EVALUATION OF BRIDGE DECK CATHODIC PROTECTION

A Final Report

by

Carey L. Younger
Principal Research Assistant

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16. Abstract

This report presents the results of the evaluation of cathodic protection systems installed on Interstate Route 80 in 1988. Both the titanium mesh anode and mounded conductive polymer systems have performed satisfactorily and are preventing further deterioration of the concrete from reinforcing steel corrosion. The titanium mesh anode exhibits the best overall performance of the systems under test. Based on the findings in this study, results of the recent national effort by the Strategic Highway Research Program (SHRP-S-337), and favorable reports by other users, it is recommended that cathodic protection be adopted as an alternate bridge deck rehabilitation method by the Department. Future Department installations should incorporate guidelines provided in the AASHTO-AGC-ARTBA Task Force #29 publication, "Guide Specification for Cathodic Protection of Concrete Bridge Decks", SHRP[5,6] and the recommendations given in this report.

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CONTENTS

PART ONE: SUMMARY OF OBSERVATIONS AND CONCLUSIONS

The principal observations and conclusions from this study of bridge deck cathodic protection (CP) are as follows:

1.1 Based on the results of recent testing and evaluation, the study installations on Rt. I-80, Sections 3AD and 4AY are performing satisfactorily and preventing further deterioration of the concrete decks from reinforcing steel corrosion.

1.2 The titanium mesh anode system exhibits the best overall performance of the systems under test. Some benefits of the titanium mesh system include:

- a. High level of corrosion protection (highest level of reinforcing steel polarization)
- b. Low anode circuit resistance (lowest driving voltage and least amount of power consumption)
- c. Good current distribution
- d. High redundancy (a break in the mesh will not negatively effect system performance)
- e. Longest projected anode life (estimated 35-40 years)[1,2,3]

1.3 Both the mounded conductive polymer and flexible conductive polymer systems exhibited increased circuit resistance over the first three years of operation (150% and 167% respectively). The latter may be an indication that the anode is depleting or portions of the anode are no longer in the circuit.

1.4 The mounded conductive polymer systems have the highest number of potential decay readings outside of the specified limits for protection (100 to 250 millivolts). This is primarily attributed to the larger spacing (12 in.) between mounds, as compared to the other anodes (1-3 in.), resulting in uneven current distribution to the reinforcing steel.

1.5 The remote monitoring systems provide a cost-effective method for routine monitoring of the CP systems.

PART TWO: RECOMMENDATIONS

2.1 Based on the findings in this study, the recent national effort by SHRP[1] and favorable reports by other users, it is recommended that CP be adopted as an alternate bridge deck rehabilitation method by the Department.

2.2 Future Department CP installations should incorporate guidelines developed by AASHTO-AGC-ARTBA Task Force #29[4], SHRP[5,6], and the recommendations given in this report.

2.3 Future use of the flexible conductive polymer wire CP system (Raychem Ferex 100 Anode) is not recommended due to the following:

a. The manufacturer has declared this system inadequate for deck application.

b. Seven (7) zones are presently inoperative due to apparent anode failure.

c. Four of nine installations have exhibited disbonding and minor spalling of the LMC overlay. Repair of the latter may not be practical due to the potential for extensive excavation of the anode and associated traffic control requirements/cost.

2.4 Since the flexible conductive polymer systems are susceptible to premature failure, it is recommended that these systems be (1) operated at the lowest possible output providing minimum acceptable corrosion protection and (2) monitored frequently so that complete system failure can be anticipated and anode/overlay replacement appropriately scheduled.

2.5 The following long term maintenance program is recommended for all CP systems:

a. Remotely monitor the cathodic protection systems at two month intervals for operational data (i.e., rectifier voltage and current).

b. Inspect the cathodic protection systems annually and perform repairs/adjustments as required.

2.6 To facilitate routine monitoring, it is recommended that remote monitoring systems (RMS) on existing and future CP installations be programmed with an alarm that identifies data out of specified range or automatically initiates communications between the office, PC computer and the rectifier[1,5].

2.7 In view of the Department's current manpower constraints, it is recommended that monitoring and servicing of existing and future CP installations be done by contract. A sample monitoring and service proposal is provided in Appendix F.

PART THREE: INTRODUCTION

3.1 Background

Premature deterioration of concrete bridge decks resulting from chloride-induced corrosion of the reinforcement steel continues to be a major problem facing the highway industry nationally and in New Jersey. The need for a more cost-effective means of combatting this problem is well known. In 1991, the FHWA estimated the cost to rehabilitate about 220,000 deteriorated decks nationally, using conventional repair strategies, would be more than $90 billion[1]. Those conventional strategies -- which include various types of special concrete overlays, membranes and sealants -- have been reasonably successful in protecting new bridges and existing decks without active corrosion, but have not generally yielded the same degree of success in arresting corrosion in salt-contaminated decks. Thus, the above strategies are really stop-gap measures since they typically extend deck life only 10 to 15 years[8,9].

