FINAL REPORT

A SLOTTED CATHODIC PROTECTION SYSTEM FOR BRIDGE DECKS

by

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(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

A non-overlay, slotted cathodic protection system was installed two years ago on a concrete bridge deck in Virginia. The design, installation, and operation of this system are fairly straightforward. A protective current density of 1.6 mA/ft^2 (17 mA/m^2) as determined by E-log I curves has been applied constantly on the deck. Various tests have shown that polarization of the structure has been achieved. After more than 18 months in service, the various components of this system appeared to be in good condition.

ACKNOWLEDGEMENT

This project has been an interesting learning process for the author, who would like to extend his appreciation to the Federal Highway Administration's Demonstration Projects Division for its financial assistance and to Donald R. Jackson of that agency for his valuable technical guidance.

Appreciation is also extended to F. G. Sutherland, state bridge engineer, and his staff for their valuable support; to W. E. Winfrey, state materials engineer and formerly assistant construction engineer, for facilitating the timely advertisement and, therefore, commencement of the construction; to W. L. Sellars, district bridge engineer, and his staff for their cooperation; and to L. D. Baker, inspector, for his suggestion that led to improvement of the original plan for the parapets.

The author also thanks the members of the Council who gave valuable assistance and H. E. Brown for his administrative guidance.

4/30/85 SI CONVERSION FACTORS

To Convert From	To	Multiply By
Length:		
in	cm	2.54
in	m	0.025 4
ft	m	0.304 8
yd	m	0.914 4
mi	km	1 . 609 344
Area:		
in^2	cm^2	6.451 600 E+00
ft^2	m^2	9.290 304 E-02
yd^2	m^2	8.361 274 E-01
mi^2	Hectares	2.589 988 E+02
acre (a)	Hectares	4.046 856 E-01
Volume:		
oz	m^3	2.957 353 E-05
pt	m^3	4.731 765 E-04
qt	m^3	9.463 529 E-04
gal	m^3	3.785 412 E-03
in^3	m^3	1.638 706 E-05
ft^3	m^3	2.831 685 E-02
yd^3	m^3	7.645 549 E-01

NOTE: $1m^3 = 1,000$ L

To Convert From	To	Multiply By
Volume per Unit Time:		
ft^3/min	m^3/sec	4.719 474 E-04
ft^3/s	m^3/sec	2.831 685 E-02
in^3/min	m^3/sec	2.731 177 E-07
yd^3/min	m^3/sec	1.274 258 E-02
gal/min	m^3/sec	6.309 020 E-05
Mass:		
oz	kg	2.834 952 E-02
dwt	kg	1.555 174 E-03
lb	kg	4.535 924 E-01
ton (2000 lb)	kg	9.071 847 E+02
Mass per Unit Volume:		
lb/yd^2	kg/m^2	4.394 185 E+01
lb/in^3	kg/m^3	2.767 990 E+04
lb/ft^3	kg/m^3	1.601 846 E+01
lb/yd^3	kg/m^3	5.932 764 E-01
Velocity: (Includes Speed)		
ft/s	m/s	3.048 000 E-01
mi/h	m/s	4.470 400 E-01
knot	m/s	5.144 444 E-01
mi/h	km/h	1.609 344 E+00
Force Per Unit Area:		
lbf/in^2	Pa	6.894 757 E+03
lbf/ft^2	Pa	4.788 026 E+01
Viscosity:		
cS_t	m^2/s	1.000 000 E-06
P	Pa·s	1.000 000 E-01

Temperature: °F-32) 5/9 = °C

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INTRODUCTION

Premature deterioration of concrete structures due to corrosion of the reinforcing steel is a major problem plaguing bridge engineers. It must be recognized that the rehabilitation of these structures must incorporate some form of corrosion control; otherwise the effect would be purely cosmetic and additional costly repair work or complete replacement would be necessary in several years. And, cathodic protection (CP) is perhaps the only available approach to controlling ongoing corrosion of the rebar in concrete. Although CP is a well-proven technology for use with buried pipelines, ships, water tanks, etc., its use in reinforced concrete is relatively new.

The study by Stratfull (1) in the early 1970s and a subsequent study (2) conducted in Canada showed that cathodic protection systems can be installed in existing reinforced concrete bridge decks to halt corrosion of the reinforcing steel and extend the service life of the decks. Until very recently, however, the cathodic protection systems had failed to gain wide acceptance among state and local highway agencies. Some of the factors contributing to this limited use were (1) the high cost of a system, (2) the lack of information on the durability of the system, and (3) the unfamiliarity of most highway engineers with the technology employed in cathodic protection.

The first hindrance can be eliminated only through wider use of CP systems and concomitant competitive pricing. Time and further developmental research will eliminate the second barrier.

The last cited hindrance can be eliminated only through education and involvement in the installation of a cathodic protection system. For this purpose, and in the belief that the technology has been sufficiently developed, the Virginia Department of Highways and Transportation decided in early 1982 to participate in the Federal Highway Administration's (FHWA) Demonstration Project 34, which provides funds for such installations.

NON-OVERLAY SLOTTED CATHODIC PROTECTION SYSTEM

The early cathodic protection systems for bridge decks used disk-shaped graphite, or high-silicon cast iron anodes, secured to the surface of the concrete deck and covered by an electrically conductive asphaltic concrete to distribute the protective current over the deck. To protect it against wear, the conductive layer was covered by a layer of more durable asphaltic concrete that served as the riding surface. The difficulty in mixing and applying the conductive asphaltic concrete, and the need to protect it with an overlay, contributed to the slow acceptance of cathodic protection systems for bridge decks.

In 1980, Nicholson introduced a new method of distributing the protective current over the bridge deck.(3) He replaced the old disk-shaped anodes with platinized niobium-copper wires laid in sawed slots regularly spaced across the concrete surface and covered with grout. Compared to the old system, this second-generation system offers the following advantages: (1) it eliminates the need for a conductive asphaltic concrete overlay and thus its associated problems, and (2) it can be installed with minimal interruption to traffic.

These improvements, together with ones subsequently made by the research staff of the FHWA (4), were sufficient to encourage the Virginia Department of Highways and Transportation to install a cathodic protection system in the deck of one of its bridges.

DESIGN OF THE SYSTEM

The bridge deck selected for the installation was built in 1962 on Route 15 over the Willis River in Buckingham County, Virginia. It consists of three reinforced concrete spans of the T-beam type. Each span is 37.5 ft (11.4 m) long and 28.0 ft (8.5 m) wide. In 1979, after approximately 17 years in service, concrete in the top few inches of the deck was found to contain 1.7 to 4.4 lb Cl^-/yd^3 (1.0 to 2.6 Kg Cl^-/m^3). At that time, a half-cell potential survey indicated a 90% probability that corrosion of the rebars was occurring in 20% of the total surface area, with at least 6% of the deck already being delaminated.

The adopted design for the slotted system includes three separate yet similar circuits, each of which serves one of the three spans. (Figure 1.) For each span, direct current is supplied by two primary anodes consisting of 0.031-in (0.78-mm) diameter platinized niobium-copper wire laid transversely in the deck. The current is then distributed longitudinally over the span by secondary anodes made of less expensive carbon strands and spaced at 1.0-ft (30.5-cm) intervals across the width of the span. Both the primary and secondary anodes are set in sawed slots approximately 0.50 in (1.3 cm) wide, 0.75 in (1.9 cm) deep, and filled with a relatively conductive polymer concrete (Figure 2).

The close spacing of the carbon strands was dictated by results from an extensive study of polarization conducted by the FHWA which suggested that the maximum spacing between two anodes should be 1 ft (30.5 cm) to ensure adequate distribution of the current.(4) The conductive polymer concrete, developed by the FHWA, was made basically of a vinyl-ester resin and carbon black (Figure 3). It is supposed to provide better resistance to degradation by chlorine and hydrochloric acid and better electrical conductivity than does the grout used in the first slotted system.(4)

A silver-silver chloride (Ag/AgCl) reference cell and three rebar probes are installed on the most anodic locations of each span to control and monitor the performance of the system. Also, two system ground connections to the top mat of rebars are provided in each span.

The direct current is supplied by a rectifier/control (R/C) unit that has a total output of 20 volts and 18 amperes, with a maximum of 6 amperes being supplied to each of the three separately controlled circuits. The unit is equipped with circuits that automatically monitor the instant-off structure-to-reference cell potential and utilize it to control the cathodic protection current. (The plan and special provisions for this installation are shown in Appendixes A and B, respectively.)

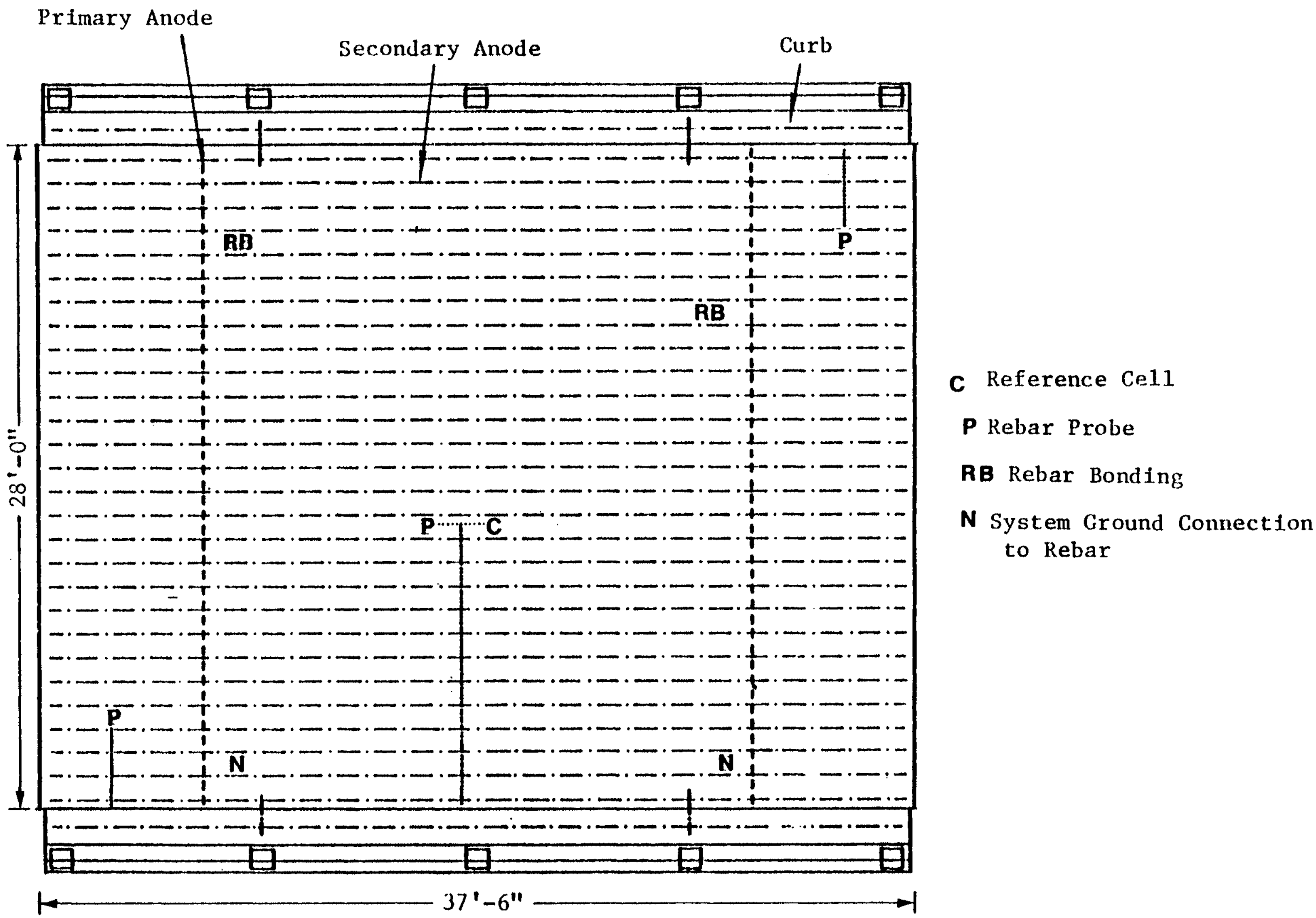


Figure 1. Design for each bridge span.

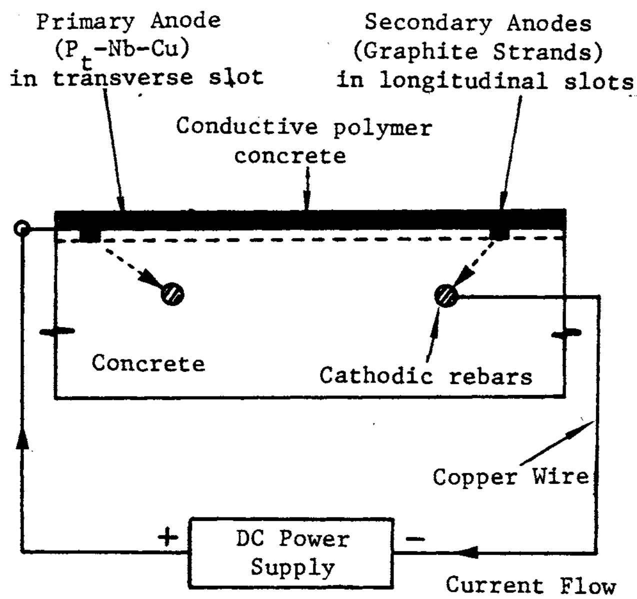


Figure 2. Transverse section of cathodically protected deck.

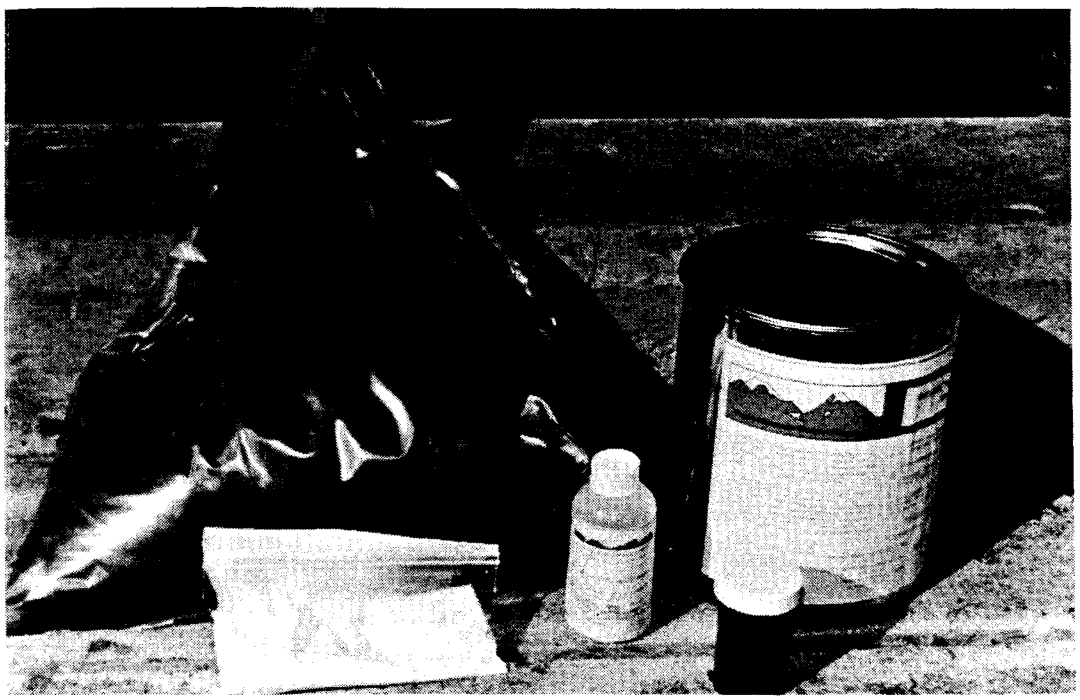


Figure 3. Ingredients in the conductive polymer concrete -- vinyl-ester resin, cool-temperature initiator, coupling agent, pigment, and carbon block (clockwise from right side.

