure 2. Typical Corrosion Measurement Field Sheet

TABLE 1. PRECONSTRUCTION SURVEY RESULTS

Illinois Highway District	Structure Number	Year Constructed	% Area ≥0.35V	% Area ≥2# Cl^- <0.35V	% Area Contaminated	Deck Length (feet)	Date of Survey
			FHWA CATEGORY II				
4	90-0024	1960	29	28	57	130	4/07/77
3	57-0018	1965	30	28	58	440	5/10/77
5	10-0032	1959	30	42	72	170	4/12/78
3	57-0019	1965	36	32	68	440	4/26/77
5	10-0002	1960	38	37	75	152	4/12/78
			FHWA CATEGORY I				
5	10-0009	1964	41	24	65	300	3/24/77
4	90-0020	1960	42	35	77	126	4/07/77
3	57-0024	1964	43	34	77	209	4/21/78
4	90-0023	1960	44	34	78	130	4/07/77
5	10-0028	1958	44	42	86	164	4/11/78
3	57-0025	1964	50	40	90	209	4/21/78
5	10-0031	1959	58	8	66	170	4/12/78
5	10-0018	1964	61	8	69	210	3/25/77
5	10-0027	1958	64	22	86	164	4/12/78
5	10-0001	1960	70	24	94	152	4/12/78
5	10-0029	1958	82	11	93	160	4/11/78
5	10-0030	1958	82	12	94	160	4/11/78
5	10-0019	1964	87	5	92	210	3/24/77
4	90-0019	1960	93[1/]	-	93+	126	4/06/77

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

Condition Survey

The surface condition of the traffic lane, acceleration lane, and shoulder was mapped to scale. Surface defects were located and dimensioned by survey personnel using a measuring wheel and 6-foot folding ruler. Preconstruction surveys were made within 2 months of the start of construction on all decks except 90-0015, which was surveyed after patching had been completed. All decks were surveyed twice prior to the start of construction, with 3 exceptions. Decks 57-0024 and 57-0025 were surveyed 4 times and 90-0019 was surveyed only once.

The types of defects mapped during the original surveys consisted of cracks, patches, spalls, scale, and popouts. Postconstruction condition surveys were mapped following the same procedures. As one would expect for new surfacings, no defects were found in the initial survey after construction (1978 survey on most decks). After 1 year service (1979 survey), some hairline cracks were observed in longitudinal construction joints on nearly every structure. On structure 10-0018 several tightly spaced transverse cracks about 1 foot long were found in the acceleration lane. All cracks were tightly closed and difficult to see.

A suspected patch failure was observed at one location on 57-0018. A hump formed near the curb with the peak cracked and located about 6 to 8 inches from the curb wall (Figure 3). An area of about 1 foot by 2 feet was affected. Apparently, the deck patching material under the hump was a high early-strength sand mix.

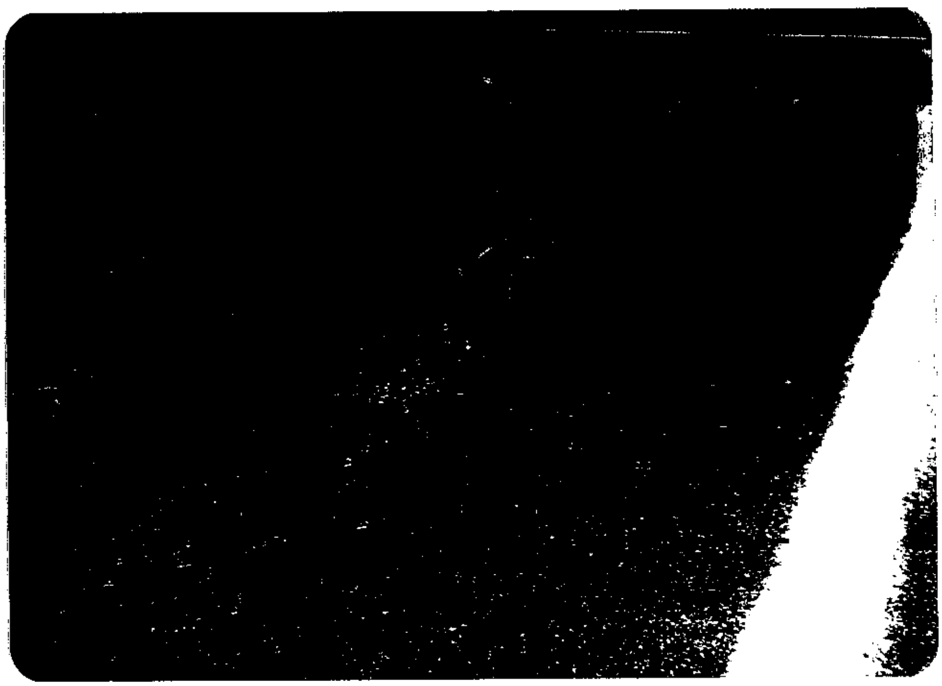


Figure 3. Possible patch failure, 1979

Dish-shaped depressions were observed to some extent in the surfaces of 15 of the 20 structures (Figures 4a and 4b). Although they detracted from the riding quality of the new surface, the author failed to see the significance of the depression during the 1979 survey. They were not quantified, tabulated, or mapped.

After 2 years service (1980 survey), the longitudinal construction joints on nearly every structure were cracked. Various amounts of transverse cracking were observed on most decks. Cracks shaped like a "Y" (Figure 5) were observed on structures 10-0009 and 10-0018. All cracks were visible but appeared to be tightly closed.

The "Y" cracks were in dish-shaped depressions. The length of each leg of the "Y" was about equal and was proportioned to the size of the dish. The junction of legs is located in roughly the center of the dish.