In 1981, cathodic protection (CP) was recognized by the FHWA as the only effective rehabilitation technique for salt-contaminated decks[8]. In contrast to conventional strategies, CP abates the corrosion mechanism and offers a solution that is potentially twice as effective. To promote the benefits of the technique and encourage its use by the states, the FHWA subsequently included Cathodic Protection of Bridge Decks in their demonstration (No. 34) projects program. Today, more than 275 structures are cathodically protected in North America. A 1988-89 survey indicated that 90% of these installations were performing as designed[1].

Basically, CP employs an electrical current to combat corrosion. The technique has been used for many years by the oil and gas industry to safeguard buried pipes and tanks. The process requires applying an external direct current to the reinforcing steel in a bridge deck (through introduced anode material) in sufficient quantity to neutralize the currents generated during the electro-chemical process of oxidation. By arresting the corrosion of the reinforcing steel, CP is expected to extend the life of a moderately deteriorated deck by some 20 to 40 years. Additionally, significant savings in reconstruction costs can be realized, since the use of CP eliminates the need to remove salt-laden concrete. The latter further reduces traffic congestion and safety hazards associated with deck reconstruction.

3.2 Statement of the Problem

The premature deterioration of concrete bridge decks resulting from chloride-induced corrosion of reinforcement steel continues to be a problem nationally and in New Jersey that is both expensive and a hazard to safety. Conventional protective strategies such as special concrete overlays, membranes and sealants have proven effective as stop-gap measures, but cannot be relied upon to completely arrest corrosion. The above measures require on-going maintenance and expensive traffic conrol.

3.3 Objectives

The objectives of this research are to (1) determine the effectiveness of an overlay-type cathodic protection system in controlling/arresting corrosion in an existing, salt-contaminated concrete bridge deck under New Jersey conditions and (2) gain the hands-on experience necessary to determine the need for and nature of any improvements in specifications, construction procedures, and methods used in assessing system performance.

PART FOUR: CONSTRUCTION AND MATERIALS

4.1 General

Test Site Description

The structures selected for this evaluation are located on Route I-80 in the northern part of the state. Route I-80 is New Jersey's primary east-west highway and carries an AADT of about 83,000. The structures are 18 to 22 year old conventional slab/girder bridges. The reinforced concrete slabs were typically 8½" to 9" thick with 1½" specified top cover. Condition surveys of the decks prior to CP installation revealed that, although they contained high levels of chlorides and were actively corroding, the decks were structurally sound and only moderately deteriorated. Because the decks did not require complete deck replacement, these bridges were considered excellent candidates for an experimental CP installation. Detailed information on the test site location and condition of the decks prior to CP installation is provided in Appendix A.

4.2 Materials

The basic CP systems under study were comprised of the following components. Additional information is provided in project specifications and the post installation/activation report[8].

CATHODIC PROTECTION SYSTEM COMPONENTS

A/C Power Supply
Anode
Corrosometer Probe
Rebar Probe
Reference Electrode
Remote Monitoring System
Temperature Probe (Research sites only)

Since none of the state-of-the-art systems had extensive track records in 1987, it was felt that the Department's first installations should include three different materials for comparison of installation and performance characteristics. Selection was based primarily on experience of other users, favorable laboratory test results, and ease of installation. The systems included Harco Anodecrete, Raychem Ferex 100 and ELGARD 210 Anode Mesh. One each of the Harco and ELGARD installations were selected for this study. A description of the systems is provided in the following table. A list of the installations and cost information is presented in Appendix A.

ANODE MATERIALS

Product/Mfg.	**Description**
Harco Anodecrete Harco Corp. (System A)	**mounded conductive polymer** Platinized-niobium copper core wire (primary anode) and carbon fibers (secondary anode) covered with a 5/8" mound of conductive polymer concrete
Raychem Ferex 100 * Raychem Corp. (System B)	**flexible conductive polymer mesh** Copper wirecore coated with flexible polymeric compound
ELGARD 210 Mesh Eltech Systems (System C)	**catalyzed titanium-coated wire mesh** expanded titanium mesh coated with a mixed precious metal oxide catalyst
Dow LidaNet *	**catalyzed titanium-coated wire grid/mesh** expanded titanium mesh coated with a mixed precious metal oxide catalyst

*not evaluated in this study

Latex Modified Concrete (LMC) Overlay

The ELGARD anode systems were topped with 1¼" inch LMC overlays while the thicker Harco and Raychem systems used a 1½" LMC cover.

Remote Monitoring System

The study installations are monitored by collecting and analyzing readings for current flow, voltage and corrosion activity. Much of this data is provided by remote monitoring equipment installed during construction. This system consists of a data monitor, rechargeable battery, telephone modem and personal computer (PC). Operating data is collected and transferred to the PC located at NJDOT headquarters in Trenton. The data is processed using custom-designed data management and graphics software. Detailed information on this equipment is provided in the project specifications and previous reports [10,11].

