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New Cathodic Protection Installations

Kenneth C. Clear and Sivaraman Venugopalan
Kenneth C. Clear, Inc.
Boston, Virginia 22713

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Program Manager: *Don M. Harriott*
Project Manager: *Joseph F. Lamond*
Consultant: *John P. Broomfield*
Production Editor: *Marsha Barrett*
Program Area Secretary: *Carina Hreib*

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Strategic Highway Research Program
National Academy of Sciences
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

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New Cathodic Protection Installations

June 1993

Project Summary

A survey was used to identify 36 cathodic protection systems being installed in North America in 1991 and 1992. Eight structures were selected to monitor the installation and commissioning under contract Strategic Highway Research Program Project C-102G. Monitoring included collecting technical and cost information and analyzing the data.

The information collected was used in SHRP project C-102D, Cathodic Protection. The technical information has been incorporated into the cathodic protection manual and specifications as appropriate. The cost information was used in the database for the cost estimating chapter of the manual.

Long-term monitoring for a further 5 years is planned under FHWA projects for SHRP trials.

Various state agencies were contacted by telephone and those agencies where cathodic protection systems were to be installed in 1991 or 1992 were identified. A survey form was sent to over 36 agencies to collect preliminary information on the cathodic protection system (a typical copy of a completed form is presented on pages 13 and 14. The responses were tabulated. A total of 36 responses were received, of which 22 were deck cathodic protection systems and 14 were substructure cathodic protection systems. The type of anodes were as follows:

Serial No.	Type of anode	Number of Decks	Number of Substructures
1	Titanium mesh in structural concrete	18	4
2	Thermally sprayed zinc (sacrificial)	0	5
3	Thermally sprayed zinc (impressed current)	0	2
4	Bulk zinc (sacrificial)	0	1
5	Perforated zinc sheet (sacrificial)	0	1
6	Water-based carbon conductive coating	0	1
7	DURCO™ pancake and coke asphalt overlay	1	--
8	Titanium ribbon anode	3	--
	Total	**22**	**14**

Eight different cathodic protection systems covering different variables (types of anodes, decks and substructures, marine, inland) were selected for monitoring. The structures were Gandy Bridge, Tampa, Florida; Maury River Bridge, Lexington, Virginia; Howard Frankland Bridge, Tampa, Florida; Sixth Street Bridge over Big Sioux River, Sioux Falls, South Dakota; East Duffins Creek Bridge, Pickering, Ontario; I-64 Bridge, Charleston, West Virgina; Brooklyn Battery Tunnel, New York, New York; and Yaquina Bay Bridge, Newport, Oregon. Detailed Reports on each of these structures are presented in the next section of this report.

The technical information was analyzed per existing standards and any cathodic protection system adjustments, if necessary, were recommended. The cost information was analyzed and only those activities related to the cathodic protection were included.

Site visits were scheduled once during installation and again during activation. During each site visit, the research personnel recorded the ongoing activities, collected copies of payrolls, pay estimates and daily progress reports, and took neccessary photographs to document the construction sequence. In addition, a summary was made from the daily progress reports filed by the state DOT inspector to identify the beginning and the end of each activity and to calculate hours.

A summary of the cost of various cathodic protection systems calculated per square foot of the concrete area are given below:

1) Substructure - Titanium mesh anode encapsulated in 5500 psi concrete
(887 ft^2 of protected concrete surface) $21.87

2) Substructure - Carbon conductive paint anode
(8260 ft^2 of protected concrete surface) $12.34

3) Deck - Titanium mesh anode encapsulated in low slump dense concrete overlay
(11,100 ft^2 of protected concrete surface) $9.76

4) Sidewalks - Titanium mesh anode encapsulated in acrylic mortar
(5203 ft^2 of protected concrete surface) $11.74

5) Deck - Non overlay slotted anode system with platinized niobium wire as primary anode and 30,000 filament carbon strand as the secondary anode
(140,164 ft^2 of protected concrete surface) $7.00

6) Deck Underside - Titanium mesh anode encapsulated in 3500 psi shotcrete

(111,212 ft^2 of protected concrete surface) $11.10

7) Substructure - Arc-sprayed sacrificial zinc anode (without enclosures for collecting zinc dust)
(126,189 ft^2 of protected concrete surface) $3.34

8) Substructure - Underwater - Bulk (commercially manufactured cast anodes) zinc sacrificial anode on piles
(160 ft^2 of protected concrete surface) $11.31

9) Substructure - Underwater - Bulk (commercially manufactured cast anodes) zinc sacrificial anode on piers $6.90

10) Substructure - Tidal zone - Perforated zinc sheet sacrificial anode
(1984 ft^2 of protected concrete surface) $38.50

Each structure, the cathodic protection system(s), and cathodic protection system performance are summarized below.

1) GANDY BRIDGE, TAMPA, FLORIDA

This marine structure is a two-lane bridge over Tampa Bay and was built in 1955. The crash wall (footing) had 887 ft^2 of concrete surface area.

The wall had vertical cracks which offered easy access of seawater to the reinforcing steel. The chloride content at steel depth varied from 2.8 to 7.2 lb/yd^3. The average half-cell potential was -362 mV CSE when measured during April 1990.

The cathodic protection system consists of a titanium mesh anode encased in 5500 psi concrete. The cathodic protection system is designed to protect the reinforcing steel in the crash wall and the new steel in the structural jacket. Potential ports were established to measure the potentials. A protection current of 1.9A was required based on E-log I findings. The corresponding current densities are:

2.14 mA/ft^2 of concrete surface
0.74 mA/ft^2 of total rebar area
7.14 mA/ft^2 of anode area

The cost of the cathodic protection system was $21.87 per square foot of the concrete surface (based on 1991 - 1992 cost figures).

The cathodic protection system as installed performed well. The polarizations of the old steel and the new steel at the protection current level were 104 mV and 97 mV CSE respectively. The current off potential of the reinforcing steel at protection current level was well below the hydrogen evolving potential. It is recommended that the system be checked by measuring the depolarization twice a year and any appropriate current adjustments be made. It is also recommended that the output waveform of the rectifier be checked for spikes when the rectifier is turned off and on for measuring instant off potentials.

2) MAURY RIVER BRIDGE, LEXINGTON, VIRGINIA

The structure is a four-lane bridge over Maury River in Lexington, Virginia and was built in 1967. The total concrete surface area of seven piers to be cathodically protected was 8260 ft^2.

The piers were delaminated (total delamination of 1369 ft^2 over the surveyed area of 9450 ft^2) as a result of deicing saltwater leakage through expansion joints. All the delaminated concrete was removed and patched to original shape with 5700 PSI pneumatically applied concrete (shotcrete).

The cathodic protection system consists of platinum wire (primary anode), water-based carbon conductive coating of thickness 15 to 20 mil (secondary anode) and a white colored decorative paint. The cathodic protection system was designed to protect the hammer head and the top 25 ft. of each pier. The potentials were measured using embedded graphite reference electrodes. A protection current of 1.9A was required based on E-log I findings. The corresponding current densities are:

1.63 mA/ft^2 of concrete surface
2.63 mA/ft^2 of rebar area
1.63 mA/ft^2 of anode area

The cost of the cathodic protection system was $12.34 per square foot of the concrete surface (based on 1991 - 1992 cost figures).

The carbon conductive paint anode responded well. The polarization at protection current was 120 mV. It is recommended that depolarization on all reference cells be monitored every 3 to 6 months and the current requirement be adjusted, if necessary, annually.

3) HOWARD FRANKLAND BRIDGE, TAMPA, FLORIDA

This marine structure is a four-lane bridge over Tampa Bay and was built in 1960. A total of 126,189 ft^2 of arc-sprayed zinc anode, 1984 ft^2 of perforated zinc sheet anode and 229 bulk zinc anode assemblies are being installed on the substructure.

The delaminations found in the area designated to receive arc-sprayed zinc were removed and left unpatched. The delaminations found in all other areas were removed and patched to restore the members to their original shapes.

The cathodic protection system consists of anodes of three different kinds:

a) Arc-sprayed zinc anodes for portions of piers above the high tide level (e.g., pier caps, beams, and underside of deck).
b) Perforated zinc sheet anodes for portions of piers exposed to tidal variations and seawater splash.
c) Bulk zinc anodes for portions of the piers submerged in seawater.

The performance of these sacrificial systems was monitored using embedded rebar probes. The current flowing to the probe was measured using a zero resistance ampmeter in series between the anode and the probe. The probe in the sprayed zinc area recorded 2.63 mA/ft^2 of rebar surface area. The corresponding polarization and depolarization values were 169 mV and 154 mV respectively. The probe in the bulk zinc anode area recorded 4.46 mA/ft^2 of rebar surface area. The corresponding polarization and depolarization values were 111 mV and 115 mV respectively. No data were available on the perforated zinc sheet anode as it was not yet installed.

The cost of each of these systems were calculated per square foot of the concrete surface (based on 1992 cost figures) and are as follows:

Bulk zinc anodes on piles	- \$11.31/ft^2
Bulk zinc anodes on piers	- \$6.90/ft^2
Arc-sprayed sacrificial zinc anode (without enclosures for collecting zinc dust)	- \$3.34/ft^2
Perforated zinc sheet anode	- \$38.50/ft^2

Polarization and depolarization of the zinc systems were rapid. Performance of the bulk zinc anodes largely depends on moisture content of the concrete. It is recommended that the adequacy and distance of protection above the water line offered by the bulk zinc anodes be studied in greater detail because previous studies indicate that a similar structure (i.e., seawater canal in Saudi Arabia) showed that protection extends only a few inches above the water line.