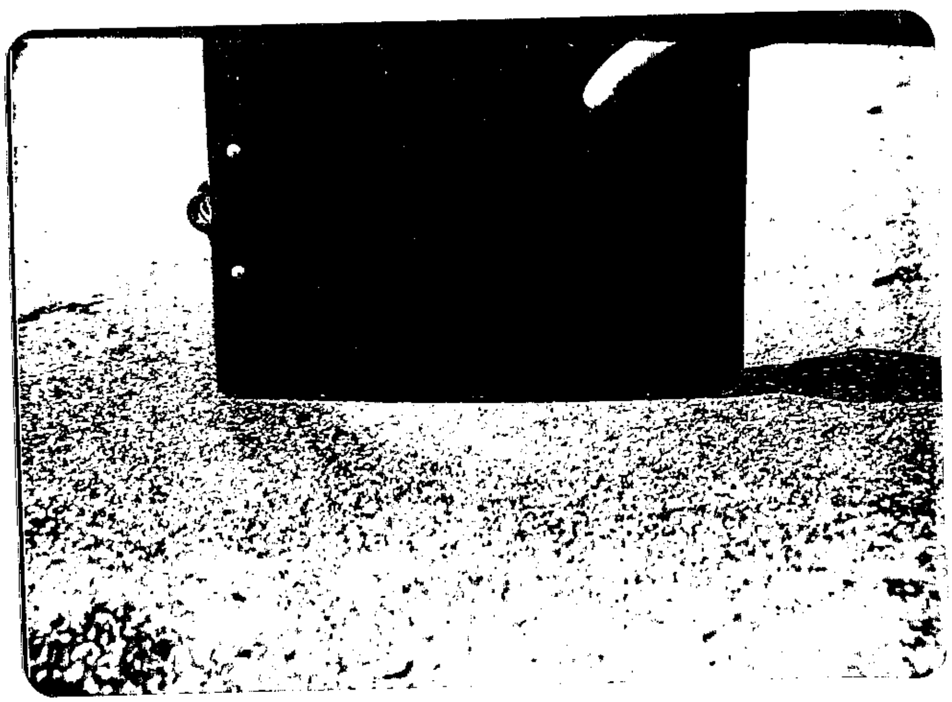
On structure 57-0018 a new hump had formed about 20 feet south of the original hump, and the original hump had grown in size (Figure 6).

On structure 57-0019, sometime during the winter of 1979 a hump had formed and had been partially cut away by a snowplow along with a strip of surface about 4 inches wide by 5 feet long (Figure 7).

Delamination Survey

Delaminations were located using an S.I.E. Delamtect (Figures 8 and 9). Each year the traces were made on 2-foot centers, with the first trace starting about 1 foot from the outside curb. Traces were made longitudinally starting from one end of the deck and returning from the other end. During the preconstruction surveys, the operator aligned the traces using the 4-foot grid marks from the half-cell

