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16. Abstract

This report presents the results of a study to evaluate the performance over a 10-year period of slabs that were impregnated to a depth of about 1 in with a monomer that was subsequently polymerized (shallow polymer impregnation). The slabs were used to widen a bridge. The report contains data obtained from evaluations done after 3, 5, 7, and 10 years in service. The study indicates that, based on rapid permeability tests done on cores removed from the slabs, rate of corrosion measurements made on the top mat of reinforcement in the slabs, and chloride ion content determinations done on samples removed from the slabs, shallow polymer impregnation can provide greater long-term protection against the infiltration of chloride ions and the consequent corrosion of reinforcement than conventional bridge deck concrete that is not impregnated.

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FINAL REPORT

POLYMER-IMPREGNATED BRIDGE SLABS

-- Performance Over 10 Years --

Michael M. Sprinkel, P.E.
Research Scientist

(The opinions, findings, and conclusions expressed in this report are
those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

This report presents the results of a study to evaluate the performance over a 10-year period of slabs that were impregnated to a depth of about 1 in with a monomer that was subsequently polymerized (shallow polymer impregnation). The slabs were used to widen a bridge. The report contains data obtained from evaluations done after 3, 5, 7, and 10 years in service. The study indicates that, based on rapid permeability tests done on cores removed from the slabs, rate of corrosion measurements made on the top mat of reinforcement in the slabs, and chloride ion content determinations done on samples removed from the slabs, shallow polymer impregnation can provide greater long-term protection against the infiltration of chloride ions and the consequent corrosion of reinforcement than conventional bridge deck concrete that is not impregnated.

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FINAL REPORT

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INTRODUCTION

The purpose of this study was to evaluate the procedures and materials used to impregnate precast concrete slabs and to evaluate the performance of the slabs as used to widen a bridge. This report summarizes the condition of six bridge slabs, four of which were impregnated to a depth of about 1 in with a methyl methacrylate and trimethylolpropane trimethacrylate monomer that was subsequently polymerized by thermal-catalytic means. The depth of impregnation is shallow when compared to deep polymer impregnation that can be achieved by grooving (1).

Impregnation Process

An interim report provides details of the impregnation process (2). The process consists of four basic steps:

1. preparation of the surface to remove contaminants

2. drying of the concrete for approximately 13 hr to remove moisture from the capillaries

3. impregnation of the concrete by submerging the slabs in a monomer bath for 6 hr

4. polymerization of the monomer by submerging the slabs in a hot water bath for 12 hr (see Figure 1).

According to the interim report:

1. The impregnation procedure was generally satisfactory from an operational standpoint.

2. The impregnated cylinders exhibited a compressive strength that was 14 percent less than that of cylinders that were not impregnated.

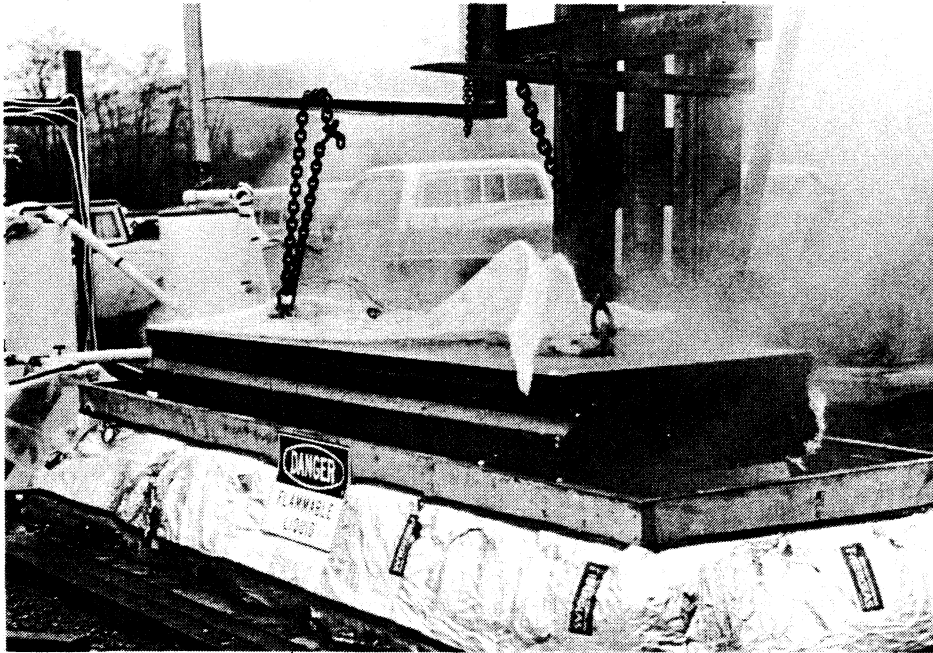3. The freeze-thaw durability of impregnated specimens was excellent.