4) SIXTH STREET BRIDGE OVER BIG SIOUX RIVER, SIOUX FALLS, SOUTH DAKOTA

The structure is a four-lane bridge (with a sidewalk on either side) over Big Sioux River and was constructed in 1975. A total of 11,100 ft^2 of deck area and 5,203 ft^2 of sidewalk was protected by cathodic protection.

The deck had 10 percent delaminations and the average rebar level chloride (from deicing salt) was 10.2 lb/yd^3.

The cathodic protection system consists of titanium mesh encapsulated in a low slump dense concrete overlay for the deck. The sidewalk had the same system except that the titanium mesh was encapsulated in a 0.75-in.-thick acrylic grout. Embedded probes were installed to monitor the performance of the cathodic protection system. The cathodic protection system was not activated due to debonding of the acrylic mortar on the sidewalk. The cause of the delamination is being investigated. It is recommended that the system be activated, adjusted and monitored after resolving the debonding issue.

The cost of the deck and sidewalk systems were \$9.76 and \$11.74 per square foot of the concrete surface respectively (based on 1991 - 1992 cost figures).

5) EAST DUFFINS CREEK BRIDGE, PICKERING, ONTARIO

The structure is a two lane bridge over East Duffins Creek and was built in 1973. A total of 6456 ft^2 of concrete surface was protected by cathodic protection.

The deck is exposed to deicing salt, had 86 ft^2 of delaminations and spalls in addition to 29 ft^2 of patched spalls. The average half-cell potential was -300 mV (CSE) with 16.6 percent more negative than -350 mV (CSE).

The cathodic protection system consists of DURCO Pancake Type I anodes overlaid with coke asphalt. Graphite reference cells were embedded in the deck to monitor the performance of the cathodic protection system. Protection current was determined by activating the system at various current levels and measuring the corresponding 4-hour depolarizations. Full protection was achieved at 0.17 mA/ft^2 of the concrete surface area. The average 4 hour depolarization was 323 mV.

No cost information was available on this structure.

6) I-64 BRIDGE, CHARLESTON, WEST VIRGINIA

The structure is a bridge-viaduct subject to deicing salt and located on I-64 in Kanawha County, West Virginia. A total of 140,164 ft^2 of concrete surface area was protected by cathodic protection in 1984.

The deck had 1 percent delaminations and spalls which were patched.

The cathodic protection system consists of platinized niobium wire placed in slots longitudinally and carbon strands placed in transverse slots. The slots were then filled with FHWA conductive polymer grout. The slots were 1/2 in. wide and 3/4 in. deep. Potentials were measured using embedded silver-silver chloride reference cells. Protection current density varied from 0.909 mA/ft^2 to 1.618 mA/ft^2 of the concrete surface for different zones. Shift in IR free potential ranged from 70 mV to 390 mV (corresponding to the protection current) for different zones.

The 1984 cost of the cathodic protection system was $5.50 per square foot of the concrete surface. This translates to $7.00 per square foot in 1992 dollars.

The cathodic protection systems have performed satisfactorily except that some rectifier circuits exhibited operational problems. It is recommended that the rectifier operation problems be corrected. It is also recommended that the cathodic protection system be checked by measuring the depolarization at least once a year and any appropriate current adjustments be made.

7) BROOKLYN BATTERY TUNNEL, NEW YORK, NEW YORK

The structure is a 31-ft. diameter concrete tunnel under water, carrying two lanes of traffic. Deicing salt is used to maintain the winter traffic. The tunnel has three levels; the fresh air duct as the first level, the roadway between the fresh air duct and the exhaust duct as the second level, and the exhaust duct as the third level. The construction of this structure took over a decade and was opened to traffic in 1950. The total area to be cathodically protected was 111,212 ft^2 of concrete surface area.

The 14-inch-thick roadway concrete slab had extensive delaminations and spalls on both the top and bottom surfaces. The chloride contents at the rebar levels were well over the chloride threshold limit. The corroded rebars exposed from under the delaminations showed extensive cross section loss and hence were replaced by fusion bonded epoxy coated rebars welded to the original uncoated reinforcing steel.

The cathodic protection system consists of a titanium mesh anode encapsulated in 3500 psi shotcrete. The potentials were measured with embedded graphite electrodes. The E-log I showed a protection current level of 5 to 8 A. Depolarization tests indicated that about 6 A of current was enough to satisfy the 100 mV NACE criteria with respect to the bottom rebar. The current density corresponding to 6 A of current is 2.25 mA/ft^2 of concrete surface area.

The cost of the cathodic protection system was $11.10 per square foot of the concrete surface area.

The cathodic protection system performed satisfactorily in that the bottom reinforcing steel exhibited depolarizations in excess of 100 mV. However, the depolarizations on the top reinforcing are less than 100 mV, indicating the possibility of only partial protection. It is recommended that the influence of a rectifier current spike on current off potential values be quantified. The source of the spike should be identified and removed to facilitate accurate measurement of current off potentials by remote monitoring.

8) YAQUINA BAY BRIDGE, NEWPORT, OREGON

This marine structure is a two-lane bridge built in 1934. A total of 273,196 ft^2 of concrete surface area (deck underside, beams and stringers) is to be cathodically protected. Work on this structure was delayed and hence the information presented herein is only that collected by mail from the Oregon Department of Transportation.

A substantial area of the deck, beam, and bent surfaces of the Yaquina Bay Bridge exhibited delaminations and spalls. A total of 14,003 ft^2 of delaminations were identified during a 1989 corrosion condition survey. All the delaminated area will be replaced with pneumatically applied mortar (shotcrete) with a mix of one part of cement to 3.5 parts of dry loose sand by volume. Sodium chloride will be added as an admixture at the rate of 4 lb/yd^3 of pneumatically applied mortar.

The cathodic protection system consists of 2.5 in. diameter brass plates attached to the concrete surface with a Concresive epoxy adhesive (primary anode) and thermally sprayed zinc over the entire surface of the concrete to be protected cathodically (secondary anode). The performance of the cathodic protection system will be monitored using embedded graphite and silver/silver chloride reference cells.

Installation of the anode was delayed due to the problems with electrical shorts. Hence Kenneth C. Clear, Inc. (KCC INC) could neither obtain technical information nor collect cost information before the C-102G contract reporting deadline.

Detailed reports on each structure follow.

INFORMATION ON NEW CP SYSTEM FOR C-102D

1	Name of the state	FLORIDA
2	Name of the structure	GANDY BRIDGE
3	Location	STATE ROAD 92 TAMPA, FLORIDA
4	Part of the structure under CP	PIER (CRASH WALL)
5	If substructure, anode position from water level	BOTTOM PORTION OF STRUCTURE (ANODE) AT LOW TIDE ELEVATION
6	Structure - Inland or coastal ? - On water or land ?	COASTAL ON WATER
7	Any repair work needed before CP	CRACK INJECTION
8	If so, cost of repair	UNKNOWN
9	Name of the contractor who did repairs	REPAIRS NOW IN PROGRESS PRESSURE CONCRETE CONSTRUCTION CO.
10	Type of anode	TITANIUM MESH
11	Any specific reason for selecting a particular type of anode	1. IT ADAPTS TO STRUCTURE CONFIGURATION 2. TESTED PERFORMANCE ON PREVIOUS PROJECTS

12	Name of the anode supplier	ELGARD CORP.
13	Total area under CP	1036 SQUARE FEET
14	Number of zones	ONE
15	Number of rectifiers	ONE
16	Number of circuits per rectifier	ONE
17	Name of the rectifier supplier	GOODALL
18	Rectifier type - Constant current - Constant voltage - Constant potential	CONSTANT CURRENT CONSTANT VOLTAGE
19	Actual rectifier specifications	VIP CONSTANT VOLTAGE - CONSTANT CURRENT WITH DIGITAL METER AND STAINLESS STEEL CABINET VOLTS - AMPS
20	Monitoring methods(remote?)	ON-SITE
21	Name of the contractor for CP work	PRESSURE CONCRERE CONSTRUCTION
22	Any consultant hired /Name	NONE
23	Expected start date	ON-GOING 05/10/91
24	Expected completion date	JUNE - JULY 1991
25	Estimated total cost	?
26	Other comments	TITANIUM MESH ANODE CAST IN STRUCTURAL CONCRETE.

Evaluation Report on The Repair and Rehabilitation of Gandy Bridge, Tampa, Florida

June, 1993

Prepared For
Florida Dept. of Transportation (FDOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

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Evaluation Report on the Repair and Rehabilitation of Gandy Bridge, Tampa, Florida

BACKGROUND

The structure is a two-lane bridge over Tampa Bay, Tampa, Florida and was built in 1955. The crash wall developed cracks due to the impact of barges. The crash wall was observed to exhibit large cracks extending from 1.5 ft. below the water line to the top. These cracks were observed on both sides of the crash wall and were concentrated on an area between the two columns. Hence, the crash wall was designated to be rehabilitated from a structural and corrosion standpoint. The rehabilitation of the crash wall was monitored under C-102G for technical viability, performance, and the cost of the cathodic protection system. A total of 887 ft^2 of concrete surface was cathodically protected.

