Bridge Deck Condition Survey

Long Term Performance Evaluations

Physical Research Report No. 100

Illinois Department of Transportation
Bureau of Materials & Physical Research

Illinois Department of Transportation
Division of Highways
Bureau of Materials and Physical Research

Final Report
IHR 306

Bridge Deck Condition Survey
Phase V Long Term Performance Evaluation

by
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Physical Research Section

A Research Project in Cooperation with
U. S. Department of Transportation
Federal Highway Administration

February 1985

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16. Abstract

Performance was monitored from 1977 through 1984 on 20 mainline Interstate bridges whose chloride-contaminated decks were rehabilitated by removal and replacement of only unsound concrete and then waterproofed and overlayed. The decks performed well with little or no repair being done. None of the decks needed immediate rehabilitation by the end of the study.

Cost analysis show that patching then sealing the surface of chloride contaminated but sound concrete can be a cost-effective alternative to total deck replacement.

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INTRODUCTION

Purpose

This study was conducted to evaluate the economic consequences associated with partial depth patching and waterproofing of PCC bridge decks where the decks were contaminated with 2 or more pounds of Chloride-per cu. yd. of concrete at the time of restoration.

Background

The performance of 20 chloride contaminated, waterproofed bridge decks was evaluated for a 3 year period ending in 1980. 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. No significant performance trends were found.

The original study goals could not be met within the time frame of the original work plan because insufficient service life performance was generated for use in evaluating the economic effectiveness associated with partial restoration. In 1982, a new study phase was added titled "Long-Term Performance Evaluation" to provide for three additional annual surveys of the study decks.

Bridge deck restoration consisted 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.

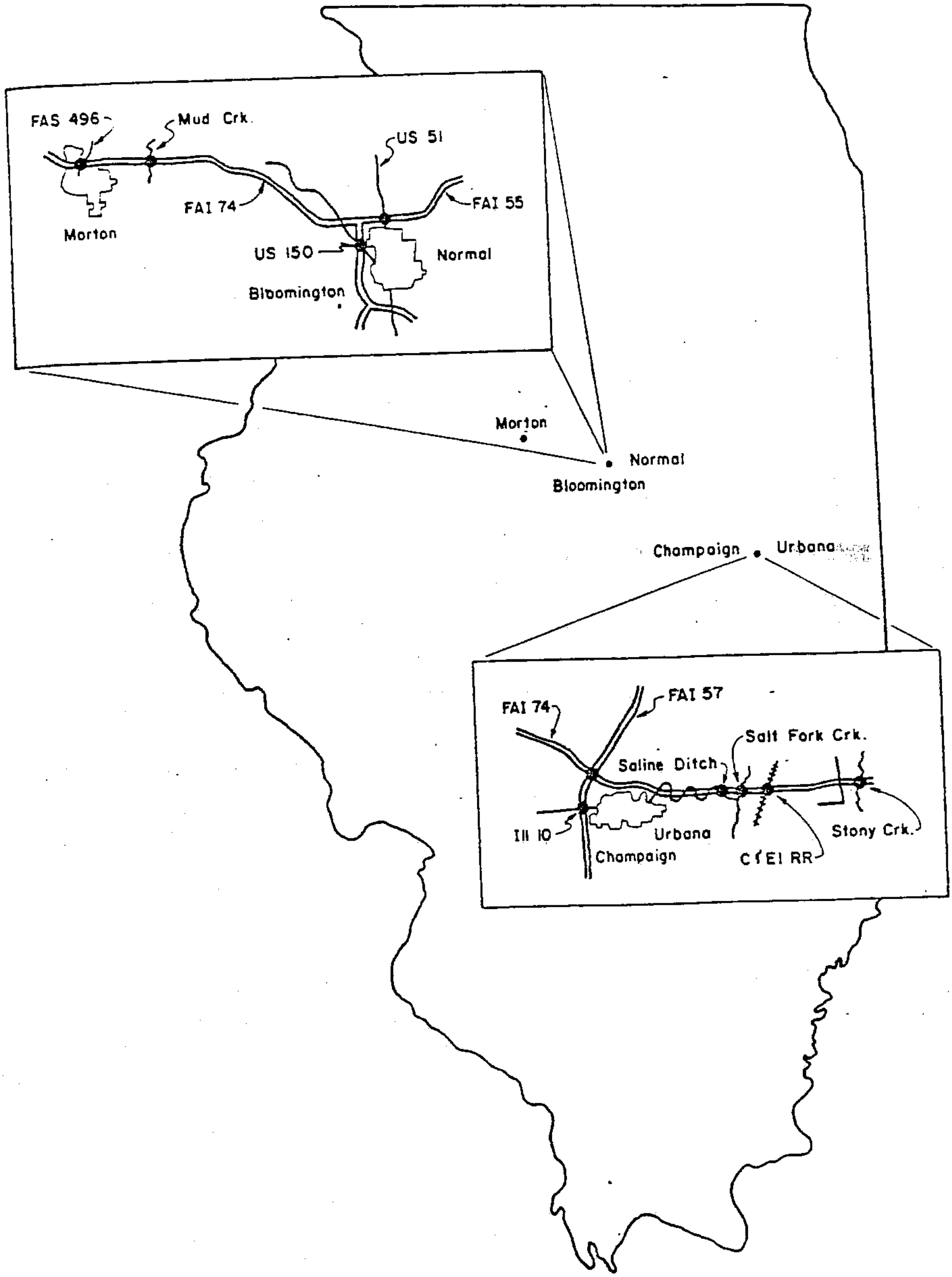
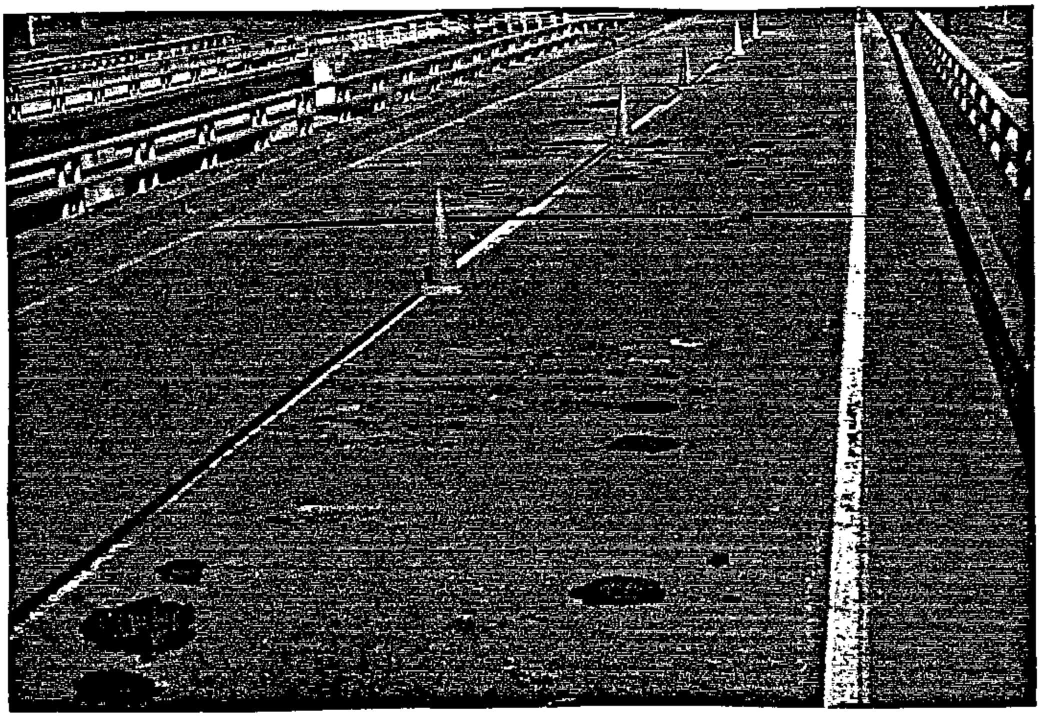


Figure 1. Deck locations



a). Typical Category I deck.

b). Typical Category II deck.

Figure 2. Photographs of typical Category I and Category II decks.

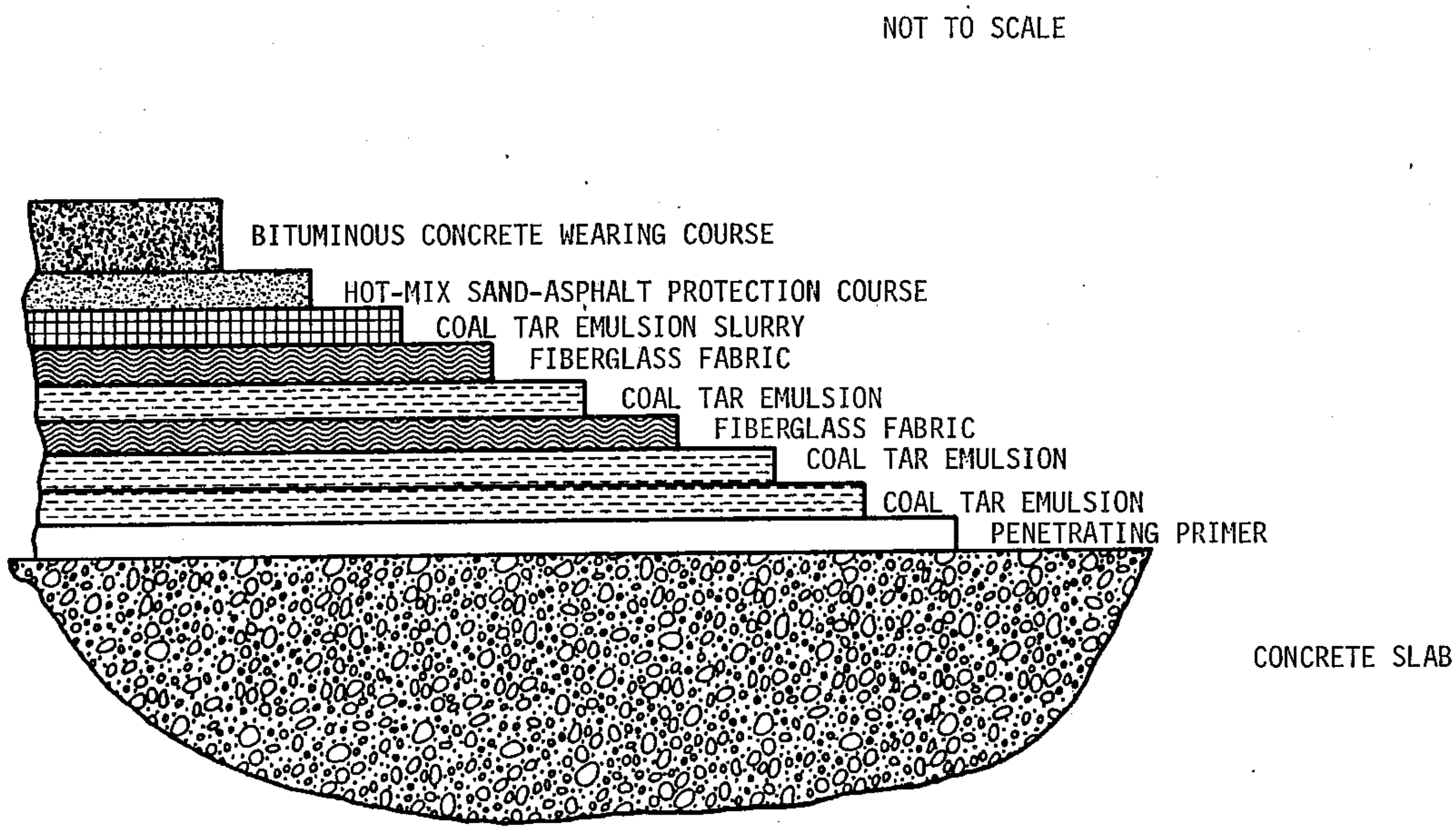


Figure 3. Waterproofing System.

Results of measurements made using the sponge method (ASTM D 3633-77) and by electrical resistivity between pairs of copper strips placed transversely on the bare decks suggested that the waterproofing prevented moisture penetration.[1] These measurements were deleted from Phase V. Most lead wires for the copper strips were damaged beyond repair by the elements or by vandalism. Equipment for making sponge measurements (ASTM D 3633-77) had been disposed of upon completion of the original study phases. The reliability of measurements did not warrant the purchase of new equipment.

From the start, delaminated concrete was to be the major factor used in evaluating the effectiveness of this bridge deck restoration process. Delaminations and subsequent spalling and patching are the symptoms of problems caused by corrosion of the reinforcement. A typical delamination is shown in Figure 4.

Delaminations are caused by excessive pressure created during the corrosion process. The volume of corrosion products is greater than the volume of the parent reinforcing steel. The increase in volume causes increases in pressure creating tensile forces in the concrete. As corrosion continues, resulting pressures exceed the tensile capacity of concrete causing it to crack or spall.

Delamination Survey

Early delamination surveys were made using a Delamtect. From 1977 through 1979, 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 along an adjacent path. A strip chart was made for each trace. The strip charts were evaluated at a later date, in the office.

During the 1980 survey, delaminations were located using the Delamtect, and the physical limits of each delamination were established using Delamtect or by sounding with a hammer. They were marked using lumber crayon, and measured and mapped.

The same procedure used in 1980 was again employed in 1982 and 1983 surveys except the limits of delamination were marked with spray paint. In most instances, sufficient paint survived from one year to the next to help in relocating suspected delaminations. Examples of this marking technique are shown in Figure 5.

Figure 5 is a photograph of structure number 10-0032, I-74 over C&EI RR, looking upstream during the 1983 survey. Five ovals, 2 with x's and 3 without, can be seen near the center of the lane. The 2 x'ed ovals were spots that sounded hollow when struck with a hammer during the 1982 survey, but <u>did not</u> sound hollow when checked during the 1983 survey. The two solid ovals were areas sounding hollow during the 1983 survey. The dotted oval is a location that sounded hollow in both 1982 and 1983.

The 1984 survey was modified significantly. Delamination results from past surveys had been confounded by the formation then healing of hollow-sounding bubble-like locations or blisters as shown in Figure 5a. Furthermore, <u>none</u> of the waterproofing appeared to be in need of replacement. Therefore, it was decided to limit the final survey to a visual inspection of the surface. Unusual surface problems were mapped and previously marked delaminations were inspected for "obvious" signs of a need for repairs in the near future.

Figure 5b is a photograph of structure 010-0032 looking with the flow of traffic during the 1984 survey. The three suspected delaminations marked in 1983 are still visible. The suspected delamination nearer the end of the deck has developed a "Y" crack.

Light-colored dust size material is being flushed from the crack. (Photo taken after a rainshower). The presence of a crack with ejected material indicates that aggregates or cement have been broken and probably have been crushed. This suggests that a delamination has formed and the marked area becomes one with "obvious" signs of a need for repairs in the near future. The dotted oval has sounded hollow every year since 1980, but has shown no apparent distress.