Figure 1. Polymer-impregnated concrete slab being removed from tank.

4. The average maximum depth of impregnation was 1.0 in based on examination of cores from the slabs (see Figure 2).

5. The impregnation process caused a series of discontinuous micro-cracks that allowed chloride ions to penetrate to a depth of 0.8 in in laboratory specimens subjected to a 120-day soak in a 2 percent NaCl solution.

6. Additional research should be done with the objective of elimi-nating the microcracking caused by the impregnation process.

7. Polymer impregnation should not be used as a protective system until the problem with the microcracking can be eliminated.
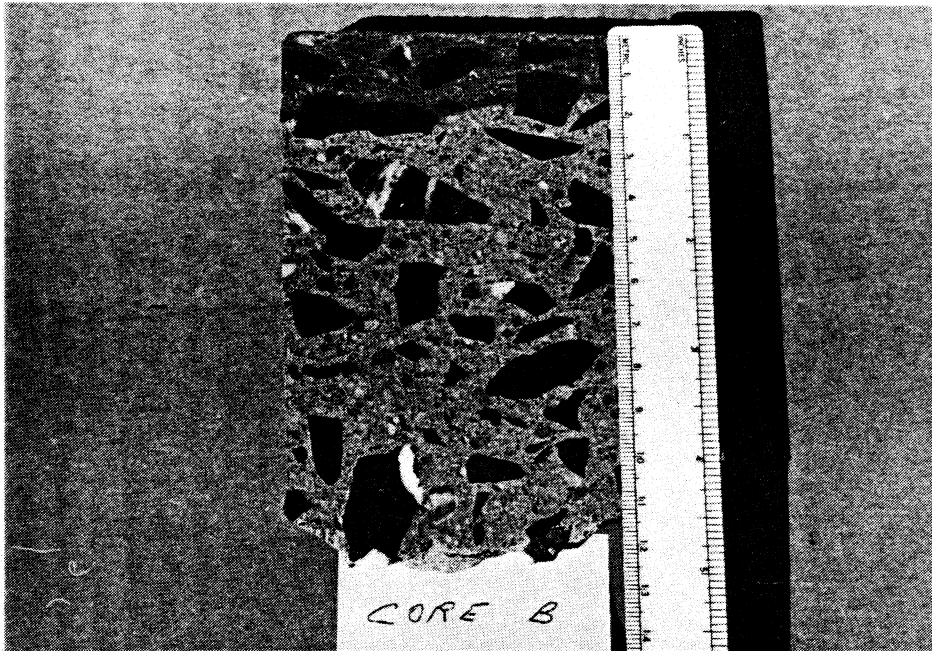
Figure 2. PIC zone in upper portion of core section from slab C (No. 5).