4a. General location of depression



4b. Close-up view of depression

Figure 4. Dish-shaped depression

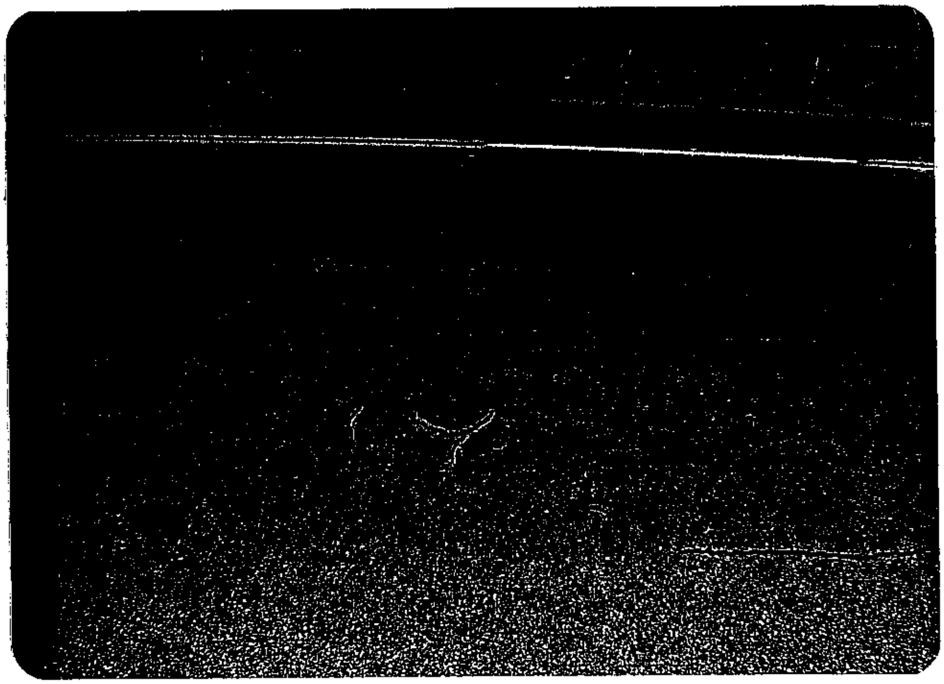


Figure 5. "Y"-shaped cracking

Figure 6. Patch failures, 1980

Figure 7. Snowplow damage to hump, 1980

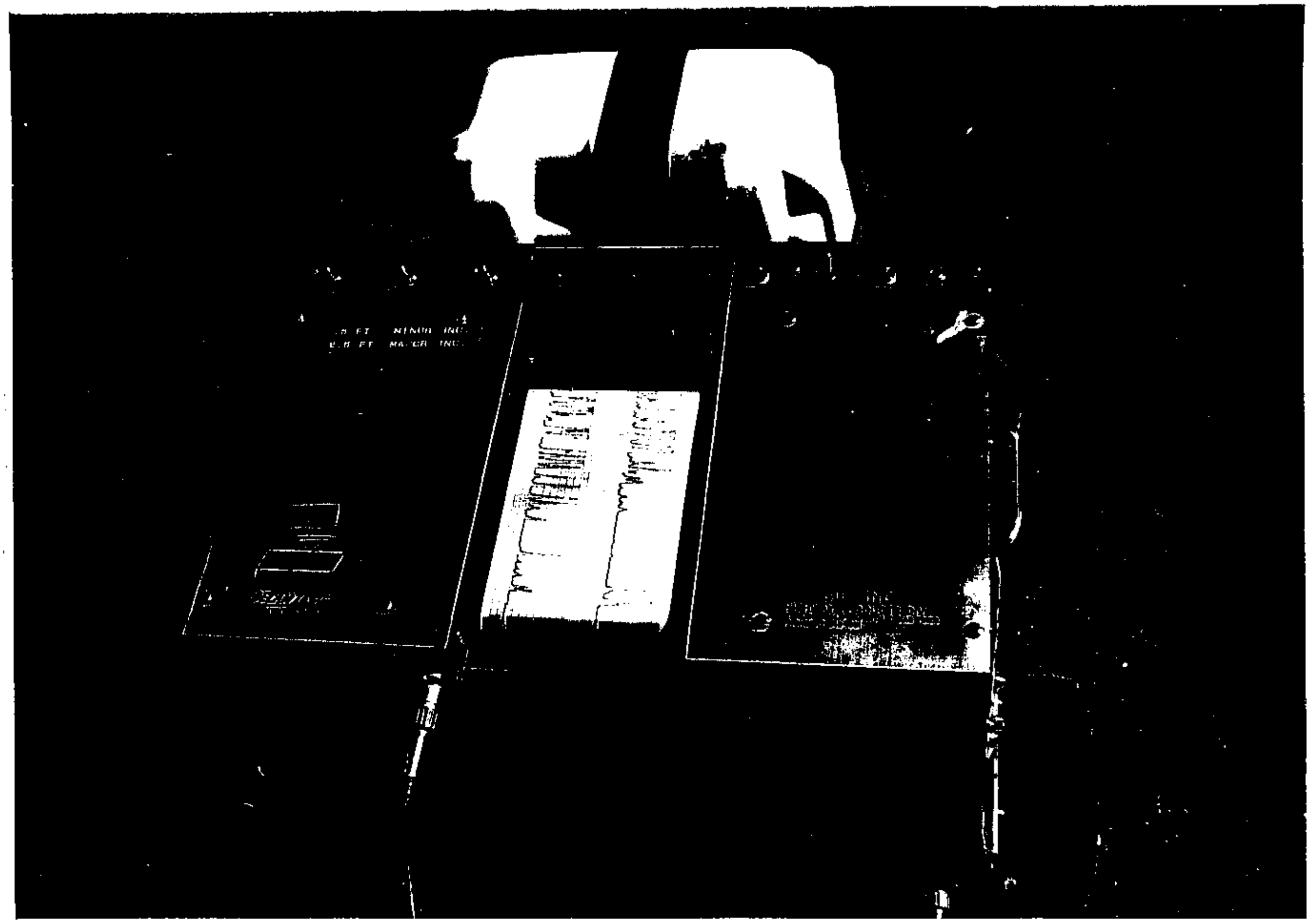


Figure 8. Delamtect

survey. With practice, satisfactory alignment was obtained without markings by gaging the distance from the curb, paint stripes, or longitudinal construction joints. Pip marks were made on the strip traces to designate the start and finish of each trace and at any distinguishing features on the deck, such as expansion joints.

Depth of delamination could not be determined in this study using the available equipment and without destructive testing. This is a definite problem when evaluating decks with overlays. The delaminations could be in the PCC at the level of reinforcement or they could be somewhere between the PCC surface and the bituminous surface. Results of the delamination surveys are shown in Table 2 as "% Area Delaminated." Until the 1980 survey, the area of delaminations was estimated from Delamtect strip tapes. During the 1980 survey, the delaminations were located, marked with lumber crayon, and measured. Area was computed from those measurements.

On the average, the new decks contained 0.4% delaminated area at the start of their service life, excluding 10-0002 results. Four decks had no delaminations. The delaminations found after construction tend toward being located within the same area as delaminations found during the preconstruction surveys. Mechanical problems with the Delamtect strip tape drive mechanism caused the tapes to be different lengths from year to year. Therefore, some doubt exists as to whether the delaminations were new or were missed during construction.

The 1979 results averaged about 0.6% delaminated area per deck, a slight increase from the previous survey. Comparison of the strip

TABLE 2. DELAMINATION SURVEY RESULTS

Structure Number	% AREA DELAMINATED Before Construction	Year Surveyed 1977	1978	1979	1980[1/]
90-0024	0.5		0.4	1.0	0.6
57-0018	3.3	0.1	0.3	0.6	0.5
10-0032	2.2		0.3	0.8	1.2
57-0019	3.0	0.5	0.7	0.7	0.6
10-0002	3.8		2.8	4.8	0.3
10-0009	2.1		0.6	1.2	0.2
90-0020	10.0		1.1	0.1	0.3
57-0024	2.0			0	0
10-0010	0.8		0.3	0.4	0.2
90-0023	4.2		0.1	1.0	0.5
10-0028	4.2		0.4	0.2	0
57-0025	2.8			0.1	0
10-0031	8.2		0.8	0.8	0
10-0018	13.0		0	0.3	0
10-0027	9.1		1.1	1.8	0.04
10-0001	10.5		0	0.5	0.1
10-0029	14.4		0.3	0.9	0.3
10-0030	10.8		0.7	1.3	0.1
10-0019	17.0		0	0.1	0
90-0020	*	0.2	0	0.5	0

1/ Prior to 1980, size of delaminations estimated from delamtect tapes.

* No before construction delamination survey.