Another example of an area with "obvious" signs of needed repairs is shown in Figure 6. The surface has advance stages of alligator type cracking, material is being ejected from the cracks, and broken deck concrete is visible at the bottom of the largest cracks on the right hand side of the area. This area will receive maintenance attention before that shown in Figure 5b.

Delamination survey results from preconstruction surveys through 1984 are shown in Table 2. Through 1983, the results are masked by uncertainties as to whether the delaminations are in the deck or if they are blisters under the bituminous surface. The 1984 results are much more indicative of actual conditions of areas where repairs have been made or will be needed at some future date.

The 1984 results show that the average study decks have less than 1% delaminated surface area after 6 to 7 years of service life. The maximum delaminated area observed in 1984 was 2.4% on structure 10-0031.

Three structures show no delamination or areas in need of repair during the 1984 survey. Results for structure 57-0024 show no areas for each year after completion of rehabilitation. Blisters were found during the first survey on the adjacent structure (57-0025), but neither blisters nor delaminations have been observed from that time on. Many blisters have been observed on structure 90-0024 during each survey but, during the 1984 survey none appeared to need maintenance.

TABLE 2 DELAMINATION SURVEY RESULTS

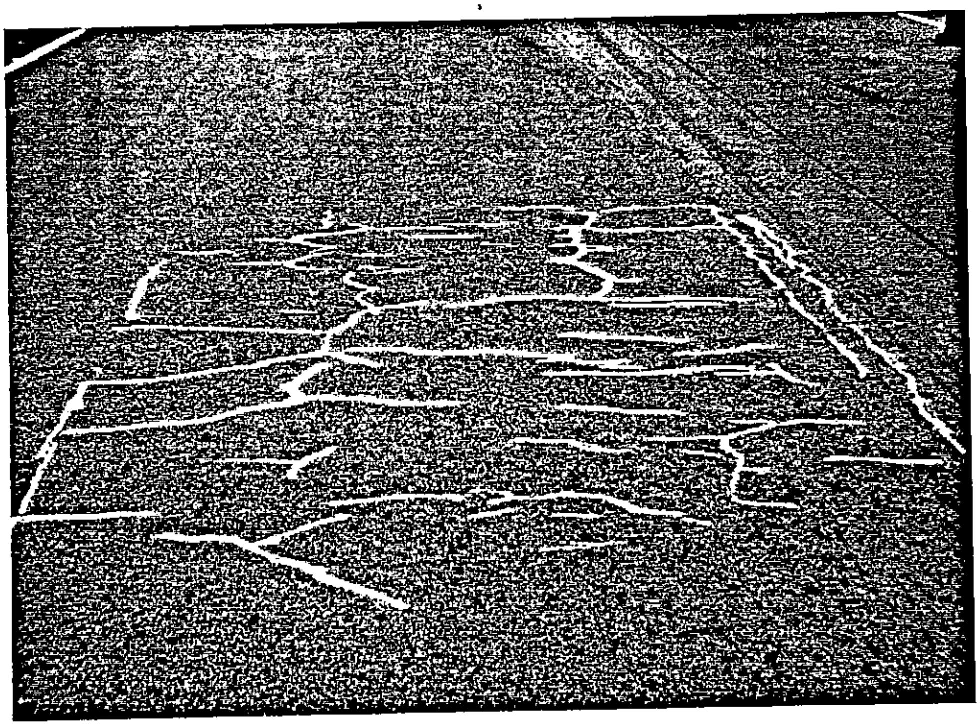
Structure Number	Percent Area Delaminated: Before Construction	1977	1978	1979	1980 1/	1982	1983	1984 4/
FHWA CATEGORY II								
90-0024	0.5		0.4	1.0	0.6	0.2	0.4	0
57-0018	3.3	0.1	0.3	0.6	0.5	2.1	2.7	1.0
10-0032	2.2		0.3	0.8	1.2	0.7	1.3	0.2
57-0019	3.0	0.5	0.7	0.7	0.6	1.5	2.6	0.8
10-0002	3.8		2.8	4.8	0.3	2.6	3.9	0.4
FHWA CATEGORY I								
10-0009	2.1		0.6	1.2	0.2	1.5	2.1	1.4
90-0020	10.0		1.1	0.1	0.3	3/	1.6	0.5
57-0024	2.0			0	0	0	0	0
10-0010	0.8		0.3	0.4	0.2	0.2	0.7	1.2
90-0023	4.2		0.1	1.0	0.5	0.6	1.3	0.2
10-0028	4.2		0.4	0.2	0	0.1	1.1	0.1
57-0025	2.8			0.1	0	0	0	0
10-0031	8.2		0.8	0.8	0	2.1	3.7	2.4
10-0018	13.0		0	0.3	0	1.0	3/	0.3
10-0027	9.1		1.1	1.8	0.04	0.8	1.8	0.1
10-0001	10.5		0	0.5	0.1	0.9	3.0	0.4
10-0029	14.4		0.3	0.9	0.3	1.9	3.5	1.7
10-0030	10.8		0.7	1.3	0.1	0.6	1.1	0.4
10-0019	17.0		0	0.1	0	1.0	3/	0.6
90-0019	2/	0.2	0	0.4	0	3/	3/	0.3

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

2/ No before construction delamination survey.

3/ Construction in immediate area, could not close lanes for survey.

4/ Surface cracked, light colored dust deposits around cracks, or patched.



a). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1982 survey (randomly selected area on 010-0018).

b). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1984 surveys (randomly selected area on 010-0019).

Figure 7. Photographs of cracking problem.

a). Patch failure (1984 photo) structure 57-0018.

b). Patch failure removed by snowplow (1984 photo) structure 57-0019.

Figure 8. Patch failures on structures 57-0018 and 57-0019.

TABLE 4

1984 Bridge Ratings

Structure Number	Bridge Rating
FHWA CATEGORY II	
90-0024	8
57-0018	6
10-0032	7
57-0019	6
10-0002	7
FHWA CATEGORY I	
10-0009	5
90-0020	7
57-0024	8
10-0010	5
90-0023	7
10-0028	8
57-0025	8
10-0031	6
10-0018	5
10-0027	8
10-0001	7
10-0029	6
10-0030	7
10-0019	5
90-0019	7

For the three year period, the average cost of partial depth patching and waterproofing chloride contaminated decks was $45,000 per deck for 716 decks. That compares to $263,000 per structure for superstructure work on 97 bridges. The data suggests that on the average, 6 decks could be partial depth patched and waterproofed for every 1 deck that is removed and replaced.

Comparisons were made of the costs of the two repair options. Annual costs were determined using the equation for capital recovery factor:

$$R = P \quad \frac{i\,(1 + i)^n}{(1 + i)^n - 1}$$

Where:
R = Capital Recovery Factor
P = Average Cost of Rehabilitation Procedure
i = Interest Rate Per Interest Period
n = Number of Interest Periods

Annual costs were calculated using the following values:

	Waterproofing	Superstructure
P	$45,000	$263,000
i	8%	8%
n	25 years	25 years
R	$ 4,217 per year x 25 years	$23,420 per year
Total Payback	$105,425	

Comparing alternatives:

$$\frac{\$105{,}425 \text{ (waterproofing, 25 years)}}{\$\ 23{,}420 \text{ (superstructure cost/year)}} = 4.5 \text{ years}$$

Evaluating costs using the average values for waterproofing and superstructure work shows that a waterproofing would only have to last 4.5 years to be economical. Because it could be argued that redecking would not cost as much as total superstructure work and that a new deck will last longer than 25 years, two "what if" evaluations were made. First, "what if" the cost of redecking was reduced by one-half ($263,000 to $131,500) and second, "what if" redecking costs were reduced by one-half and the life span was doubled (25 years to 50 years).

For the second analysis, costs for the two repair procedures will be compared for a deck 210 ft. long, 30 feet wide and 8 inches thick. Thirteen percent of the top surface requires partial depth patching. Eighty percent of the deck concrete is chloride contaminated beyond the 2 lb./yd^3 threshold. Option I is total deck removal while Option II calls for partial depth patching, elimination of longitudinal joint, repair and replace transverse expansion joints and make one small full-depth repair. Prices reflect costs in 1976.

Option I - Total deck removal and replacement

1.	Remove and replace 700 $yd.^2$ ($165/$yd^2$) =	$115,500
2.	Standard lane reduction from 4 lanes to 2 lanes -	
	Temporary crossover, Class I 500 yd^2 installed ($6.57)	3,285
	Traffic control costs 2190 ft. ($34.98)	76,606
	Total	$195,391

Option II - Partial Depth Patching

1.	Partial depth patching	91 yds^2	($100)	$ 9,100
2.	Full-depth patching	2 yds	($176)	352
3.	Transverse expansion jts.	120 ft.	($111.30)	13,596
4.	Eliminate longitudinal jts.	210 ft.	($38.52)	8,085
5.	Traffic control (2 lanes to one) saw horse barricades 46 days		($73.50)	3,381
			Totals	$34,514

The cost of waterproofing would be the same for each option. The cost difference between epoxy coated bars and waterproofing is negligible for Option I.

CONCLUSIONS

The following conclusions are drawn from the results of analysis of data collected in this study:

1. After an average of 6 years service, the majority of study decks are in generally good condition. Some decks show potential for major maintenance. None of the decks need immediate rehabilitation.

2. Repairing chloride contaminated but otherwise sound bridge decks by partial patching and waterproofing can be a cost-effective alternative to total deck replacement.

December 19, 1985

Mr. Jay W. Miller, Division Administrator
Federal Highway Administration
320 West Washington Street, 7th Floor
Springfield, Illinois 62701

Subject: IHR-306, Illinois HPR Research Study
"Bridge Deck Condition Survey"

Dear Mr. Miller:

Enclosed for your review and approval are four copies of the report entitled "Bridge Deck Condition Survey, Phase V Long-Term Performance Evaluation". This report represents final documentation of work on the subject study. Your comments of August 6 and October 9, 1985 were incorporated into this report.

Very truly yours,

H. W. Monroney
Director of Highways

Eric E. Harm

By
Eric E. Harm
Engineer of Physical Research

JEL:dly

cc: Jay W. Miller (2)
R. K. Taylor
H. R. Morgan

TECHNICAL REPORT STANDARD TITLE PAGE

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Background

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The original study goals could not be met within the time frame of the original work plan because insufficient service life performance was generated for use in evaluating the economic effectiveness associated with partial restoration. In 1982, a new study phase was added titled "Long-Term Performance Evaluation" to provide for three additional annual surveys of the study decks.

Bridge deck restoration consisted 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.

This procedure of partially restoring decks had been used for many years to extend bridge deck service life. However, in the early 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 threshold level of 2.0 lb. $Cl^-/yd.^3$ of concrete. It was argued 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.

Early investigations showed that most of Illinois' decks are chloride-contaminated and more than half the total number of PCC bridge decks in service contain more than 2.0 lbs. Cl^-/yd^3 of concrete. With thousands of bridge decks in need of repairs, hard data were needed for use in evaluating the benefits of partial deck restoration versus total deck replacement.

This report contains the results and evaluations of data collected during the 9 year study of waterproofed bridge decks. The long-term performance evaluation described in this report was conducted under Phase V of Illinois Highway Research Project IHR-306, "Bridge Deck Condition Survey".

FIELD TEST PROGRAM

Study Decks

Twenty decks were selected for study. Fourteen of the decks are on FAI 74, and two each are located on FAI 55, FAI 57, and FAI 55-74 (Figure 1).