4.3 Construction Sequence

Installation of the studied CP systems generally consisted of the following:

1) Preparation of the deck surface for concrete overlay
2) Continuity testing and connection of system negative lead wires to the reinforcing steel (2 per zone)
3) Installation, hook-up and testing of embedded reference cells, and research probes
4) Installation, hook-up and testing of anodes
5) Light waterblast of the deck after the CP system installation
6) Placement of the latex modified concrete overlay

7) Installation of electrical hardware necessary to connect anode, ground, and reference cell lead wires to the system power source

8) Rectifier installation and connection to line power

9) System commissioning and evaluation, prior to acceptance

4.4 Other CP Installations in New Jersey

Route NJ 17

An additional research installation was completed in December 1991 on Rt. NJ 17, Section 6J. This project included an overlay type system using 3" inch wide titanium ribbon/mesh anodes on one deck and a non-CP (LMC overlay) control installation on the adjacent structure. A unique aspect of this project is that the performance of the systems will be compared using corrosion monitors embedded in the CP deck as well as the non-CP control installation. Post installation/activation information is provided in an earlier report[12]. These installations are performing satisfactorily and will be further discussed in a future report.

Interstate Route I-80

Although not under study in this evaluation, sixteen (16) additional installations were made under the Route I-80 Section 3AD & 4AY contract. These included four (4) titanium mesh, three (3) mounded conductive polymer, and nine (9) flexible conductive polymer anode systems. A list of the installations, location, and cost information is provided in Appendix A. With the exception of several flexible conductive polymer systems, the above installations are performing satisfactorily. Additional information is provided in Section Six herein and previous project reports[10,13].

PART FIVE: METHOD OF EVALUATION

5.1 Post Installation and Activation Testing

The following testing was conducted on the study installations September through November 1988. An overview of the test methods is presented below. Detailed information and test data is provided in the post installation/activation report [10] .

Electrical resistance measurements

The following measurements were made to verify proper operation of the CP system and its monitoring components. All measurements were taken with a Nilsson Model 400 AC resistance meter.

- **Anode-to-system ground circuit resistance** - verifies that each zone will operate within rectifier capacity
- **System negative-to-reference cell ground** - indicates electrical continuity of the deck rebar network

Static potential and system energized measurements

The following measurements were made between various components and embedded monitors to verify proper operation and electrical continuity. All potential measurements were taken with a Miller LC-4 high input impedance voltmeter.

- **Anode-to-system negative and reference cell to reference ground** - normal for operation
- **System negative-to-reference cell ground** - verifies electrical continuity of the deck rebar network

- **Resistance, reference cell potential and rebar probe current measurements** - verify monitors are installed and operating properly

Corrosion Rate Measurements

The purpose of this testing is to monitor both short and long term deck rebar corrosion rates. A Model 4208 Corrosometer System manufactured by Rohrback was used on the study structures.

Rebar Probe Current Measurements

This testing is conducted to determine the amount of cathodic protection corrosion generated and the amount of impressed current required to mitigate corrosion of macrocell rebar probes installed in the study structures.

E Log I Testing

Standard test criteria recognized by the National Association of Corrosion Engineers (NACE) [1,7] was used. This testing is used primarily as a start-up test to determine cathodic protection current requirements for mitigating existing and further corrosion.

Polarization Decay Testing

The most widely used evaluation criteria is that recommended by NACE [1,5,6,7]. The amount of polarized potentials is measured by denergizing the CP system and recording the decay in polarization over time. A difference or shift in potential from the instant "off" value of at least 100 millivolts satisfies the criterion. Testing was conducted using the permanent silver/silver chloride reference cells in conjunction with the automatic potential data logging remote monitoring computer. To confirm the accuracy of the remote monitoring system, depolarization testing was also performed at the rectifier.

5.2 Monitoring of Test Installations

Periodic performance testing of the study installations consisted of the following.

- Visual Inspection
- Delamination Survey
- Polarization Decay Testing
- Electrical Resistance Measurements
- Rebar Probe Current Measurements
- E log I Testing
- Corrosion Rate Measurements

PART SIX: RESULTS AND DISCUSSION

6.1 General

At this writing, the study installations have been in service for about five years and continue to function satisfactorily. The following section presents observations and conclusions from the summer 1993 evaluation .

6.2 Observations and Conclusions

Visual Examination

Bridge No. 1415-157, titanium mesh - overlay appears in very good condition except for a 25 s.f. area (less than 1% of total deck surface area) in the outer shoulder where some concrete is missing to an average depth of 1/2" in several spots (appears to be a construction-related problem -- e.g., uncured concrete was damaged, then refinished).

Bridge No. 1415-158, conductive polymer mound - overlay appears in generally good condition; fine cracking over about 10 percent of the deck surface area.

Delamination Survey

This testing was conducted using chain dragging and hammer sounding techniques.

Bridge No. 1415-157, titanium mesh - four (4) areas totalling 3 s.f. of delamination were detected. The total area affected represents less than 1% of the deck surface area.

Bridge No. 1415-158, conductive polymer mound - sixteen (16) areas totalling 35 s.f. of delamination were detected. However, overlay disbonding, rather than delamination, is suspected in several of the above areas. The total area affected represents less than 1% of the deck surface area. Survey results are summarized in Appendix E.

Depolarization Testing

The results of this testing indicate the cathodic systems are providing adequate corrosion control to both the top and bottom mats of reinforcing steel in the study decks. Depolarization data is presented in Appendix B.