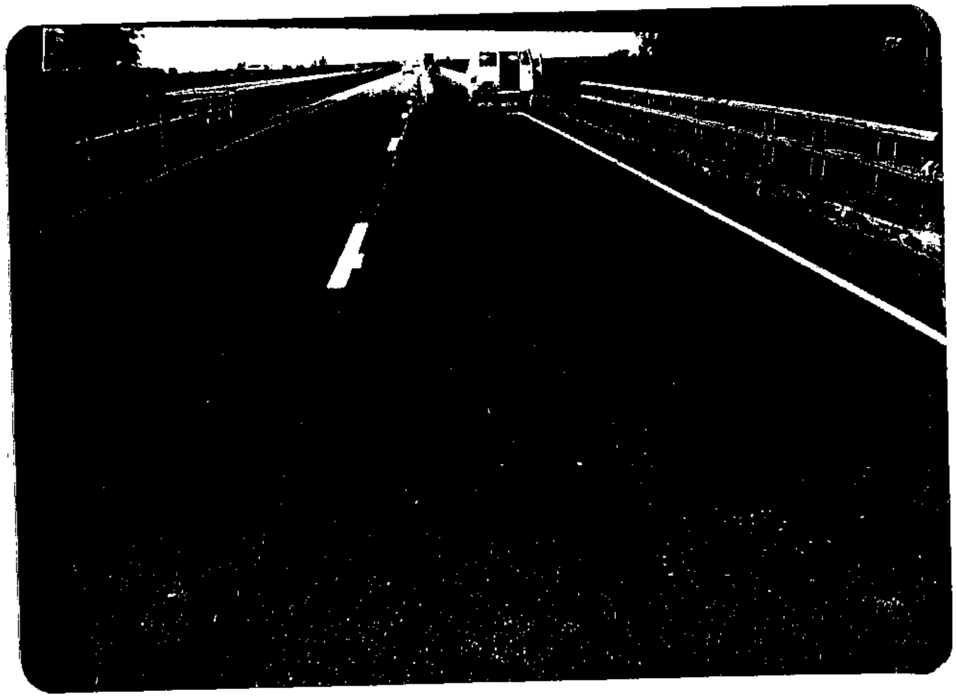
tapes told another story. It was next to impossible to match delaminations from one year to the next. Some delaminations apparently disappeared while others appeared to have moved.

On structure 10-0002, the delaminated area was nearly 3% initially and increased to nearly 5% over one winter. Large areas of the east and center spans apparently were delaminated. Figures 10a and 10b show the delaminated area outlined. A slurry mix was used to fill the numerous aggregate popouts in the original PCC surface. During 1978 and 1979 it was thought that the slurry had become disbonded and that large areas of the waterproofing and bituminous surface would soon strip off.

The 1980 delamination survey results show that 18 of the 20 decks had less delaminations than the previous year. Seven decks had no delaminations. The average area was about 0.3%. The average decrease in area was 0.3% on the 7 decks with no delaminations. On 10-0002 the delaminated area dropped from 4.8% to 0.3%.

The photographs in Figures 11a and 11b were taken in 1980 and are of the same area shown in the 1979 photographs shown in Figures 10a and 10b. Delaminated area is outlined in lumber crayon on the deck surface. The entire area of each span was sounded extensively using delamtect and manually with a hammer (evidenced by the white specks on the surface). Over 4.5% of the delaminated area apparently has rebonded.

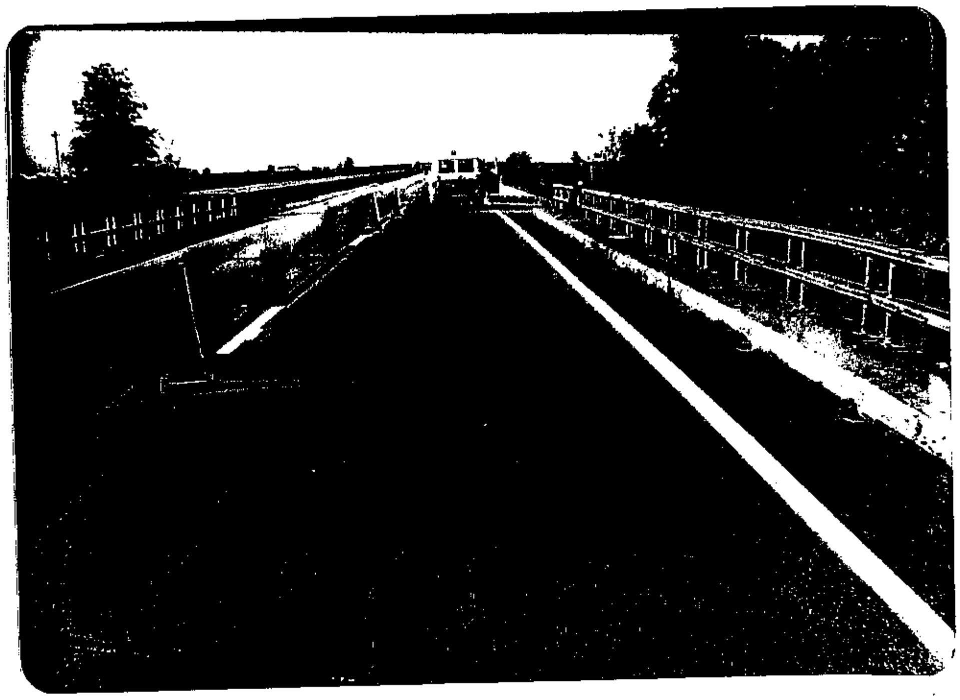
It is believed that most of the delaminations are blisters under the interlayer. The dish-shaped depressions observed during the initial preconstruction surveys, the apparent healing of