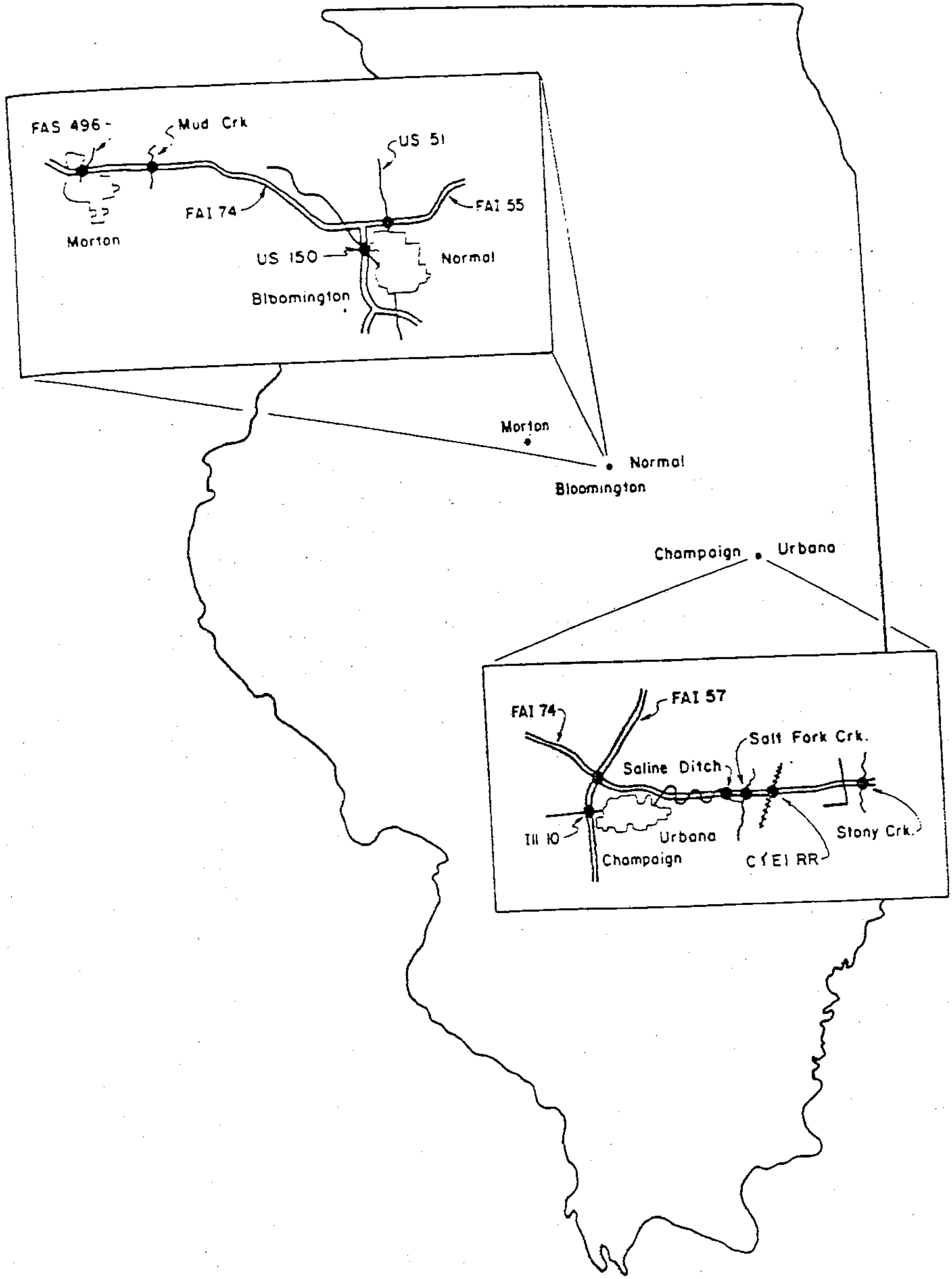


Figure 1. Deck locations

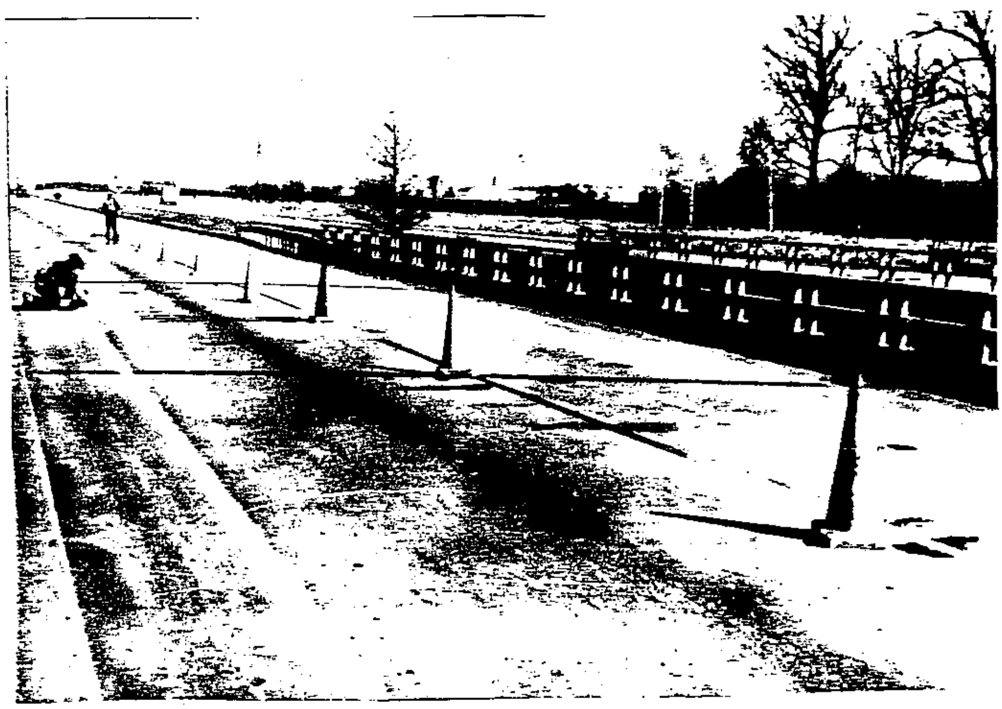
Structure numbers to be used through the remainder of the report are as follows:

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 10-0028, 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

The bridges were selected based upon chloride content and corrosion activity in the top mat of reinforcement prior to rehabilitation. Fifteen of the decks had 40 percent or more of the top mat reinforcement actively corroding (FHWA Category I), and the other five decks have less than 40 percent of the top mat actively corroding (FHWA Category II), according to copper-copper sulphate electrode (CSE) measurements. Photographs of the surface of typical Category I and II decks are shown in Figure 2.

Deck restoration and waterproofing were completed in accordance with Illinois prevailing standards and specifications. No new or unique

a). Typical Category I deck.



b). Typical Category II deck.

Figure 2. Photographs of typical Category I and Category II decks.

specifications or changes were included for research purposes. The same waterproofing system was used on each deck (Fig. 3) and consisted of a penetrating primer, a built-up coal tar pitch emulsion membrane with two plies of coated fiberglass fabric, and a hot-mix sand-asphalt protective course. This was topped with a bituminous concrete wearing course. Spalled and delaminated areas were repaired prior to placement.

Prior-to-Rehabilitation Results

Prior-to-rehabilitation surveys consisted of estimating delaminated area using a Delamtect, mapping surface conditions, estimating the area of corroding steel using copper-sulphate electrode (CSE) half-cell measurements, determining chloride contents of concrete dust samples collected from near the top mat reinforcement in areas where half-cell readings suggested no active corrosion, and making some random steel-depth measurements. Results of delamination and chloride evaluation surveys are shown in Table 1.

Results in Table 1 show that every structure had more than 50% of the deck concrete contaminated with chloride in excess of the threshold value. If the 1974 FHWA guidelines had been followed, all concrete to the top mat reinforcement would have had to be removed from every deck. Complete deck removal would have been required on most of the structures.

Preconstruction condition surveys consisted of mapping defects such as cracks, patches, spalls, scale, and popouts. The Category II decks generally had much less surface deterioration than did the Category I decks.

Long-Term Performance

During initial phases of the study, attempts were made to determine the rate of corrosion, to determine if moisture could migrate through the waterproofing, to determine if moisture was present at the interface of the PCC deck and the waterproofing, and to determine rate of change in the percent

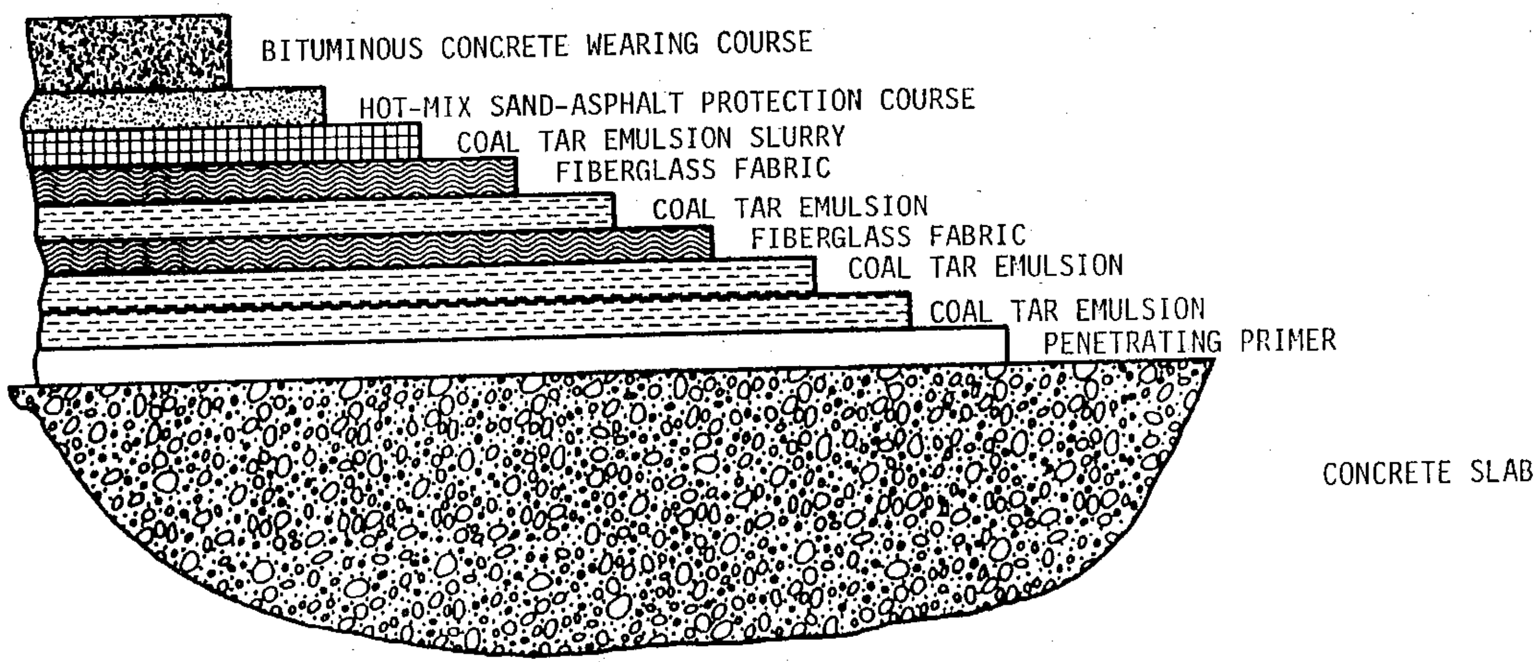


Figure 3. Waterproofing System.

of deck area with delaminations and with other surface problems. Results of the corrosion measurements made during the initial phases of the study were considered by the author (1) to be inconclusive.

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	2/24/77
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.

Results of measurements made using the sponge method (ASTM D 3633-77) and by electrical resistivity between pairs of copper strips placed transversely on the bare decks suggested that the waterproofing prevented moisture penetration.[1] These measurements were deleted from Phase V. Most lead wires for the copper strips were damaged beyond repair by the elements or by vandalism. Equipment for making sponge measurements (ASTM D 3633-77) had been disposed of upon completion of the original study phases. The reliability of measurements did not warrant the purchase of new equipment.

From the start, delaminated concrete was to be the major factor used in evaluating the effectiveness of this bridge deck restoration process. Delaminations and subsequent spalling and patching are the symptoms of problems caused by corrosion of the reinforcement. A typical delamination is shown in Figure 4.

Delaminations are caused by excessive pressure created during the corrosion process. The volume of corrosion products is greater than the volume of the parent reinforcing steel. The increase in volume causes increases in pressure creating tensile forces in the concrete. As corrosion continues, resulting pressures exceed the tensile capacity of concrete causing it to crack or spall.

Delamination Survey

Early delamination surveys were made using a Delamtect. From 1977 through 1979, 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 along an adjacent path. A strip chart was made for each trace. The strip charts were evaluated at a later date, in the office.

Figure 4. Typical delamination of bridge deck concrete at the top mat reinforcement. (Photo compliments of J. L. Saner)

During the 1980 survey, delaminations were located using the Delamtect, and the physical limits of each delamination were established using Delamtect or by sounding with a hammer. They were marked using lumber crayon, and measured and mapped.

The same procedure used in 1980 was again employed in 1982 and 1983 surveys except the limits of delamination were marked with spray paint. In most instances, sufficient paint survived from one year to the next to help in relocating suspected delaminations. Examples of this marking technique are shown in Figure 5.

Figure 5 is a photograph of structure number 10-0032, I-74 over C&EI RR, looking upstream during the 1983 survey. Five ovals, 2 with x's and 3 without, can be seen near the center of the lane. The 2 x'ed ovals were spots that sounded hollow when struck with a hammer during the 1982 survey, but did not sound hollow when checked during the 1983 survey. The two solid ovals were areas sounding hollow during the 1983 survey. The dotted oval is a location that sounded hollow in both 1982 and 1983.

The 1984 survey was modified significantly. Delamination results from past surveys had been confounded by the formation then healing of hollow-sounding bubble-like locations or blisters as shown in Figure 5a. Furthermore, none of the waterproofing appeared to be in need of replacement. Therefore, it was decided to limit the final survey to a visual inspection of the surface. Unusual surface problems were mapped and previously marked delaminations were inspected for "obvious" signs of a need for repairs in the near future.

Figure 5b is a photograph of structure 010-0032 looking with the flow of traffic during the 1984 survey. The three suspected delaminations marked in 1983 are still visible. The suspected delamination nearer the end of the deck has developed a "Y" crack.

a). 1983 survey, upstream on 10-0032.

b). 1984 survey, downstream on 10-0032.

Figure 5. Photographs of structure 10-0032 taken during the 1983 and 1984 surveys.

Light-colored dust size material is being flushed from the crack. (Photo taken after a rainshower). The presence of a crack with ejected material indicates that aggregates or cement have been broken and probably have been crushed. This suggests that a delamination has formed and the marked area becomes one with "obvious" signs of a need for repairs in the near future. The dotted oval has sounded hollow every year since 1980, but has shown no apparent distress.

Another example of an area with "obvious" signs of needed repairs is shown in Figure 6. The surface has advance stages of alligator type cracking, material is being ejected from the cracks, and broken deck concrete is visible at the bottom of the largest cracks on the right hand side of the area. This area will receive maintenance attention before that shown in Figure 5b.

Delamination survey results from preconstruction surveys through 1984 are shown in Table 2. Through 1983, the results are masked by uncertainties as to whether the delaminations are in the deck or if they are blisters under the bituminous surface. The 1984 results are much more indicative of actual conditions of areas where repairs have been made or will be needed at some future date.

The 1984 results show that the average study decks have less than 1% delaminated surface area after 6 to 7 years of service life. The maximum delaminated area observed in 1984 was 2.4% on structure 10-0031.

Three structures show no delamination or areas in need of repair during the 1984 survey. Results for structure 57-0024 show no areas for each year after completion of rehabilitation. Blisters were found during the first survey on the adjacent structure (57-0025), but neither blisters nor delaminations have been observed from that time on. Many blisters have been observed on structure 90-0024 during each survey but, during the 1984 survey none appeared to need maintenance.

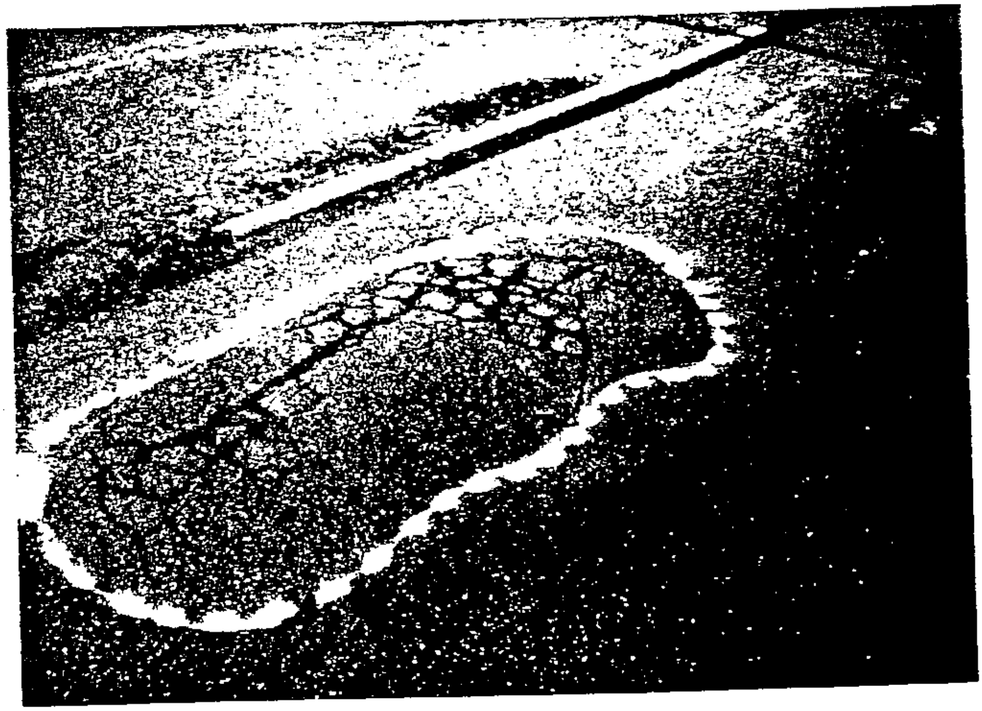


Figure 6. Delaminated area on structure 010-0029.