Half-cell potential testing done prior to the repair of the crash wall indicated active potentials at elevations up to 4.5 ft. above the high water line. Summary of half-cell potential (CSE) measurements are as follows:

Number of Measurements = 15
Average = -362mV
Maximum = -568mV
Minimum = -201mV
Standard Deviation = 98mV

Analysis of chloride samples from the field showed a chloride content at the reinforcing steel depth in the range of 2.8 to 7.2 lb/yd^3. As the structural jacket was needed to strengthen the cracked crash wall it was recommended by the Florida Department of Transportation (FDOT) that mesh cathodic protection system be installed to achieve protection against corrosion of the existing reinforcing steel (old) as well as the new (outer) steel for the structural jacket.

REHABILITATION BEFORE INSTALLATION OF CP

The structure was surveyed in April 1990 by personnel from the FDOT Materials Office. The cracks that developed, due to impact of barges, were believed to have accelerated the ingress of chlorides to the steel and caused corrosion of rebar. Also, previously a gunite repaired area on the crash wall showed extensive cracking and some delamination. Severe corrosion and metal loss were observed by the FDOT in the past during earlier repairs.

The delaminations were removed and patched with regular FDOT class IV concrete. The cracks in the crash wall, which were perpendicular to the future anode plane, were epoxy injected. The concrete surface was prepared by bush hammering. The concrete surface was also lightly sandblasted just before fixing the Elgard 300 mesh anode. The mix design of the FDOT class IV concrete (5500 psi) used for the patching and the structural jacket is as follows:

Coarse Aggregate (crushed limestone)	1600 lb
Fine Aggregate (silica sand)	1120 lb
Cement (type II)	575 lb
Air Entraining Admixture (Darex, W.R. Grace)	4 oz
Water Reducing Admixture (WRDA 79, W.R. Grace)	56.4 oz
Fly Ash	130.0 lb
Water	279.1 lb
Slump Range	0 to 3.5 in.
Air Content	3% to 6%
Water Cementitious Ratio	0.40

The actual values of slump, air content, and 28 day compressive strength achieved were 3.25 in., 3.7 percent, and 7290 psi respectively.

The new (outer) reinforcing steel cage and the PVC conduits for the post-tensioning cables were erected in place taking care to ensure the electrical isolation between the anode and the steel.

THE CP SYSTEM

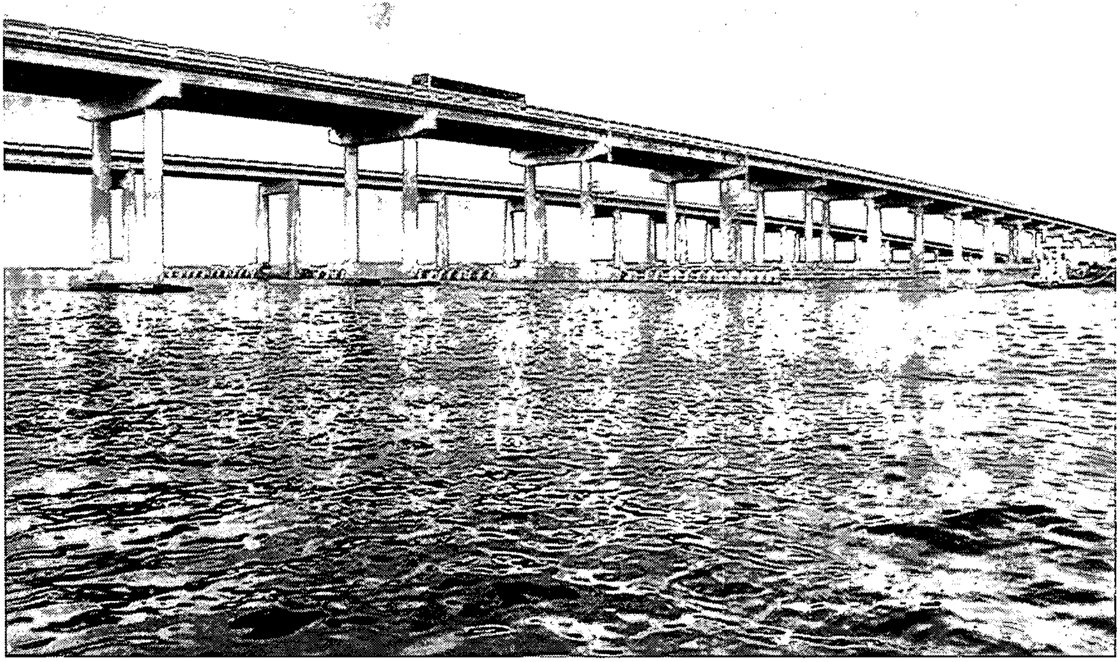
The mixed metal oxide mesh anode (Elgard 300) was secured onto the lightly sandblasted surface using the plastic fasteners. The titanium strip, to be used as the current distributor bar (CD bar), was welded to the mesh at 3 in. intervals. The entire system (mesh, new reinforcement, and the PVC conduits for post-tensioning cables) was encased in FDOT class IV structural concrete. Figure 1 shows the anode installation process.

Ports were established to monitor the half-cell potential of the anode and the steel. Ports for monitoring the potential of the anode were drilled past the new (outer) steel cage (but not through it) to within 3 in. of the anode.

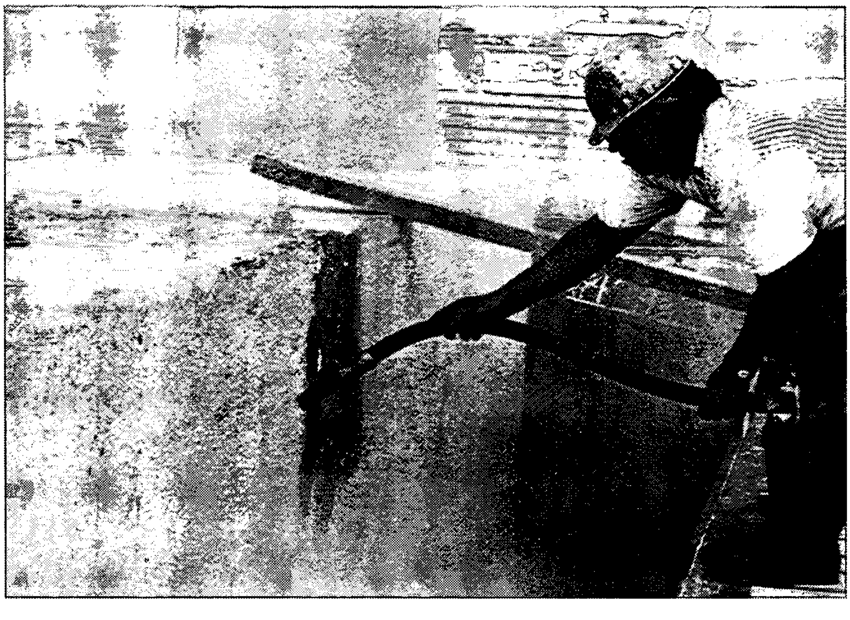
Ports for monitoring the potential of the old (inner) steel cage were drilled past the new (outer) steel cage and the anode to within 2 in. from the old (inner) steel cage. The sides of these port holes were epoxy coated. Also, hollow PVC tubes were installed in all these ports to facilitate the snug fit of the half-cells and to eliminate the possibility of the half-cell touching and wetting the sides of the port hole while being inserted. Potential of the new (outer) steel was measured from the surface of the concrete (structural jacket).

The rectifier is a silicon controlled, air cooled, constant current DC output rectifier. The rectifier has one circuit with 4 A and 24 V capacity. A portable rectifier with a full wave, unfiltered output was used to do E-log I testing as the installed rectifier was suspected to introduce spikes whenever the circuit was turned on and turned off. All the connections for the E-log I test were established and checked to ensure proper connections. The old (inner) and the new (outer) steel were tied together and powered using one circuit.