OBSERVATION AND DISCUSSION

System Installation

Installation of the system was started on October 7, 1982, on the northbound lane of the two-lane deck, while the other lane remained open to traffic. Cutting one slot at a time, it took approximately 5½ days to cut the approximately 1,700 lin ft (516 lin m) needed in this lane. This translates to an average cutting rate of 39 lin ft (12 lin m) of slots per hour, which needs to be improved upon so that installation costs can be reduced.

While the slots were being cut, reference cells, rebar probes, and system ground connections were installed (Figures 4 and 5).

On October 18, the anodes were laid in the slots in slightly more than 2 hours. Immediately afterwards, the slots were filled with the conductive polymer concrete under an early morning temperature of 40°F (4°C). This relatively cold temperature didn't impede the proper setting of the polymer. The only problem encountered was difficulty in ensuring uniform dispensation of this material (Figure 6). This difficulty resulted from the contractor's use of a "Zip-Loc" type plastic bag, from which the still-pourable, freshly mixed material was squeezed through a small hole cut in the corner. In addition, the workers had to be constantly crouching on the deck to dispense the material, which made this a relatively labor-intensive operation. The use of mechanical equipment such as that being used for dispensing joint sealant during the repair of concrete pavements should be tried in future installations. This equipment has a long, wand-like dispenser with a nozzle that ensures uniform, powered discharge of the sealant.

All installations on the northbound lane were completed in 2 weeks. On October 21, similar installations were started in the southbound lane. This portion also took approximately 2 weeks. Figure 7 shows the finished deck.

The original plan for the parapets was modified. Originally, carbon strands were to be run from the deck surface to the parapets in slots sawed into the face of the curb. However, it was determined that installing the strands in this manner would make them susceptible to damage by snowplows, so they were brought up the parapets in 1/2-in (1.3-cm) diameter holes drilled through the concrete approximately 1 in (2.5 cm) below the face of the curb.

Subsequent work on the underside of the deck included connecting the primary anodes, reference cells, rebar probes, and system grounds to copper lead wires, then routing these wires in conduits and connecting them to the R/C unit. (Appendix C.)

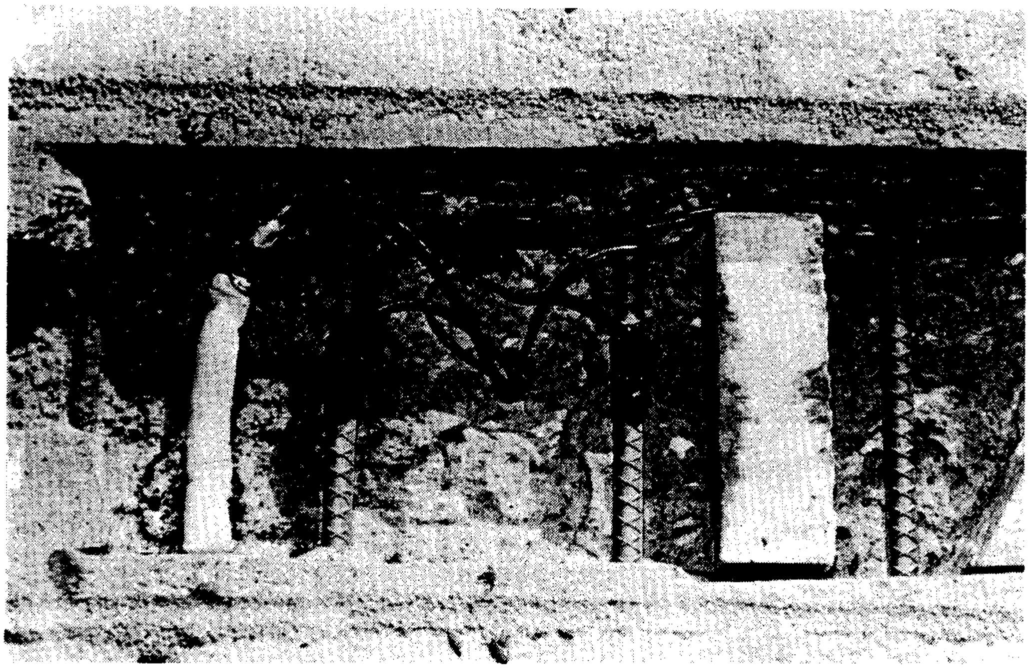


Figure 4. A reference cell (left) and a rebar probe were installed at the level of the top mat of rebars. Note the connections of the two corresponding ground wires to the rebars and the routing of these wires and the lead wires from the reference cell and the rebar probes through the deck to the R/C unit.

Figure 5. System ground connection consisting of a stranded copper wire "cadwelded" onto a rebar. Weld was covered by an epoxy-type insulating resin.

Figure 6. Filling slots with conductive polymer concrete.

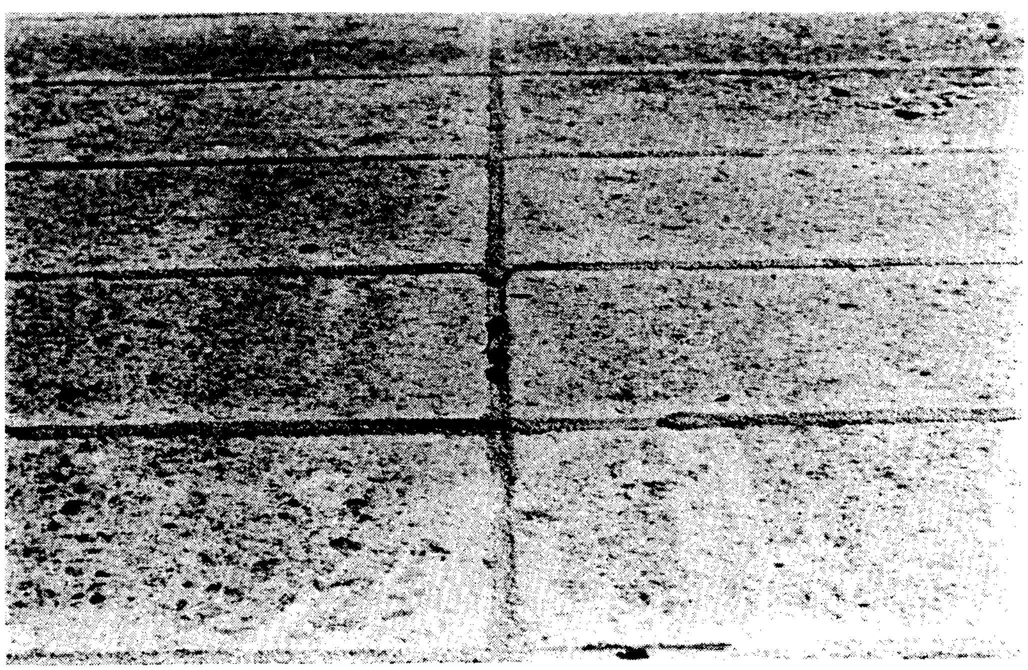


Figure 7. Appearance of finished deck.

Because of a delay in the delivery of the unit, the system wasn't completed until March 1983.

System Polarization

An important aspect of the operation of a cathodic protection system concerns the level of required cathodic protection. One of the criteria recommended by the National Association of Corrosion Engineers (NACE) for cathodic protection of buried steel pipelines requires a structure-to-electrolyte voltage at least as negative as that originally established at the beginning of the Tafel segment of the E-log I curve.(5) In accordance with this criterion, an E-log I curve was obtained for each span immediately after the system was energized by measuring the instant-off potential as current to each span was increased in 100-mA increments at 3-minute intervals.

From the resulting three curves (Figures 8 through 10), the minimum current outputs that the three circuits must provide to protect their respective spans were determined. As shown in Table 1, these outputs vary from 1.4 to 2.0 amperes for the three spans, and for the entire deck these total 4.9 amperes, which translates into 1.6 mA/ft^2 (17 mA/m^2) in terms of the surface area of the deck.

The R/C unit was subsequently set to apply and maintain these levels of protective current for the three spans at a maximum structure -Ag/Agcl potential of -800 mV. Thereafter, negative voltage shifts were observed in the instant-off structure-Ag/AgCl potential in the span. The shifts ranged from -79 to -147 mV (Table 2).

Shifts in the potentials for all nine rebar probes in the deck were also observed and are shown in Table 3. The observed shifts toward positive polarity for all nine probes indicated that these rebars, and therefore the reinforcement in the deck, were receiving protective current. However, it appeared that the protection afforded probes 3, 6, and 7 and their surrounding areas wasn't sufficient. It must be noted that these probes were made with the rebar encased in concrete spiked with chloride at a concentration of 15 lb Cl^-/yd^3 (8.9 Kg Cl^-/m^3) to simulate very extreme salt contamination in concrete. This chloride concentration is at least three times that of the highest chloride concentration found in this deck, and therefore is likely unnecessarily high. (In future installations, consideration might be given to encasing the rebar probes in concrete having considerably less than this amount of chloride.) Consequently, the deck areas immediately surrounding probes 3, 6, and 7 are not necessarily insufficiently protected by the applied amperages.

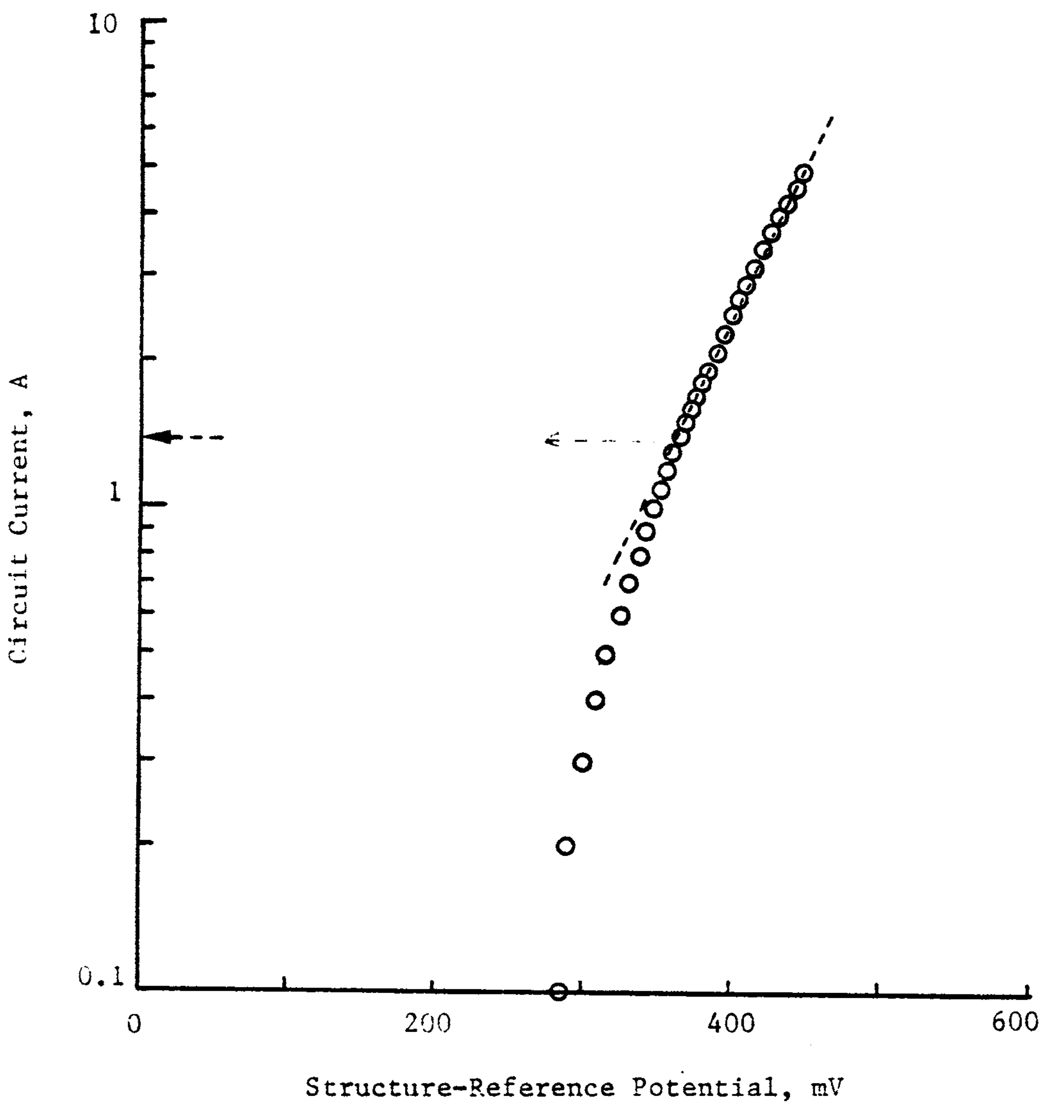


Figure 8. E-log I curve for circuit 3 serving span 1.

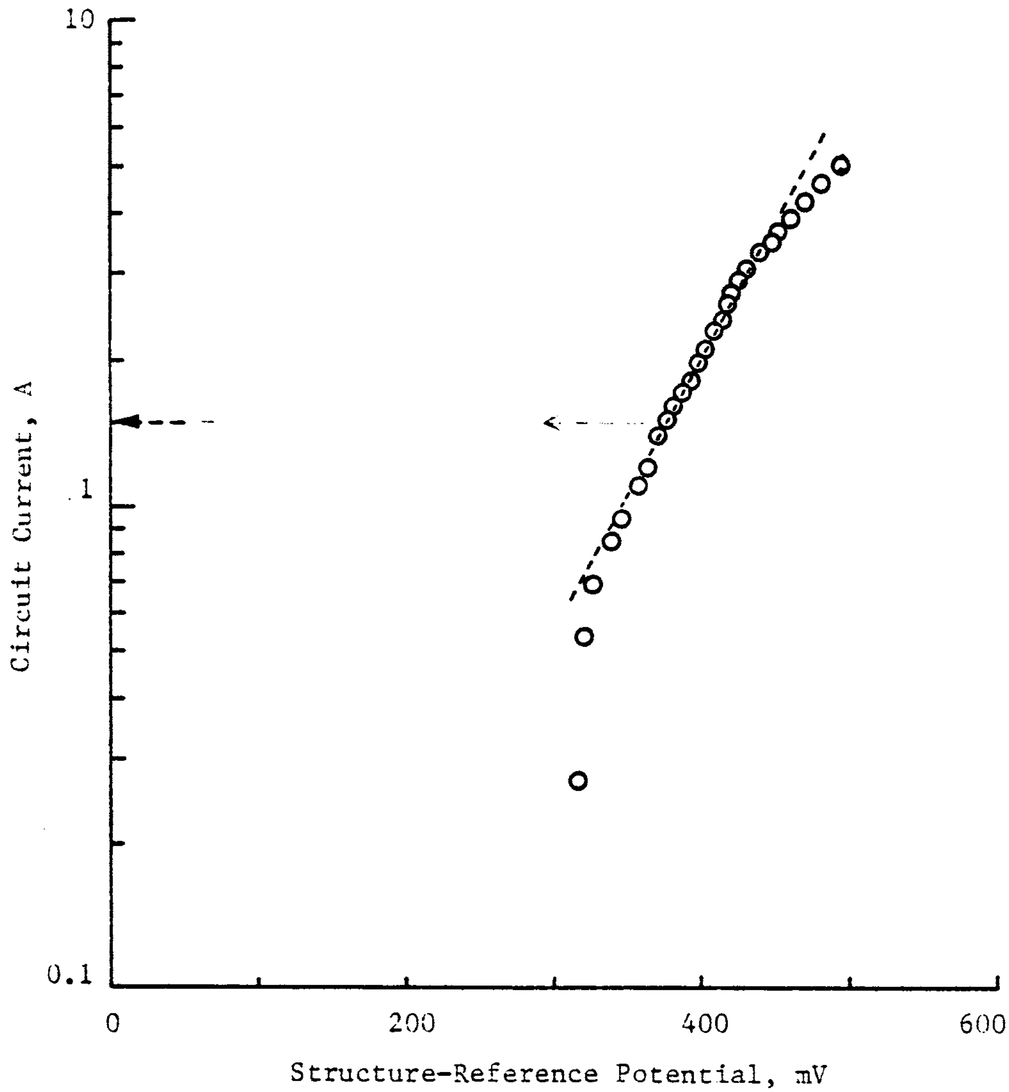


Figure 9. E-log curve for circuit 2 serving span 2.