The mixed metal oxide titanium mesh (ELGARD Anode Mesh) exhibits the highest level of reinforcing steel polarization of the systems under test, thus providing the greater level of corrosion protection.

One reference cell in the conductive polymer mound system is defective and one other cell failed to meet the NACE 100 mV shift criteria.

Electrical Resistance Measurements

The conductive polymer mound system continues to show a significantly higher (1.58 - 3.59) anode circuit resistance than the titanium mesh (0.56 -0.87), yet is still operating within system design parameters. This data is summarized in Appendix B.

Rebar Probe Measurements

This testing was not performed during the 1993 evaluation due to malfunctioning of the remote monitoring system and time/manpower constraints. Results of previous testing[13] indicated the rebar probe is an effective method for evaluating system performance.

E Log I Testing

This testing was not performed in 1993 due to time/manpower constraints. Results of previous testing are provided in earlier project reports[10,13].

Corrosion Rate Measurements

This data has not been collected since 1991 due to unreliability of the test equipment as described section 6.2.1.

Performance Monitoring/System Maintenance

While the remote monitoring systems provide a cost-effective approach to routine monitoring/evaluation, this method could be enhanced by the inclusion of an alarm that identifies data out of specified range or automatically initiates communication between the office, PC computer and rectifier[1].

All CP systems should be inspected semi-annually and remote data analyzed annually by a qualified corrosion engineer to ensure optimum performance. In view of the Department's current time/manpower constraints, the alternate use of a corrosion engineer/consultant should be considered to handle system maintenance and annual check ups.

6.2.1 Performance of Other New Jersey Installations

The results of the evaluation by Corrpro Companies, Inc. in 1991 indicated that the titanium mesh and mounded conductive polymer systems on Rt. I-80, Section 3AD & 4AY project were performing as designed[11]. However, several problems were detected with the flexible conductive polymer installations. Conclusions and recommendations by Corrpro are summarized as follows:

1. Fifty one (51) of fifty eight (58) cathodic protection zones on the eighteen (18) bridge decks are receiving a high degree of corrosion protection.

2. The following rectifier control adjustments were made to operational cathodic protection zones:

Bridge No.	Zone No.	Reference Cell No.
1414-175 (5)	1,3,8&9	Increased current
1414-176 (5)	3	Decreased current
1415-155 (8)	1	Decreased current
1415-156 (8)	2	Decreased current
1415-157 (11)	3	Decreased current
1415-158 (12)	8	Decreased current
0726-151 (14)	7	Decreased current

3. The following trends for the three (3) different anode systems were determined:

Mounded Conductive Polymer (System A) - Circuit resistance steadily increased by 150% over the initial resistance in the three years of continuous operation. At the same time there has been a reduction in the current required to maintain levels of corrosion protection. These systems produced the highest number of reference cell potential decays out of specified protection criteria range (100-250 mV).

Flexible Conductive Polymer (System B) - Highest circuit resistance increase (steadily increased by 167%

over initial) in three years on continuous operation. Reduction in protection current required to maintain initial levels of corrosion protection. These are the only systems showing LMC overlay damage and failed anode material.

Titanium Mesh (System C) - Lowest circuit resistance increase (steadily increased by 33% over initial) in three years of continuous operation. Reduction in protection current required to maintain initial levels of corrosion protection. These systems produced the least number of reference cell potential decays out of specified protection criterion range.

4. A total of seven (7) zones on flexible conductive polymer installations (Bridge Nos. 3,4,5 & 7) are not receiving cathodic protection due to anode failure. It is projected that at least two other zones on these installations (Bridge Nos. 4 & 5) will have anode failure in the near future. Other states and Canadian provinces have reported similar premature failures of the Raychem Ferex anode systems resulting in complete or partial loss of cathodic protection.

Premature anode system failure will occur if the flexible conductive polymer copper core acts as an anode rather than as a current conductor. This can occur if the anode is physically damaged or if operating at too high a current density. The amount of anode wire damaged may be minimal or extensive depending on its location(s) along the network. If these failures are few, they can probably be exposed, repaired, and then reactivated with minimal time and cost.

Techniques for finding failures and repairing damaged anode wire are considered developmental. To be most technically and economically effective, it is recommended that the damaged anode wire locations be determined, repairs made, and testing conducted during the same traffic control schedule.

5. Spalled overlay concrete was found only on decks with flexible conductive polymer anode systems (Bridge Nos. 3,5,7 & 17). This may be unique to this NJ project since other states using this system have not reported this condition.

   It is recommended that all Raychem Ferex installations be tested for overlay disbonding and spalling. All damaged overlay areas should be repaired with concrete patch material. Repair to these areas should include repair to the damaged anode wire.

6. All rectifier units were operational at the conclusion of this evaluation. Various repairs included power module and control card replacement by NJDOT personnel. It is recommended that spare rectifier parts be maintained.

7. Five of twelve remote monitor systems were tested and

determined to be operational at the conclusion of this evaluation. Typical problems included phone line outages, polycorder and/or modem failures.

Polycorders and modems were removed and inoperative equipment appropriately labeled by NJDOT personnel. It is recommended that all equipment be repaired and remote monitoring systems be placed back into service as soon as possible.