TABLE 2 DELAMINATION SURVEY RESULTS

Structure Number	Before Construction	1977	1978	1979	1980 1/	1982	1983	1984 4/
				Percent Area Delaminated				
			FHWA CATEGORY II					
90-0024	0.5		0.4	1.0	0.6	0.2	0.4	0
57-0018	3.3	0.1	0.3	0.6	0.5	2.1	2.7	1.0
10-0032	2.2		0.3	0.8	1.2	0.7	1.3	0.2
57-0019	3.0	0.5	0.7	0.7	0.6	1.5	2.6	0.8
10-0002	3.8		2.8	4.8	0.3	2.6	3.9	0.4
			FHWA CATEGORY I					
10-0009	2.1		0.6	1.2	0.2	1.5	2.1	1.4
90-0020	10.0		1.1	0.1	0.3	3/	1.6	0.5
57-0024	2.0			0	0	0	0	0
10-0010	0.8		0.3	0.4	0.2	0.2	0.7	1.2
90-0023	4.2		0.1	1.0	0.5	0.6	1.3	0.2
10-0028	4.2		0.4	0.2	0	0.1	1.1	0.1
57-0025	2.8			0.1	0	0	0	0
10-0031	8.2		0.8	0.8	0	2.1	3.7	2.4
10-0018	13.0		0	0.3	0	1.0	3/	0.3
10-0027	9.1		1.1	1.8	0.04	0.8	1.8	0.1
10-0001	10.5		0	0.5	0.1	0.9	3.0	0.4
10-0029	14.4		0.3	0.9	0.3	1.9	3.5	1.7
10-0030	10.8		0.7	1.3	0.1	0.6	1.1	0.4
10-0019	17.0		0	0.1	0	1.0	3/	0.6
90-0019	2/	0.2	0	0.4	0	3/	3/	0.3

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

2/ No before construction delamination survey.

3/ Construction in immediate area, could not close lanes for survey.

4/ Surface cracked, light colored dust deposits around cracks, or patched.

Condition Survey

Through 1983, surface conditions were mapped to scale. The survey crew walked along the deck near the parapet. Longitudinal distance from one end of the deck was measured using a measuring wheel. Transverse distance from the parapet and size of defect was measured with a 6-foot folding ruler.

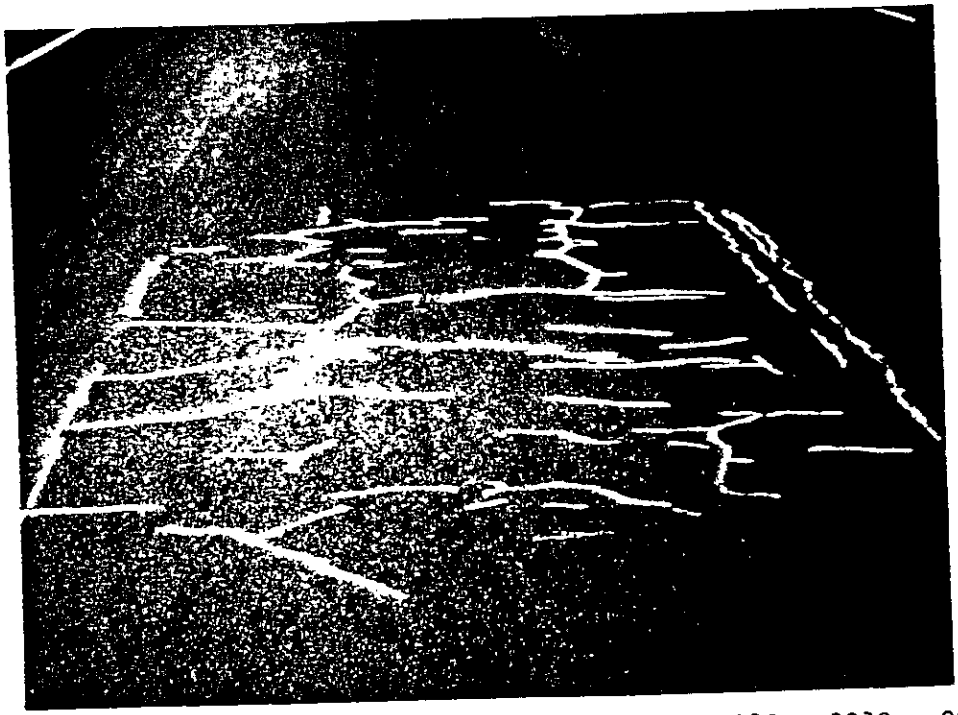
By the end of Phase IV of the study (1980 survey), that included 2 years of service life, little surface deterioration had been observed. Most longitudinal construction joints had cracked and various amounts of transverse cracking had been observed on most decks. All cracks were tightly closed.

A blistering problem was documented on most structures. Dish-shaped depressions were observed on 15 of 20 structures. Cracks shaped like a "Y" were found in dish-shaped depressions on 2 structures. From one year to the next, delaminations apparently healed and some appeared to have moved.

Humps were observed in the surface of two structures. The areas were determined to be deck patch failures. Apparently, the deck patching material under the hump was a high early-strength sand mix.

The 1982 and 1983 surveys show increases in the amounts of transverse and longitudinal cracking on most structures. On structures 010-0018, 010-0019, 010-0009 and 010-0010 a severe cracking problem appeared to be developing in the bituminous surface.

Figure 7a contains a 1982 photograph of a typical, randomly selected area of the severe cracking problems (structure 010-0018). The hairline cracks were tight and barely visible. The cracks shown were highlighted with paint to show the number of cracks per unit area. This type of cracking was observed on only the four structures mentioned.



a). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1982 survey (randomly selected area on 010-0018).

b). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1984 surveys (randomly selected area on 010-0019).

Figure 7. Photographs of cracking problem.

Figure 7b contains a photograph taken in 1984 of a typical, randomly selected area of the severe cracking problem (structure 010-0019). The cracks are plainly visible with many being open 1/4-inch to 1/2-inch in width. The waterproofing of all four structures was part of the same contract. No other structures show cracking to this extent.

Figure 8 contains photographs of patch failures found on structures 57-0018 and 57-0019. In Figure 8a the hump is clearly visible along with vegetation growing in the crack at the parapet. In Figure 8b it can be seen that the hump has been removed by a snowplow.

During the 1984 survey, all structures were rated using FHWA's rating system shown in Table 3. Ratings for the individual deck surfaces for 1984 are shown in Table 4.

As can be seen in Table 4, the author rated the surfacing as five or better. Repair of delaminated area such as shown in Figure 6 or humps such as shown in Figure 8 is rated minor maintenance (7 rating) or major maintenance (6 rating) depending upon the total area of delaminations or humps observed. Repair of the cracking condition shown in Figure 7 is considered minor rehabilitation (5 rating). The top surface and sand cushion could be removed and replaced leaving the waterproofing intact.

No maintenance work has been performed on 13 of 20 decks. On 4 of the 20 decks, crack and joint sealer has been poured liberally around all cracks. All obvious delaminations on two of the severely cracked surfaces (10-0018) and 10-0019) were patched. On the remaining structure, one delaminated area similar to that shown in Figure 6 was patched. Average maintenance cost per deck is virtually nil.

a). Patch failure (1984 photo) structure 57-0018.

b). Patch failure removed by snowplow (1984 photo) structure 57-0019.

Figure 8. Patch failures on structures 57-0018 and 57-0019.

TABLE 3

BRIDGE DECK RATING SYSTEM*

Rating	Rating Conditions Descriptions
9	New condition
8	Good condition - no repairs needed
7	Generally good condition - potential exists for minor maintenance
6	Fair condition - potential exists for major maintenance
5	Generally fair condition - potential exists for minor rehabilitation
4	Marginal condition - potential exists for major rehabilitation
3	Poor condition - repair or rehabilitation required immediately
2	Critical condition - the need for repair or rehabilitation is urgent. Facility should be closed until the indicated repair is complete.
1	Critical condition - facility is closed. Study should determine the feasibility for repair.
0	Critical condition - facility is closed and is beyond repair

* From FHWA Instruction Manual for Highway Condition and Quality of Highway Construction Survey.

TABLE 4

1984 Bridge Ratings

Structure Number	Bridge Rating
FHWA CATEGORY II	
90-0024	8
57-0018	6
10-0032	7
57-0019	6
10-0002	7
FHWA CATEGORY I	
10-0009	5
90-0020	7
57-0024	8
10-0010	5
90-0023	7
10-0028	8
57-0025	8
10-0031	6
10-0018	5
10-0027	8
10-0001	7
10-0029	6
10-0030	7
10-0019	5
90-0019	7

BENEFIT/COST ANALYSIS

Two economic evaluations were made. In the first, the statewide costs of superstructure rehabilitation were compared to statewide cost for bridge deck waterproofing. The second consists of evaluating the alternatives for a typical deck with dimensions similar to those in the study.

Table 5 contains the number of structures, contract costs and average cost per structure for waterproofing and superstructure work for the years 1975, 1976 and 1977. For this analysis it is assumed that if a deck were removed during rehabilitation then any other structural problems would also be repaired. Some contracts were not included because the length of structure or location of the structure caused the cost of rehabilitation to be significantly greater than the average.

TABLE 5
COST OF BRIDGE WORK IN ILLINOIS DURING
1975, 1976 and 1977

	Number of Structures	Contract Cost $	Average Cost Per Structure
		Waterproofing	
1975	313	15,445,701	49,000
1976	263	10,703,774	41,000
1977	140	6,108,283	44,000
Totals	716	$32,257,785	45,000
		Superstructure	
1975	68	18,438,618	271,000
1976	24	5,429,965	226,000
1977	5	1,630,617	326,000
Totals	97	$25,499,200	263,000

For the three year period, the average cost of partial depth patching and waterproofing chloride contaminated decks was $45,000 per deck for 716 decks. That compares to $263,000 per structure for superstructure work on 97 bridges. The data suggests that on the average, 6 decks could be partial depth patched and waterproofed for every 1 deck that is removed and replaced.

Comparisons were made of the costs of the two repair options. Annual costs were determined using the eouation for capital recovery factor:

$$R = P \quad \frac{i\,(1 + 1)^n}{(1 + i)^n - 1}$$

Where: R = Capital Recovery Factor
P = Average Cost of Rehabilitation Procedure
i = Interest Rate Per Interest Period
n = Number of Interest Periods

Annual costs were calculated using the following values:

	Waterproofing	Superstructure
P	$45,000	$263,000
i	8%	8%
n	25 years	25 years
R	$ 4,217 per year x 25 years	$23,420 per year
Total Payback	$105,425	

Comparing alternatives:

$$\frac{\$105{,}425 \text{ (waterproofing, 25 years)}}{\$\ 23{,}420 \text{ (superstructure cost/year)}} = 4.5 \text{ years}$$

Evaluating costs using the average values for waterproofing and superstructure work shows that a waterproofing would only have to last 4.5 years to be economical. Because it could be argued that redecking would not cost as much as total superstructure work and that a new deck will last longer than 25 years, two "what if" evaluations were made. First, "what if" the cost of redecking was reduced by one-half ($263,000 to $131,500) and second, "what if" redecking costs were reduced by one-half and the life span was doubled (25 years to 50 years).

1. Redecking estimate halved:

	Waterproofing	Superstructure
P	$45,000	$131,500
i	8%	8%
n	25 years	25 years
R=	$45,000 (0.0937)	$131,500 (0.0937)
		R = $12,760/yr Annual Cost
	$ 4,217 per year X 25 years	
Total Payback Waterproofing	$105,425	

Comparison:

$105,425 (total payback waterproofing) / $127,760/year (annual cost, redecking) = 8.3 years

2. Redecking halved, life-span doubled:

	Waterproofing	Superstructure
Total Payback	$105,425	
P		$131,500
i		8%
n		50 years
R =		$131,500 (0.08174)
		10,749/yr Annual Cost - 50 years

Comparison:

$105,425 (total payback waterproofing) / $ 10,749/yr (annual cost redecking - 50 years) = 9.8 years

Results of the two "what if" analysis also show that patching and waterproofing is an economical alternative to redecking.

For the second analysis, costs for the two repair procedures will be compared for a deck 210 ft. long, 30 feet wide and 8 inches thick. Thirteen percent of the top surface requires partial depth patching. Eighty percent of the deck concrete is chloride contaminated beyond the 2 lb./yd^3 threshold. Option I is total deck removal while Option II calls for partial depth patching, elimination of longitudinal joint, repair and replace transverse expansion joints and make one small full-depth repair. Prices reflect costs in 1976.

Option I - Total deck removal and replacement

1. Remove and replace 700 yd.^{2} (\$165/yd^2)	=	\$115,500
2. Standard lane reduction from 4 lanes to 2 lanes -		
Temporary crossover, Class I 500 yd^2 installed (\$6.57)		3,285
Traffic control costs 2190 ft. (\$34.98)		76,606
	Total	\$195,391

Option II - Partial Depth Patching

1. Partial depth patching	91 yds^2	(\$100)	\$ 9,100
2. Full-depth patching	2 yds	(\$176)	352
3. Transverse expansion jts.	120 ft.	(\$111.30)	13,596
4. Eliminate longitudinal jts.	210 ft.	(\$38.52)	8,085
5. Traffic control (2 lanes to one) saw horse barricades 46 days		(\$73.50)	3,381
		Totals	\$34,514

The cost of waterproofing would be the same for each option. The cost difference between epoxy coated bars and waterproofing is negligible for Option I.

Cost comparisons are as follows:

	Waterproofing	Redeck
P	\$34,514	\$195,391
i	8%	8%
n	25 years	25 years
R =	\$34,514 (0.0937)	\$195,391 (0.0937)
R =	\$ 3,234/yr X 25 years	\$18,308/yr
Total Payback	\$80,850	

$$\frac{\$80{,}850 \text{ (total payback, waterproofing)}}{\$18{,}308 \text{ per year (Redeck, Annual, 25 years)}} = 4.4 \text{ years}$$

Assume new deck will last 50 years:

R = \$195,391 (0.08174)
R = \$ 15,971 per year - Annual Cost of Redeck

$$\frac{\$80{,}850 \text{ (Total payback, waterproofing)}}{\$15{,}971 \text{ (Annual Cost, Redeck, 50 years)}} = 5.1 \text{ years}$$

The data shows that partial-depth patching and waterproofing would have to survive 4.4 years to be the most economical alternative, or 5.1 years if a 50 year life is assumed for Option I.

Current Illinois guidelines for bridge deck repair projects (May 1983) recommend the following limits for use in determining cost-effectiveness of deck repairs:

Repair cost expressed as a percentage of replacement costs.

35% or less - deck repair is cost-effective

More than 35% to 65% - deck repair is cost effective in the presence of well documented exterior constraints

Greater than 65% - deck repair is not cost-effective

When deck repair is not cost-effective total replacement is in order.

CONCLUSIONS

The following conclusions are drawn from the results of analysis of data collected in this study:

1. After an average of 6 years service, the majority of study decks are in generally good condition. Some decks show potential for major maintenance. None of the decks need immediate rehabilitation.

2. Repairing chloride contaminated but otherwise sound bridge decks by partial patching and waterproofing can be a cost-effective alternative to total deck replacement.

REFERENCE

[1]LaCroix, John E., "Bridge Deck Condition Survey," Report FHWA/IL/PR-094 Final Report, Illinois Department of Transportation, June 1981.