A total of 887 ft^2 of concrete surface area was under CP. The ratio of area of steel to concrete on plane surfaces was taken as 1 and at the curved nose area as 1.5 per FDOT. The surface area of the old steel was calculated based on the concrete surface of the crash wall covered by the anode mesh, and that of the new steel was calculated based on the concrete surface of structural jacket (crash wall surface area, covered by the anode mesh, after casting

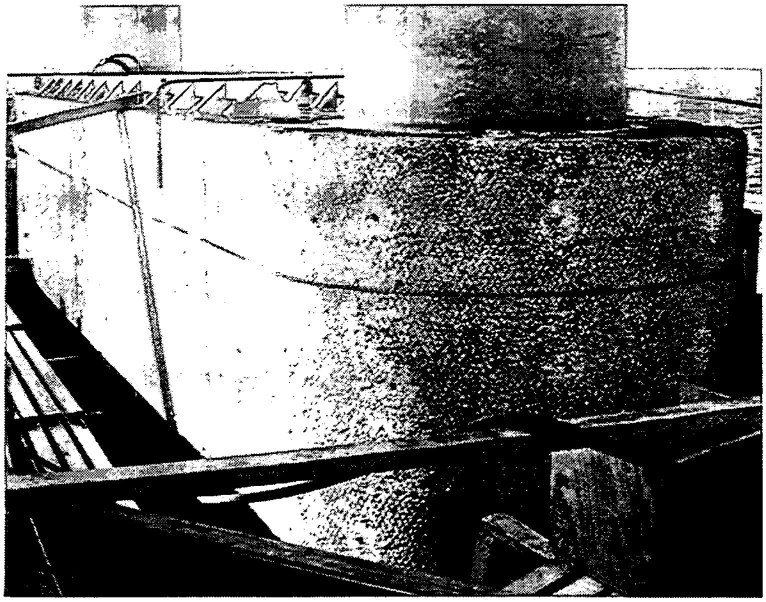


Overall View of the Structure

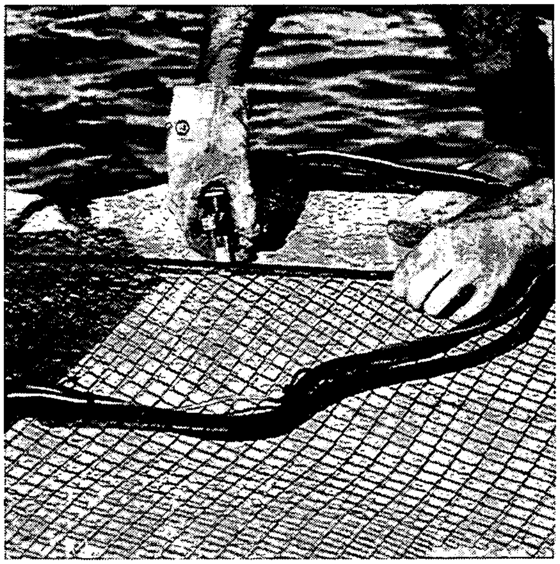


Sandblasting in Progress

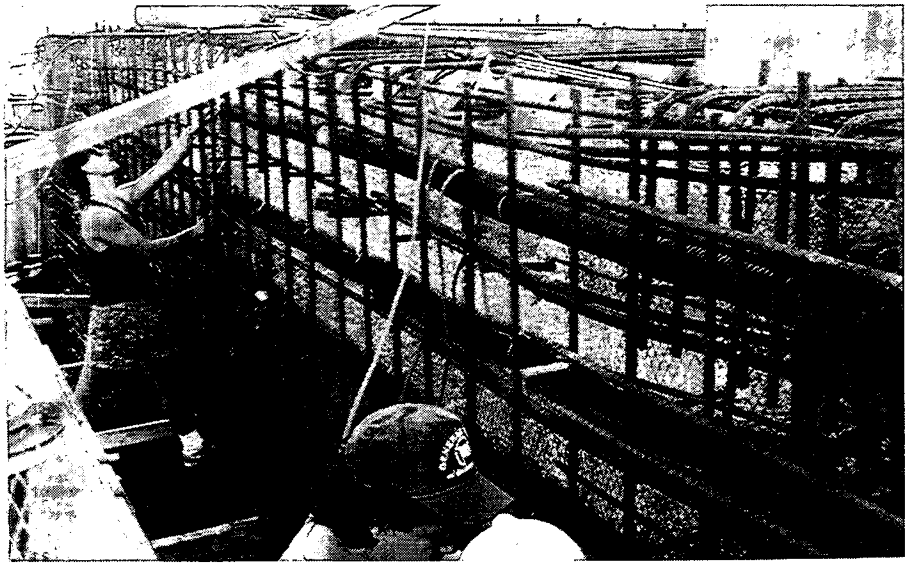
Figure 1. Installation and Activation of Anode



Installation of Anode in Progress

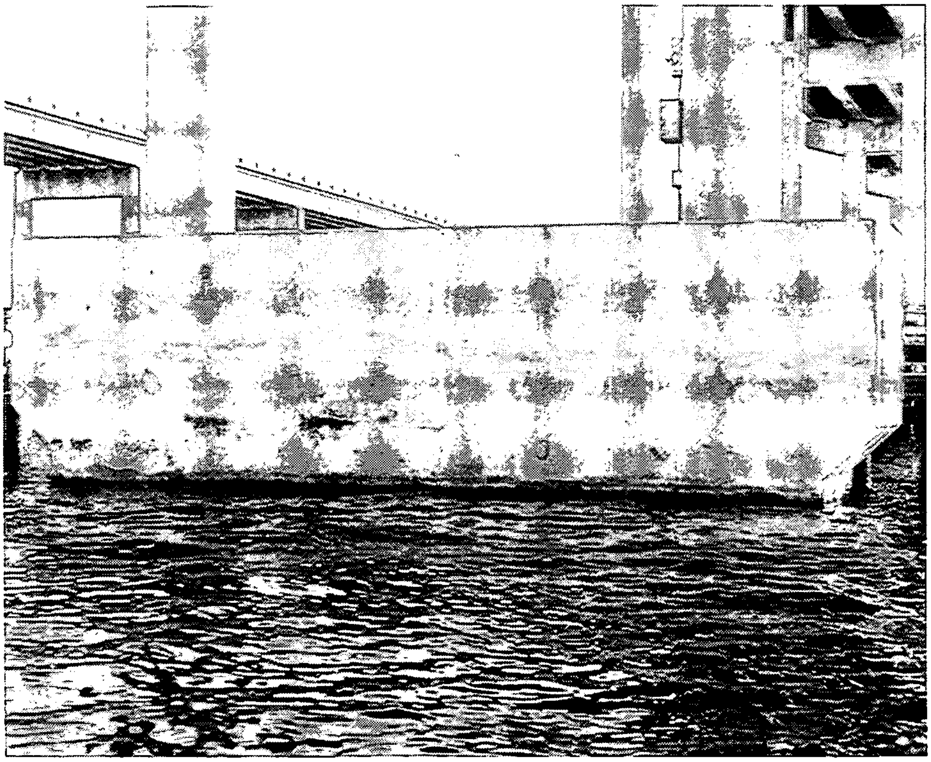


Current Distributer Bar Resistant Spot Welded to the Anode Mesh

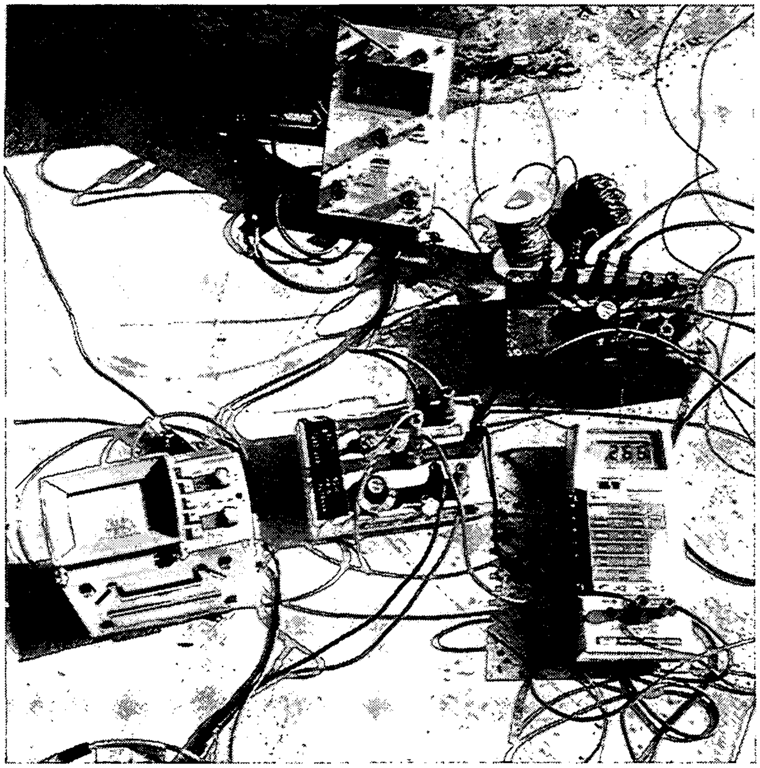


Post-tensioning Duct and New Steel in Place

Figure 1. (cont'd) Installation and Activation of Anode



Completed Cathodic Protection System and the Structural Jacket



Activation in Progress

Figure 1.(cont'd) Installation and Activation of Anode

the structural jacket). The surface area of the old and the new steel were 1,000 ft^2 and 1,565 ft^2 respectively. The total surface area of steel under CP is 2,565 sq. ft.