8. All embedded reference cells (including extras at the research sites) are functioning properly with the exception of the following:

Bridge No.	Zone No.	Reference Cell No.
1415-150 (5)	1	2
1415-150 (5)	2	2
1415-153 (8)	1	1&2
1415-153 (8)	2	1
1415-157 (11)	2	2
0726-153 (15)	2	2
0726-156 (18)	7	1

The validity of the above reference cells is questioned because of their measured high circuit resistances.

9. All rebar probes embedded in the research decks are responding correctly with and without cathodic protection applied. The rebar probes have shown to be an effective monitor for evaluating the performance of CP systems on the research sites.

10. All Corrosometer measurements obtained in December 1991 are invalid. The embedded sensing elements are either used-up, defective or the instrument cannot properly process the data. It is concluded that this instrument (Corrosometer Model 4208 with type C-S8 elements) is not an effective method to evaluate the performance of the CP systems at the research sites.

Based on these findings, experience with other corrosometer systems and discussions with other CP researchers, the corrosometer system is not an effective method to evaluate a CP system for reinforced concrete.

11. Resistance measurements between reference cell ground lead wires and system negative lead wires at the rectifier for Bridge Nos. 7 & 8 are extremely high. The half-cell measurements from these embedded reference cells are unstable. Preliminary checks did not identify a CP system wiring problem -- a poor or non-existing grounding system for these bridges is suspected. A detailed investigation is recommended to determine and correct this condition.

12. In the fall of 1992, it is recommended that all CP monitoring data is reviewed, depolarization testing on all zones, and E Log I testing of selected zones be conducted after four continuous years of operation. It is also recommended that all systems be re-adjusted for voltage control and with current limit based on

analysis of this review and test data obtained at that time. It has been shown (FHWA Report RD-88-267) that constant voltage control with current limit can provide effective corrosion control to reinforcing steel that has been previously polarized under cathodic protection constant current control. It is also more reasonable to project optimum anode system life with voltage control/current limit adjusted CP systems.

Summary

The studied systems and most of the other CP installations on Rt. I-80 continue to function as designed after five years in service. The systems will significantly reduce, if not completely eliminate the corrosion of reinforcing steel embedded in the subject decks. The reduction or elimination of corrosion products will significantly decrease the amount of concrete delamination and spalling due to corrosion, thus reducing annual maintenance costs and prolonging the structural integrity of the decks.

PART SEVEN: ECONOMICS

The chief benefit of CP is long-term protection against the corrosion of steel in salt-laden concrete. Another benefit is the savings in construction costs realized by eliminating the need to remove sound, but salt-laden concrete. (Conventional rehabilitation methods normally require all salt-laden concrete to be removed. The presence of salt is beneficial to CP installations, since salt promotes the flow of the electrical protection current.) The savings in concrete removal is directly proportional to the quantity of concrete left in place. An estimated net savings of $570,000 in construction costs was realized on the I-80, Section 3AD & 4AY project (18 installations). About $15,000 of the above total was saved on the two study installations. In view of the recent decline in the cost of CP systems[5] and the hands-on experience gained by the Department and contractors, even greater savings are expected in the future.

In addition to budgetary savings CP also eliminates much of the traffic congestion and safety hazards associated with deck reconstruction. One of the goals of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) was to reduce the air quality problems and fuel loss that result from congestion.

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APPENDIX A: Cathodic Protection Installations

Table 1: Bridge Location and Anode System

Table 2: Pre-Construction Condition of Study Installations

Table 3: Installed Cost of CP Systems

TABLE 1: SUMMARY OF BRIDGE LOCATION AND ANODE SYSTEM

BRIDGE NO.	STRUCTURE NO.	ANODE SYSTEM	LOCATION
1	1414-175	Harco, mound	I-80 EB over EB 46
2	1414-176	Elgard, mesh	I-80 WB over EB 46 & Ramp D
3	1414-178	Raychem, wire	I-80 EB over Ramp over WB 46
4	1414-179	Raychem, wire	I-80 WB over WB 46
5	1415-150	Raychem, wire	I-80 EB over Edward Rd.
6	1415-151	Raychem, wire	I-80 WB over Edward Rd.
7	1415-152	Raychem, wire	I-80 EB over Rockaway River
8	1415-153	Raychem, wire	I-80 WB over Rockaway River
9	1415-155	Harco, mound	I-80 EB over Hook Mt. Rd.
10	1415-156	Elgard, mesh	I-80 WB over Hook Mt. Rd.
11*	1415-157	Elgard, mesh	I-80 EB over Passaic River
12*	1415-158	Harco, mound	I-80 WB over Passaic River
13	0726-150	Harco, mound	I-80 EB over Horseneck Rd.
14	0726-151	Elgard, mesh	I-80 WB over Horseneck Rd.
15	0726-153	Raychem, wire	I-80 EB over Two Bridge Rd.
16	0726-154	Raychem, wire	I-80 WB over Two Bridge Rd.
17	0726-155	Raychem, wire	I-80 EB over Passaic River
18	0726-156	Elgard, mesh	I-80 WB over Passaic River