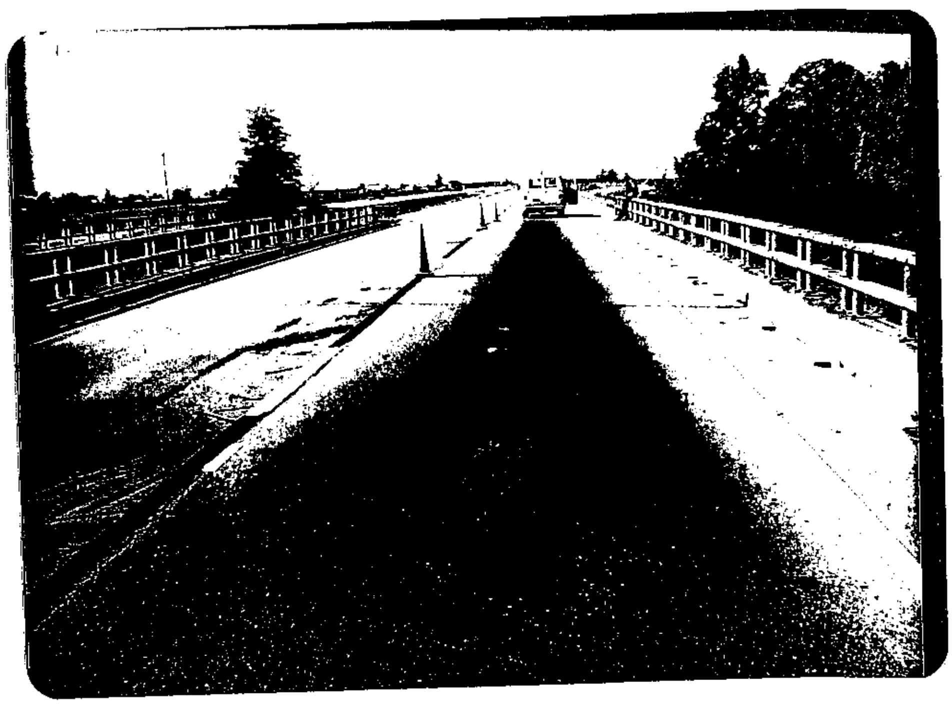
10a. East end of center span

10b. West end of east span

Figure 10. Delaminated area of Structure 10-0002 in 1979



11a. East end of center span



11b. West end of east span

Figure 11. Delaminated area of Structure 10-0002 in 1980

delaminations, and movement of delaminations are strong evidence that blisters have formed. Until recently, the formation of blisters was not believed to be a problem with the coal tar interlayer membrane-asphalt overlay waterproofing system.

On structures 57-0018 and 57-0019 the grout fillet placed in the cove between the deck surface and parapet has failed. A 2-inch to as much as 5-inch-wide band of delamination adjacent to the curb nearly full-deck length on each structure has formed. With time, water and salt will migrate into the deck from the edge to contribute to early failure of the waterproofing. As can be seen in Figure 7, snowplows scraped off the surface when it raises in this manner. The grout fillet was placed too thick during construction, but was not thought to be a problem at the time. Because of its uniqueness, the area of this delamination was not included in the data summaries for the two structures.

Permeability Measurements

Two methods were used to evaluate the effectiveness of the waterproofing system in preventing the penetration of surface water. Permeability measurements were made on the new surfaces using the sponge method similar to that described in ASTM D3633-77 and by measuring the resistance between pairs of copper strips placed transversely on the bare decks at about the points of dead load contraflexure.

The conductive strips consist of two 9-foot copper strips placed 4 inches apart. Three sets of strips were placed on each deck. The strips were installed just prior to the placement of the penetrating primer. Lead wires were taped to the deck and up the curb wall. All sets survived construction; however, some were lost each year to snowplow damage. Readings were made twice by reversing voltmeter connections. Results of the 2 readings were averaged. Average resistance values between pairs of wires greater than 10K ohms represents good protection while any lesser value is questionable.

Results of all meaurements made on the copper strips show only one structure with questionable protection. The 1979 readings made on the three pairs of strips on structure 10-0030 average 3, 4, and 5K ohms. Rains had occurred each day for 6 days prior to taking the readings in 1979. The 1980 measurements averaged 5, 6, and 10K ohms. No rain had fallen for 10 days prior to making the 1980 measurements. By 1980, only 70% of the pairs of copper strips were still in service; the rest could not be located.

Sponge measurements were made at copper strip locations (Figure 12). Two rows of three sponges were set on 4-foot grids on each side of and 4 feet from the copper strips. The sponges were saturated with water when placed, then sprayed periodically to insure saturation. Resistance measurements were made until the readings stabilized. Readings greater than .5 megohms represent good protection, from .1 to .5 megohms is considered to represent doubtful protection, and readings less than .1 megohm indicate that the protection is not satisfactory.

Readings on the sponges show good initial protection on 15 decks and some doubtful areas on the other 5. On those 5 decks, the readings indicate that 94 to 97 percent of the surface area has good