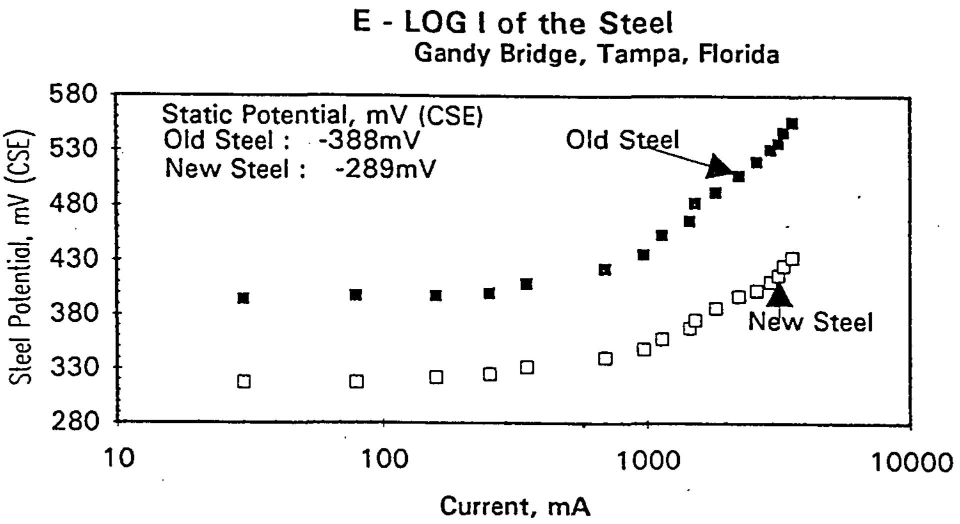
TEST PROCEDURE DESCRIPTION FOR COMMISSIONING THE SYSTEM

Various tests including continuity, system resistance, E-log I and current off potential were done to determine the feasibility and the performance of the CP system. Continuity tests were performed by FDOT using a procedure similar to AASHTO TF #29 (final draft) section 650.37. The system resistance (i.e., the resistance between the steel and the anode lead) was measured to detect any electrical shorts or near shorts per AASHTO TF #29 (final draft) section 653.39.12. The E-log I test was performed per the NACE standard RPO290-90. The anode was connected to the positive of the rectifier and the steel to the negative of the rectifier. The current was increased in steps at regular intervals. An electronic current interrupter with varying off period capability was used to precisely and regularly shut the current off for 100 milliseconds in every 2 seconds. The current off potential (i.e., IR free) of the steel and the anode were measured at each current increment using the scope null method. These values along with the corresponding current levels were plotted as an E-log I plot to determine the polarization characteristics, the appropriate cathodic protection current, and the corresponding current density on the steel and the anode.

RESULTS OF TESTING

The continuity of the old and the new steel cage were checked by FDOT and found to be continuous. The system resistance between the old steel and the anode, and the new steel and the anode was measured by the DC volts method and found to be 369 mV and 363 mV respectively. As these values are much higher than 1 mV defined in AASHTO, as an indicator of continuity, it can be concluded that the anode is electrically isolated from both the old and the new steel cage.

Figure 2 shows the E-log I plot for both the steel and the anode. It was determined that 1.9A of current was required for protection. The polarization of the old and the new steel at this current level were 104 mV and 97 mV respectively. Also, at this current level E-log I of



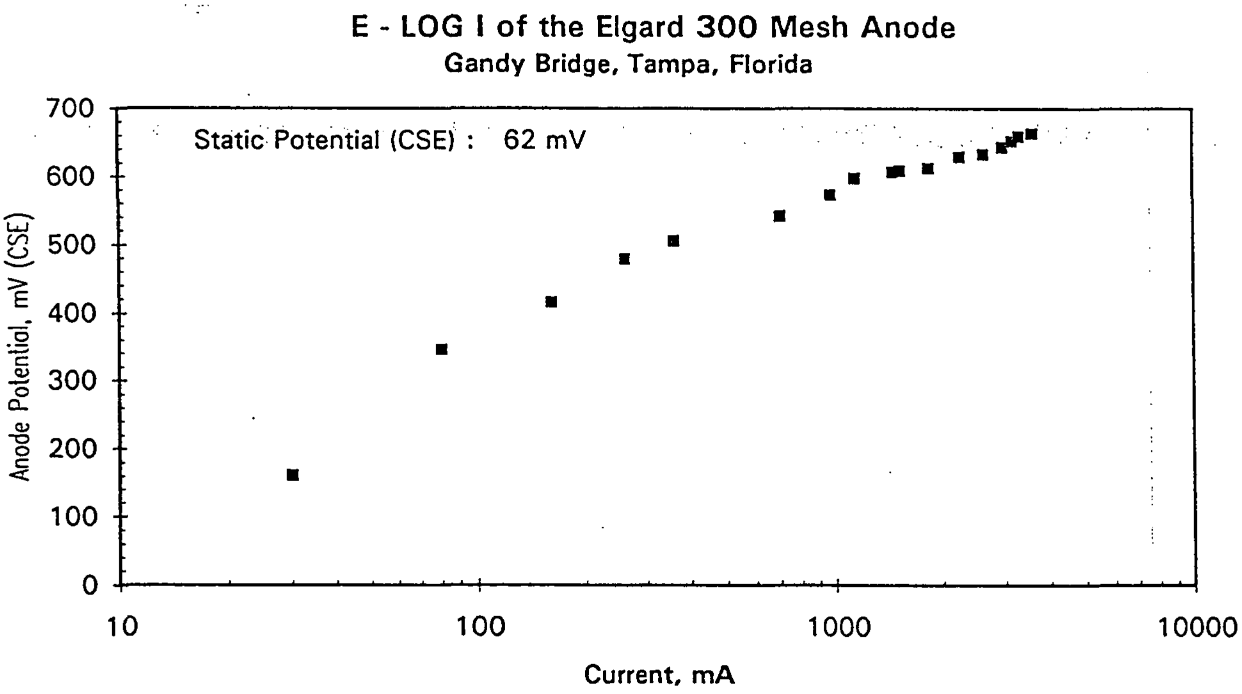


Figure 2. E-log I Plot for Steel and Anode

the anode showed that the anode operated at a potential more positive than 700 mV CSE. The potential of the anode seemed to level off at this range indicating in all likelihood a stable operating polarized potential at the current level required for protection. The corresponding current densities are:

2.14 mA/ft^2 of concrete surface
0.74 mA/ft^2 of total rebar area
7.14 mA/ft^2 of anode area

CONCLUSIONS

- The CP system as installed performed well.
- Protection was achieved at 2.14 mA per square foot of the concrete surface area.
- Current off potential of steel at this current level was well below the hydrogen evolving potential.

RECOMMENDATIONS

- The output waveform of the rectifier should be checked for spikes when the rectifier is turned off and on.
- The performance of the CP system should be checked by measuring the depolarization twice a year and any appropriate current adjustments should be made.

COST ANALYSIS

The cost of CP system was $21.87 per square foot of the concrete surface.

This was primarily a structural strengthening project and, as such, many costs were incurred which did not relate to cathodic protection. However, cost data were collected on as many activities as possible.

The cost of the CP system was obtained as the sum of labor, material, and special equipment used. The total hours of labor for each activity, the skill level, and the hourly rate for each skill level were obtained primarily from the payroll in conjunction with the bi-weekly progress report from the state DOT inspector and by direct field observation. The labor rates were calculated to reflect the overhead and profit (overhead and profit were taken as 100 percent of the basic labor rates; FDOT provided a figure of 85 percent overhead and assuming 15 percent profit and variations).

A summary of total man-hours of each skill level (spent by each contractor) towards each CP related activity was listed using the payrolls, state inspectors bi-weekly progress reports, and the direct field observation notes. The quantity of materials used was obtained from the supervisor and compared with the estimate made by direct observation during the field visit. The unit prices of materials were obtained from the manufacturer to calculate the cost of the materials. The cost of rentals for any special equipment employed was also determined and included in the appropriate activity. The costs of labor, material, and equipment for activation, data processing, and report writing were calculated based on field observation notes and estimation.

Table 1 lists all the costs of all pertinent work done on the crash wall. Only those activities that were directly related to CP were considered for calculating the cost of CP (e.g., neither the cost of installing the structural jacket work nor the cost of post-tensioning system were considered as these were needed repairs whether the CP was installed or not). In other words, the calculation defines only the extra cost of CP. The overall project cost was about $130,444.65 (taken from the final pay estimate). Thus, CP represents about 15 percent of the total cost.

Table 1. Cathodic Protection Cost Estimate

Gandy Bridge, Tampa, Florida

Description	Labor			Material			Special Equipment		
	Man-hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
1. Surface Preparation - bush hammering									
Skilled	51.00	19.00	969.00						
Unskilled	97.75	15.00	1466.25						
2. Anode Installation - mesh & CD bar				1000ft^2	L.S.	6982.00	Welder	L.S.	500.00
Skilled	51.00	19.00	969.00						
Unskilled	68.00	15.00	1020.00						
Supervisor	17.00	25.00	425.00						
Corrosion Tech.	17.00	20.00	340.00						
3. Rectifier Installation				1	each	2100.00			
Electrician	17.00	23.10	392.70						
4. A.C. Power				1	L.S.	130.00	1 Switches, JB's	L.S.	128.00
Electrician	17.00	23.10	392.70						
5. Pre-activation									
Technician	20.00	20.00	400.00						
Specialist	10.00	42.00	420.00						
6. Activation				1	L.S.	100.00	1 Scope & Rectifier	L.S.	250.00
Technician	20.00	20.00	400.00						
Specialist	10.00	42.00	420.00						
7. Data Processing & Preparing Activation Report							1 Computer use	L.S.	130.00
Technician	10.00	20.00	200.00						
Specialist	30.00	42.00	1260.00						
Total Cost = 19,394.65			**9074.65**			**9312.00**			**1008.00**

Cost per sq. ft. of area covered by anode = 19,394.65 = $21.87

Evaluation Report on The Repair and Rehabilitation of Maury River Bridge, Rockbridge County, Lexington, Virginia

June, 1993

Prepared For
Virginia Dept. of Transportation (VADOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for them to interact with various agencies to collect the technical and cost data. KCC INC would also like to thank the Virginia Department of Transportation for their cooperation and timely assistance. State research engineer, Dr. Jerry Clemena, and his fellow workers are appreciated for their assistance in collecting the data on technical performance of the carbon conductive paint anode system and the cost of installing this system.