* research site

TABLE 2: RESULTS OF PRE-CONSTRUCTION SURVEY OF CATHODICALLY PROTECTED DECKS

SITE & SURVEY DATE	SPAN	AREA (sf)	CONC. COVER (In)	SPALLING Area (sf)	SPALLING %	DELAMINATIONS Area (sf)	DELAMINATIONS %	CHLORIDE CONTENT DATA, (lbs/cy) Depth (In)	Avg	Range	% Samples 1.1 - 2	% Samples > 2.0	% POTENTIALS > 0.35v
Rt. I-80, WB	East	5244	1-1/8	81	2	43	1	A	3.6	1.0 - 5.9	0	83	10
over Passaic								B	0.5	0	0	0	
River	Center	6315	1-1/4	60	1	33	< 1	A	3.8	1.0 - 6.6	0	75	3
#1415158								B	0.4	0.4 - 0.5	0	0	
May 1988	West	5299	1	160	3	70	1	A	3.3	0.7 - 5.7	0	67	14
Built 1968								B	0.3	0.3 - 0.4	0	75	
	TOTAL	16808	1-1/8	301	2	146	1	A					9
(HARCO)								B					
Rt. I-80, EB	East	5205	1-1/4	50	1	40	1	A	4.8	2.8 - 7.4	0	100	14
over Passaic								B	0.6	0.4 - 0.6	0		
River	Center	6196	1-3/8	15	< 1	11	< 1	A	6.0	0.7 - 9.7	0	75	3
#1415157								B	0.6	0.3 - 1.6	0		
May 1988	West	5189	1-1/4	200	4	76	1	A	4.7	2.0 - 6.7	0	83	28
Built 1968								B	0.4	0.2 - 0.6	0		
(ELGARD)	TOTAL	16588	1-1/4	265	2	121	1	A				85	14
								B					

TABLE 3: INSTALLED COST OF CATHODIC PROTECTION SYSTEMS

Rt. I-80, Section 3AD & 4AY

System	Structure No.	Deck Area (s.f.)	Anode ($/s.f.)	Total System ($/s.f.)
A	0726150	10,882	$4.13	$9.21
A	0726151	10,883	$3.68	$8.75
A	1415158	10,084	$3.51	$7.86
A	1415155	4,368	$4.35	$11.86
A	1415156	4,368	$4.35	$11.86
A	1414175	27,466	$3.28	$6.65
A	1414176	13,477	$3.71	$10.15
B	1415150	7,183	$4.18	$6.97
B	1415151	6,740	$4.30	$7.28
B	1415152	11,804	$3.30	$8.94
B	1415153	11,804	$3.30	$8.94
B	1414178	9,254	$5.08	$15.10
B	1414179	11,069	$3.79	$11.71
B	0726153	4,624	$4.54	$10.17
B	0726154	4,715	$4.67	$10.19
B	0726155	19,884	$3.47	$6.38
C	1415157	16,637	$3.91	$8.37
C	0726156	19,884	$3.27	$6.18
	Average Cost,	System, A	$3.86	
		" B	$4.07	
		" C	$3.59	

(shaded) = research site

APPENDIX B: Depolarization Test Results

Table 4: Summary of 4-Hour Polarization Decay Data
(Bridge No. 1415-157, Titanium Mesh)

Table 5: Summary of 4-Hour Polarization Decay Data
(Bridge No. 1415-158, Mounded Conductive Polymer)

Table 6: Depolarization Test Data

TABLE 4: SUMMARY 4-HOUR POLARIZATION DECAY, (-mV)
Bridge No. 1415-157, Titanium Mesh

Zone Number	Reference Cell [a]	Nov 1988	Nov 1990	Dec 1991	June 1993
1	1 2	317 81	475 207	215 246	459 220
2	1 2	156 170	195 79	214 256	165 167
3	1 2	176 210	270 188	288 217	216 162
4	1 2	189 115	179 194	146 236	102 128

TABLE 5: SUMMARY 4-HOUR POLARIZATION DECAY, (-mV)
Bridge No. 1415-158, Rigid Conductive Polymer

Zone Number	Reference Cell [a]	Nov 1988	Nov 1990	Dec 1991	June 1993
5	1 2	144 53 [c]	141 86 [c]	221 154	126 102
6	1 2	179 159	185 181	194 181	236 58 [c]
7	1 2	177 219	269 324	258 260	235 58
8	1 2	234 137	294 160	249 NA [b]	175 148
9	1 2	194 189	253 182	170 171	146 172
10	1 2	220 150	350 257	386 326	NA [b] 207

Notes:
[a] embedded Ag/AgCl reference cell
[b] NA = results could not be analyzed (suspect bad cell)
[c] failed to meet 100-250 mV shift criteria (NACE)