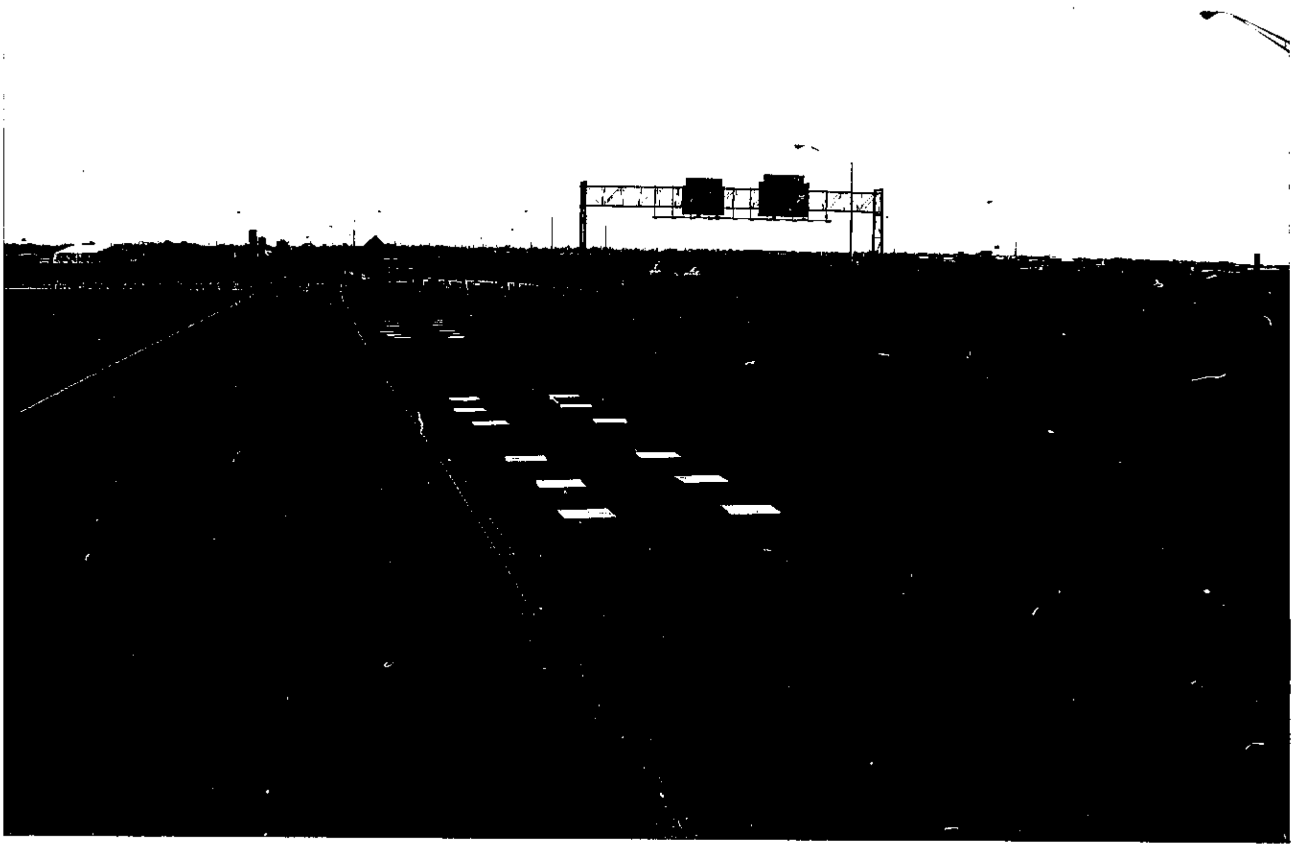


Figure 12. Permeability measurements

protection, with the remaining 3 to 6 percent being in the doubtful range (.1 to .5 megohms).

Rate of Corrosion

Corrosion rate measurements were made in an effort to determine if the waterproofings were effective in controlling the corrosion process. Those that believe the waterproofing is effective suggest that the rate of corrosion should decrease with time. On the other hand, others believe the waterproofing is not effective; therefore, corrosion should continue or could even be accelerated.

Estimates of corrosion rate were made from polarization resistance data and from data collected on commercially available corrosometer probes. Six decks were selected for corrosion-monitoring installations, with a total of 24 devices installed. Installations were made in areas where the copper-copper sulphate half-cell indicated active corrosion. Polarization resistance installations were made simultaneously with and in close proximity to the corrosometer probes.

Corrosometer Probes

The corrosometer probe (trade name for electrical resistance probe) is a 50-mil-thick 13-inch-long piece of mild steel. The probes were buried in the bridge deck near to but not touching the top reinforcement and are electrically connected to the rebars except while making measurements. Three quarters of the probe, called the measuring element, is exposed to the corrosion environment. The remaining portion, called the reference element, is encapsulated in epoxy to protect it from corrosion. As the measuring element corrodes, the resistance ratio between the two elements increases. Micro inches of metal loss are read directly with a Model CK-3 Portable Corrosometer®.

A total of 6 probes were available for use in monitoring corrosion rate. Initial installations were in structures 57-0018 and 57-0019 on September 6 and 9, 1977, respectively. The remaining 4 probes were installed in structures 10-0029 and 10-0030 on July 20 and 24, 1978, respectively.

Probes were installed with the chloride contents equal to or greater than the original environment (Table 3). The first two probes were installed, as suggested by the manufacturer, with a backfill chloride content equal to the original values of 516 ppm and 1737 ppm (about 2 and 7 lbs. Cl^-/yd^3, respectively). The remaining probes were installed at 1000, 2500, 3750, and 5000 ppm (4, 10, 15, and 20 lbs. Cl^-/yd^3).

Probes were installed at chloride contents different than the existing environment to answer two questions. First, would the rate of corrosion change if a differential in chloride content exists between the new patch and the existing pavement? During restoration, the patching mix is not Cl^- adjusted to the surroundings. Second, is corrosion rate affected by variations in the magnitude of differential Cl^- rates?

Results of the corrosometer probe corrosion rate measurements are shown in Table 4. Corrosion rate, in mils per year, was calculated using the manufacturer's formula:

TABLE 3. CORROSOMETER PROBE INSTALLATION DATA

Structure Number and Probe Location	Probe Designation	Backfill Cl^- PPM	Backfill Cl^- lbs/yd^3	Original Cl^- PPM	Original Cl^- lbs/yd^3
57-0018, No. End, Cntr. of Traffic Lane	CP 2	416	2	416	2
10-0029, W. End, Cntr. of Traffic Lane	CP 4	1000	4	558	7
57-0019, No. End OWP of Traffic Lane	CP 7	1737	7	1737	7
10-0030, W. End OWP of Traffic Lane	CP 10	2500	10	1792	7
10-0030, E. End OWP of Traffic Lane	CP 15	3750	15	838	3
10-0029, E. End Cntr. of Traffic Lane	CP 20	5000	20	942	4

TABLE 4. CORROSION RATE - CORROSOMETER PROBES

TEST DATE Mo./Yr.	Probe Number - Chloride Content, #Cl⁻/yd³ Concrete 2	4	7	10	15	20
	CORROSION RATE, MILS/YEAR					
11-77	11.7		3.7			
1-78	5.7		2.3			
4-78	3.0		0.9			
7-78	0.5		0.4			
9-78	0.6	0.8	0.5	1.7	0.6	2.5
10-78	1.6	1.6	0.4	2.4	1.1	3.6
11-78	0.6	1.2	0.4	1.8	0.7	2.7
12-78	0.6	2.2	0.4	2.0	0.6	3.1
1-79	*	1.6	0.5	1.6	1.0	2.8
2-79	0.9	1.3	0.5	1.4	0.4	2.5
3-79	0.7	1.3	0.3	1.3	0.4	2.2
4-79	0.7	0.2	0.3	0.4	0.4	1.5
5-79	3.4	0.4	0.2	0.4	0.3	1.3
6-79	2.8	0.4	0	0.3	0.3	1.2
7-79	1.1	0.1	0	0.4	0.3	1.4
8-79	0.2	0.2	0.1	0.3	0.2	1.3
9-79	0.7	0.2	0.1	0.4	0	1.3
12-79	0.3	0.2	0.1	0.3	0	1.3
3-80	0.5	0.2	0.1	0.3	0.1	1.2
5-80	0.3	0.2	0.1	0.2	0.1	1.0
7-80	0.2		0			
8-80		0		0	0	0.7