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Evaluation Report on The Repair and Rehabilitation of Maury River Bridge, Rockbridge County, Lexington, Virginia

BACKGROUND

The structure is a four-lane bridge over Maury River in Rockbridge County, Lexington, VA and was built in 1967. Both the northbound and southbound bridge decks and substructures were designated for repair. However, the substructure was also protected cathodically in addition to repair work. The work on the substructure of the northbound bridge was monitored under C102G for technical viability, performance, and the cost of the cathodic protection system per the recommendation of SHRP.

The substructure was extensively surveyed in 1991 for delaminations and spalls. A total of 1369 ft^2 of delamination was observed over a total surface area of 9450 ft^2.

The leakage of the deck deicing salt through the joints seemed to be the cause of distress observed on the substructure.

REHABILITATION BEFORE INSTALLATION OF CP

All the delaminated and spalled concrete was removed and restored to the original shape using pneumatically applied mortar (shotcrete). The shotcrete eliminated the need for form work to do repairs, and also aided in achieving the original shape and still have a repair concrete of good quality. The mix design used for shotcrete was one part of cement to 3 parts of fine aggregate by volume.

The average comprehensive strength of the shotcrete was 5710 psi (obtained by testing the cores extracted from the test panels).

THE CP SYSTEM

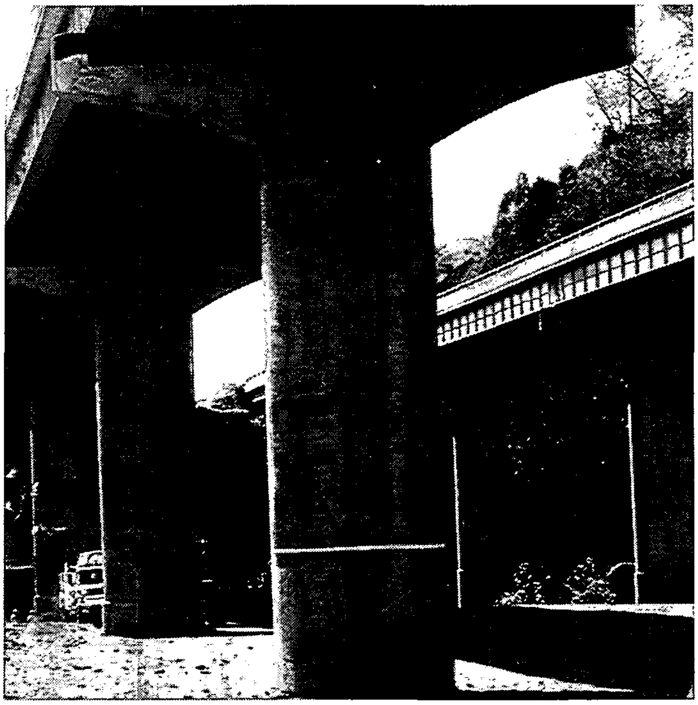
The concrete surface, after repair, was lightly sandblasted prior to application of the anode. The platinum wire was fixed to the concrete surface using a mesh tape. This was then coated with conductive paint. Then the entire surface designated to receive the anode was painted with water-based carbon conductive coating to a wet thickness of 15 to 20 mil. The anode was coated with a white color decorative paint (Latex SW B-66 with a coverage rate of 200 sq. ft per gallon per coat). Figure 1 shows the anode installation process and the instrumentation for E-log I tests.

The rectifier is a full wave, unfiltered rectifier and has two modes of operation; auto and manual. Each circuit has 10 A, 24 V capacity. The rectifier had seven circuits (one pier per circuit) and each circuit had three levels of coarse tap settings and six levels of fine tap settings. A combination of these tap settings were used to obtain different current levels. E-Log I was done using these current outputs. The instant off potential of the reinforcing steel was measured by switching off the rectifier for about one second. The circuits were set at the required current level determined from the E-log I plot.

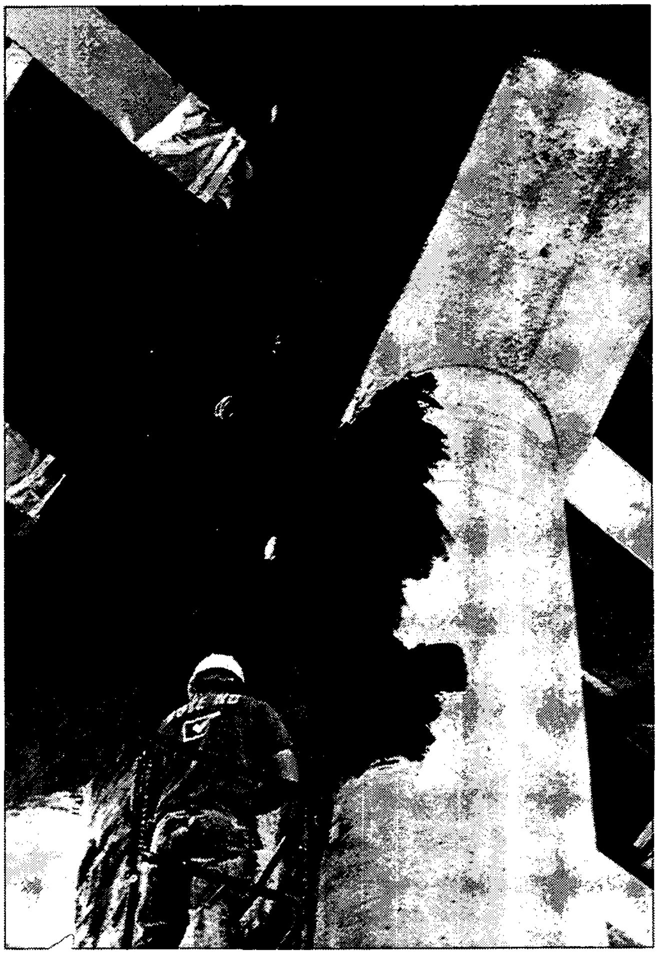
Each pier had 1,180 ft^2 of concrete surface under CP, totalling 8,260 ft^2 of CP area. The ratio of concrete to steel area is 0.62. The total surface of steel per pier (in the area covered by the anode) is 731 ft^2.

TEST PROCEDURE DESCRIPTION FOR COMMISSIONING THE SYSTEM

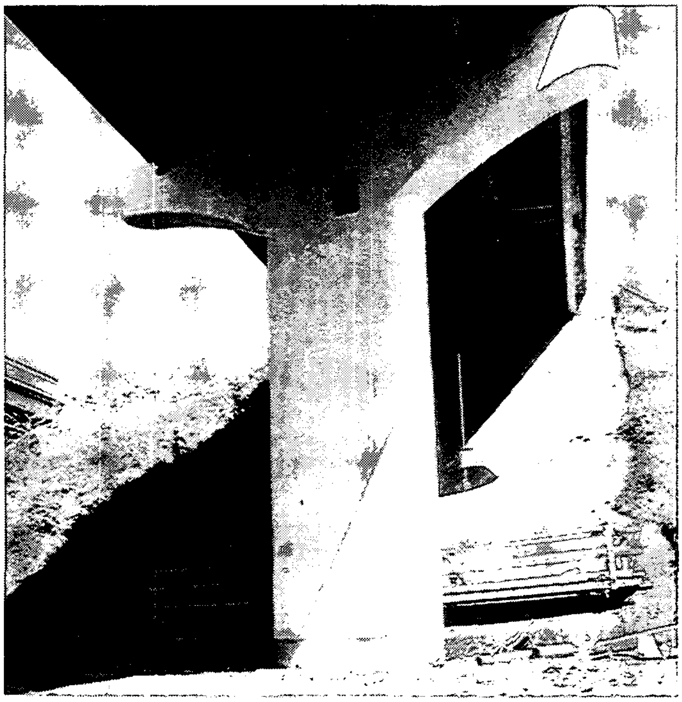
Various tests including continuity, system resistance, E-log I, and current off potentials were done to determine the feasibility and the performance of the CP system. Continuity and system resistance were measured per AASHTO TF #29 (final draft), sections 650.37 and 653.39.12 respectively. E-log I was performed per the NACE Standard RPO290-90. For E-log I, the anode was connected to the positive of the rectifier and the steel to the negative of the rectifier. The current was increased in steps at regular intervals. The current off potential of the steel and the anode were measured at each current increment by manually switching off the rectifier for 1 second per minute. The potential thus measured along with the corresponding current level