May 29, 1985

Mr. Jay W. Miller, Division Administrator
Federal Highway Administration
320 West Washington Street, 7th Floor
Springfield, Illinois 62701

Subject: Bridge Deck Condition Survey Phase V
Long-Term Performance Evaluation

Dear Mr. Miller:

Enclosed for your review and approval are four copies of the report entitled, "Bridge Deck Condition Survey". This report represents final documentation of the work on the subject study.

Study results show that after six years of service, the majority of study decks are in generally good condition. Some decks show potential for major maintenance. None of the decks need immediate rehabilitation. Cost analysis show that patching then sealing the surface of chloride contaminated but sound concrete can be a cost-effective alternative to total deck replacement.

Very truly yours,

H. W. Monroney
Director of Highways

By
Marvin L. Traylor, Jr.
Engineer of Physical Research

JEL:dly

cc: Jay W. Miller (2)
R. K. Taylor
H. R. Morgan

Illinois Department of Transportation
Division of Highways
Bureau of Materials and Physical Research

Final Report
IHR 306

Bridge Deck Condition Survey
Phase V Long Term Performance Evaluation

by
J. E. LaCroix
Surface Properties Engineer
Physical Research Section

A Research Project in Cooperation with
U. S. Department of Transportation
Federal Highway Administration

February 1985

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16. Abstract

Performance was monitored from 1977 through 1984 on 20 mainline Interstate bridges whose chloride-contaminated decks were rehabilitated by removal and replacement of only unsound concrete and then waterproofed and overlayed. The decks performed well with little or no repair being done. None of the decks needed immediate rehabilitation by the end of the study.

Cost analysis show that patching then sealing the surface of chloride contaminated but sound concrete can be a cost-effective alternative to total deck replacement.

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PHASE V. LONG TERM PERFORMANCE EVALUATION

INTRODUCTION

Purpose

This study was conducted to evaluate the economic consequences associated with partial depth patching and waterproofing of PCC bridge decks where the decks were contaminated with 2 or more pounds of Chloride-per cu. yd. of concrete at the time of restoration.

Background

The performance of 20 chloride contaminated, waterproofed bridge decks was evaluated for a 3 year period ending in 1980. 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. No significant performance trends were found.

The original study goals could not be met within the time frame of the original work plan because insufficient service life performance was generated for use in evaluating the economic effectiveness associated with partial restoration. In 1982, a new study phase was added titled "Long-Term Performance Evaluation" to provide for three additional annual surveys of the study decks.

Bridge deck restoration consisted 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.

This procedure of partially restoring decks had been used for many years to extend bridge deck service life. However, in the early 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 threshold level of 2.0 lb. $Cl^-/yd.^3$ of concrete. It was argued 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.

Early investigations showed that most of Illinois' decks are chloride-contaminated and more than half the total number of PCC bridge decks in service contain more than 2.0 lbs. Cl^-/yd^3 of concrete. With thousands of bridge decks in need of repairs, hard data were needed for use in evaluating the benefits of partial deck restoration versus total deck replacement.

This report contains the results and evaluations of data collected during the 9 year study of waterproofed bridge decks. The long-term performance evaluation described in this report was conducted under Phase V of Illinois Highway Research Project IHR-306, "Bridge Deck Condition Survey".

FIELD TEST PROGRAM

Study Decks

Twenty decks were selected for study. Fourteen of the decks are on FAI 74, and two each are located on FAI 55, FAI 57, and FAI 55-74 (Figure 1).

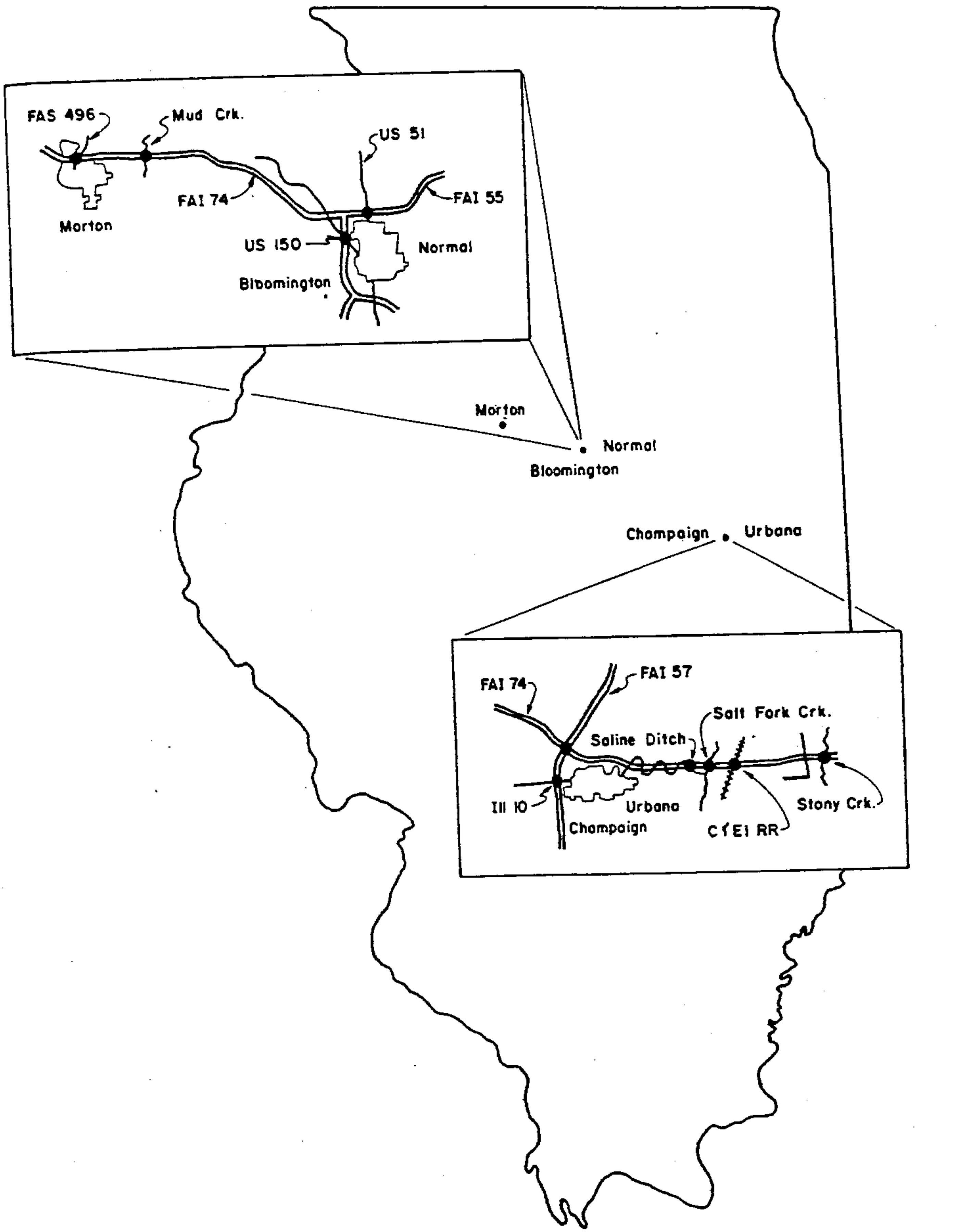


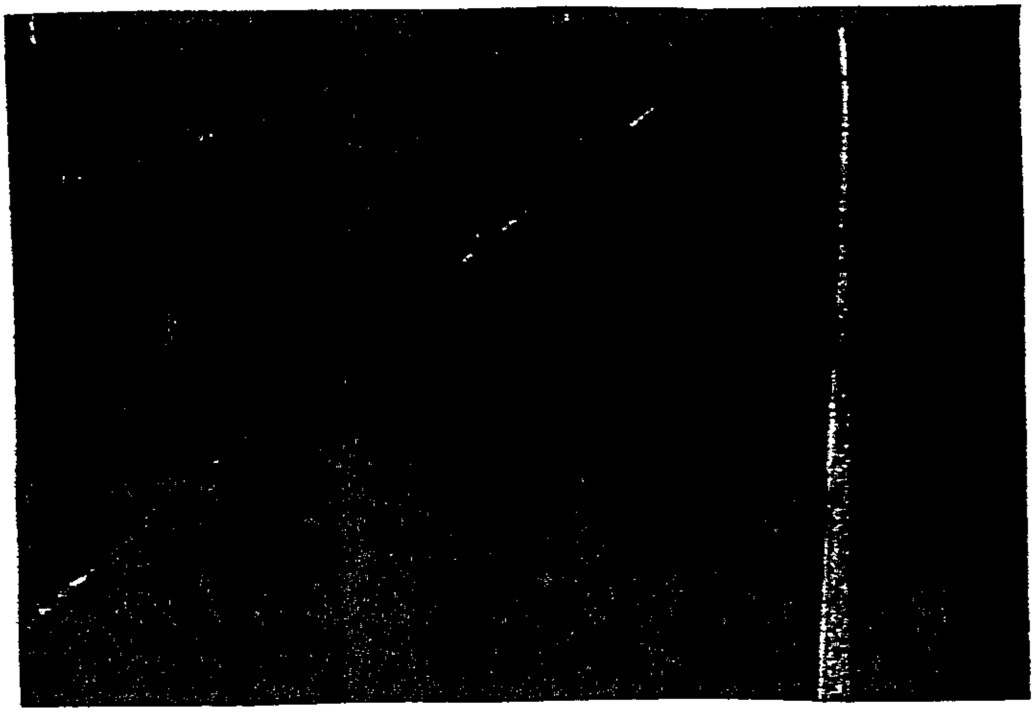
Figure 1. Deck locations

Structure numbers to be used through the remainder of the report are as follows:

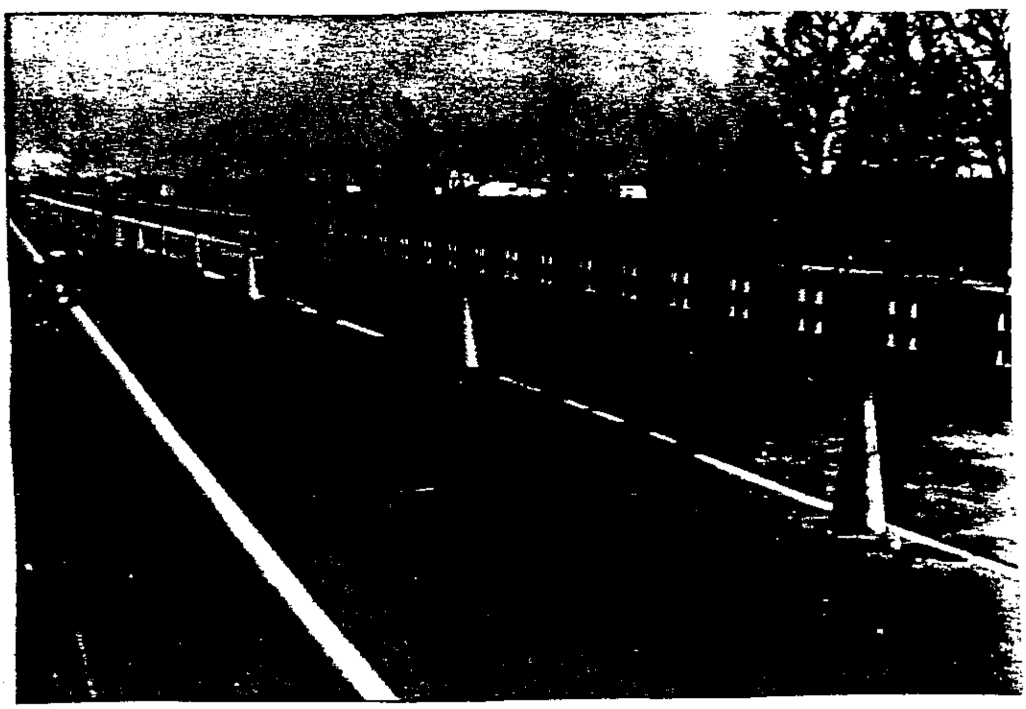
Illinois Highway District	Structure Location	Direction of Traffic and Structure Number
4	FAI 74 over FAS 496 NE of Morton	EB 90-0019, WB 90-0020
4	FAI 74 over Mud Creek, 5 mi. W of Ill. 17 Interchange	EB 90-0023, WB 90-0024
3	FAI 55 over US 51, N of Normal	NB 57-0024, SB 57-0025
3	FAI 55-74 over US 150 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 10-0028, 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

The bridges were selected based upon chloride content and corrosion activity in the top mat of reinforcement prior to rehabilitation. Fifteen of the decks had 40 percent or more of the top mat reinforcement actively corroding (FHWA Category I), and the other five decks ~~have~~ had less than 40 percent of the top mat actively corroding (FHWA Category II), according to copper-copper sulphate electrode (CSE) measurements. Photographs of the surface of typical Category I and II decks are shown in Figure 2.

Deck restoration and waterproofing were completed in accordance with Illinois prevailing standards and specifications. No new or unique



a). Typical Category I deck.



b). Typical Category II deck.

Figure 2. Photographs of typical Category I and Category II decks.

specifications or changes were included for research purposes. The same waterproofing system was used on each deck (Fig. 3) and consisted of a penetrating primer, a built-up coal tar pitch emulsion membrane with two plies of coated fiberglass fabric, and a hot-mix sand-asphalt protective course. This was topped with a bituminous concrete wearing course. Spalled and delaminated areas were repaired prior to placement.

Prior-to-Rehabilitation Results

Prior-to-rehabilitation surveys consisted of estimating delaminated area using a Delamtect, mapping surface conditions, estimating the area of corroding steel using copper-sulphate electrode (CSE) half-cell measurements, determining chloride contents of concrete dust samples collected from near the top mat reinforcement in areas where half-cell readings suggested no active corrosion, and making some random steel-depth measurements. Results of delamination and chloride evaluation surveys are shown in Table 1.

Results in Table 1 show that every structure had more than 50% of the deck concrete contaminated with chloride in excess of the threshold value. If the 1974 FHWA guidelines had been followed, all concrete to the top mat reinforcement would have had to be removed from every deck. Complete deck removal would have been required on most of the structures.

Preconstruction condition surveys consisted of mapping defects such as cracks, patches, spalls, scale, and popouts. The Category II decks generally had much less surface deterioration than did the Category I decks.