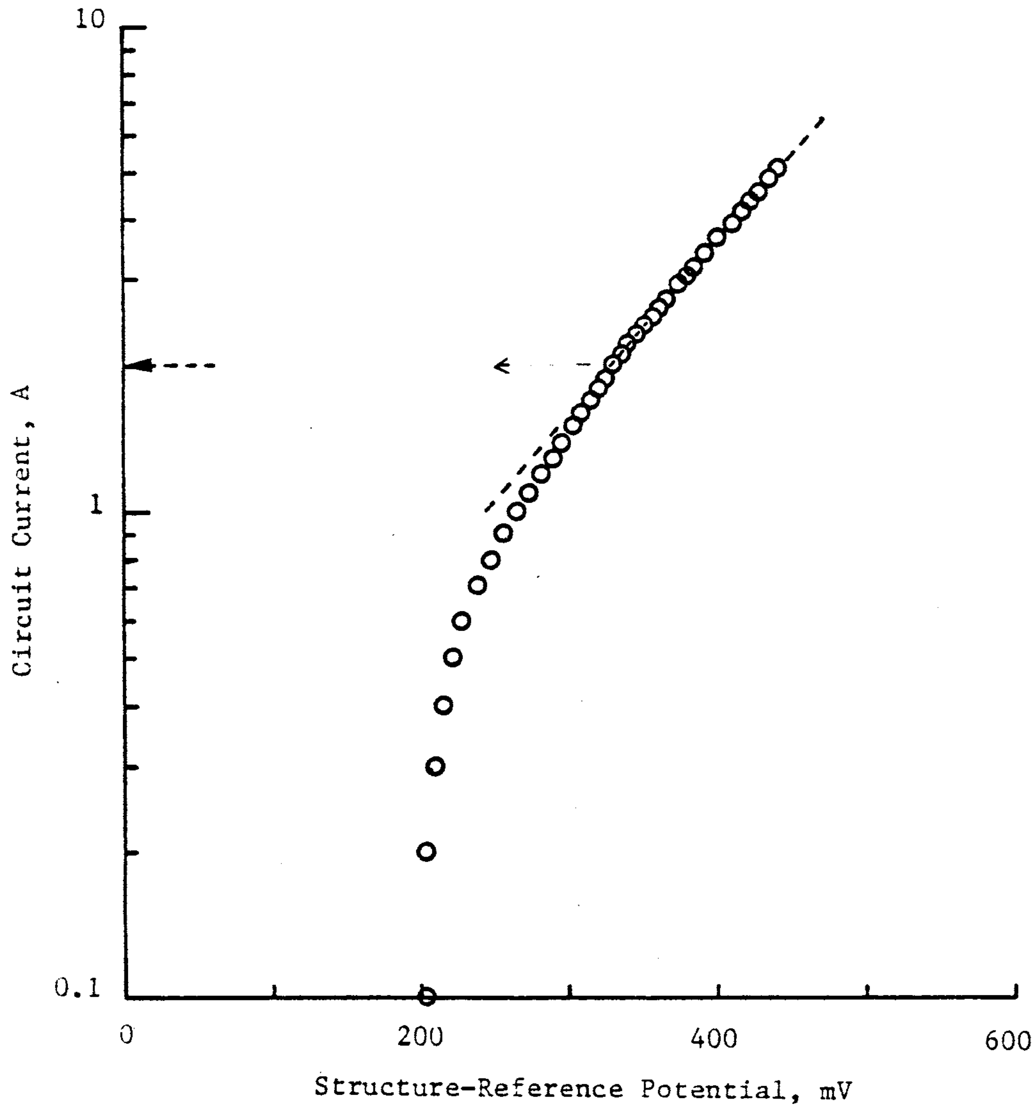


Figure 10. E-log I curve for circuit 1 serving span 3.

Table 1

Required Current Outputs of the Three DC Circuits
As Determined From E-log I Curves

Span	Circuit	Amperes
1	3	1.4
2	2	1.5
3	1	2.0

Table 2

Shifts in the Structure-Reference Cell Potential
After Application of Protective Current

Bridge Span	Structure-Reference Potential (mV) Before	After	ΔV (mV)
1	-281	-360	- 79
2	-290	-437	-147
3	-200	-347	-147

Table 3

Shifts in the Rebar Probe Potentials After Application
of Protective Current

Bridge Span	Rebar Probe No.	Rebar Probe Potential (mV) Before	After	ΔV (mV)
1	7	-2.0	-0.3	+1.7
	8	-0.7	+0.2	+0.9
	9	-1.5	+0.2	+1.7
2	4	-1.3	+0.2	+1.5
	5	-1.3	+0.4	+1.7
	6	-3.4	-0.3	+3.1
3	1	-1.4	+0.1	+1.5
	2	-0.9	+0.7	+1.6
	3	-2.3	-0.5	+1.8

Behavior of System Since Polarization

Since the cathodic protection system was energized in March 1983 it has been inspected about every 2 weeks. During each inspection, the electrical output, instant-off structure-Ag/AgCl potential, and rebar potentials in each span, and the ambient air temperature have been measured. The results are shown in Figures 11 through 14.

It appeared that except for a brief period around the end of April 1983, when the R/C unit had blown fuses, likely during a severe thunderstorm, the unit successfully maintained the required current level to each span.

During the first summer (1983), when extreme dryness and high temperatures usually resulted in increased resistivity in the concrete, anodic activities of various degrees were observed around six of the nine rebar probes, with probes 3 and 6 being most anodic. It must be noted that these two were among the three probes that had failed to become completely cathodic at the start of the cathodic protection. By the second summer, only probe 6 in span 2 still showed appreciable anodic activity; however, this activity was of comparatively smaller magnitude than that in the preceding summer. It appears, then, that after a concrete structure becomes polarized for a time sufficient to halt all existing corrosion activity, less current would be needed to prevent new corrosion. This trend towards a reduction in needed current with time has been observed in other installations.

Similar seasonable shifts in the instant-off potentials of the three embedded Ag/AgCl electrodes were also observed. With the exception of the mentioned brief interruption in April 1983, these potential readings indicated that various degrees of polarization were established in the three spans (Table 4).

In August 1984, after 17 months of polarization, half-cell potentials were measured over the surface of each span using a $Cu/CuSo_4$ electrode. In comparison to similar measurements made before the installation of the system, the resulting potentials represented negative shifts of various degrees (Figure 15). Analyses indicated that the shifts in the averaged potentials ranged from 230 to 270 mV for the entire deck (Table 5). It should be noted that the potential readings obtained in August 1984 were not instant off and therefore included "IR drop" errors. Additionally, it should be noted that the resistivity of concrete can vary throughout a deck due to many factors. These differences accounted for some of the differences in the polarizations shown in Tables 4 and 5. Nevertheless, both sets of data indicate that polarization was achieved in the entire bridge deck.

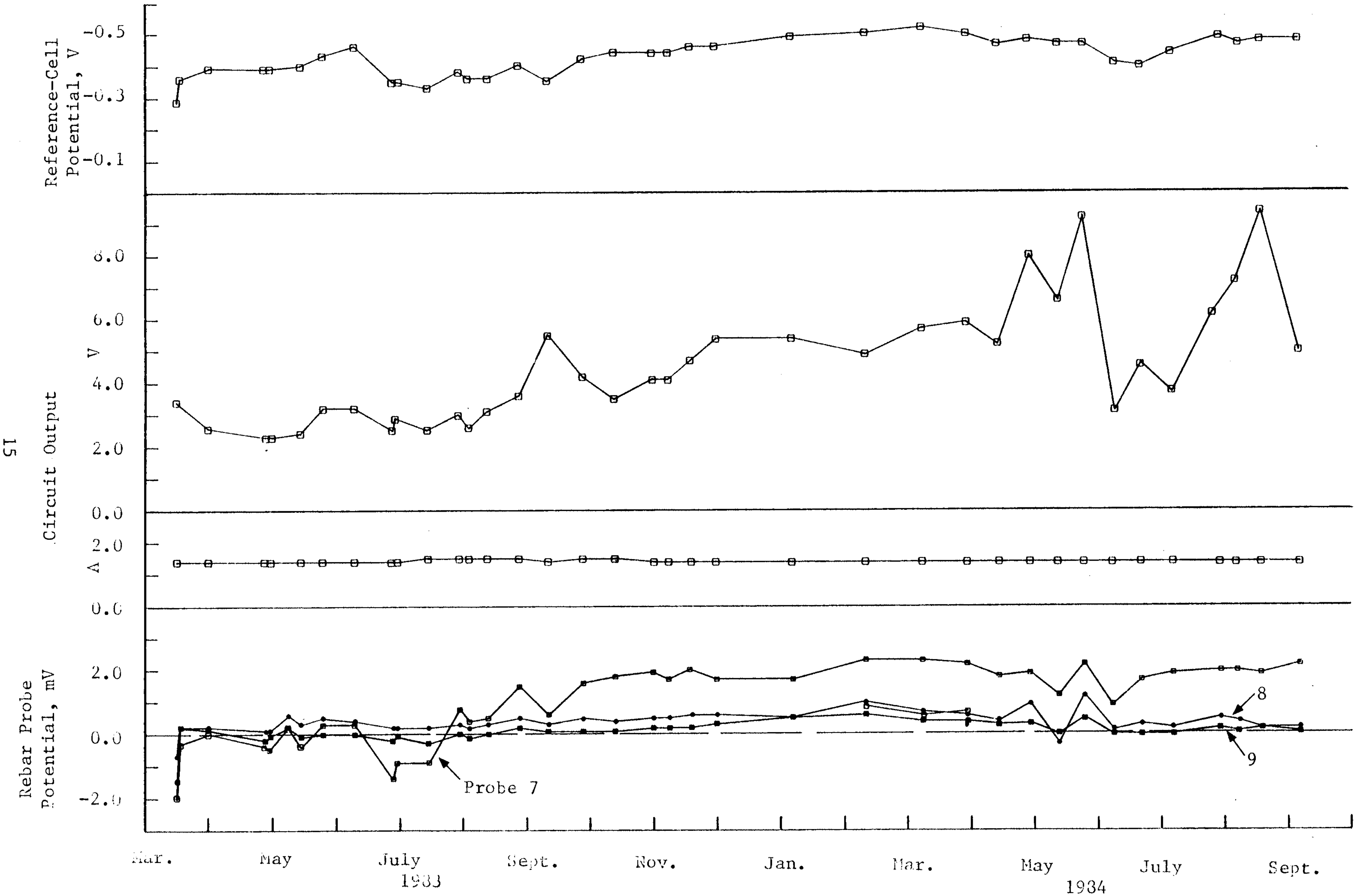


Figure 11. Performance of circuit 3 — span 1.

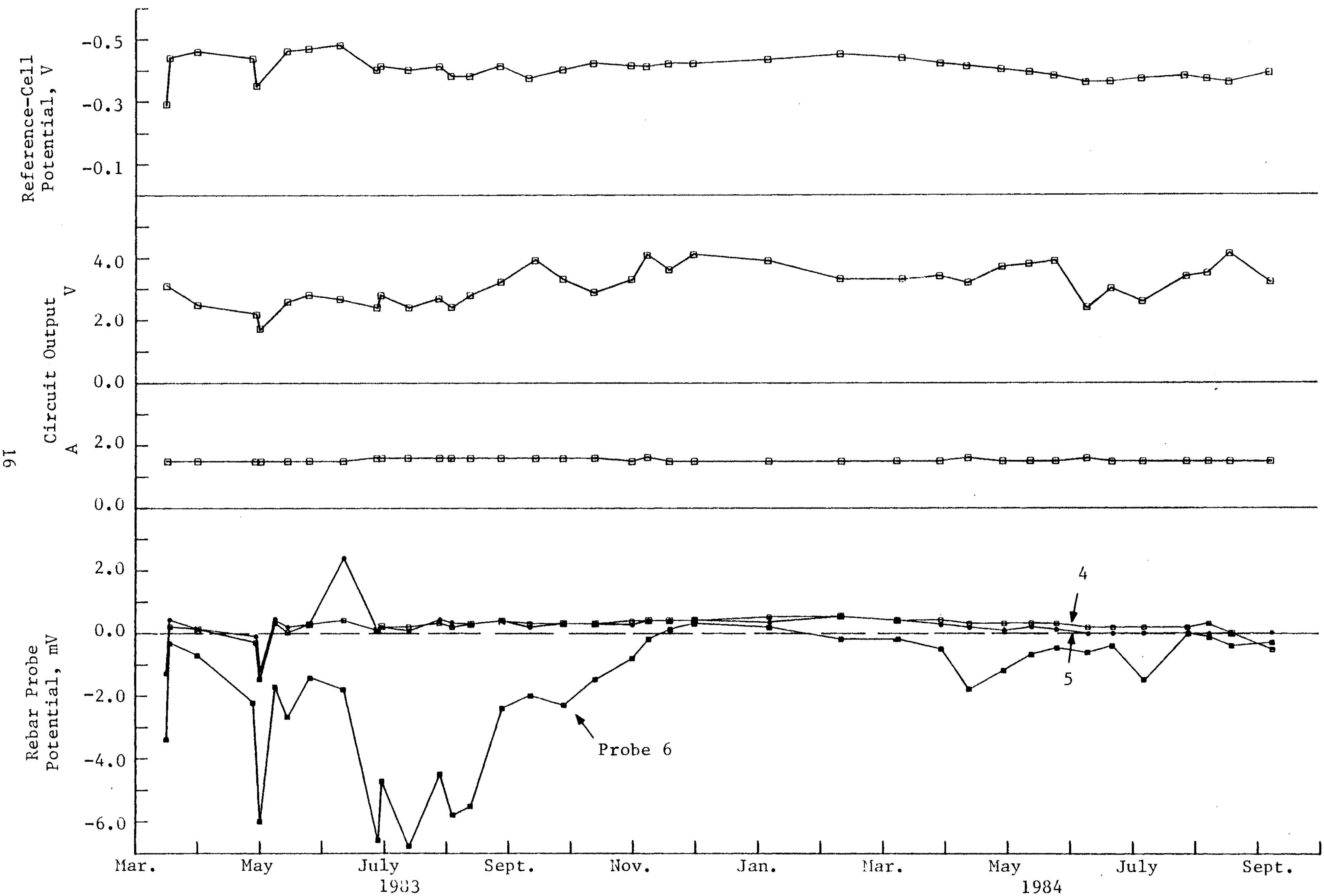


Figure 12. Performance of circuit 2 — span 2.