Anode Wires Fixed on the Piers

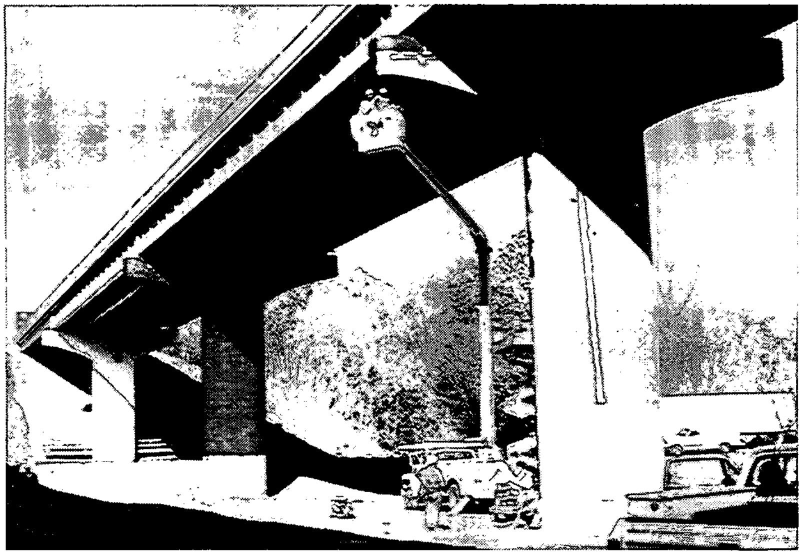


Application of Carbon Conductive Paint Anode

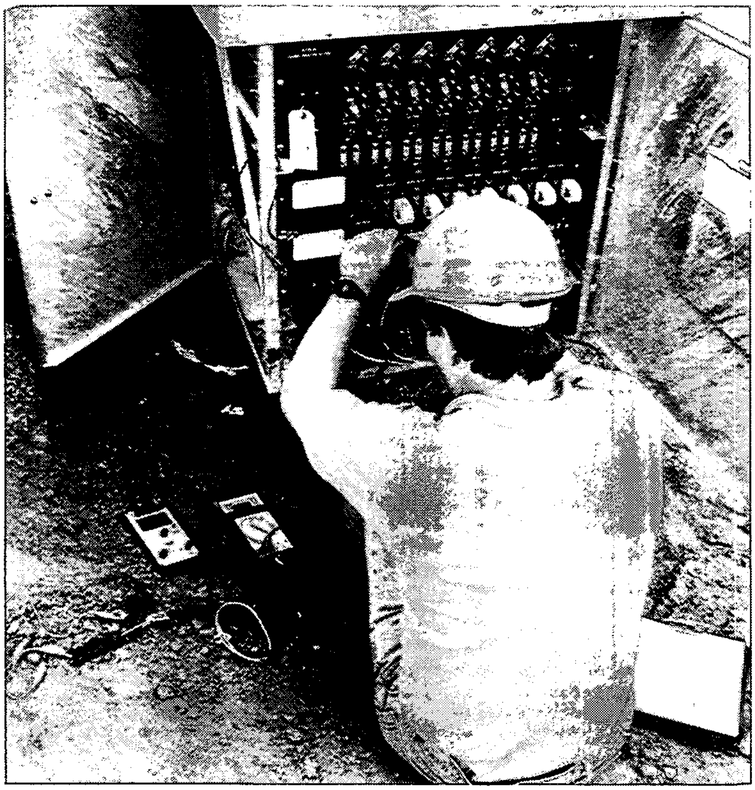


White Decorative Coat (Latex SW B-66) Over Conductive Paint

Figure 1. Installation and Activation of Anode



Steps in Anode Installation



Activation in Progress

Figure 1. (cont'd) Installation and Activation of Anode

was plotted as E-log I to determine the polarization characteristics, the appropriate cathodic protection current, and the corresponding current densities on the steel and the anode.

RESULTS OF TESTING

Continuity between rebar grounds and the system resistance of each zone were measured by AC resistance and the DC volts methods. AC resistances were measured using the Nilsson soil resistance meter and DC volts were measured using a digital multimeter. Table 1 gives the system resistance for each zone. AC resistance value ranged from 1.65 ohms to 2.30 ohms and the DC volts ranged from 0.374 V to 0.515 V. This clearly shows that the anode is electrically isolated from the rebar. Table 2 shows the individual measurements taken to check the continuity between rebar grounds. Although the AC resistance method indicated some areas of discontinuity (greater than 1 ohm), the DC volts measurements showed that they were all continuous within a zone. Half-cell potentials (both instant-off and static) of the anode and steel were measured using the embedded graphite electrode reference cells. The static potentials of the steel and the anode were measured before powering the system. The potentials thus measured were converted to copper-copper sulphate reference by adding -139 mV and are given in Table 3.

The E-log I test was performed on pier 6 and anode and steel polarization curves were obtained. The rectifier was operated in an auto mode in conjunction with taps and the current control knob to better adjust the current output. Care was taken to ensure that the current was continuously increased even when the tap setting had to be changed to the next higher level. At each current level, the anode and the steel were allowed to polarize for two minutes before measuring the instant-off potential. There were two embedded half-cells per zone, of which, one was used for measuring the potential of steel and the other for measuring the potential of the anode. The potential of the anode was measured between the embedded half-cell and the anode and of the steel between the embedded half-cell and the rebar. The instant-off potential was measured by manually switching off the rectifier. Figure 2 shows the anode and the steel polarization curves. The protection current for pier 6 is about 1.9 A. The corresponding concrete, anode, and steel densities are 1.63, 1.63, and 2.63 mA/ft^2 respectively. The rebar showed about 120 mV of

Table 1. Anode to Steel System Resistance - Maury River Bridge, Lexington, Virginia

Zone #	Resistance	
	A.C. Resist. ohms	D.C. Volts volts
1	1.70	0.515
2	1.65	0.454
3	2.00	0.430
4	2.20	0.435
5	2.20	0.374
6	2.30	0.403
7	2.05	0.378

Table 2. Rebar Continuity Measurements - Maury River Bridge, Lexington, Virginia

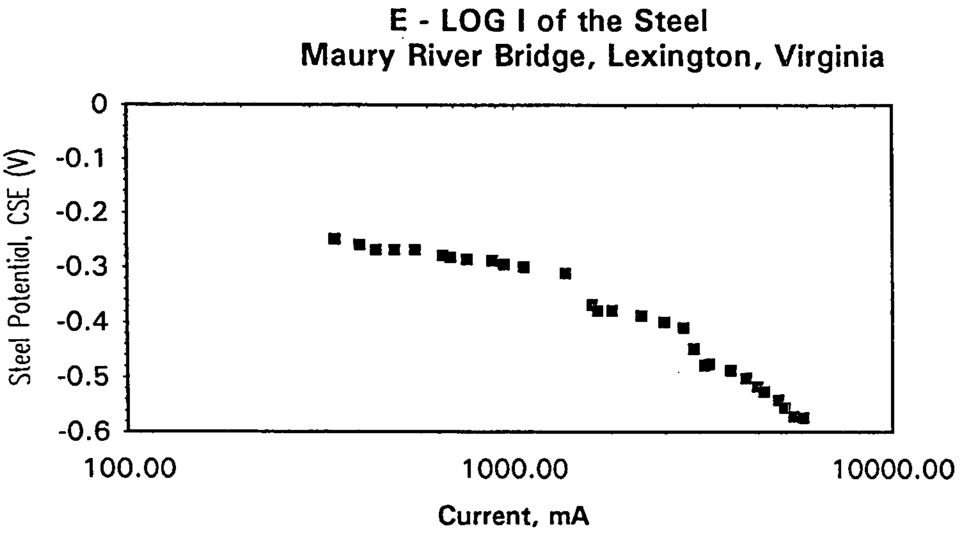
Description	Resistance	
	A.C. Resist. ohms	D.C. Volts volts
Zone 1 - Probe 1	0.350	0.00
Zone 1 - Probe 2	0.350	0.00
Probe 1 - Probe 2	0.365	0.00
Zone 2 - Probe 1	0.540	0.00
Zone 2 - Probe 2	0.540	0.00
Probe 1 - Probe 2	0.545	0.00
Zone 3 - Probe 1	0.730	0.00
Zone 3 - Probe 2	0.740	0.00
Probe 1 - Probe 2	0.545	0.00
Zone 4 - Probe 1	0.900	0.00
Zone 4 - Probe 2	0.890	0.00
Probe 1 - Probe 2	0.910	0.00
Zone 5 - Probe 1	1.080	0.00
Zone 5 - Probe 2	1.070	0.00
Probe 1 - Probe 2	1.100	0.00
Zone 6 - Probe 1	1.200	0.00
Zone 6 - Probe 2	1.200	0.00
Probe 1 - Probe 2	1.250	0.00
Zone 7 - Probe 1	1.450	0.00
Zone 7 - Probe 2	1.450	0.00
Probe 1 - Probe 2	1.450	0.00
Zone 1 - Zone 2	23.000*	12.60*
Zone 1 - Zone 3	24.000*	29.70*
Zone 1 - Zone 4	23.000*	121.80*
Zone 1 - Zone 5	22.500*	205.00*
Zone 1 - Zone 6	22.500*	77.00*
Zone 1 - Zone 7	21.500*	60.00*

* Values were unstable

Table 3. Static Potentials Measured Using Embedded Cells

Zone #	Half-Cell #	Half-Cell Potential before Powering	
		Steel CSE (V)	Anode CSE (V)
1	1	-0.239	0.284
	2	-0.231	0.291
2	1	-0.229	0.223
	2	-0.220	0.233
3	1	-0.282	0.146
	2	-0.274	0.154
4	1	-0.222	0.211
	2	-0.246	0.187
5	1	-0.284	0.088
	2	-0.279	0.092
6	1	-0.315	0.085
	2	-0.222	0.179
7	1	*	
	2	-0.255	0.121