* Heavy ice load on wires and connector; could not take readings

$$MPY = \frac{\Delta Reading}{\Delta Time} \times 9.125$$

Where: MPY = corrosion rate in mils (.001") per year
ΔReading = difference in dial readings
ΔTime = time elapsed between readings in days

As can be seen in the table, corrosion rate decreases with time at each installation. By July and August of 1980, most probes appeared to be totally inactive. Corrosion may have stopped as early as April 1979 on probes 4, 7, 10, and 15. Probe 20 generally was the most active, followed by probes 10 and 4.

Polarization Resistance

Three types of installations were made in six structures to collect polarization resistance data for use in estimating corrosion rate. Two-element installations were made in structures 57-0018, 57-0019, 57-0024, and 57-0025. Three-element installations were made in structures 10-0029 and 10-0030. Split bar installations were made in structures 57-0024 and 57-0025.

In the two- and three-element installations, 6-inch segments of the top rebars were electrically insulated from the rest of the mat. The three-element installations have a zinc bar installed about 1/8 to 1/4 inch above one of the 6-inch segments. The zinc bar was 1/4-in. x 1/4-in. cut to the same length as the test segment. The bar was installed in a 1-in. slot backfilled with a slurry consisting of 85 percent plaster, 10 percent bentonite, and 5 percent zinc sulphate.

The split bar specimens are 6-inch-long pieces of number 5 bar cut in half, lengthwise (Figure 13). The two halves are spaced about 3/4 inch apart, with the cut faces facing each other. Small plastic

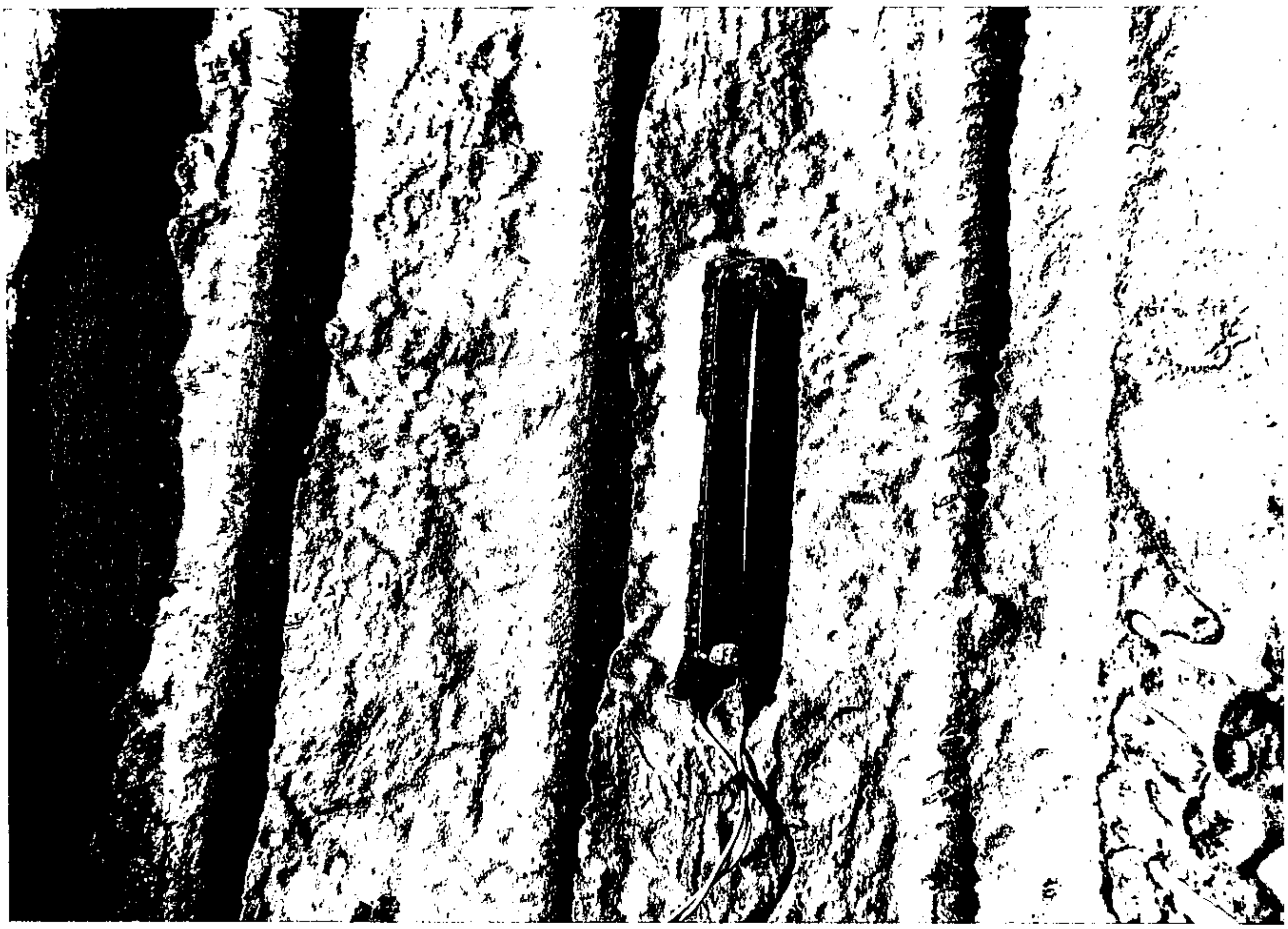


Figure 13. Split bar specimens

spaces are placed between the bars at each end and secured with tape. Lead wires are secured in holes in one end of the bar and taped. Except for the cut faces, all exposed metal and tape are sealed using an electrically insulating epoxy. The specimen is placed near a rebar and the area between the bars is filled with mortar paste with a chloride content just prior to backfilling with concrete patching materials containing slightly less than 2 lbs. Cl^-/yd^3.