Long-Term Performance

During initial phases of the study, attempts were made to determine the rate of corrosion, to determine if moisture could migrate through the waterproofing, to determine if moisture was present at the interface of the PCC deck and the waterproofing, and to determine rate of change in the percent

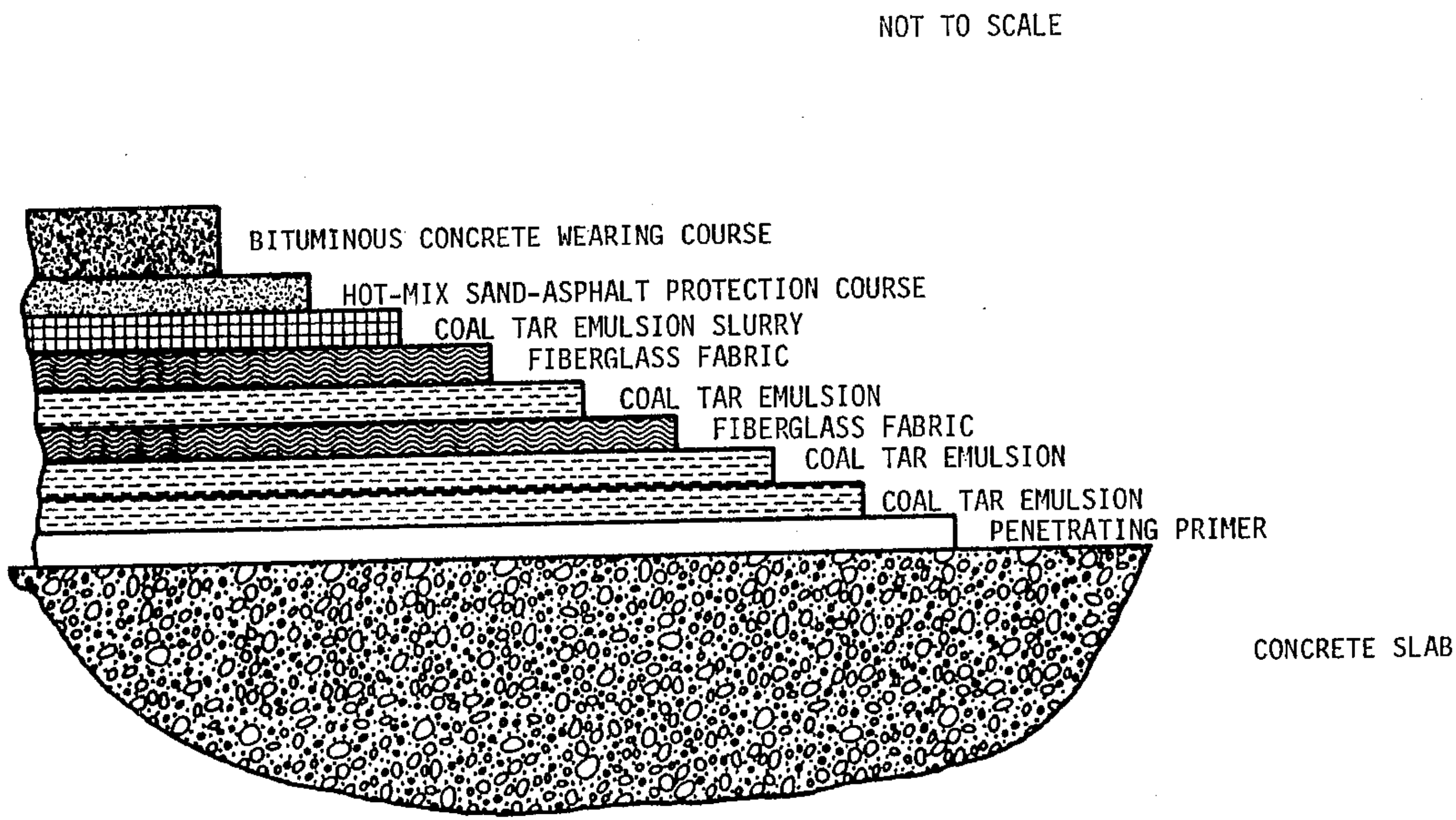


Figure 3. Waterproofing System.

of deck area with delaminations and with other surface problems. Results of the corrosion measurements made during the initial phases of the study were considered by the author (1) to be inconclusive.

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	2/24/77
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.

Results of measurements made using the sponge method (ASTM D 3633-77) and by electrical resistivity between pairs of copper strips placed transversely on the bare decks suggested that the waterproofing prevented moisture penetration.[1] These measurements were deleted from Phase V. Most lead wires for the copper strips were damaged beyond repair by the elements or by vandalism. Equipment for making sponge measurements (ASTM D 3633-77) had been disposed of upon completion of the original study phases. The reliability of measurements did not warrant the purchase of new equipment.

From the start, delaminated concrete was to be the major factor used in evaluating the effectiveness of this bridge deck restoration process. Delaminations and subsequent spalling and patching are the symptoms of problems caused by corrosion of the reinforcement. A typical delamination is shown in Figure 4.

Delaminations are caused by excessive pressure created during the corrosion process. The volume of corrosion products is greater than the volume of the parent reinforcing steel. The increase in volume causes increases in pressure creating tensile forces in the concrete. As corrosion continues, resulting pressures exceed the tensile capacity of concrete causing it to crack or spall.

Delamination Survey

Early delamination surveys were made using a Delamtect. From 1977 through 1979, 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 along an adjacent path. A strip chart was made for each trace. The strip charts were evaluated at a later date, in the office.

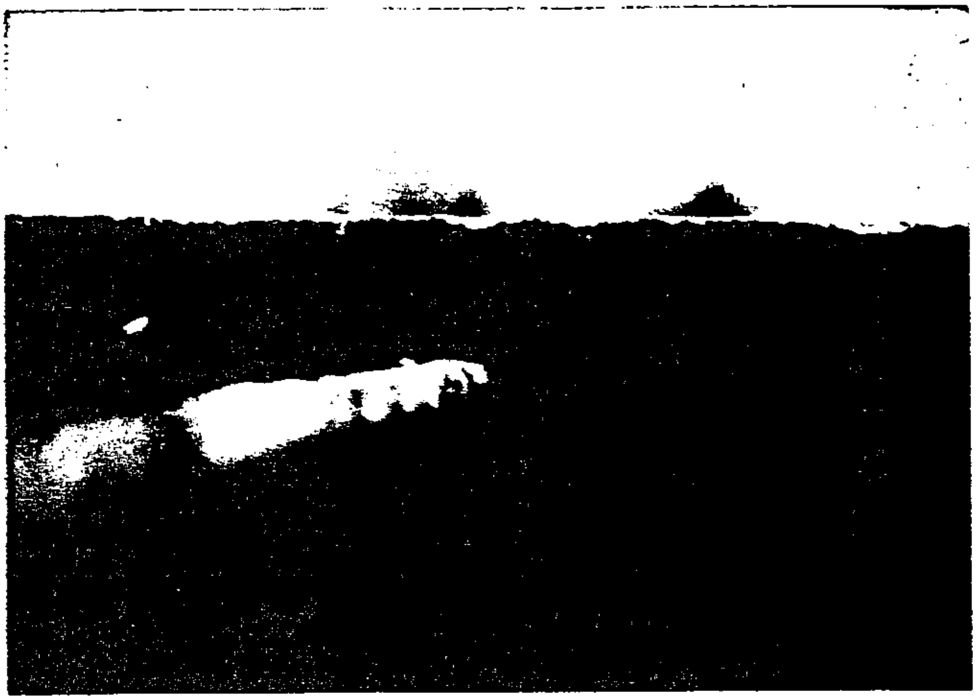


Figure 4. Typical delamination of bridge deck concrete at the top mat reinforcement. (Photo compliments of J. L. Saner)

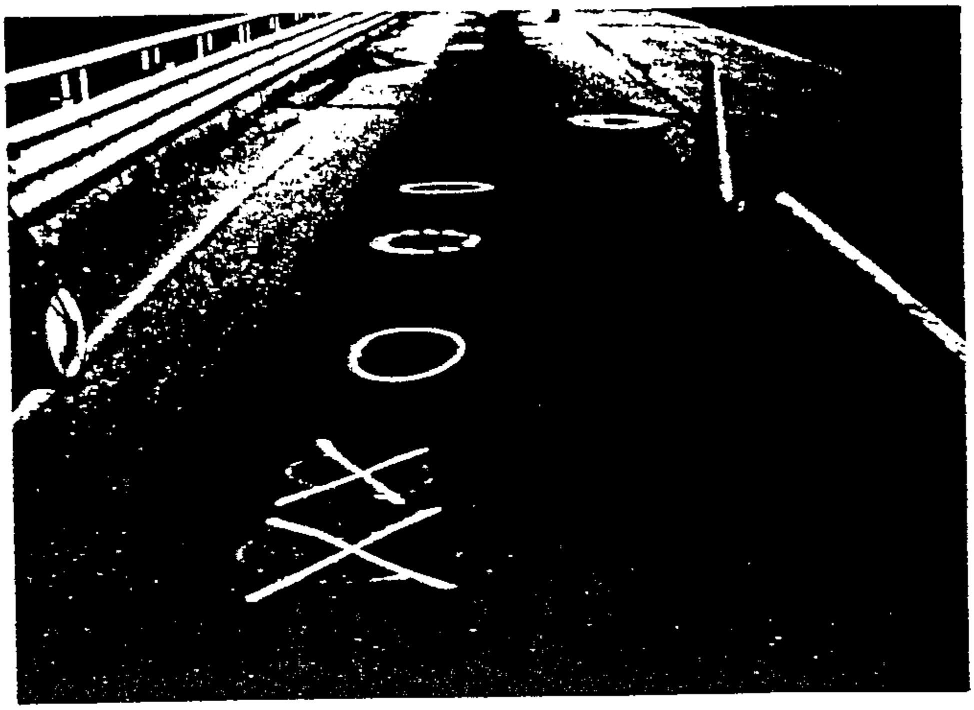
During the 1980 survey, delaminations were located using the Delamtect, and the physical limits of each delamination were established using Delamtect or by sounding with a hammer. They were marked using lumber crayon, and measured and mapped.

The same procedure used in 1980 was again employed in 1982 and 1983 surveys except the limits of delamination were marked with spray paint. In most instances, sufficient paint survived from one year to the next to help in relocating suspected delaminations. Examples of this marking technique are shown in Figure 5.

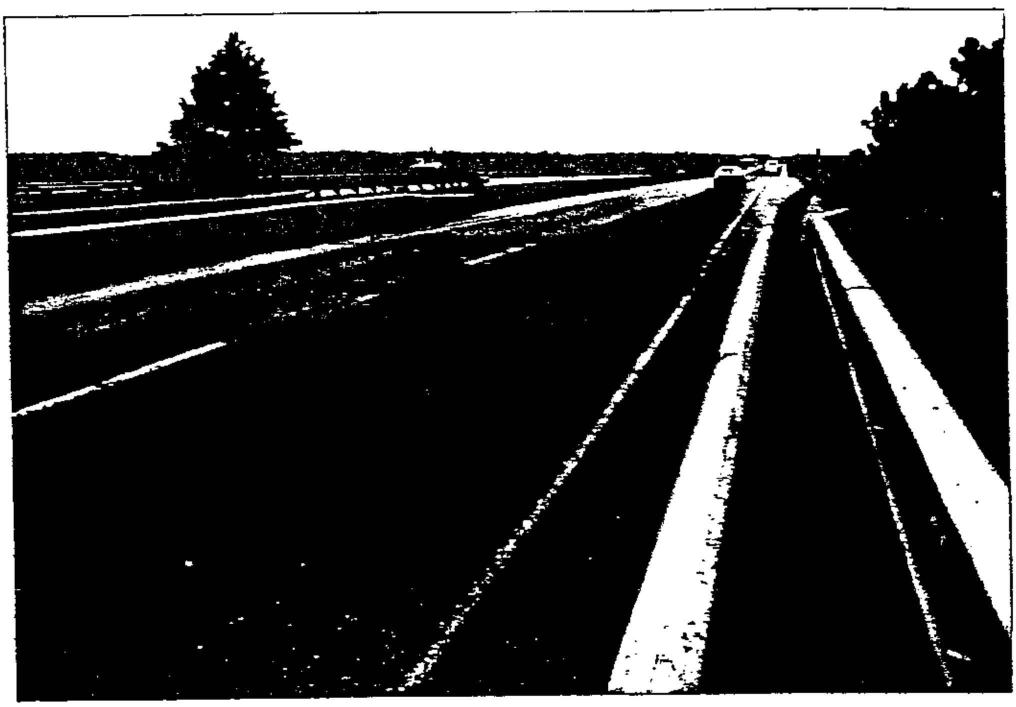
Figure 5 is a photograph of structure number 10-0032, I-74 over C&EI RR, looking upstream during the 1983 survey. Five ovals, 2 with x's and 3 without, can be seen near the center of the lane. The 2 x'ed ovals were spots that sounded hollow when struck with a hammer during the 1982 survey, but did not sound hollow when checked during the 1983 survey. The two solid ovals were areas sounding hollow during the 1983 survey. The dotted oval is a location that sounded hollow in both 1982 and 1983.

The 1984 survey was modified significantly. Delamination results from past surveys had been confounded by the formation then healing of blisters as shown in Figure 5a. Furthermore, none of the waterproofing appeared to be in need of replacement. Therefore, it was decided to limit the final survey to a visual inspection of the surface. Unusual surface problems were mapped and previously marked delaminations were inspected for "obvious" signs of a need for repairs in the near future.

Figure 5b is a photograph of structure 010-0032 looking down stream during the 1984 survey. The three suspected delaminations marked in 1983 are still visible. The delamination furthest downstream has developed a "Y" crack.



a). 1983 survey, upstream on 10-0032.



b). 1984 survey, downstream on 10-0032.

Figure 5. Photographs of structure 10-0032 taken during the 1983 and 1984 surveys.

Light-colored dust size material is being flushed from the crack. (Photo taken after a rainshower). The presence of a crack with ejected material indicates that aggregates or cement have been broken and probably have been crushed. This suggests that a delamination has formed and the marked area becomes one with "obvious" signs of a need for repairs in the near future. The dotted oval has sounded hollow every year since 1980, but has shown no apparent distress.

Another example of an area with "obvious" signs of needed repairs is shown in Figure 6. The surface has advance stages of alligator type cracking, material is being ejected from the cracks, and broken deck concrete is visible at the bottom of the largest cracks on the right hand side of the area. This area will receive maintenance attention before that shown in Figure 5b.

Delamination survey results from preconstruction surveys through 1984 are shown in Table 2. Through 1983, the results are masked by uncertainties as to whether the delaminations are in the deck or if they are blisters under the bituminous surface. The 1984 results are much more indicative of actual conditions of areas where repairs have been made or will be needed at some future date.

The 1984 results show that the average study decks have less than 1% delaminated surface area after 6 to 7 years of service life. The maximum delaminated area observed in 1984 was 2.4% on structure 10-0031.

Three structures show no delamination or areas in need of repair during the 1984 survey. Results for structure 57-0024 show no areas for each year after completion of rehabilitation. Blisters were found during the first survey on the adjacent structure (57-0025), but neither blisters nor delaminations have been observed from that time on. Many blisters have been observed on structure 90-0024 during each survey but, during the 1984 survey none appeared to need maintenance.