TABLE : 6 DEPOLARIZATION TEST DATA

Bridge No.: 1415-157 & 158 Date: 06-30-93 Time: 10:15am Ambient Temp.: 84 F

ZONE	1		2		3		4		5		6		7		8		9		10	
Ref. Cell	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1[a]	2
Time (min) 0	390	356	398	408	439	340	278	288	396	513	398	487	455	309	356	333	342	325	---	507
15	286	316	361	378	395	306	248	260	367	499	361	460	410	280	319	311	312	293	---	480
30	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
45	219	272	337	348	368	291	216	240	329	480	325	435	364	259	291	285	284	260	---	434
60	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
75	186	247	329	327	354	285	200	221	315	469	309	426	344	250	280	270	272	244	---	420
120	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
150	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
180	125	198	298	281	312	263	181	193	314	443	280	404	310	228	258	226	253	215	---	390
210	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
240	114	183	278	265	290	247	174	179	309	422	269	394	298	220	250	211	247	204	---	375
4 hr Decay	459	220	165	167	216	162	102	128	126	102	236	58[b]	235	161	175	148	146	172	---	207

Notes:
[a] defective cell
[b] failed to meet 100 - 250 mV shift criteria

APPENDIX C: Electrical Resistance Test Data

Table 7: Summary of Electrical Testing

Table 8: Summary of Anode-to-Structure Circuit Resistance

TABLE 7: SUMMARY OF ELECTRICAL TESTING (June 1993)

	Titanium Mesh	**Conductive Polymer**
Operating Current (Amps DC/zone)	r = 2.5 - 4.0	2.5 - 4.0
Current Density (mA/s.f.)	r = 0.9 - 1.5	0.9 - 1.5
Circuit Resistance (ohms)	r = 0.56 -0.87	1.58 - 3.59
4-Hour Polarization Decay (mV)	r = 102 - 450 x = 184	58 - 236 160

TABLE 8: SUMMARY OF CALCULATED ANODE-TO-STRUCTURE CIRCUIT RESISTANCE (ohms)

Bridge & Zone Number	**Nov 1988**	**Nov 1990**	**Dec 1991**	**June 1993**
1415-157 [1]	0.439	0.561	0.659	0.610
[2]	0.442	0.300	0.545	0.558
[3]	0.692	0.818	0.935	0.870
[4]	0.745	0.745	0.870	0.837
1415-158 [5]	0.950	2.366	0.976	1.585
[6]	1.185	2.704	4.308	1.963
[7]	1.167	2.400	4.100	1.833
[8]	1.156	2.594	4.516	1.903
[9]	1.370	2.296	3.593	1.852
[10]	1.407	2.179	3.607	3.592

* rectifier in <u>current</u> mode of operation

APPENDIX D: Rectifier Data

Table 9: Summary of Rectifier Operational Data

and Rectifier Maintenance Sheet

TABLE 9: SUMMARY OF RECTIFIER OPERATIONAL DATA

Bridge & Zone Number	Nov 1988		Nov 1990		Dec 1991		June 1993	
	Initial Voltage (V)	Initial Current (A)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Current (A)
1415-157 [1]	2.6	4.1	3.1	4.1	3.5	4.1	3.2	4.0
[2]	2.7	4.3	2.6	4.4	3.2	4.4	3.1	4.0
[3]	3.5	3.9	3.5	3.3	3.7	3.1	4.3	4.0
[4]	4.3	4.7	4.3	4.7	4.8	4.6	4.4	4.3
1415-158 [5]	4.6	4.0	10.5	4.1	4.8	4.1	7.0	4.0
[6]	4.0	2.7	8.1	2.7	12.0	2.6	5.9	2.7
[7]	4.3	3.0	8.0	3.0	13.1	3.0	6.1	2.7
[8]	4.5	3.2	9.1	3.2	14.8	3.1	6.5	3.1
[9]	4.5	2.7	7.0	2.7	10.5	2.7	5.6	2.5
[10]	4.6	2.7	6.9	2.8	10.9	2.8	10.05	2.5

* rectifier in current mode of operation

RECTIFIER MAINTENANCE SHEET

Project I-80, Section 3AD & 4AY Bridge Identification 1415-157 & 158

Rectifier Model No. VADCC 20-100CZ Rectifier Serial No. MP 88F 001

Rectifier Output: 20 Volts DC 100 Amps DC 10A Circuits

Anode System 1415-157 (Elgard); 1415-158 (Harco)

Tester CY & SD Deck Conditions dry

Date 06-30-93 Time 10:15 am Ambient Temperature 84°F

Remarks As found
Corrosometers disconnected

Zones #1-4, Bridge 1415-157
" 5-10, " 1415-158

ZONE	Voltage (V)	Current (A)	Mode of Operation Voltage/ Current/ Potential	Ref. Cell #1 (mv)		Ref. Cell #2 (mv)		Potential Set (mv)	Potential Control Switch On/Off	Reference Cell Switch Position 1/2	Reference Cell "ON" Monitor Position 1/2
				IR Drop Free	ON	IR Drop Free	ON				
1	3.3 (3.25)	4.1 (4.0)	Current	-573	-656	-403	-460		on	1	2
2	3.2 (3.10)	4.3 (4.0)	Current	-443	-468	-432	-510		on	2	1
*3	113.8 (4.28)	4.1 (4.0)	Current	-506	-557	-409	-430		on	2	1
4	4.6 (4.40)	4.7 (4.3)	Current	-276	-278	-307	-540		on	1	2
5	7.3 (6.99)	4.1 (4.0)	Current	-435	-456	-524	-551		on	2	1
6	6.1 (5.90)	2.7 (2.7)	Current	-505	-498	-452	-507		on	1	2
7	6.3 (6.11)	3.0 (2.7)	Current	-533	-582	-381	-403		on	1	2
8	6.7 (6.50)	3.1 (3.1)	Current	-425	-469	-359	-379		on	1	2
9	5.8 (5.63)	2.7 (2.5)	Current	-393	-414	-376	-403		on	1	2
10	10.5 (10.05)	2.7 (2.5)	Current	+096 (+912)	+1001	-46 (-582)	-732		on	1	2