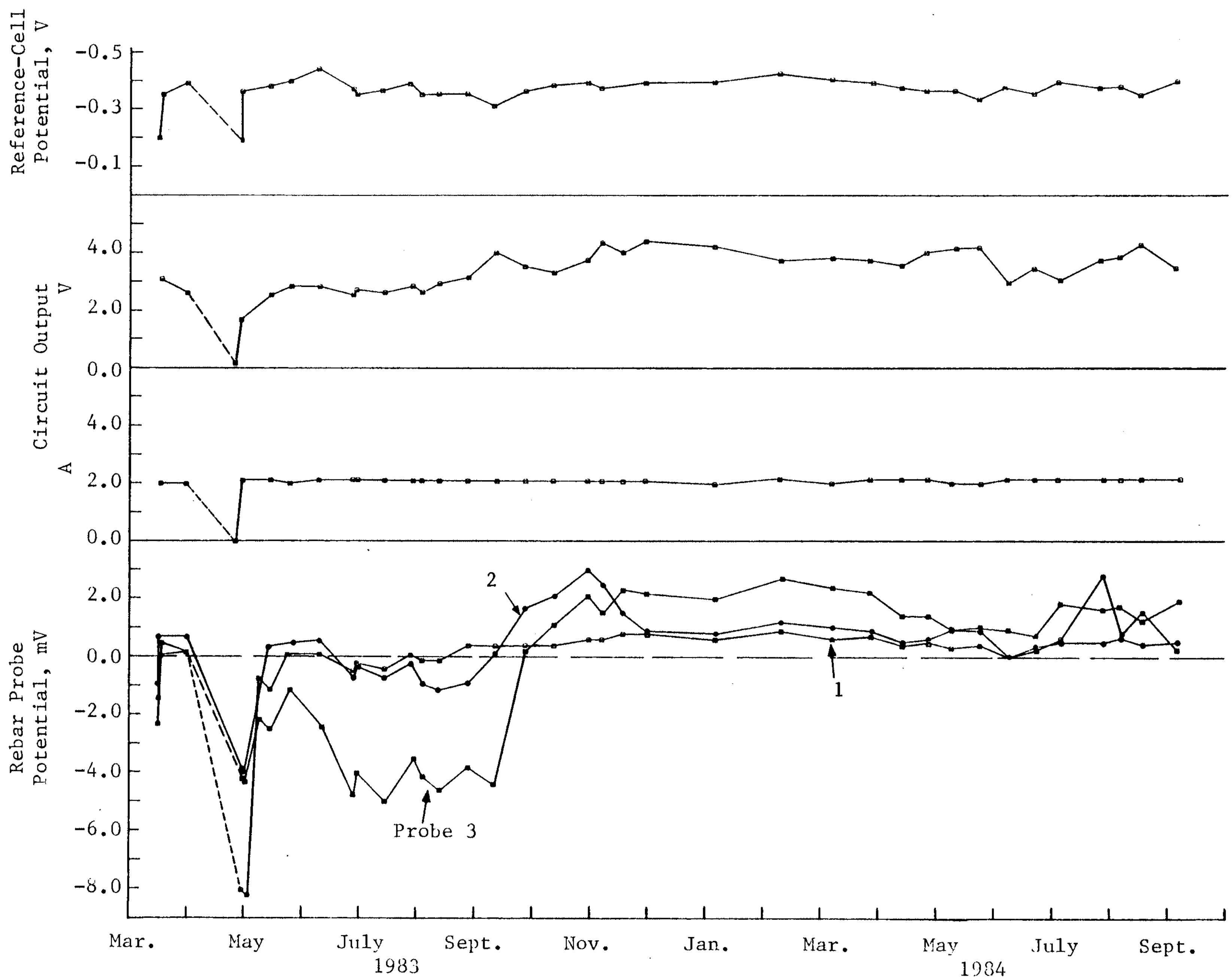


Figure 13. Performance of circuit 1 — span 3.

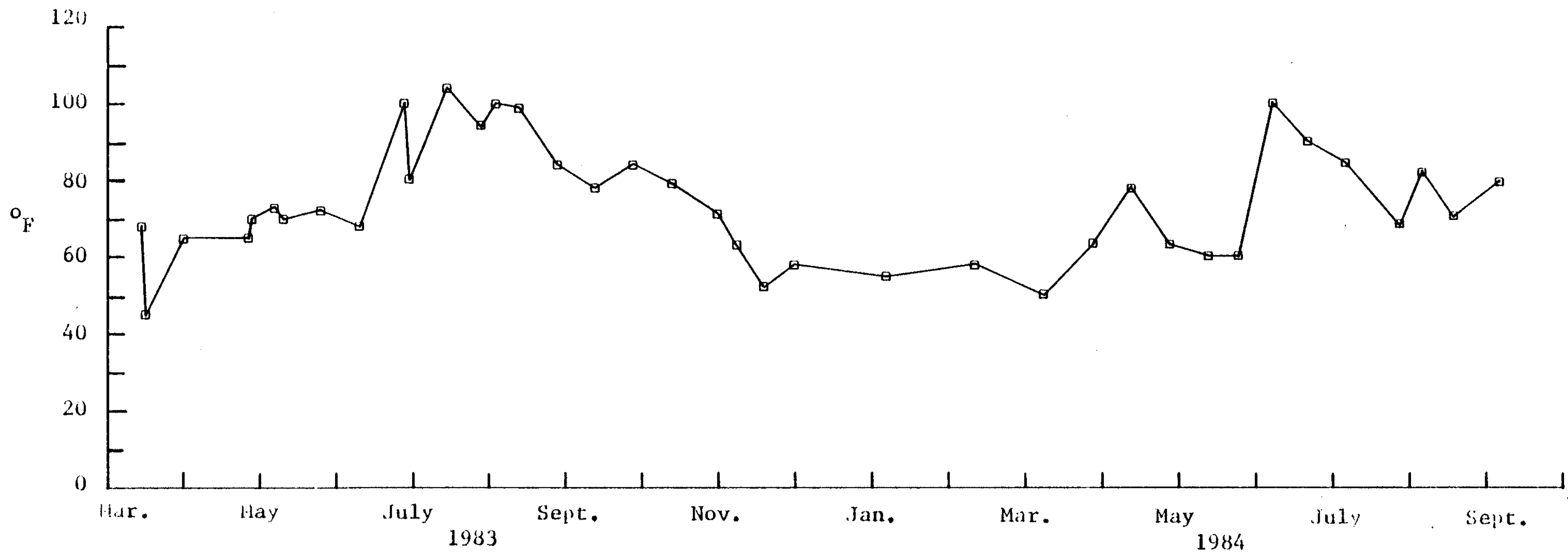


Figure 14. Ambient temperature at the installation.

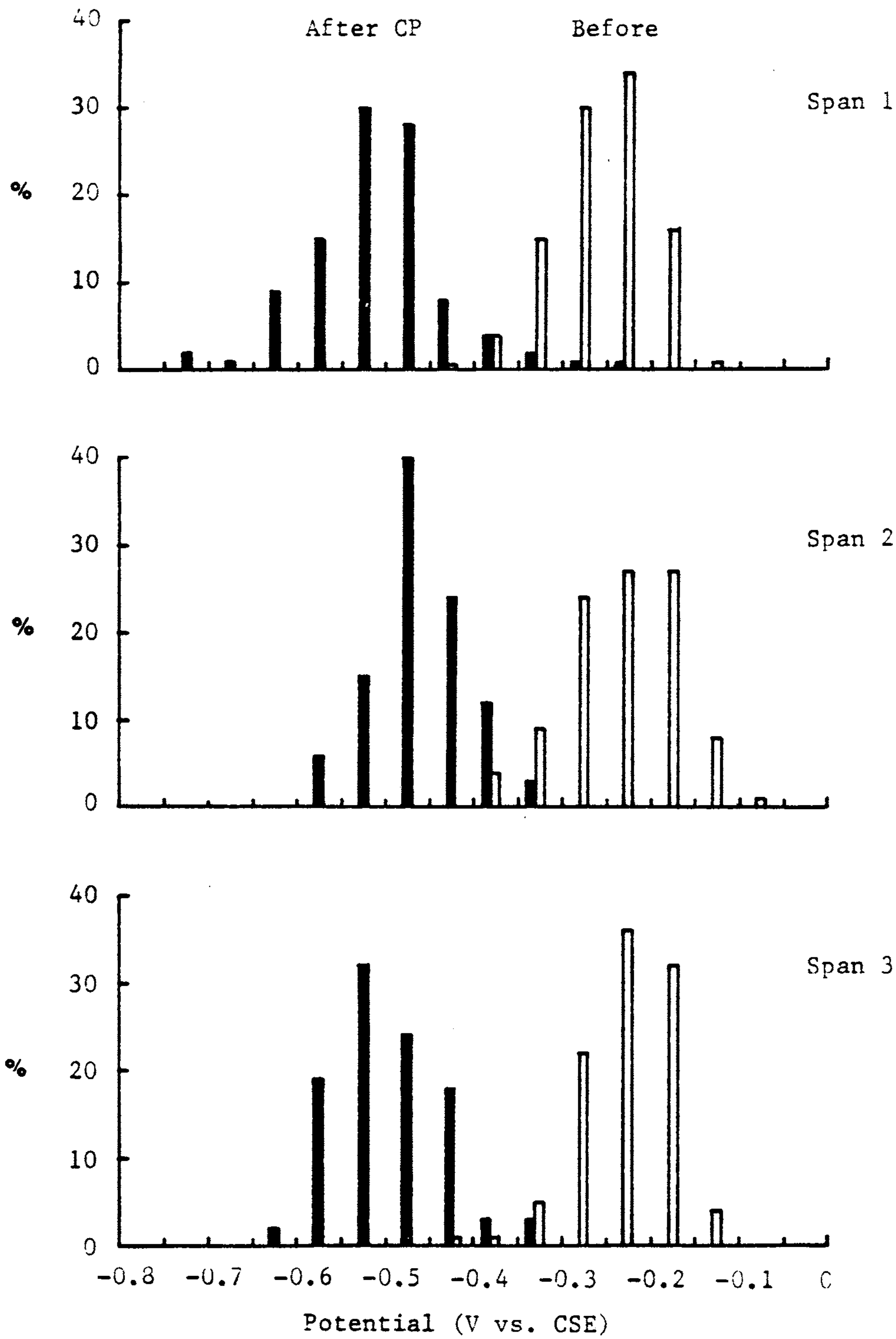


Figure 15. Distribution of potentials before and after cathodic protection.

Table 4

Polarization Observed in Each Span During
18 Months of Cathodic Protection

Span	Circuit	Polarization* (mV vs. Ag/AgCl) Minimum	Maximum	Average
1	3	- 52	-270	-153
2	2	- 66	-186	-118
3	1	-105	-240	-169

*Based on the difference between "instant off" static potential and potential during operation of CP.

Table 5

Potential Readings on Surface of Deck Before and
After 17 Months of Cathodic Protection

Span	Circuit	Average Potential (mV vs. CSE) Before CP	After CP	Shift
1	3	-280	-520	-240
2	2	-240	-470	-230
3	1	-230	-500	-270

System Depolarization

Another approach to estimating polarization is to observe the decay of polarization, or depolarization. For this purpose, the external power to the system was turned off on Nov. 2, 1984. As expected, immediately after the system was deenergized, all three embedded Ag/AgCl electrodes showed immediate voltage shifts ranging from 90 to 100 mV. Potential readings made over the next 8 hours showed that at least 80% of the decay occurred within the first 4 hours, as can be seen in Figure 16. Over the ensuing 8 hours, total decays ranging from 120 to 210 mV were observed for the three spans. These decays indicated that a minimum polarization shift of 100 mV was achieved in each span, which represented compliance with another criterion recommended by the NACE.(5)

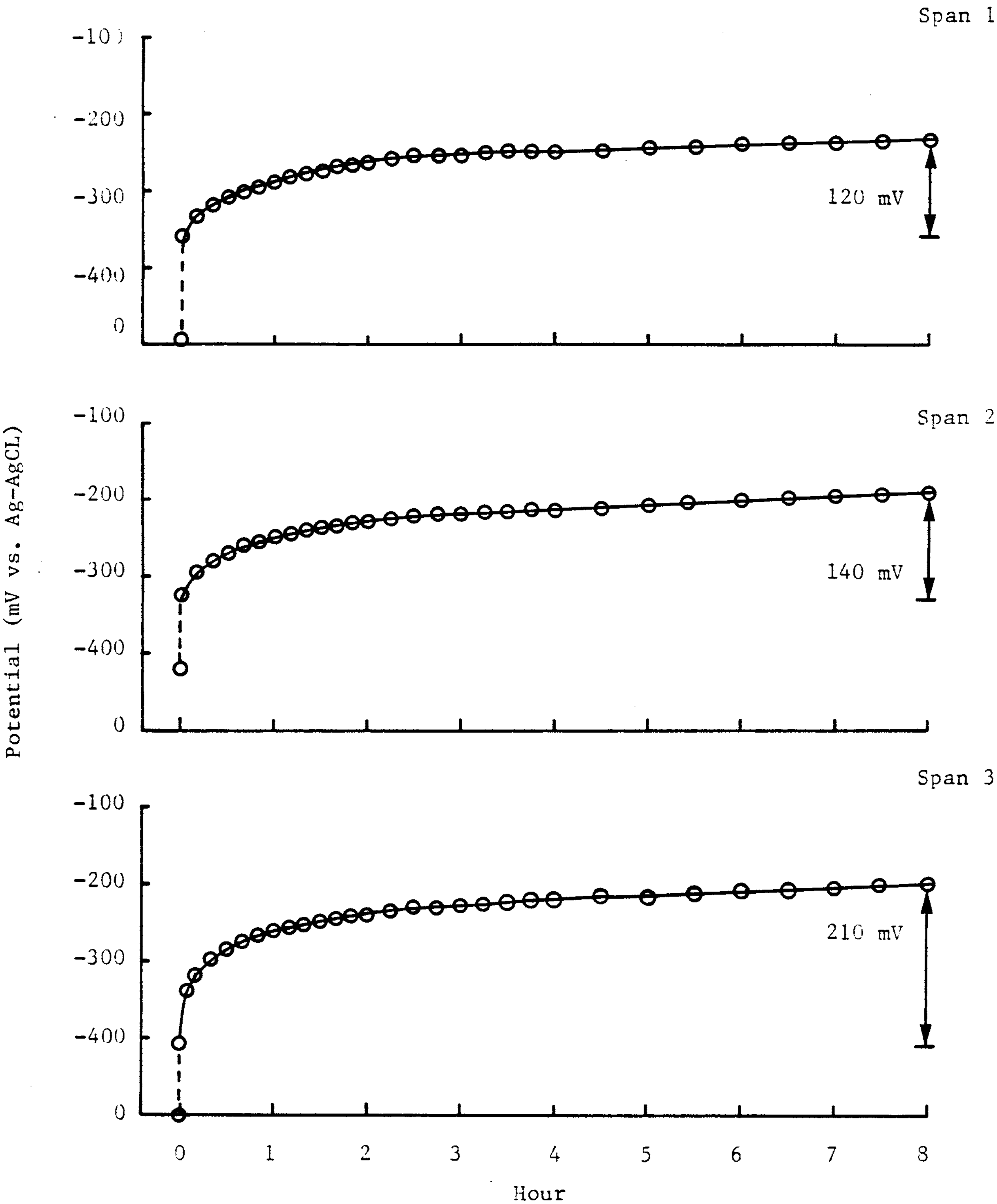


Figure 16. Polarization decay after CP current turned off following 19 months of polarization.

Condition of Deck

A concern about this slotted system has been the stability of the conductive polymer concrete used to fill the sawed slots, since problems with this and similar materials had been reported.(6) Consequently, the condition of this material has been closely observed. About 6 months after the system was energized, several expected, isolated yellowish brown spots (less than 3 in [7.5 cm] across) were observed around the boundary between the polymer concrete and the portland cement concrete, i.e., along the edges of the sawed slots (Figure 17). Also as expected, these spots disappeared following rain. It is believed that such spots will continue to appear, since they are caused by the release of chlorine formed by the oxidation of chloride ions.

A general darkening of the polymer concrete has also been observed after 1 year in service (Figure 18). This indicates that some change has occurred; however, it doesn't appear to have any accompanying adverse effect on the bonding of this material to the deck, nor on the polarization of the entire deck.

The closely spaced and filled slots didn't appear to adversely affect the riding quality, the skid resistance, or the appearance of the deck.

Chain-dragging of the deck in August 1984 identified 10 previously unnoticed delaminations. As shown in Figure 19, these varied from 0.8 to 4.0 ft^2 (0.07 to 0.37 m^2), and encompassed a total area of 19.3 ft^2 (1.8 m^2). Except for the three delaminations in a large patch in span 1, practically all were located near patches. This suggests that most of the delaminations may not really be new; i.e., some of them may represent deteriorated concrete not detected and repaired before the cathodic protection system was installed.

On the other hand, estimates of the degree of polarization around these delaminations, which were obtained by comparing the aforementioned $Cu/CuSO_4$ potentials before and after the system was in operation, revealed that these areas appeared to be less polarized than the rest of the spans (Table 6). Further, as shown in Figure 19, these delaminations were located in areas for which there was a high probability for corrosion activity based on the half-cell potentials obtained prior to installation of the system. These findings probably indicate that even though the E-log I and 100-mV depolarization criteria were met, sufficient protection to completely stop the corrosion in these small areas had not been achieved.