Performance Evaluation

The evaluation of the performance of the slabs was based on visual
inspections, a chain drag of the surface, electrical half-cell potential
measurements (ASTM C876-77), electrical resistivity measurements (ASTM
D3633), chloride ion permeability measurements (AASHTO T277), measurements
of the three-point linear polarization (3LP) rate of corrosion, and chloride
ion content determinations. The four polymer-impregnated slabs (A, B, C,
and E) and the two control slabs (D and F) were placed to widen a bridge on
Rte. 42 over a tributary of Little Calf Pasture River, 0.08 mi south of Rte.
614 (Str. #1077) in Rockbridge County (see Figures 3 and 4). The slabs are
3 ft wide x 10 ft long x 12 in thick. A curb section 1 ft wide at the base
was cast on the exterior slabs. The depth of cover over the top mat of
reinforcement is 2 to 2 1/2 in. The slabs were placed in December 1979
after having been fabricated and impregnated in October and November 1978.
The slabs were inspected on 10/26/82, 10/29/84, 4/14/87, 9/27/89, and
9/28/89 after 3, 5, 7, and 10 years in service (3).
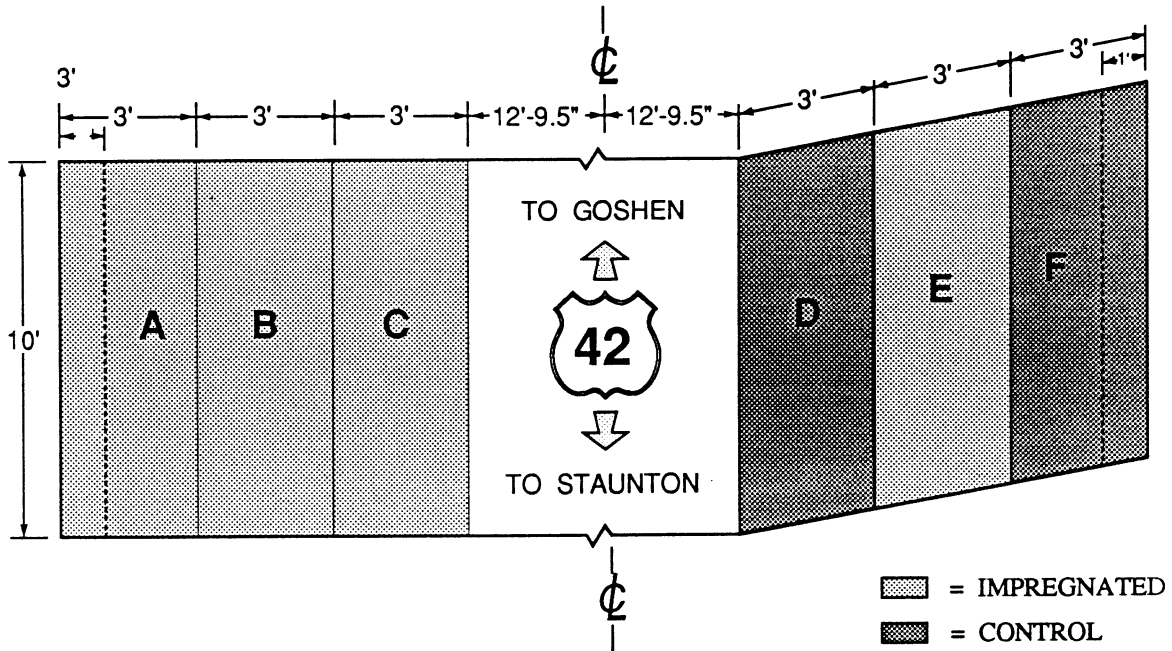
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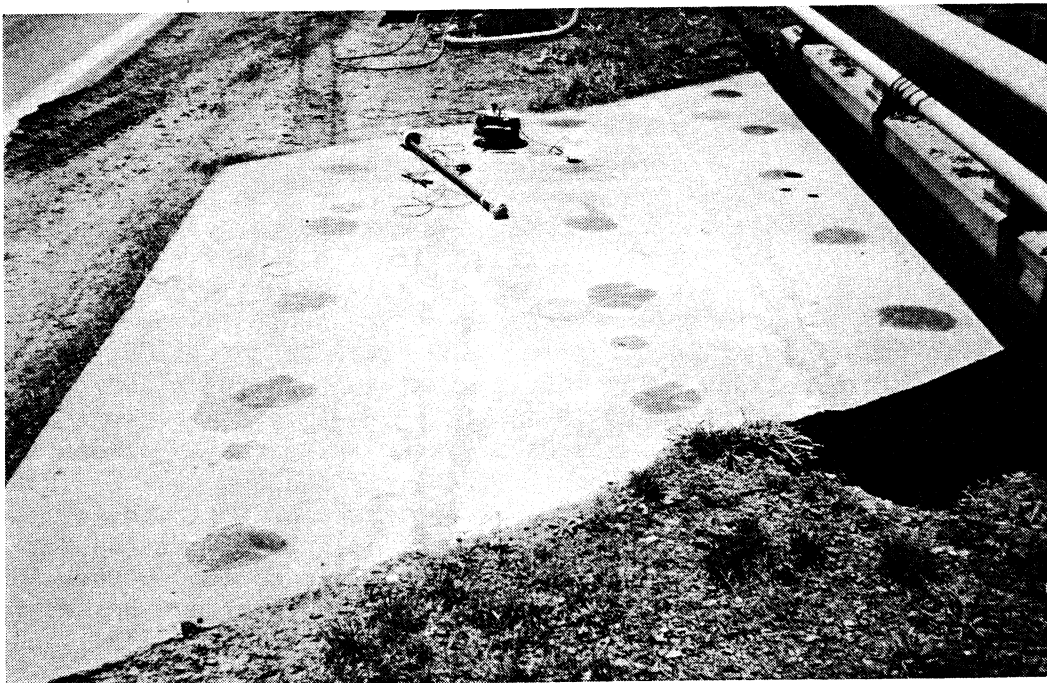Figure 3. Sketch of slab layout showing location of impregnated slabs A, B, C, and E and control slabs D and F.