* Voltage does not match portable meter.

APPENDIX E: Delamination Survey Results

FIELD SERVICE REPORT
Delamination Survey

Structure: Bridge 1415-157
Location: I-80 New Jersey
Owner: NJDOT

Date: 9/16/93 - 9/20/93
Performed by: J. E. McNaughton
Anode Type ELGARD

DELAM #	SIZE	AREA(ft)	LOCATION
A	7" x 18"	0.88	25.25' from North curb, 12.5' west of joint "C"
B	8" x 12"	0.67	25.25' from North curb, 4' west of joint "E"
C	4" x 12"	0.33	25.25' from North curb, 44.75' west of joint "D"
D	7" x 24"	1.17	25.25' from North curb, 39' west of joint "D"

Delam # 4
Total Delam Area 3.0 SF
Area Surveyed 12,978 SF
% Delams of total area 0.02 %

Structure: Bridge 1415-158
Location: I-80 New Jersey
Owner: NJDOT

Date: 9/16/93 - 9/20/93
Performed by: J. E. McNaughton
Anode Type HARCO

DELAM #	SIZE	AREA(sf)	LOCATION
A	6" x 66"	2.75	8.5' from North edge, 24' East of joint "A"
B	1' Diam	0.79	20.25' from North edge, 35' West of joint "B"
C	1' Diam	0.79	19.5' from North edge, 1' East of joint "B"
D	6" x 18"	0.75	12.25' from North edge, along West side of joint "C"
E	6" x 18"	0.75	18' from North edge, along East side of joint "C"
F	10" x 96"	6.67	19' from South edge, along West side of joint "D"
G	24" x 16"	2.67	6.3' from South edge, 7.5' west of joint "D"
H	34" x 28"	6.61	16.75' from South edge, 12.5' west of joint "D"
I	1' Diam	0.79	13.5' from South edge, 16' west of joint "D"
J	12" x 18"	1.50	12' from South edge, 33' west of joint "D"
K	24" x 18"	3.00	6.5' from South edge, 41' west of joint "D"
L	6" x 24"	1.00	18' from South curb, east of joint "C"
M	3" x 24"	0.50	8' from South curb, east of joint "C"
N	15" x 24"	2.50	17' from South curb, 14.6' east of joint "B"
O	24" x 29"	4.83	24.5' from South curb, 2.5' east of joint "B"
P	24" x 7"	1.17	16.75' from South curb, west of joint "B"

Delam # 16
Total Delam Area 35.9 SF
Area Surveyed 13,560 SF
% Delams of total area 0.26 %

APPENDIX F: Proposed Maintenance Plans

OPTION #1: Routine monitoring, annual inspection and service by contract (Estimated lump sum cost, $12,700)

- The consultant will remotely monitor the CP rectifiers at specified intervals for operational data. This monitoring will consist of measuring rectifier DC voltage and current output for each zone. (This data is considered essential to ensure that each rectifier circuit is operational.) Data will be submitted bi-monthly to the NJDOT in a standard report format. If a problem exists the consultant will provide an exception report to the Department with recommendations for remedial action.
- The consultant will perform an annual inspection of the CP installations consisting of the following:

  1) Depolarization tests using the embedded reference cells at selected sites (testing frequency should ensure that each cell is tested on a three-year cycle)

  2) Rectified adjustments as required

  3) Visual inspection of concrete decks, rectifier, Remote Monitoring Unit, and conduit.

  4) Rectifier and remote monitoring unit maintenance; authorized repair work will be invoiced in accordance with the following fee schedule.

Option #2 - Routine monitoring by NJDOT personnel; annual inspection and service by contract (Estimated lump sum cost, $6,400)

- NJDOT personnel perform routine monitoring and report any deficiencies in the rectifier or RMU operation to the consultant for servicing/repair as necessary. Work would be invoiced in accordance with the fee schedule below.
- The consultant will perform an annual inspection of the CP installations (same as Option #1).

Estimated Engineering Services Fee Schedule

Project Engineer (in-house)	$85.00/hour
Project Engineer (field)	$865.00/day
Technician (field)	$685.00/day
Travel	Cost plus 10%
Rectifier & RMU Parts	Cost plus 20%

Notes:

[1] Does not include costs for traffic control, repair to electrical conduit, wiring, telephone lines and deck concrete work.

[2] Required repair/replacement of existing equipment would be accomplished in accordance with the above fee schedule.