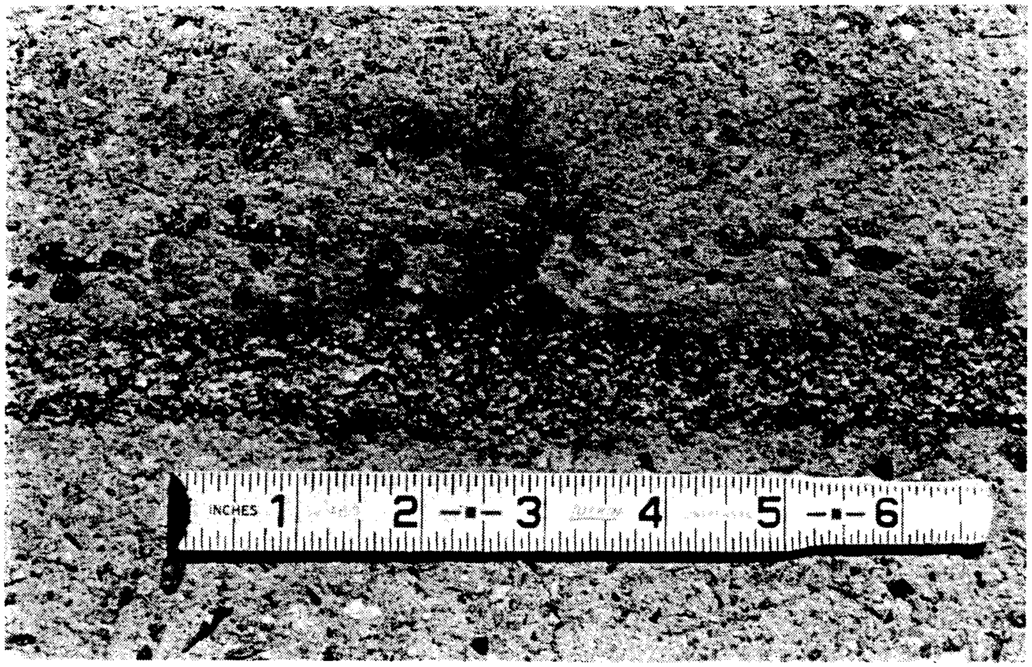


Figure 17. Yellowish brown spot along the edge of sawed slot. Such spots disappeared after washing by rain.

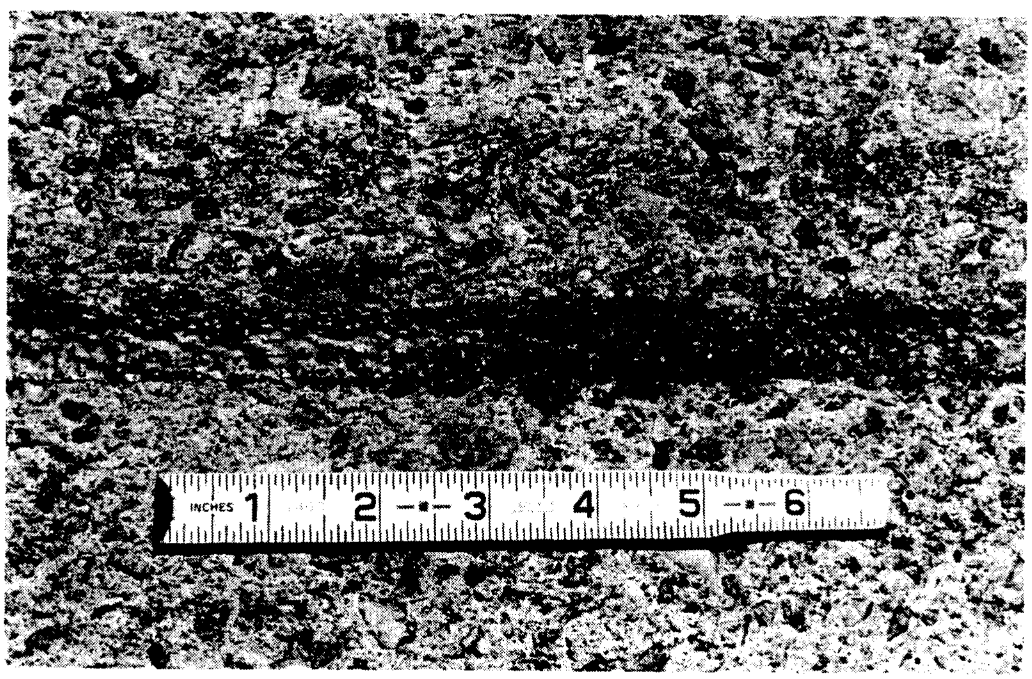


Figure 18. Isolated darkening of the polymer concrete in the slot.

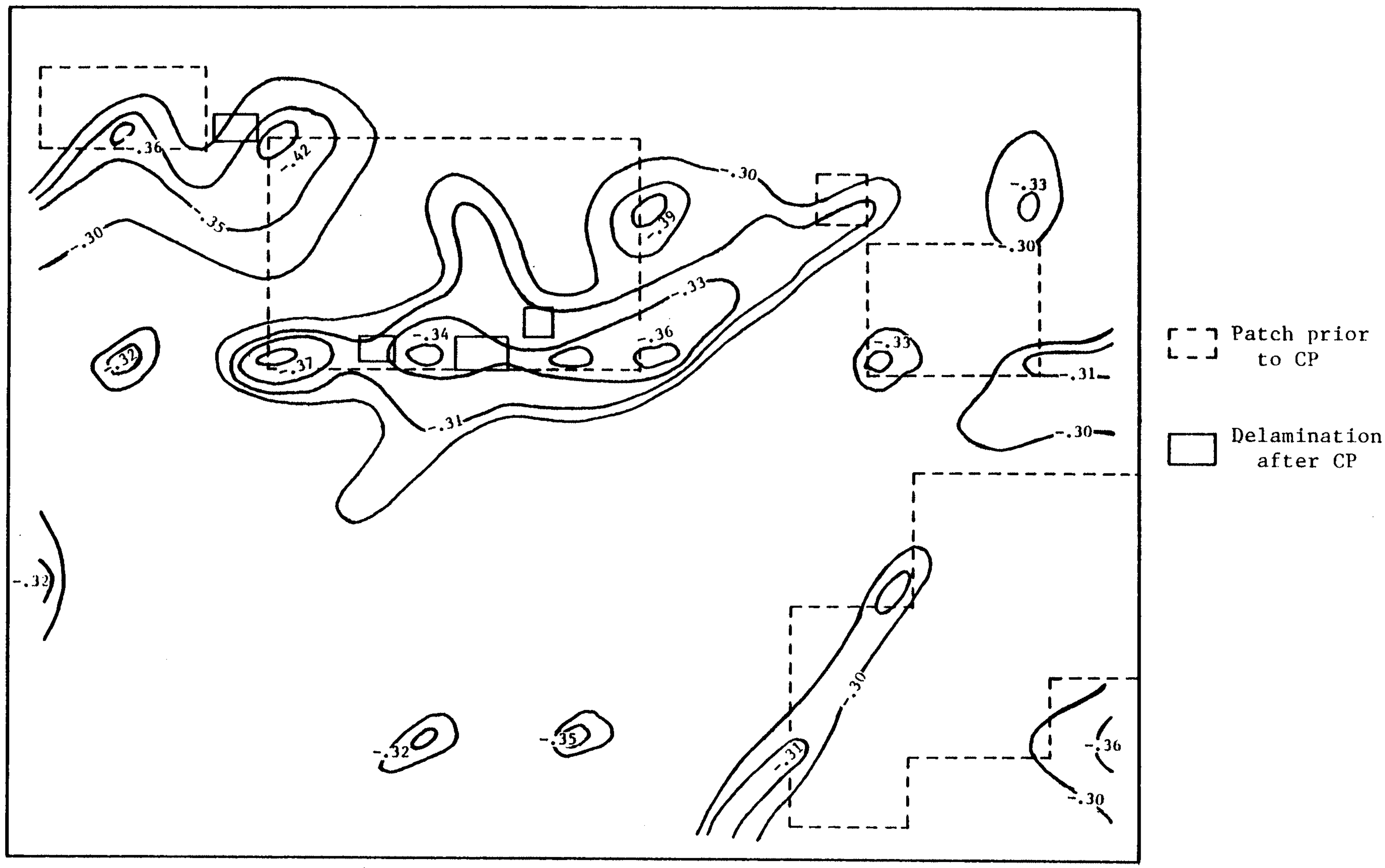


Figure 19. Results of deck survey after 18 months of cathodic protection and potential contours obtained from previous survey — span 1.

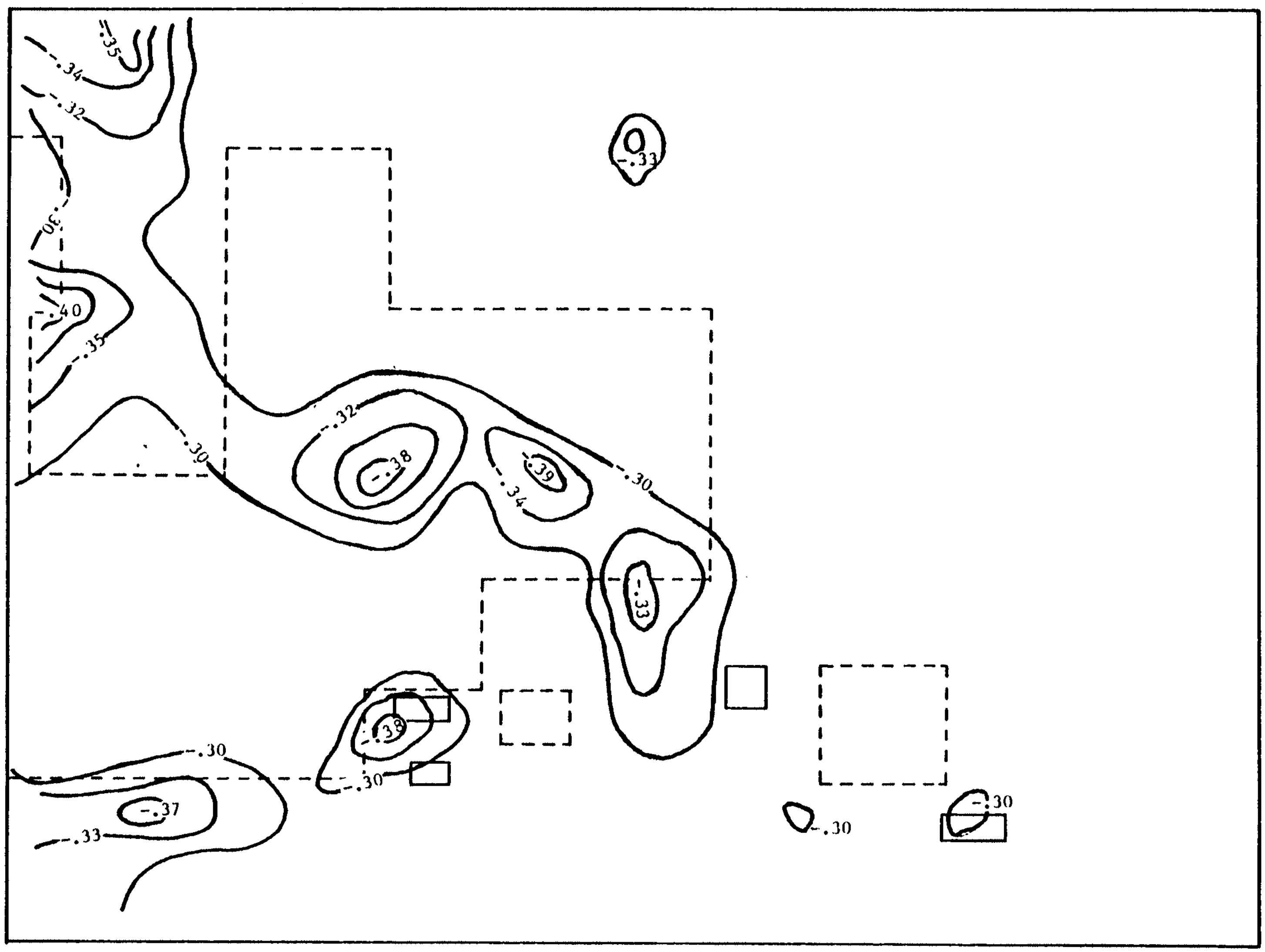


Figure 19 Continued — span 2.

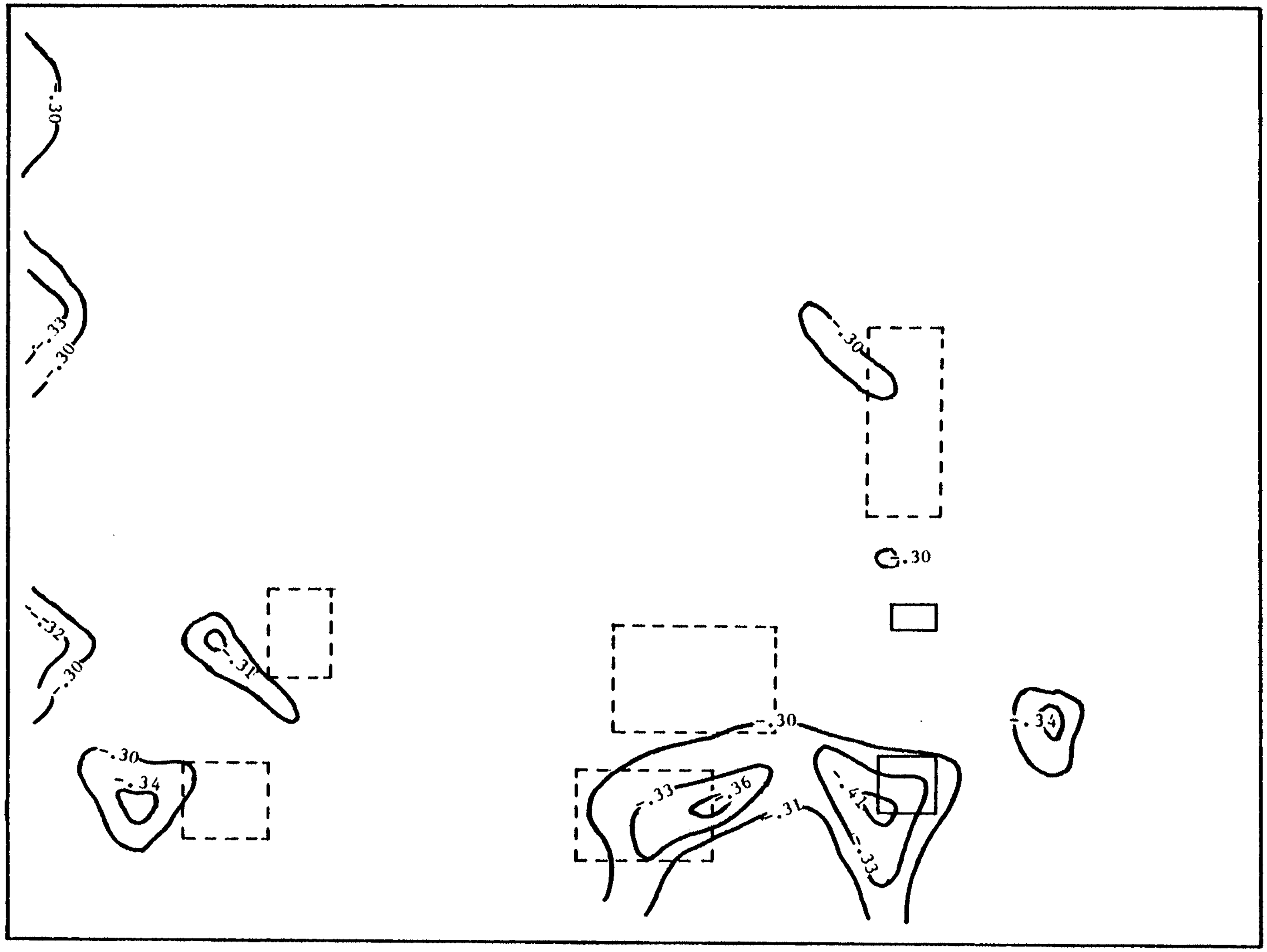


Figure 19 Continued – span 3.