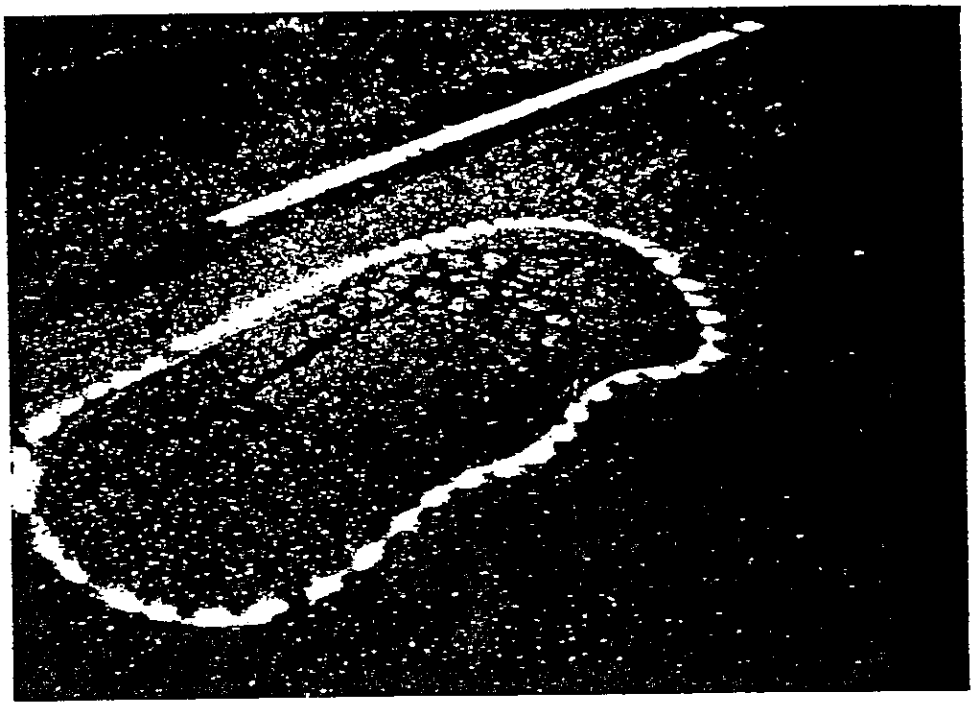


Figure 6. Delaminated area on structure 010-0029.

TABLE 2 DELAMINATION SURVEY RESULTS

Structure Number	Before Construction	Percent Area Delaminated 1977	1978	1979	1980 1/	1982	1983	1984 4/
				FHWA CATEGORY II				
90-0024	0.5		0.4	1.0	0.6	0.2	0.4	0
57-0018	3.3	0.1	0.3	0.6	0.5	2.1	2.7	1.0
10-0032	2.2		0.3	0.8	1.2	0.7	1.3	0.2
57-0019	3.0	0.5	0.7	0.7	0.6	1.5	2.6	0.8
10-0002	3.8		2.8	4.8	0.3	2.6	3.9	0.4
				FHWA CATEGORY I				
10-0009	2.1		0.6	1.2	0.2	1.5	2.1	1.4
90-0020	10.0		1.1	0.1	0.3	3/	1.6	0.5
57-0024	2.0			0	0	0	0	0
10-0010	0.8		0.3	0.4	0.2	0.2	0.7	1.2
90-0023	4.2		0.1	1.0	0.5	0.6	1.3	0.2
10-0028	4.2		0.4	0.2	0	0.1	1.1	0.1
57-0025	2.8			0.1	0	0	0	0
10-0031	8.2		0.8	0.8	0	2.1	3.7	2.4
10-0018	13.0		0	0.3	0	1.0	3/	0.3
10-0027	9.1		1.1	1.8	0.04	0.8	1.8	0.1
10-0001	10.5		0	0.5	0.1	0.9	3.0	0.4
10-0029	14.4		0.3	0.9	0.3	1.9	3.5	1.7
10-0030	10.8		0.7	1.3	0.1	0.6	1.1	0.4
10-0019	17.0		0	0.1	0	1.0	3/	0.6
90-0019	2/	0.2	0	0.4	0	3/	3/	0.3

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

2/ No before construction delamination survey.

3/ Construction in immediate area, could not close lanes for survey.

4/ Surface cracked, light colored dust deposits around cracks, or patched.

Condition Survey

Through 1983, surface conditions were mapped to scale. The survey crew walked along the deck near the parapet. Longitudinal distance from one end of the deck was measured using a measuring wheel. Transverse distance from the parapet and size of defect was measured with a 6-foot folding ruler.

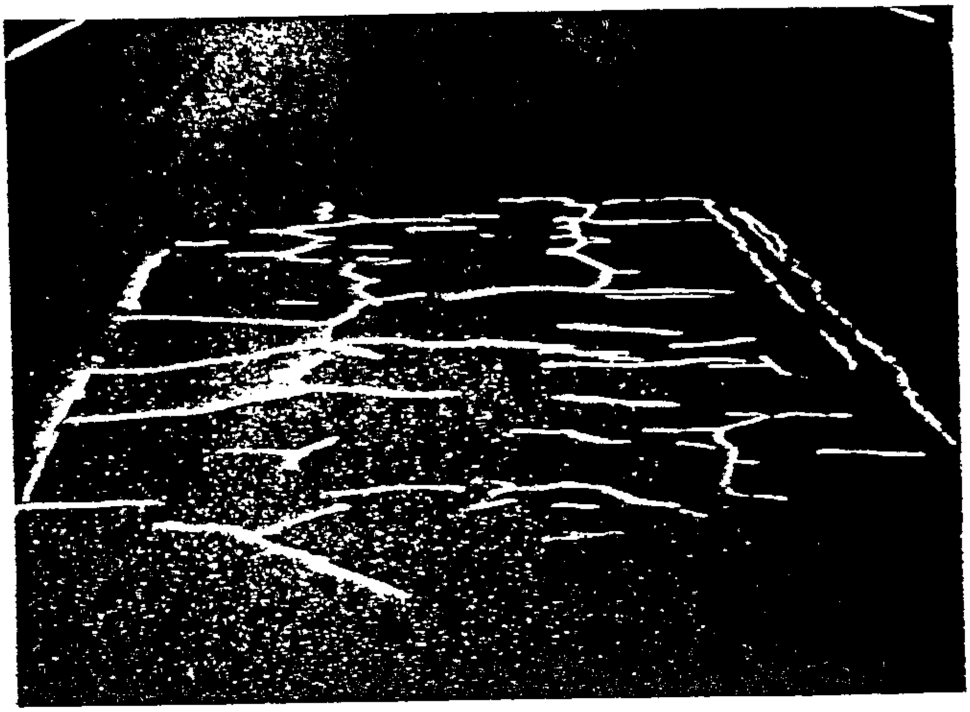
By the end of Phase IV of the study (1980 survey), that included 2 years of service life, little surface deterioration had been observed. Most longitudinal construction joints had cracked and various amounts of transverse cracking had been observed on most decks. All cracks were tightly closed.

A blistering problem was documented on most structures. Dish-shaped depressions were observed on 15 of 20 structures. Cracks shaped like a "Y" were found in dish-shaped depressions on 2 structures. From one year to the next, delaminations apparently healed and some appeared to have moved.

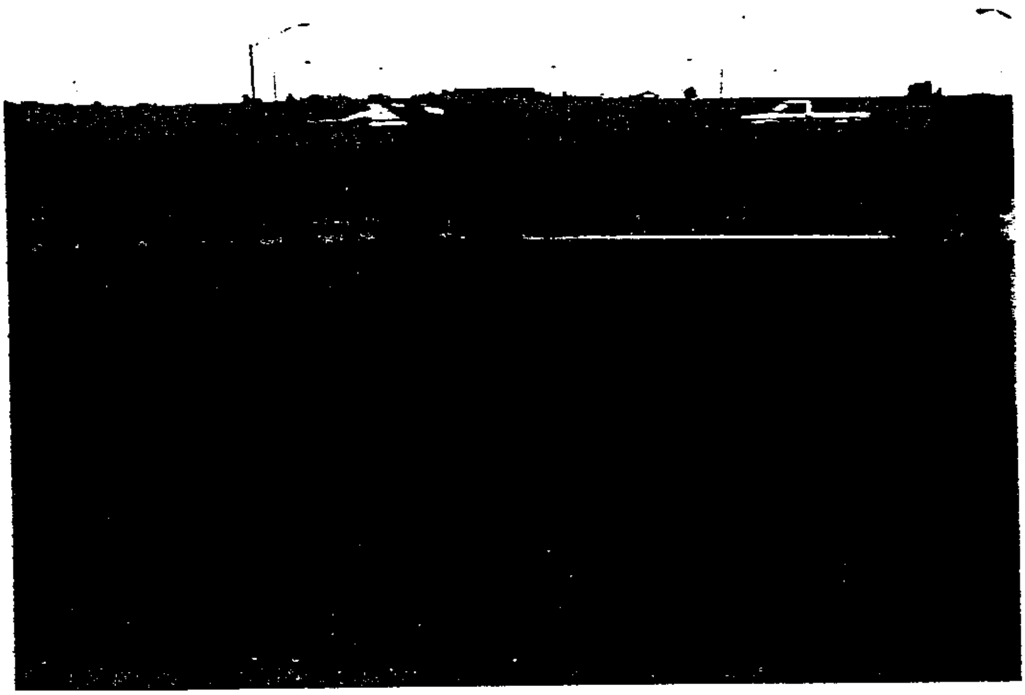
Humps were observed in the surface of two structures. The areas were determined to be deck patch failures. Apparently, the deck patching material under the hump was a high early-strength sand mix.

The 1982 and 1983 surveys show increases in the amounts of transverse and longitudinal cracking on most structures. On structures 010-0018, 010-0019, 010-0009 and 010-0010 a severe cracking problem appeared to be developing in the bituminous surface.

Figure 7a contains a 1982 photograph of a typical, randomly selected area of the severe cracking problems (structure 010-0018). The hairline cracks were tight and barely visible. The cracks shown were highlighted with paint to show the number of cracks per unit area. This type of cracking was observed on only the four structures mentioned.



a). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1982 survey (randomly selected area on 010-0018).



b). Typical cracking on structures 10-0009, -0010, -0018, -0019 during 1984 surveys (randomly selected area on 010-0019).

Figure 7. Photographs of cracking problem.

Figure 7b contains a photograph taken in 1984 of a typical, randomly selected area of the severe cracking problem (structure 010-0019). The cracks are plainly visible with many being open 1/4-inch to 1/2-inch in width. The waterproofing of all four structures was part of the same contract. No other structures show cracking to this extent.

Figure 8 contains photographs of patch failures found on structures 57-0018 and 57-0019. In Figure 8a the hump is clearly visible along with vegetation growing in the crack at the parapet. In Figure 8b it can be seen that the hump has been removed by a snowplow.

During the 1984 survey, all structures were rated using FHWA's rating system shown in Table 3. Ratings for the individual deck surfaces for 1984 are shown in Table 4.

As can be seen in Table 4, the author rated the surfacing as five or better. Repair of delaminated area such as shown in Figure 6 or humps such as shown in Figure 8 is rated minor maintenance (7 rating) or major maintenance (6 rating) depending upon the total area of delaminations or humps observed. Repair of the cracking condition shown in Figure 7 is considered minor rehabilitation (5 rating). The top surface and sand cushion could be removed and replaced leaving the waterproofing intact.

No maintenance work has been performed on 13 of 20 decks. On 4 of the 20 decks, crack and joint sealer has been poured liberally around all cracks. All obvious delaminations on two of the severely cracked surfaces (10-0018) and 10-0019) were patched. On the remaining structure, one delaminated area similar to that shown in Figure 6 was patched. Average maintenance cost per deck is virtually nil. ?

a). Patch failure (1984 photo) structure 57-0018.

b). Patch failure removed by snowplow (1984 photo) structure 57-0019.

Figure 8. Patch failures on structures 57-0018 and 57-0019.

TABLE 3

BRIDGE DECK RATING SYSTEM*

Rating	Rating Conditions Descriptions
9	New condition
8	Good condition - no repairs needed
7	Generally good condition - potential exists for minor maintenance
6	Fair condition - potential exists for major maintenance
5	Generally fair condition - potential exists for minor rehabilitation
4	Marginal condition - potential exists for major rehabilitation
3	Poor condition - repair or rehabilitation required immediately
2	Critical condition - the need for repair or rehabilitation is urgent. Facility should be closed until the indicated repair is complete.
1	Critical condition - facility is closed. Study should determine the feasibility for repair.
0	Critical condition - facility is closed and is beyond repair

* From FHWA Instruction Manual for Highway Condition and Quality of Highway Construction Survey.

TABLE 4

1984 Bridge Ratings

Structure Number	Bridge Rating
FHWA CATEGORY II	
90-0024	8
57-0018	6
10-0032	7
57-0019	6
10-0002	7
FHWA CATEGORY I	
10-0009	5
90-0020	7
57-0024	8
10-0010	5
90-0023	7
10-0028	8
57-0025	8
10-0031	6
10-0018	5
10-0027	8
10-0001	7
10-0029	6
10-0030	7
10-0019	5
90-0019	7

BENEFIT/COST ANALYSIS

Two economic evaluations were made. In the first, the statewide costs of superstructure rehabilitation were compared to statewide cost for bridge deck waterproofing. The second consists of evaluating the alternatives for a typical deck with dimensions similar to those in the study.

Table 5 contains the number of structures, contract costs and average cost per structure for waterproofing and superstructure work for the years 1975, 1976 and 1977. For this analysis it is assumed that if a deck were removed during rehabilitation then any other structural problems would also be repaired. Some contracts were not included because the length of structure or location of the structure caused the cost of rehabilitation to be significantly greater than the average.

TABLE 5
COST OF BRIDGE WORK IN ILLINOIS DURING
1975, 1976 and 1977

	Number of Structures	Contract Cost $	Average Cost Per Structure
		Waterproofing	
1975	313	15,445,701	49,000
1976	263	10,703,774	41,000
1977	140	6,108,283	44,000
Totals	716	$32,257,785	45,000
		Superstructure	
1975	68	18,438,618	271,000
1976	24	5,429,965	226,000
1977	5	1,630,617	326,000
Totals	97	$25,499,200	263,000

For the three year period, the average cost of partial depth patching and waterproofing chloride contaminated decks was $45,000 for 716 decks. That compares to $263,000 per structure for superstructure work on 97 bridges. The data suggests that on the average, 6 decks could be partial depth patched and waterproofed for every 1 deck that is removed and replaced.

If a 25 year life if assumed for superstructure work then:

$$\text{average cost per year} = \frac{\$263000}{25 \text{ years}} = \$10{,}520/\text{year}$$

Depreciating the waterproofing cost at $10,520 per year:

$$\frac{\$45{,}000}{\$10{,}520/\text{year}} = 4.3 \text{ years}$$

A waterproofing job would have to last only 4.3 years to be the most economical alternative. If a 50 year superstructure life expectancy is assumed, the waterproofing would have to last 8.6 years.

For the second analysis, the deck is 210 ft. long, 30 feet wide and 8 inches thick. Thirteen percent of the top surface requires partial depth patching. Eighty percent of the deck concrete is chloride contaminated beyond the 2 lb./yd^3 threshold. Option I is total deck removal while Option II calls for partial depth patching, elimination of longitudinal joint, repair and replace transverse expansion joints and make one small full-depth repair. Prices reflect costs in 1976. 1985 report should not reflect nine yr old costs.