Figure 4. Photograph of slabs D, E, and F after electrical half-cell potentials were measured in 1987.

RESULTS

Delaminations

The inspections conducted over the 10-year period indicated that all six slabs were in excellent condition. No delaminations or spalls were detected with the chain drag or by visual inspection.

Electrical Half-Cell Potentials

The results of half-cell potential measurements (ASTM C876-77) (see Table 1) taken over the 10-year period were similar, with the exception of the measurements taken for slab B in 1989 and slab D in 1987. Most measurements taken for control slabs D and F were less negative than -0.20 volts, which indicates a 90 percent probability that no corrosion is occurring at the test locations. In 1987, all measurements for slab D were more negative than -0.35 volts, which indicates a 90 percent probability that corrosion is occurring at the test locations. Three measurements taken in 1989 for impregnated slab B were -0.36 volts, whereas in other years, all measurements were less negative than -0.35 volts. Measurements taken in 1989 for the other slabs were less negative than -0.35 volts. On the whole, the data in Table 1 show a general increase in the magnitude of the values (more negative than -0.20 volts) for the impregnated slabs with age. Also, based on the data taken in 1989, the corrosion potential of the impregnated slabs is significantly greater than that of the control slabs. This could be due to microcracks in the impregnated layer that reduce the effective depth of cover over the reinforcement. Further research is needed to explai the half-cell potential results since they do not support the rate of corrosion and permeability to chloride ion test results.

Rate of Corrosion

Because of the inconsistencies in the half-cell data, the 3LP device was used during the 1989 evaluations to measure the electrical half-cell potentials (see Table 1) and the rate of corrosion (see Table 2) of the reinforcement at the same locations the earlier half-cell potential measurements were made. Half-cell potentials recorded with the 3LP device generally agreed with the potentials taken with the digital half-cell meter. The one exception was that for impregnated slab B: no values were more negative than -0.35 volts.

The 3LP device was used to measure the rate of corrosion at 6 locations on the exterior slabs (A and F) and at 12 locations on the interior slabs (B through E). The procedure is described in detail by Clear (4). The procedure involves taking current measurements in mA at four levels of voltage (0, 4, 8, and 12 mV), inputting the data in a preprogrammed calculator, and calculating the rate of corrosion in mA/ft^2 and mils per year (MPY). The average rate of corrosion and standard deviation for the slabs are reported in Table 2. It can be seen from the data that the top

TABLE 1

Half-Cell Data (% of Readings in Each Range)