Table 6

Estimated Polarization Around Concrete Delaminations

Span	Delamination	Polarization (mV vs. CSE) Local	Average for Span	Difference (mV)
1	1	130	240	-110
	2	150		- 90
	3	180		- 60
	4	210		- 30
2	1	100	230	-130
	2	200		- 30
	3	200		- 30
	4	130		-100
3	1	170	270	-100
	2	180		- 90

The inspection records for this deck were examined. As illustrated in Figure 20, there was a fairly steady increasing trend in which new delaminations were being found after rebar corrosion had started when the deck was approximately 10 to 12 years old. And after the CP system was installed, that trend was reversed to a very significant extent, even if the aforementioned delaminations were all considered to be new. This indicates, beyond any doubt, that CP also works in reinforced concrete bridge decks.

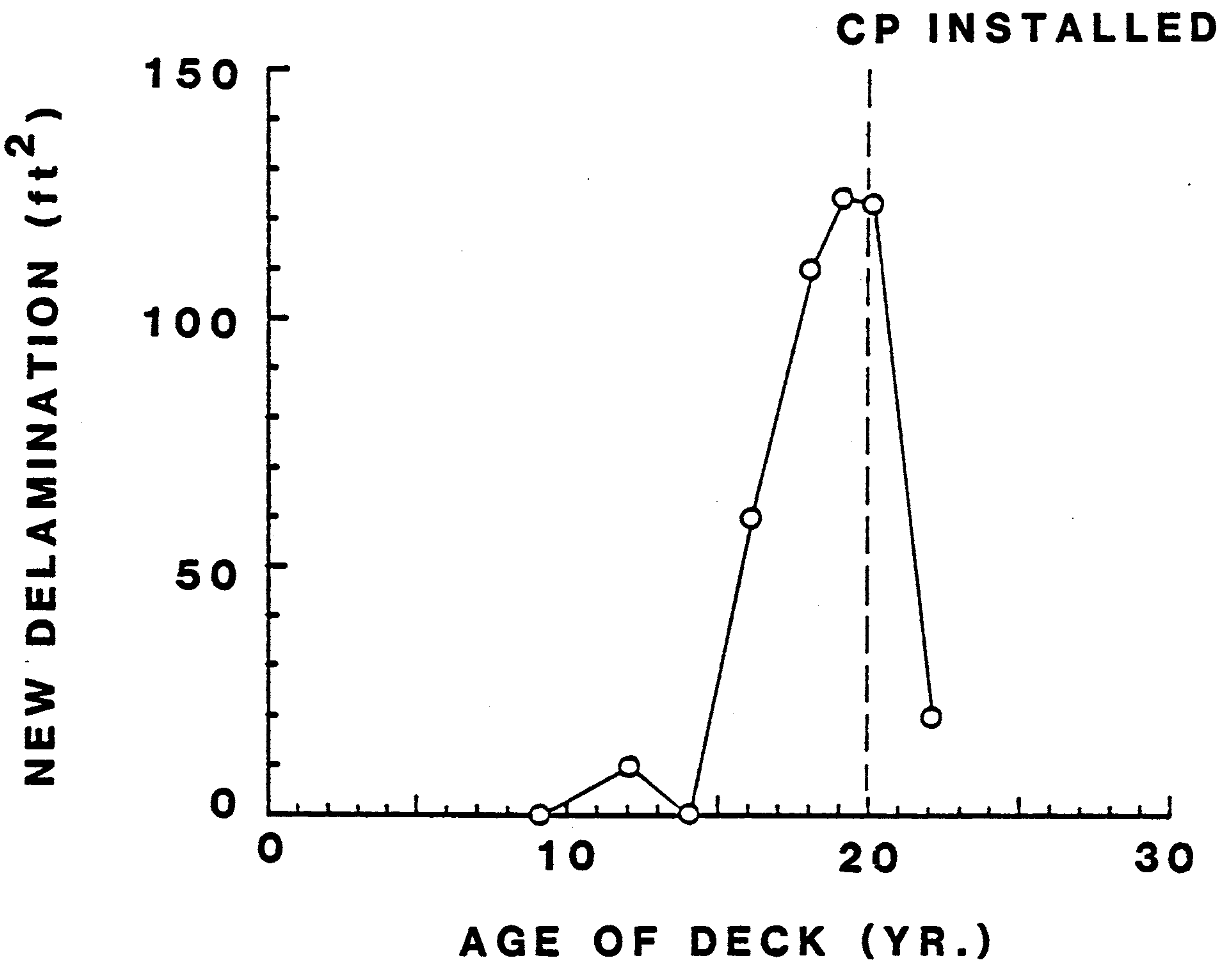


Figure 20. New concrete delaminations found on the deck during inspections.

CONCLUSIONS AND DISCUSSION

Based on results presented, the following conclusions can be made:

1. CP works in reinforced concrete bridge decks.

2. The design and installation of a slotted cathodic protection system for bridge decks are very straightforward.

3. Because the installation discussed here is relatively small, its cost of $16.67/ft^2$ ($179.3/m^2$) might not be representative of what similar installations might cost. Because this was the first installation in the state, it is believed that the bidders built in an appreciable cushion to protect themselves. In addition, there were some basic costs that would be essentially the same regardless of the size of the deck. Thus for a larger deck, such costs would mean relatively smaller costs per unit area. As a matter of fact, a similar installation in West Virginia(5) cost only approximately $5/ft^2$ ($54/m^2$).

4. After more than 18 months in service, the various components of this installation, in particular the conductive polymer concrete and the Ag/AgCl electrodes, appeared to be in good condition.

5. The constant-current mode is a convenient and effective way of operating the R/C unit.

6. It is uncertain whether all of the 10 small delaminations located after the deck had been polarized for 18 months developed after the protective system was installed.

7. Subsequent development of the delaminations would mean that the applied protective currents, which averaged 1.6 mA/ft^2 (17 mA/m^2) and corresponded to the E-log I curve for each of the 3 spans, were not sufficient to completely halt the existing corrosion activity in the deck, particularly during the early stage of operation. Thus, it follows that the applied current should have been higher, at least during the first several months of operation, but not high enough to adversely affect the conductive polymer concrete used to cover the anodes.

The slotted cathodic protection system described here not only adds to the growing list of installations on bridge decks that have proved that cathodic protection is also effective in reinforced concrete structures, it has also provided an excellent opportunity for the

Virginia Department of Highways and Transportation to gain valuable working knowledge on this useful technology.

Since not all bridge engineers may prefer to use the slotted anodes, it must be mentioned that other anode systems have since come into the market, or will shortly. An example of other systems is the mesh of wire-like anodes that can be laid on a deck after the replacement of deteriorated concrete, and then be covered with either a latex-modified concrete or another overlay material. The important point is that CP is now a proven technology for use in reinforced concrete and bridge engineers should benefit from including CP in their strategies for rehabilitating bridge decks.

REFERENCES

1. R. F. Stratfull, "Experimental Cathodic Protection of a Bridge Deck," Transportation Research Record 500, pp. 1-7, 1974.

2. H. J. Fromm and G. P. Wilson, "Cathodic Protection of Bridge Decks: A Study of Three Ontario Bridges," Transportation Research Record 604, pp. 38-47, 1976.

3. J. P. Nicholson, "New Approach to Cathodic Protection of Bridge Decks and Concrete Structures," Transportation Research Record 762, pp. 13-17, 1980.

4. Y. P. Virmani and K. C. Clear, personal communication.

5. NACE Recommended Practice RP-01-69, NACE, Houston, Texas, 1969.

6. D. R. Jackson, personal communication.

APPENDIX A

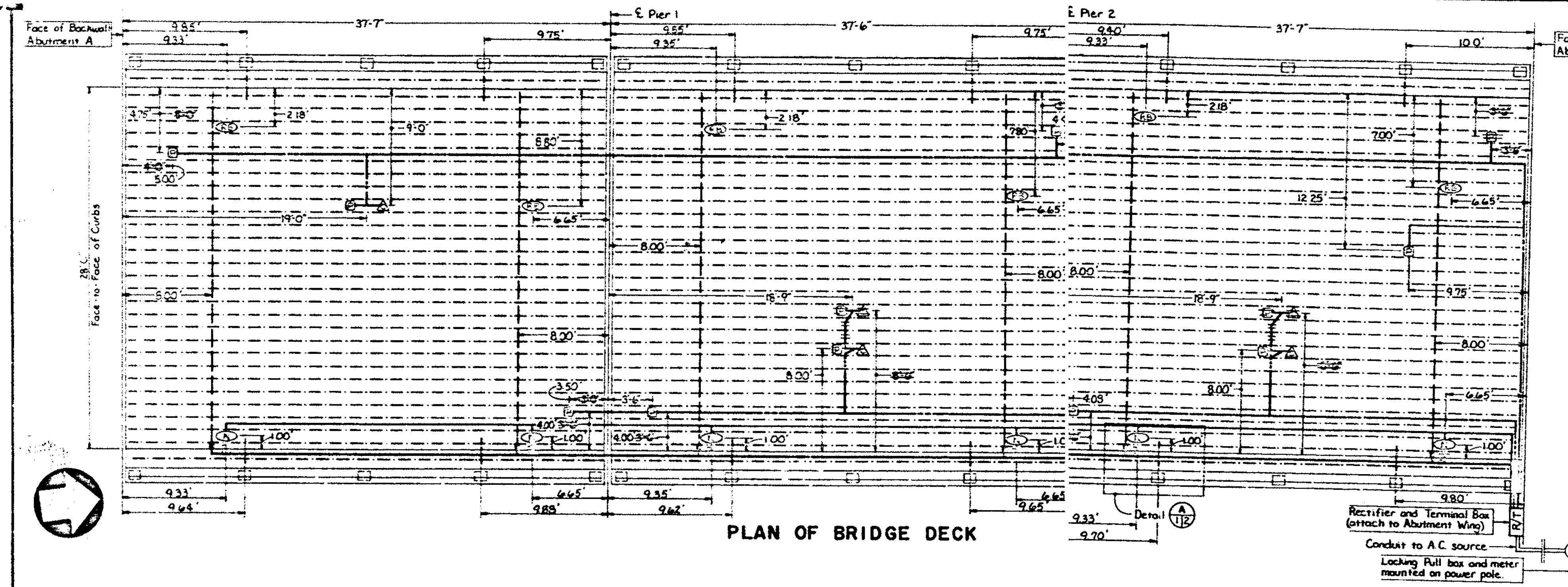
PLAN FOR CATHODIC PROTECTION SYSTEM

FHWA REGION	STATE	FEDERAL AID ROUTE	FEDERAL AID PROJECT	STATE ROUTE	STATE PROJECT	SHEET NO.
3	VA.		*	15	0015-014-1002	

*DTFH71-82-34-VA-04

No Additional Right-of-Way Required

X021



PLAN OF BRIDGE DECK

GENERAL NOTES

CONSTRUCTION SPECIFICATIONS - VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION ROAD AND BRIDGE SPECIFICATIONS, 1978. THESE PLANS ARE INCOMPLETE UNLESS ACCOMPANIED BY THE SUPPLEMENTAL SPECIFICATIONS AND SPECIAL PROVISIONS INCLUDED IN THE CONTRACT DOCUMENTS.

DETAILS OF EXISTING STRUCTURE ARE SHOWN ON PLAN NUMBER 157-16. COPIES OF THIS PLAN MAY BE OBTAINED FROM VDH&T. THE CONTRACTOR SHOULD BECOME FAMILIAR WITH ALL DETAILS OF THE EXISTING STRUCTURE THAT WILL BE AFFECTED BY THIS WORK. BRIDGE NUMBER OF EXISTING STRUCTURE IS 1002.

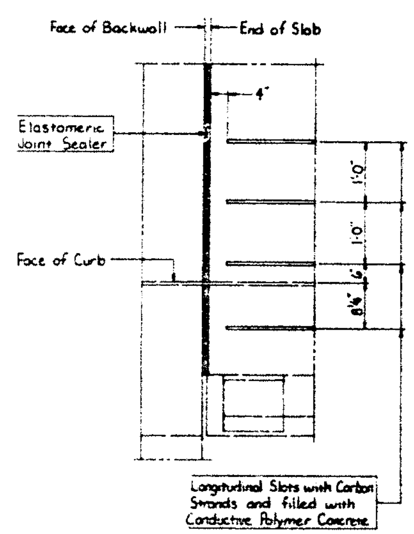
BRIDGE TO BE KEPT OPEN TO TRAFFIC AT ALL TIMES WITH A 12'-0" MINIMUM CLEAR ROADWAY.

TRAFFIC SIGNALS WILL BE FURNISHED, INSTALLED, AND MAINTAINED BY VDH&T.

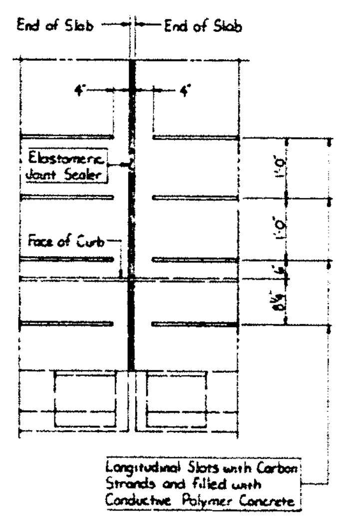
ANODE LEAD WIRES, NEGATIVE RETURN CABLES, BOND CABLES, REFERENCE CELL LEAD WIRES, REFERENCE CELL GROUND WIRES, REBAR PROBE LEAD WIRES, AND REBAR PROBE GROUND WIRES SHALL BE AWG NO. 10 STRANDED COPPER WIRE WITH THHN INSULATION (OR APPROVED EQUAL).

THE RECTIFIER AND TERMINAL BOX (AND THE STEEL CASE IN WHICH THEY WILL BE HOUSED) SHALL BE MOUNTED TO THE WING WALL ON THE EAST SIDE OF ABUTMENT B. THIS WORK SHALL BE DONE AS DIRECTED BY THE ENGINEER USING APPROVED ANCHOR DEVICES.

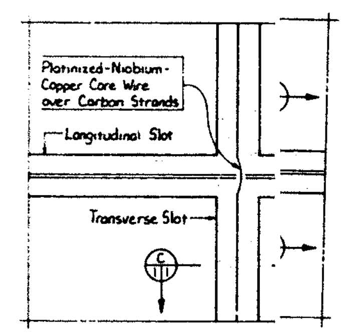
As Built Note: The Cathodic Protection System was furnished by the Cathodic Protection Division of the Harco Corporation.



PART PLAN AT ABUTMENTS



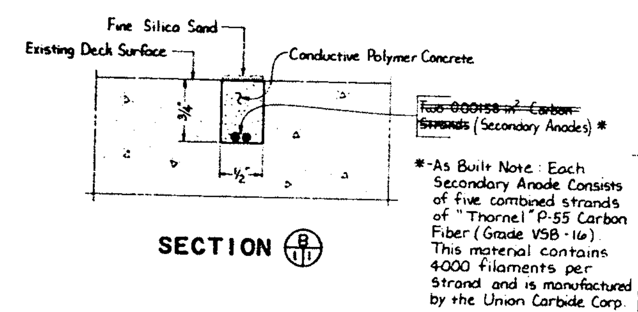
PART PLAN AT PIERS



PART PLAN SH ANODE SYS

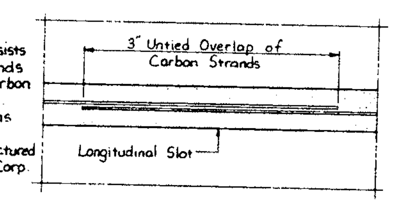
~~Estimated~~ Actual Quantities
Cathodic Protection System (Structure No 1002) (The quantities shown in the table below are f purposes only)

Work Order No 1 - 10 S.F. of Bridge Deck Repair (Variable Depth)

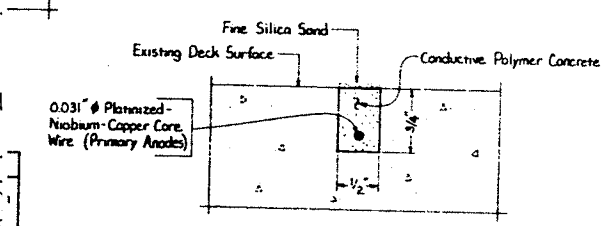


SECTION B

*As Built Note: Each Secondary Anode Consists of five combined strands of "Thornel" P-55 Carbon Fiber (Grade VSB-16). This material contains 4000 filaments per Strand and is manufactured by the Union Carbide Corp.