Option I - Total deck removal and replacement

1. Remove and replace 700 $yd.^2$ ($165/$yd^2$) = $115,500
2. Traffic control standard 4 lanes to 2 lanes -

Temporary crossover, Class I 500 yd^2 installed ($6.57)	3,285
Concrete barricades 2190 ft. ($34.98)	76,606
Total	$195,391

Assume 25 years life:
Cost per year (not counting user cost) = $\frac{\$195391}{25y}$ = \$7800/year

Option II - Partial Depth Patching

1.	Partial depth patching	91 yds^2	(\$100)	\$ 9,100
2.	Full-depth patching	2 yds	(\$176)	352
3.	Transverse expansion jts.	120 ft.	(\$111.30)	13,596
4.	Eliminate longitudinal jts.	210 ft.	(\$38.52)	8,085
5.	Traffic control (2 lanes to one) saw horse barricades 46 days		(\$73.50)	3,381
			Totals	\$34,514

The cost of waterproofing would be the same for each option. The cost difference between epoxy coated bars and waterproofing is negligible for Option I.

Comparing Option I to Option II and disregarding user costs:

Average cost per year Option I = \$7800/year

Depreciation of Option II versus Option I:

$$\frac{\$34514}{\$7800/\text{year}} = 4.4 \text{ years}$$

The data shows that partial-depth patching and waterproofing would have to survive 4.4 years to be the most economical alternative, or 8.8 years if a 50 year life is assumed for Option I.

Current Illinois guidelines for bridge deck repair projects (May 1983) recommend the following limits for use in determining cost-effectiveness of deck repairs:

Repair cost expressed as a percentage of replacement costs.

35% or less - deck repair is cost-effective

More than 35% to 65% - deck repair is cost effective in the presence of well documented exterior constraints

Greater than 65% - deck repair is not cost-effective
When deck repair is not cost-effective total replacement is in order.

CONCLUSIONS

The following conclusions are drawn from the results of analysis of data collected in this study:

1. After an average of 6 years service, the majority of study decks are in generally good condition. Some decks show potential for major maintenance. None of the decks need immediate rehabilitation.

2. Repairing chloride contaminated but otherwise sound bridge decks by partial patching and waterproofing can be a cost-effective alternative to total deck replacement.

REFERENCE

[1]LaCroix, John E., "Bridge Deck Condition Survey," Report FHWA/IL/PR-094 Final Report, Illinois Department of Transportation, June 1981.

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Cost comparisons are as follows:

	Waterproofing	Redeck
P	$34,514	$195,391
i	8%	8%
n	25 years	25 years
R =	$34,514 (0.0937)	$195,391 (0.0937)
R =	$ 3,234/yr X 25 years	$18,308/yr
Total Payback	$80,850	

$$\frac{\$80{,}850 \text{ (total payback, waterproofing)}}{\$18{,}308 \text{ per year (Redeck, Annual, 25 years)}} = 4.4 \text{ years}$$

Assume new deck will last 50 years:

R = $195,391 (0.08174)
R = $ 15,971 per year - Annual Cost of Redeck

$$\frac{\$80{,}850 \text{ (Total payback, waterproofing)}}{\$15{,}971 \text{ (Annual Cost, Redeck, 50 years)}} = 5.1 \text{ years}$$

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1. Redecking estimate halved:

	Waterproofing	Superstructure
P	$45,000	$131,500
i	8%	8%
n	25 years	25 years
R=	$45,000 (0.0937)	$131,500 (0.0937)
		R = $12,760/yr Annual Cost
	$ 4,217 per year X 25 years	
Total Payback Waterproofing	$105,425	

Comparison:

$\frac{\$105,425 \text{ (total payback waterproofing)}}{\$127,760\text{/year (annual cost, redecking)}}$ = 8.3 years

2. Redecking halved, life-span doubled:

	Waterproofing	Superstructure
Total Payback	$105,425	
P		$131,500
i		8%
n		50 years
R =		$131,500 (0.08174)
		10,749/yr Annual Cost - 50 years

Comparison:

$\frac{\$105,425 \text{ (total payback waterproofing)}}{\$ 10,749\text{/yr (annual cost redecking - 50 years)}}$ = 9.8 years

Results of the two "what if" analysis also show that patching and waterproofing is an economical alternative to redecking.

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Figure 7b contains a photograph taken in 1984 of a typical, randomly selected area of the severe cracking problem (structure 010-0019). The cracks are plainly visible with many being open 1/4-inch to 1/2-inch in width. The waterproofing of all four structures was part of the same contract. No other structures show cracking to this extent.

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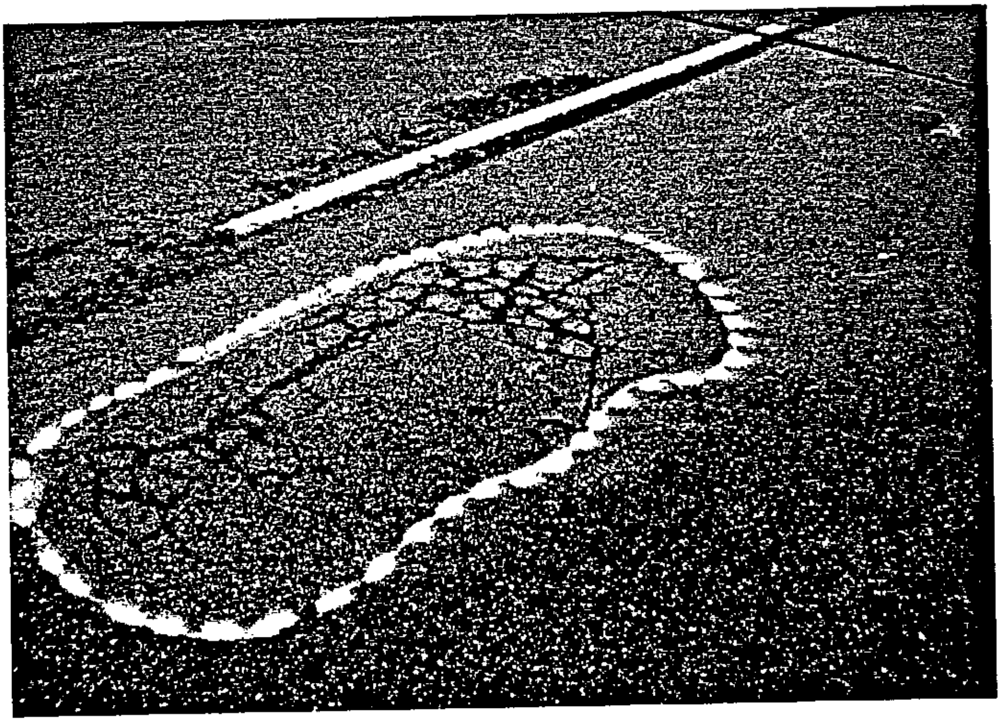
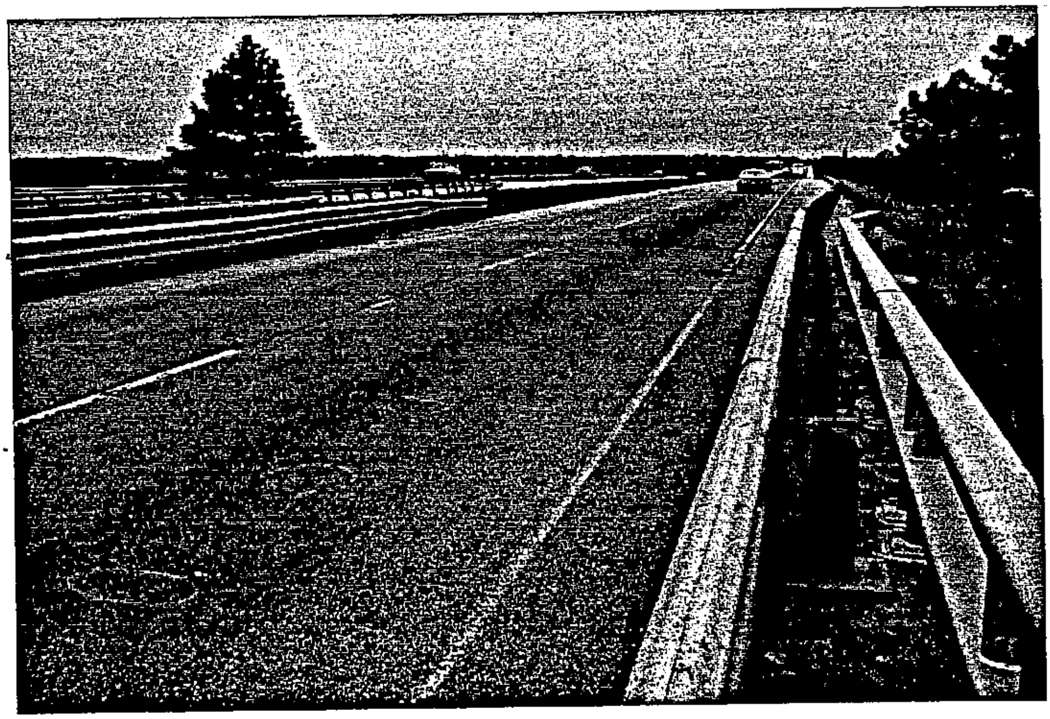


Figure 6. Delaminated area on structure 010-0029.

a). 1983 survey, upstream on 10-0032.



b). 1984 survey, downstream on 10-0032.

Figure 5. Photographs of structure 10-0032 taken during the 1983 and 1984 surveys.

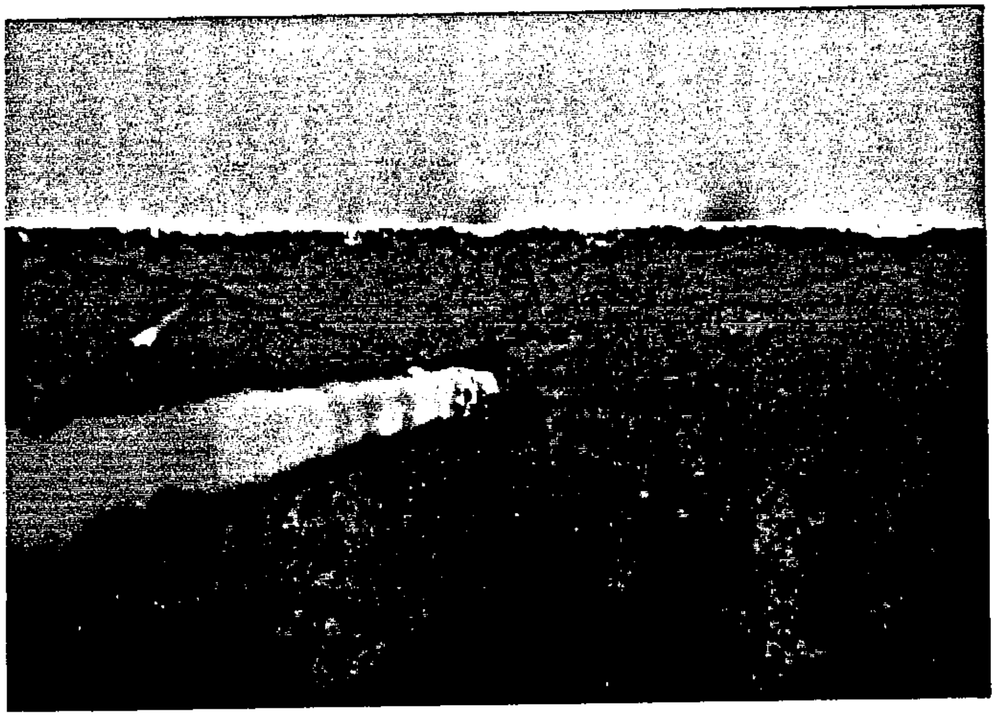


Figure 4. Typical delamination of bridge deck concrete at the top mat reinforcement. (Photo compliments of J. L. Saner)

of deck area with delaminations and with other surface problems. Results of the corrosion measurements made during the initial phases of the study were considered by the author (1) to be inconclusive.

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	2/24/77
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.

specifications or changes were included for research purposes. The same waterproofing system was used on each deck (Fig. 3) and consisted of a penetrating primer, a built-up coal tar pitch emulsion membrane with two plies of coated fiberglass fabric, and a hot-mix sand-asphalt protective course. This was topped with a bituminous concrete wearing course. Spalled and delaminated areas were repaired prior to placement.

Prior-to-Rehabilitation Results

Prior-to-rehabilitation surveys consisted of estimating delaminated area using a Delamtect, mapping surface conditions, estimating the area of corroding steel using copper-sulphate electrode (CSE) half-cell measurements, determining chloride contents of concrete dust samples collected from near the top mat reinforcement in areas where half-cell readings suggested no active corrosion, and making some random steel-depth measurements. Results of delamination and chloride evaluation surveys are shown in Table 1.

Results in Table 1 show that every structure had more than 50% of the deck concrete contaminated with chloride in excess of the threshold value. If the 1974 FHWA guidelines had been followed, all concrete to the top mat reinforcement would have had to be removed from every deck. Complete deck removal would have been required on most of the structures.

Preconstruction condition surveys consisted of mapping defects such as cracks, patches, spalls, scale, and popouts. The Category II decks generally had much less surface deterioration than did the Category I decks.

Long-Term Performance

During initial phases of the study, attempts were made to determine the rate of corrosion, to determine if moisture could migrate through the waterproofing, to determine if moisture was present at the interface of the PCC deck and the waterproofing, and to determine rate of change in the percent

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 10-0028, 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

The bridges were selected based upon chloride content and corrosion activity in the top mat of reinforcement prior to rehabilitation. Fifteen of the decks had 40 percent or more of the top mat reinforcement actively corroding (FHWA Category I), and the other five decks have less than 40 percent of the top mat actively corroding (FHWA Category II), according to copper-copper sulphate electrode (CSE) measurements. Photographs of the surface of typical Category I and II decks are shown in Figure 2.

Deck restoration and waterproofing were completed in accordance with Illinois prevailing standards and specifications. No new or unique

This procedure of partially restoring decks had been used for many years to extend bridge deck service life. However, in the early 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 threshold level of 2.0 lb. $Cl^-/yd.^3$ of concrete. It was argued 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.

Early investigations showed that most of Illinois' decks are chloride-contaminated and more than half the total number of PCC bridge decks in service contain more than 2.0 lbs. Cl^-/yd^3 of concrete. With thousands of bridge decks in need of repairs, hard data were needed for use in evaluating the benefits of partial deck restoration versus total deck replacement.

This report contains the results and evaluations of data collected during the 9 year study of waterproofed bridge decks. The long-term performance evaluation described in this report was conducted under Phase V of Illinois Highway Research Project IHR-306, "Bridge Deck Condition Survey".

FIELD TEST PROGRAM

Study Decks

Twenty decks were selected for study. Fourteen of the decks are on FAI 74, and two each are located on FAI 55, FAI 57, and FAI 55-74 (Figure 1).