Date of Evaluation	Years in Service	Reading Range	Impregnated Slabs					Control Slabs		
			A	B	C	E	X̄	D	F	X̄
10/26/82	3	>-0.2	100	100	25	100	94	100	100	100
	3	-0.20 to -0.35	0	0	75	0	6	0	0	0
	3	<-0.35	0	0	0	0	0	0	0	0
10/29/84	5	>-0.2	100	100	80	100	95	40	70	70
	5	-0.2 to -0.35	0	0	20	0	5	60	30	30
	5	<-0.35	0	0	0	0	0	0	0	0
4/14/87	7	>-0.2	60	0	60	0	30	0	40	40
	7	-0.2 to -0.35	40	100	40	100	70	0	10	10
	7	<-0.35	0	0	0	0	0	100	50	50
9/28/89	10	>-0.2	29	0	31	44	26	100	100	100
	10	-0.2 to -0.35	71	77	69	56	68	0	0	0
	10	<-0.35	0	23	0	0	0	0	0	0
9/28/89	10	>-0.2*	33	0	92	56	45	100	100	100
	10	-0.2 to -0.35*	67	100	8	44	55	0	0	0
	10	<-0.35*	0	0	0	0	0	0	0	0

*Readings taken with 3LP device.

X̄ = average.

TABLE 2

Rate of Corrosion Data

Date Data Taken	Years in Service	Slabs Unit		Impregnated Slabs					Control Slabs		
				A	B	C	E	X̄	D	F	X̄
9/28/89	10	MPY	X̄	0.033	0.030	0.008	0.189	0.065	1.000	0.700	0.850
	10	mA/ft²	X̄	0.073	0.098	0.063	0.391	0.156	2.040	1.430	1.735
	10	mA/ft²	s	0.034	0.054	0.063	0.194	0.097	0.220	0.644	0.432

X̄ = average; s = standard deviation.

mats of reinforcement in the control slabs are corroding at an average rate that is significantly higher (13 times greater) than that of the mats in the impregnated slabs (0.065 MPY v. 0.850 MPY). According to Clear (4), for corrosion rates less than 0.20 mA/ft^2, no corrosion damage is expected (impregnated slabs A, B, and C). For rates between 0.20 and 1.0 mA/ft^2, corrosion damage is possible in 10 to 15 years (impregnated slab E). For rates between 1.0 and 10 mA/ft^2, corrosion damage is expected in 2 to 10 years (control slabs D and F).

Electrical Resistance Measurements

As can be seen from Table 3, all electrical resistance measurements (ASTM D3633) made on all six slabs in 1982 were less than 10,000 $ohms/ft^2$, which is typical of concrete not having a protective membrane. Evidently, the number of cracks in the impregnated layer was great enough to cause the readings to be low. The readings were an order of magnitude higher in 1984 but the same for the impregnated and control slabs. The readings were not taken in evaluations done after 1984 because low values had been recorded in 1982 and 1984. It is not known why higher values were recorded in 1984 than in 1982.

Permeability to Chloride Ion

Rapid permeability tests (AASHTO T277) done on the top 2 in of cores taken from the slabs on September 27, 1989, indicated that the permeability of the impregnated slabs was 31 percent of that of the control slabs (591 v. 1,878 C) (see Table 4). Similar results were found in 1984 after 5 years of service. At that time, the permeability of the impregnated slabs was 33 percent of that of the control slabs. A greater difference was observed in 1982 after 3 years in service. At that time, the permeability of the impregnated slabs was only 17 percent of that of the control slabs.

Chloride Ion Content Measurements

The results of chloride ion content measurements made on four samples taken from each slab on 9/27/89 after 10 years in service are shown in Table 5. The data indicate that there is insufficient chloride ion at the level of the top mat of reinforcement to cause corrosion in any of the slabs < 1.3 lb/yd^3). However, the data show that the chloride ion content of the control slabs is 3 to 6 times greater than that of the impregnated slabs. The chloride data support the data from permeability and rate of corrosion tests.