SECONDARY ANODE SPLICING



SECTION C

APPROXIMATE QUANTITY		LEGEND
200 LF	—■	Platinized-Niobium-Copper Core Wire (Primary Anodes) in Transverse Slots (■=Plastic-Sleeved in Drill Hole Thru Deck)
8000 LF	-·-·-	Carbon Strands (Secondary Anodes) in Longitudinal Slots
200 LF	——	PVC Conduit For Primary Anode Leads And System Negative Leads - Under Deck (Possible Junction Box)
400 LF	——	PVC Conduit For Reference Cell Leads, Rebar Probe Leads, And Ground Leads - Under Deck (Possible Junction Box)
30 LF	═══	Galvanized Conduit (AC)
2200 LF		AWG No. 10 Stranded Copper

QUANTITY		
3	A	Reference Cell With ... tion To Rebar (Drill Hole Thru Deck)
9	P	Rebar Probe With G... ion To Rebar (Drill Hole Thru Deck)
6	N	System Negative Con... bar (Drill Hole Thru Deck)
6	RB	Rebar Bonding
1	R/T	Rectifier And Term...

Finals Posted in Lynchburg District Bridge Office by J.L. Milton on April 22, 1983.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
~~PROPOSED~~ As Built CATHODIC PROTECTION SYSTEM FOR BRIDGE ON RTE. 15 OVER WILLIS RIVER BUCKINGHAM CO.-7.7 MI. SE. INT. RTE. 60

PROJ.-0015-014-1002

Recommended For Approval: F. A. Sutherland 4-23-82 Bridge Engineer

Recommended For Approval: [signature] 4-26-82 Director of Engineering

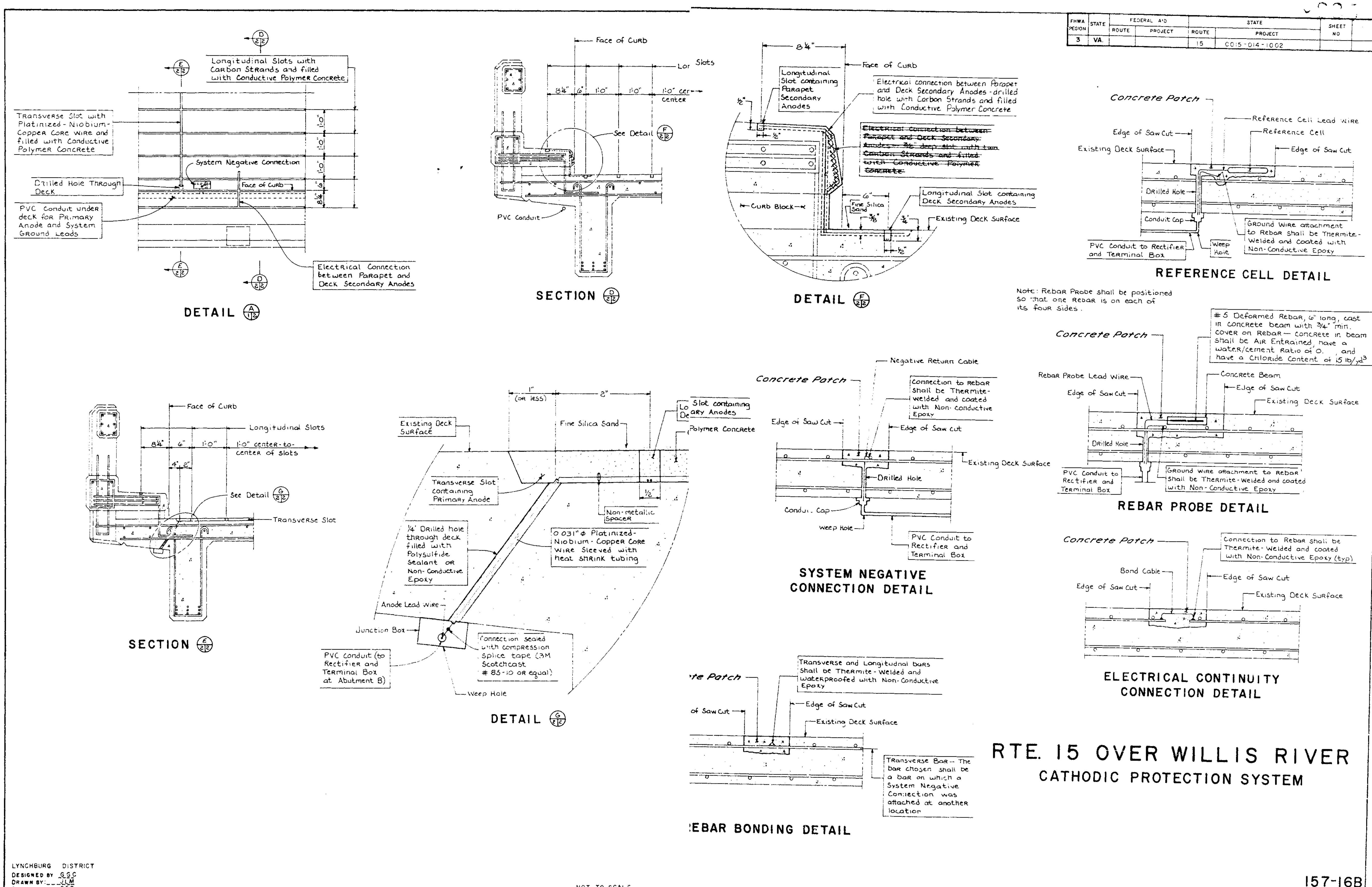
Approved: [signature] 4-26-82 Deputy Commissioner and Chief Engineer

LYNCHBURG DISTRICT
SUPERVISED BY W.L.S.
DESIGNED BY
DRAWN BY
CHECKED BY

Date APRIL 20, 1982

157-16B

Sheet 1 of 2


FHWA REGION 3
STATE VA.
FEDERAL AID ROUTE PROJECT
STATE ROUTE 15 PROJECT 0015-014-1002
SHEET NO
Longitudinal Slots with Carbon Strands and filled with Conductive Polymer Concrete
Transverse Slot with Platinized-Niobium-Copper Core wire and filled with Conductive Polymer Concrete
System Negative Connection
Drilled Hole Through Deck
Face of Curb
PVC Conduit under deck for Primary Anode and System Ground Leads
Electrical Connection between Parapet and Deck Secondary Anodes
DETAIL A
SECTION D
PVC Conduit
See Detail F
DETAIL F
Longitudinal Slot containing Parapet Secondary Anodes
Electrical connection between Parapet and Deck Secondary Anodes - drilled hole with Carbon Strands and filled with Conductive Polymer Concrete
~~Electrical connection between Parapet and Deck Secondary Anodes - 3/4" deep slot with two Carbon Strands and filled with Conductive Polymer Concrete~~
Curb Block
Fine Silica Sand
Longitudinal Slot containing Deck Secondary Anodes
Existing Deck Surface
Concrete Patch
Reference Cell Lead Wire
Reference Cell
Edge of Saw Cut
Existing Deck Surface
Drilled Hole
Conduit Cap
Weep Hole
PVC Conduit to Rectifier and Terminal Box
Ground Wire attachment to Rebar shall be Thermite-Welded and Coated with Non-Conductive Epoxy
REFERENCE CELL DETAIL
Note: Rebar Probe shall be positioned so that one Rebar is on each of its four sides.
#5 Deformed Rebar, 6" long, cast in concrete beam with 3/4" min. cover on Rebar - concrete in beam shall be Air Entrained, have a water/cement Ratio of 0. and have a Chloride Content of 15 lb/yd³
Rebar Probe Lead Wire
Concrete Beam
Ground wire attachment to Rebar shall be Thermite-Welded and coated with Non-Conductive Epoxy
REBAR PROBE DETAIL
SECTION E
Longitudinal Slots
1'-0" center-to-center of slots
See Detail G
Transverse Slot
Existing Deck Surface
Transverse Slot containing Primary Anode
Fine Silica Sand
Slot containing Deck Secondary Anodes
Polymer Concrete
Non-metallic Spacer
1/4" Drilled hole through deck filled with Polysulfide Sealant or Non-Conductive Epoxy
0.031" ⌀ Platinized-Niobium-Copper Core wire Sleeved with heat shrink tubing
Anode Lead Wire
Junction Box
PVC Conduit (to Rectifier and Terminal Box at Abutment B)
Connection sealed with compression splice tape (3M Scotchcast #85-10 or equal)
Weep Hole
DETAIL G
Negative Return Cable
Connection to Rebar shall be Thermite-welded and coated with Non-conductive Epoxy
Drilled Hole
SYSTEM NEGATIVE CONNECTION DETAIL
Connection to Rebar shall be Thermite-Welded and coated with Non-Conductive Epoxy (typ)
Bond Cable
ELECTRICAL CONTINUITY CONNECTION DETAIL
Transverse and Longitudinal bars shall be Thermite-Welded and waterproofed with Non-Conductive Epoxy
Transverse Bar - The bar chosen shall be a bar on which a System Negative Connection was attached at another location
REBAR BONDING DETAIL
RTE. 15 OVER WILLIS RIVER
CATHODIC PROTECTION SYSTEM
LYNCHBURG DISTRICT
DESIGNED BY GSC
DRAWN BY JLM
CHECKED BY GSC
NOT TO SCALE
APRIL, 1982
157-16B
Sheet 2 of 2

APPENDIX B

SPECIAL PROVISION FOR CATHODIC PROTECTION SYSTEM

VIRGINIA DEPARTMENT OF HIGHWAYS AND TRANSPORTATION
SPECIAL PROVISION FOR
CATHODIC PROTECTION SYSTEM FOR BRIDGE DECK
Project: 0015-014-1002

√June 3, 1982

Section I Description -

The work shall consist of furnishing, installing, energizing and adjusting a complete cathodic protection system for the bridge deck in accordance with these specifications and as shown on the plans.

Quantities of instrumentation probes and reference cells are as shown on the plans.

Anode, wire lead, and conduit lengths shown on the plans are approximate only. Actual lengths are to be determined by the Contractor.

Section II Materials -

A. The cathodic protection system may be obtained from one of the following listed sources:

Harco
1055 W. Smith Road
Medina, Ohio 44256
(216) 725-6681
Attn: Dave Dluzynski
Jim Jankowski

Matcor, Inc.
P.O. Box 687
Doylestown, Pennsylvania 18901
(215) 348-2974
Attn: John Keldfen

In addition, the cathodic protection system shall be of the impressed current type and the components shall conform to the following:

1. Rectifier and Terminal Box -

a. Rectifier

(1) The rectifier shall be a multiple circuit air cooled rectifier with provisions for operation by either constant voltage or constant current control at up to 20 volts, 3 circuit of 18 amperes (total).

(2) A. C. Input: 230 volt
60 hertz
1 phase

(3) D. C. Output: Available output shall be variable, to a maximum of 20 volts/6 amps per circuit, 3 circuits.

(4) The rectifier shall be air-cooled with silicon stacks.

(5) The rectifier shall be provided with A.C. and D.C. lightning protection.

(6) The rectifier shall have a 1-percent accuracy D.C. volt-ammeter with a digital readout display and selector switches to read each circuit voltage and current.

(7) Each output shall have a current limiting device factory set at 6.0 amperes.

(8) The rectifier shall contain an ON-OFF circuit breaker.

(9) The rectifier output shall be unfiltered and full wave at maximum output. It shall be equipped with a device to allow automatic measurement of the IR drop-free electrical potential of a single reference cell (portable or permanent). The reference cell connection point shall be easily accessible on the front of the rectifier panel.

b. Terminal Box

(1) The terminal box shall be contained within the rectifier unit.

(2) The terminal box shall contain 3 internal connections of anode circuit output wires from the rectifier to the 6 individual anode circuit lead wires through 0.01 ohm shunts.

(3) The terminal box shall contain 1 connection of system negative from the rectifier to the 6 individual negative circuit lead wires through a common buss bar.

(4) The terminal box shall contain terminals for 3 reference cell leads and 3 reference cell grounds.

(5) The terminal box shall contain terminals for 9 rebar probe leads and the 9 corresponding ground wires (common grounds with the reference cells). A 10-ohm precision (1 percent accuracy - 1 watt) resistor shall be located between each corresponding terminal pair. Terminals shall be arranged such that the voltage drop across each resistor can be easily measured.

c. Mounting

(1) The rectifier and terminal connections shall be housed in a steel case suitable for pole or wall mounting with insect screening.

(a) The case shall be finished in baked enamel.

(b) The case shall contain all knockouts and fittings as required.

(c) The unit shall be tamperproof with provisions for locking.

(d) The unit shall be small-arms-proof.

(2) The unit shall be mounted at the location shown on the plans.

2. Reference cells shall be zinc-zinc sulfate, silver-silver chloride or equal approved by the Engineer, with attached lead wires and a covering of dielectric insulation at the leadwire-cell junction.

3. The rebar probes shall be a 6-inch length of Number 5 deformed reinforcing bar (ASTM A615), Grade 60 with attached lead wire. Prior to the installation in the deck, the rebar probes shall be cast in the center of a portland cement concrete beam (0.75 inch minimum concrete cover). The concrete shall be Class A4 as specified herein and shall contain sufficient admixed sodium chloride to yield a chloride content of 15 lbs. per cubic yard.

4. The primary anode material shall be 0.031-inch diameter platinized niobium copper core wire installed at the transverse locations shown on the plans. The wire shall have a minimum of 25 microinches of platinum in all areas.

5. Secondary anodes shall be two 30,000-filament carbon strands (tensile strength = 390,000 psi, resistivity = .0018 ohm-cm, fiber area in yarn cross section = 0.00158 in. 2). The strands shall be placed in the bottom of each longitudinal slot shown on the plans.

6. Conductors -

   (a) No. 10AWG stranded copper wire, conforming to ASTM B8, with THHN insulation (or approved equal) shall be used for the anode lead wires, negative return cables, bond cables, reference cell lead wires, reference cell ground wires, rebar probe lead wires and rebar probe ground wire.

   (b) No. 8AWG stranded copper wire, conforming to ASTM B8, 600 volts, UL listed RHH/RHW/USE shall be used for service conductor.

   (c) No. 4AWG stranded copper wire, conforming to ASTM B8, insulated shall be used for ground wire.

7. Ground Rod shall be copper clad, diameter of 3/4-inch and a length of at least 8 ft.

8. Conduit -

   (a) Metal and polyvinyl-chloride (PVC) conduit shall conform to Section 248 of the Specifications.

9. Conductive polymer concrete requires six weeks notice prior to shipping date. The shelf life of polymer concrete expires approximately nine weeks after shipping date therefore the Contractor shall plan and coordinate the work schedule accordingly. The conductive polymer concrete may be obtained from one of the following listed sources:

Harco	Corrosion Spec., Inc.	Arixona Corrosion Control
1055 W. Smith Rd.	646 Chaney Drive	Thomas Rd.
Medina, Ohio 44256	Collierville, Tenn 38017	Suite 603
(216) 725-6681	(901) 853-1060	Phoenix, Arizona 8501 75375
Attn:Dave Dluzynski	Attn:Jack Goodson	(602) 267-7641
Jim Jankowski	Phyllis Goodson	Attn:John Hull
		Phyllis Anderson

In addition, the conductive polymer concrete shall conform to the following:

The conductive polymer concrete shall be a gray colored, pourable, electronically conductive, polymer concrete which has been shown to be extremely resistant to degradation by acid, chlorine gas, freezing and thawing, and thermal cycling while bonded to concrete. Compressive strength of the material shall exceed 4,000 psi at 4 hours (70 F.), the electrical resistivity shall not exceed 5 ohm-cm, and the 24-hr. water absorption shall not exceed 0.5 percent. The Contractor shall submit laboratory test results on the-lots of material proposed for use which documents compliance with the above properties and shall submit a material storage placement and handling (safety) plan prior to receiving the material at the jobsite. An electrical resistivity sample shall be obtained from each batch of material produced in the field and evaluated by a qualified laboratory to assure the above resistivity requirement was met.