Corrosion rate was calculated using the equation:

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

where: CR = corrosion rate in mils (.001 inch) per year
K = 0.012, based upon electrochemical constants and coefficients for steel in concrete
Δi = current density, microamps per sq. cm.
ΔE = polarizing potential, volts

On the two-element (2 EPR) and split-bar installations, initial current and voltage were measured between the same pairs of wires. A 5-millivolt polarizing potential was then applied and new current and voltage measurements taken. Finally, all leads were reversed and the routine completed again. On the three-element (3 EPR) specimens, initial current was measured between the isolated rebars and initial voltage was measured between the zinc reference bar and the specimen immediately beneath it. The 5-millivolt potential was applied to the two rebars. Final current was measured between the two rebars and final voltage was measured between the zinc bar and test specimen.

Corrosion rate estimates are shown in Tables 5, 6, and 7. These results are included as documentation of the effort expended in an attempt to attain a study goal. The accuracy of field measurements is

TABLE 5. CORROSION RATE, 2 EPR

TEST DATE Mo./Yr.	STRUCTURE NUMBER 57-0018	57-0018	10-0029 W	10-0029 E	10-0030 E	10-0030 W	57-0025 N	57-0025 S	57-0024 N	57-0024 S
	CORROSION RATE, MILS/YEAR									
11-77	.06 1/	.06								
1-78	.06	.06								
4-78	.06	.06								
7-78	.07	.06								
9-78	.07	.07								
10-78	.07	.03	.35	.03	.27	.29				
11-78	.07.	.03	.32	.03	.34	.24				
12-78	.07	.02 2/	.19	0	0	.12				
2-79	.07	.12	.21	.03	.25	.08				
3-79	.06	.64	.24	.03	.28	.10				
4-79	.07	.35	.10	.04	.17	.05				
5-79	.07	1.6	.34	.04	.30	.23				
6-79	.07	1.2	.29	.04	.33	.29				
7-79	.07	.85	.10	.01	.17	.08	0.09	0.12	0.52	1.6
8-79	.07	.80	.19	.04	.28	.23	-	-	-	-
9-79	.07	.79	.20	.04	.19	.19	0.01	0.06	0.36	0.8 3/
5-80	.07	1.7	-	-	-	-	0	0	0.20	
7-80	.07	1.7	-	-	-	-	-	-	-	-
8-80	-	-	.37	.01	.28	.22	0	0	0.15	-

1/ Current readings never greater than 0.13 microamps.

2/ Until this reading, natural current flow from bar 2 to bar 3. From this reading on, current flow from bar 3 to bar 2.

3/ Wires severed by vandals.

TABLE 6. CORROSION RATE, 3 EPR

TEST DATE Mo./Yr.	STRUCTURE NUMBER 10-0030 W	10-0030 E	10-0029 E	10-0029 W
	CORROSION RATE, MILS/YEAR			
10-78	.04	.01	.13	.05
11-78	.01	.01	.05	.01
12-78	0	0	0	0
2-79	.01	.03	.07	.02
3-79	.02	.01	.07	.02
4-79	.01	0	.03	0
6-79	.05	.01	.03	.03
7-79	.05	.03	.03	.03
8-79	0	.04	.02	.02
11-79	.02	.01	.02	.01
5-80	0	.02	.01	0
8-80	0	.01	.01	0

TABLE 7. CORROSION RATE, SPLIT BARS

TEST DATE Mo./Yr.	STRUCTURE NUMBER 57-0025 S	57-0025 N	57-0024 N	57-0024 S
	CORROSION RATE, MILS/YEAR			
7-79	.01	.01	.05	.04
10-79	.04	.01	.07	.01 1/
5-80	.05	.05	0	
8-80	.02	.03	0	

1/ Wires severed by vandals.

questionable because of their extremely low values, i.e., few current readings were greater than 10 microamps.

The 2 EPR results for structure 57-0019 (Table 5) show the greatest rate of corrosion from March 1979 to August 1980. This installation is located about 5 feet from the curb wall in an area where the grout fillet has failed and a 4-inch band of delamination was formed next to the curb.

SUMMARY

As one would expect of newly constructed waterproofing, the majority of study decks show no failures or problem areas. After 2 or 3 years service, no performance trends are evident. The data show localized failure of grout fillet on 2 structures, with possible patch failures on the same structures and hairline cracking on most structures.

Test results document the presence of voids or blisters in the waterproofing system. How long the blisters will remain is unknown. Some subsided and rebonded during the first summer as evidenced by the dish-shaped surface depressions. Blisters were squeezed out of the wheelpaths toward the center of the lane or to the shoulder or to the area between lanes. Some blisters formed during the first summer after construction. Delaminations could not be distinguished from blisters without destructive testing.

Results of the rate of corrosion determinations are difficult to assess. The commercially available probes, thought to be the most reliable, apparently ceased operation within the first year of service. The rate of corrosion measured by the polarization resistance installations shows little activity before the waterproofings were completed and less after completion, with one exception. The corrosion rate measured by the 2 EPR installation on structure 57-0019 shows an increase in C.R. from February 1978 to July 1980. An increase of twice the original rate to nearly 30 times the original rate is shown.

Years of service life are a key factor in the comparison of economic benefits of the practice of partial restoration versus any other method of rehabilitation. This study was too short to produce any service life performance trends; therefore, the evaluation of economic consequences associated with rehabilitating chloride-contaminated PCC bridge decks was not possible within the time period allotted in the original work plan.