TABLE 3

Electrical Resistivity Data (% of Readings in Each Range)

Date Data Taken	Years Slabs in Service	Reading Range	Impregnated Slabs					Control Slabs		
			A	B	C	E	X̄	D	E	X̄
10/26/82	3	Poor $<10^4$ ohm/ft^2	100	100	100	100	100	100	100	100
	3	Fair 10^4–$<10^6$ ohm/ft^2	0	0	0	0	0	0	0	0
	3	Good $\geq 10^6$ ohm/ft^2	0	0	0	0	0	0	0	0
10/29/84	5	Poor $<10^4$ ohm/ft^2	0	0	0	0	0	0	0	0
	5	Fair 10^4–$<10^6$ ohm/ft^2	100	100	100	100	100	100	100	100
	5	Good $\geq 10^6$ ohm/ft^2	0	0	0	0	0	0	0	0

X̄ = average.

TABLE 4

Rapid Permeability Test Data (Coulombs)

Date Cores Taken	Years Slabs in Service	Impregnated Slabs					Control Slabs		
		A	B	C	E	X̄	D	F	X̄
10/26/82	3	292	455	305	303	339	2,387	1,502	1,945
10/29/84	5	---	560 (3,726)	550 (3,776)	536 (6,037)	549 (4,513)	1,648 (3,955)	---	1,648 (3,955)
9/27/89	10	554	698 (3,606)	546	526 (3,377)	581 (3,492)	1,677	2,078	1,878

( ) = 2-in slices from cores representing a depth of 2 in to 4 in from the surface.

X̄ = average.

TABLE 5

Chloride Content (lb/yd^3)*

Depth of Samples from Surface (in)	Impregnated Slabs						Control Slabs				$\overline{X}$ Control / $\overline{X}$ Impregnated
	A	B	C	E	$\overline{X}$	s	D	E	$\overline{X}$	s	
0.1-0.5	0.37	0.29	0.37	0.29	0.33	0.047	1.96	1.98	1.97	0.012	6.0
0.5-1.0	0.40	0.24	0.22	0.34	0.30	0.083	0.99	1.02	1.01	0.023	3.4
1.0-1.5	0.17	0.16	0.14	0.29	0.19	0.068	0.52	0.67	0.60	0.109	3.2
1.5 -2.0	0.12	0.09	0.12	0.22	0.14	0.054	0.37	0.36	0.37	0.006	2.7

*Includes background chloride = 0.15 lb/yd^3.

$\overline{X}$ = average; s = standard deviation.

CONCLUSIONS

Based on rapid permeability tests on cores removed from the slabs, rate of corrosion measurements taken on the top mat of reinforcement in the slabs, and chloride ion content determinations made on samples removed from the slabs that had been in service for 10 years, shallow polymer impregnation can provide greater long-term protection against the infiltration of chloride ions and the consequent corrosion of reinforcement than conventional bridge deck concrete slabs that are not impregnated.

Implementation of findings would require that precast concrete producers set up drying and soaking facilities so that slabs could be impregnated. Because of developments with admixtures and blended cements that have occurred during the past 10 years, the precasting or overlaying of precast slabs with concretes that have a low permeability should be more economical than shallow polymer impregnation. Tyson (2) had indicated that the initial cost of shallow polymer impregnation was twice as much as overlaying the slabs with a 1.25-in layer of latex modified concrete and, therefore, use of shallow polymer impregnation would have to be justified on a life cycle cost basis.

ACKNOWLEDGMENTS

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REFERENCES

1. Cady, P. D.; and Weyers, R. C. 1986. <u>Deep polymer impregnation of a bridge deck using the grooving technique</u>. Report No. FHWA-PA-85-014. State College: The Penn State University, The Pennsylvania Transportation Institute.

2. Tyson, Samuel S. 1980. <u>Polymer impregnated bridge slabs</u>. VHTRC Report No. 80-R34. Charlottesville: Virginia Transportation Research Council.

3. Sprinkel, Michael M. 1983. <u>Polymer impregnated bridge slabs: Interim report: Condition of slabs after three years in service</u>. VHTRC Report No. 83-R23. Charlottesville: Virginia Transportation Research Council.

4. Clear, Kenneth C. 1989. Measuring rate of corrosion of steel in field concrete structures. In <u>Concrete Bridge Design and Maintenance: Steel Corrosion in Concrete</u>. TRR Report No. 1211: Washington, D.C., pp. 28-37.

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