B. Class A4 Concrete for patches shall conform to Section 219 of the Specifications except that coarse aggregate shall be nonpolishing Size No. 7 or No. 8. The concrete shall be modified also as specified herein:

(1) Patches for Reference Cells, System Negative, Rebar Bonding and Electrical Continuity shall have a chloride content equal to that of the surrounding concrete. Chloride content shall be determined from random samples taken from the bridge deck and analyzed by the Department. (Note: The Rebar Probe patch shall not have chloride added.)

Section III Construction Methods -

A. Wiring:

All wiring shall be done in conformance with the National Electrical Code.

All wires shall be of sufficient length so as to eliminate any field splicing and shall be tagged to indicate their position in the deck and their purpose.

All reinforcing steel ground wires shall be attached to the reinforcing steel using the Cadweld thermite welding process, in accordance with the manufacturer's instructions. Following the attachment, the connection shall be coated with an epoxy approved by the engineer.

Anode leads, negative return leads and reference cell leads beneath the bridge deck shall be enclosed in PVC conduit.

Anode leads and system negative return leads may be routed in the same conduit. The reference cell ground leads, rebar prove and probe ground leads must be routed in a separate conduit.

Weep holes shall be provided at appropriate locations to drain any moisture in the conduit lines before reaching the terminal box.

As suggested routing of conduit is as shown on the plans. Other methods shall be subject to approval by the engineer.

A locking pull box and meter shall be supplied and mounted on a post as shown on the plans.

All necessary conduit caps, couplings, expansion connections, and hangers shall be provided.

B. Reference Cells:

Each reference-cell lead wire and each corresponding ground wire shall be placed in prepared ares that have sawcut vertical edges in the deck surface and brought through a hole drilled in the deck.

The cell shall be positioned within 1 inch, but not in the direct contact with top-mat reinforcing steel.

Each reference cell shall have a separate ground wire attached to the reinforcing steel not more than 12 inches from the cell location.

The concrete patch material shall completely encapsulate the cell.

C. Rebar Probes:

The installation area shall have sawcut, vertical edges.

The rebar probe lead wire and the probe ground wire shall be brought through a drill hole in the deck and run to the terminal box.

Each probe beam position shall be chosen such that it is located between top-mat reinforcing bars in the deck at a location approximately equal to that on the plans and <u>between longitudinal anode lines</u>.

Preparation for installation shall consist of removal of all concrete in a rectangular probe installation area encompassing one deck reinforcing bar on each of the 4 sides of the probe beam position. The deck rebars shall be exposed on all sides and the depth of concrete removal shall be to a level 1-inch below the deck rebar. All exposed rebars shall be cleaned to remove all concrete and rust in a manner approved by the Engineer.

A rebar probe ground wire shall be attached to the reinforcing steel in the probe installation area.

D. <u>Anode Sytem</u> -

1. <u>Anode Slots (Sawcuts)</u> -

The anode system shall be wholly contained in sawcut slots, approximately 0.50-inch wide and 0.75-inch deep, cut in the deck surface at the locations shown on the plans.

Slots shall be terminated within 4 inches of each parapet wall and 4 inches from each expansion joint.

Slots shall be routed around all exposed steel components in the deck such that no portion of slot is closer than 3 inches to said components.

Location of all slots (sawcuts) shall be as shown on the plans (i.e. generally 1-ft. on center in the longitudinal direction and two slots per span, 25-ft. apart, in the transverse direction) except as follows: All areas of the deck in which the reinforcing steel cover is less than 0.75 inch shall be identified. In these areas, the slot locations shall be moved up to 4 inches in either direction, as necessary to maximize the thickness of concrete between the reinforcing steel and the bottom of the slot. In any areas <u>where at least ½-inch cover of concrete does not exist</u>, the bottom of the slots shall be electrically insulated in a manner approved by the Engineer.

Anode slots shall be cleaned after sawing such that they are free of all foreign material.

2. <u>Primary Anodes</u> -

The anode wire shall not be kinked or scored. Damaged anode wires shall be rejected.

The anode wire shall be positioned in the lower one-half of each transverse sawed slot in the bridge deck as shown on the plans. This may be done using non-metallic spacers or other approved methods.

The anode wire <u>shall be electrically shielded from</u> any possible contact with <u>any exposed reinforcing bars</u>. Each anode wire shall be plastic sleeved when brought through the deck in a drilled hole.

Each anode wire shall be connected to a <u>separate continuous</u> length of wire leading from the terminal box.

The connection shall be sealed with a compression splice tape, 3M Scotchcast #85-10 or approved equal, and contained in a conduit junction box on the underside of the bridge deck.

6 Anode leads shall be tagged at the rectifier end to identify their location in the deck.

3. Secondary Anode Strands -

   Secondary anode strands shall run continuously along the length of each slot and may be spliced by simply providing a 3-inch untied overlap.

   Secondary anode strands shall be placed prior to placement of primary anode wire.

   Secondary anode strands shall be electrically shielded from contact with exposed reinforcing bars or other metallic components.

   No positive connections between secondary anode strands and other components of the anode system are required.

4. System Negatives and Rebar Bonding -

   The negative return cables shall be connected to the top-mat reinforcing bars at the locations shown as "N" on the plans, placed in slots in the deck surface and run through holes drilled in the deck.

   Positive rebar bonding shall be performed at all locations marked RB on the plans by welding a transverse bar to a crossing longitudinal bar and waterproofing the weld. The transverse bar chosen shall, in all possible cases, be a bar on which a negative return cable was attached at another location.

   If the top reinforcing steel mat is determined by the Contractor to be electrically discontinuous in any area, bond cables shall be connected to the rebars so as to remove the discontinuity.

5. Replacing Deck Surface -

   a. Class A4 Concrete Patches shall be cured in accordance with Section 416.

   b. Conductive Polymer Concrete:

      (1) The sawcuts shall be free of moisture (visible dry), dirt, grease, oil, asphalt, slurry from sawcutting or other foreign material when placing conductive polymer concrete.

      (2) Conductive Polymer Concrete shall be installed when the deck temperature is in excess of 40°F and expected to remain above that value for 4 hours. Additionally, no polymer shall be placed when precipatation is forecast within 4 hours.

      (3) Precautionary measures shall be taken to insure the conductive polymer concrete does not come in contact with any reinforcing bars or other exposed metallic components.

      (4) The conductive polymer concrete shall not be placed in the slot until the anode wire and strands are in place and all drill holes in the deck have been completely filled with nonconductive epoxy.

      (5) The quantity of conductive polymer concrete mixed at any given time shall not exceed that which can be installed within 30 minutes.

(6) The conductive polymer concrete shall be mixed in strict accordance with the instructions provided and shall be periodically agitated during slot filling such that no significant separation of the coke and the resin occurs within the mixing or pouring containers.

(7) The conductive polymer concrete shall be poured into each slot to a level equal to that of the surrounding deck surface. Conductive polymer concrete shall not be spilled onto other areas of the surface.

(8) Within 15 minutes of the conductive polymer concrete placement, dry, fine silica sand shall be broadcast to excess over all backfill and lightly compacted.

(9) Excess sand shall be removed from the surface by brooming after the material has set.

6. Technical Requirements -

a. A technical representative, qualified in the field of cathodic protection of reinforced concrete structures shall be available during construction to assist in quality assurance.

b. Upon completion of the installation phase, the system shall be energized and adjusted for proper operation.

(1) This work shall be performed under supervision of a Registered Professional Engineer certified by the National Association of Corrosion Engineers as a Corrosion Specialist or other corrosion specialist approved by the Engineer.

c. The following tests shall be performed:

(1) Static potentials prior to energizing.

(2) Reinforcing rod continuity tests.

(3) E Log I tests and other polarization and depolarization tests as deemed necessary by the Engineer to determine cathodic protection requirements in a given area.

(4) Natural rebar probe corrosion currents and probe currents with system operational at various power levels.

d. Energize and adjust rectifier in accordance with the results of the above tests. Check rectifier for proper operation, current and voltage outputs.

e. Prepare a report documenting the findings of these studies and presenting all data collected.

f. Instruct Department personnel in the operation and maintenance of the system.

g. Supply three complete sets of operating and maintenance instructions

Section IV Method of Measurement -

Cathodic Protection System will be paid for on a lump sum basis wherein no measurement will be made.

Section V Basis of Payment -

Cathodic Protection System will be paid for at the contract lump sum 'price.

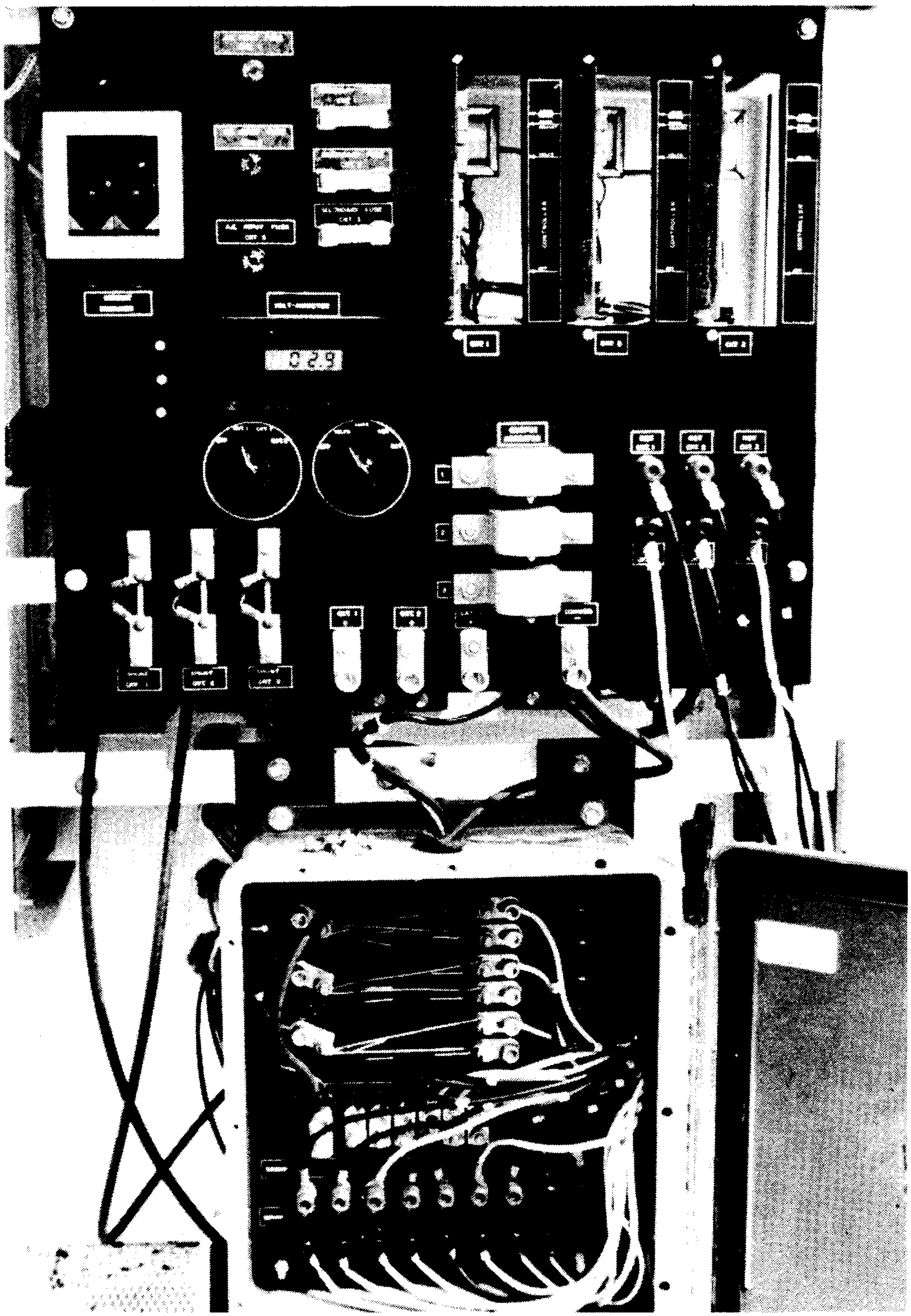
The contract price shall include furnishing all labor, tools, equipment and materials necessary for complete installation of the system, including electrical resistivity evaluation of the conductive polymer concrete, energizing and adjustment certification by Registered Professional Engineer and erection and movement of signs in keeping with daily operations.

Payment will be made under:

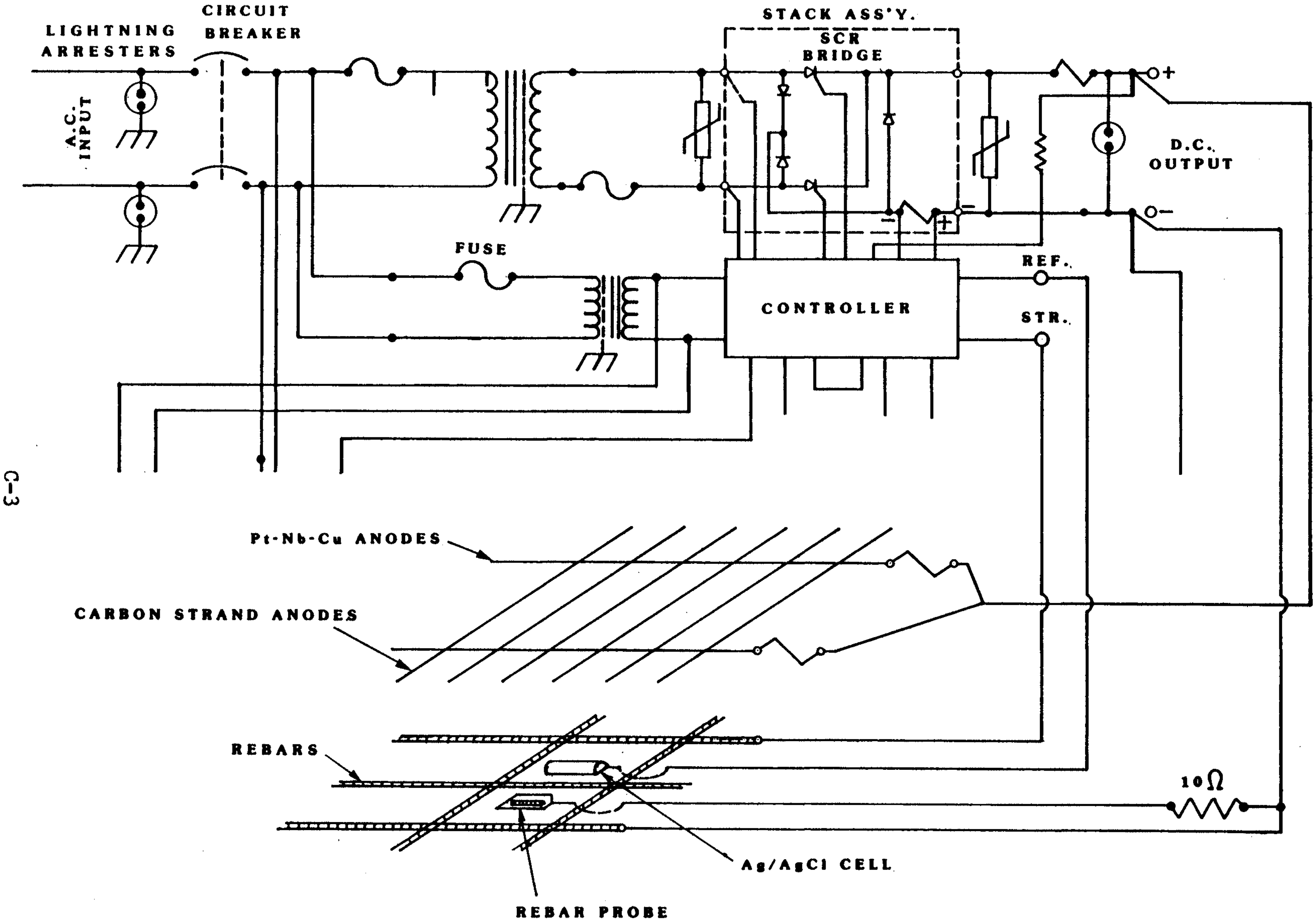
Pay Item	Pay Unit
Cathodic Protection System	Lump Sum

APPENDIX C

R/C UNIT AND CIRCUIT DIAGRAM



Front View of the Rectifier/Control Unit



Simplified Diagram of Circuit for Each Span