* Values were unstable



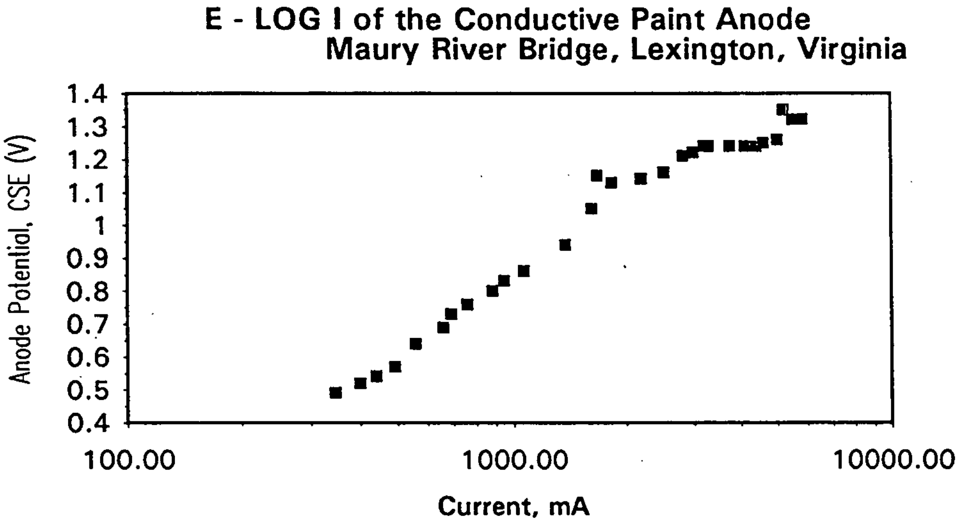


Figure 2. Anode and Steel Polarization Curves

polarization at this current level. The anode operated at 1.12 V (vs CSE) at this current level.

CONCLUSIONS

- The carbon conductive paint anode responded well to the applied protection current.
- Protection was achieved at a current density of 1.63 mA/ft^2 of concrete surface.
- Current off potential of steel at this current level was well below the hydrogen evolving potential.

RECOMMENDATIONS

- Re-evaluate the system at least annually and adopt any lower protection current requirements.
- Monitor depolarization on all reference cells every 3 to 6 months.

COST ANALYSIS

The cost of the CP system was $12.34 per square foot of the concrete surface.

The cost of the CP system was obtained as a sum of labor, material, and special equipment used. The total hours of labor, skill level, and the hourly rate for each activity was taken from the payroll in conjunction with the daily report from the State DOT inspector. The labor rates were calculated to reflect the overheads and profit (overheads and profits were assumed as 100 percent of the basic labor rates). A summary of the total man-hours of each skill level, spent by each contractor, toward each CP related activity was listed using the payrolls, State inspector's daily notes and direct field observations. The cost of any special equipment used on the job was calculated on the basis of rental charges. The AC power was equally divided between the northbound bridge and the southbound bridge. The AC power was tapped from a point 1,000 ft away from the rectifier. The cost of AC power was calculated as both per linear foot length and per square foot of the CP area. The cost of the external engineering services could not be obtained from the consultant and hence were estimated.

Table 4 lists the cost of all pertinent work done on the substructure. Only those activities directly related to CP (as given below) were considered for calculating the cost of CP (for example the cost of removal of delaminated concrete and the application of pneumatic concrete were not included as the structure had experienced extensive delamination and needed this repair work irrespective of whether the CP was applied or not). The overall project cost was about $481,343.28 (taken from the final pay estimate). Thus CP represents about 21 percent of the total cost.

CATHODIC PROTECTION COST

1. Surface preparation = 8,358.52
2. Instrumentation = 4,002.42
3. Checking for continuity = 5,556.04
4. Anode Installation = 41,358.68
5. Electrical Connections, Conduits = 25,011.33
6. Rectifier = 9,804.00
7. AC power (50% of 9975) = 4,987.50
8. External Engineering Services = 2,880.00

Total Cost = $101,958.49

Cost per ft^2 = 101,958.49/8260.00 = $12.34/ft^2

Table 4 provides additional detail.

Table 4. Cathodic Protection Cost Estimate

Maury River Bridge, Rock Bridge County, Lexington, Virginia

Description	Labor			Material			Special Equipment		
	Man-Hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
1. Concrete Removal and Sandblasting							Scaffolding 1.5 months	L.S	3,000.00
Power Tool Operator	335.50	20.00	6,710.00						
Skilled	587.50	18.00	10,575.00				Sandblaster	L.S.	2,055.00
Skilled	16.00	19.02	304.32				1		
Foreman	20.00	27.50	550.00				1.5 months		
Superintendent	62.00	24.00	1,488.00						
Superintendent	143.00	26.26	3,755.18						
Unskilled	311.00	15.00	4,665.00						
Subtotal = $33,102.50			28,047.50						5,055.00
2. Pneumatic Concreting & Finishing (3" deep)							Scaffolding 1	L.S	3,000.00
Power Tool Operator	241.00	20.00	4,820.00	2817 ft^2	1.00	2817.00	1.5 months		
Skilled	453.00	18.00	8,154.00				Pneumatic	L.S.	2,055.00
Superintendent	217.00	26.26	5,698.42				Pump		
Unskilled	283.00	15.00	4,245.00				1		
							1.5 months		
Subtotal = $30,789.42			22,917.42			2817.00			5,055.00
3. Surface Preparation							Sandblaster 1	L.S.	685.00
Unskilled	178.00	12.00	2,136.00				1.5 months		
Skilled	31.00	13.50	418.50						
Skilled	46.00	13.00	598.00						
Skilled	97.00	15.50	1,503.50						
Skilled	198.00	15.24	3,017.52						

Description	Labor			Material			Special Equipment		
	Man-Hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
Subtotal = $8,358.52			7,673.52						685.00
4. Instrumentation				14 Graphite Half-cells	150.00	2,100.00			
Unskilled	29.00	12.00	348.00						
Skilled	29.00	13.50	391.50						
Skilled	18.00	15.50	279.00						
Skilled	58.00	15.24	883.92						
Subtotal = $4,002.42			1,902.42			2,100.00			
5. Checking for Continuity									
Skilled	121.00	15.24	1,844.04						
Skilled	80.00	15.50	1,240.00						
Skilled	104.00	13.50	1,404.00						
Unskilled	89.00	12.00	1,068.00						
Subtotal = $5,5556.04			5,556.04						
6. Anode Installation				1 Lot	L.S.	23,991.00	Scissor Lift 1.5 months	2,000	3,000.00
Skilled	257.00	15.24	3,916.68						
Skilled	186.00	15.50	2,883.00						
Skilled	269.50	13.50	3,631.50						
Unskilled	308.00	12.00	3,696.00						
Skilled	18.50	13.00	240.50						
Subtotal = $41,358.68			14,367.68			23,991.00			3,000.00

Description	Labor			Material			Special Equipment		
	Man-Hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
7. Electrical Connections, Conduits, and Others				1	L.S.	5,148.83	Scissor Lift 1.5 months	2,000	3,000.00
Foreman	179.00	26.00	4,654.00						
Foreman	28.00	28.00	784.00						
Skilled	106.50	18.00	1,917.00						
Skilled	331.00	19.00	6,289.00						
Skilled	102.50	17.00	1,742.50						
Unskilled	123.00	12.00	1,476.00						
Subtotal = $25,011.33			16,862.50			5,148.83			3,000.00
8. Rectifier	16.00	19.00	304.00	1	L.S.	9,500.00			
Subtotal = $9,804.00			304.00			9,500.00			
9. A.C. Power				1	L.S.	4,000.00	1	L.S.	1,000.00
Foreman	66.50	26.00	1,729.00						
Skilled	35.50	18.00	639.00						
Skilled	55.00	19.00	1,045.00						
Skilled	40.00	17.00	680.00						
Unskilled	63.00	14.00	882.00						
Subtotal = $9,975.00			4,975.00			4,000.00			1,000.00

Description	Labor			Material			Special Equipment		
	Man-Hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
10. External Engineering Services									
Activation									
Engineer	18.00	40.00	720.00						
Technician	18.00	20.00	360.00						
Remote Monitoring Installation									
Engineer	18.00	40.00	720.00						
Monitoring									
Engineer	18.00	40.00	720.00						
Technician	18.00	20.00	360.00						
Subtotal = $2,880.00			2,880.00						

Evaluation Report on The Repair and Rehabilitation of Howard Frankland Bridge, Tampa, Florida

June, 1993

Prepared For
Florida Dept. of Transportation (FDOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to interact with various state agencies to collect the technical and cost data. KCC INC would also like to thank the Florida Department of Transportation's Corrosion Research Laboratory at Gainesville, Florida for their cooperation and timely assistance. State corrosion engineer, Mr. Rodney Powers, and his fellow workers are appreciated for their assistance in collecting the data on technical performance of the thermally sprayed sacrificial zinc system and the cost of installing this system.

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Evaluation Report on the Repair and Rehabilitation of Howard Frankland Bridge, Tampa, Florida

BACKGROUND

The structure is a four-lane bridge over Tampa Bay in Tampa, Florida and was built in 1960. All substructure members (piers, piling, footings and beams) that exhibited severe distress are designated to be repaired and rehabilitated. A total of 126,189 ft^2 of arc-sprayed zinc anode, 1984 ft^2 of perforated zinc sheet anode and 229 bulk zinc anode assemblies will be installed.

The delaminations found on the pilings and the footers were removed and patched. The portion of the footers and pilings underwater were protected using sacrificial bulk zinc anodes and the portion in the tidal and splash zones were protected using sacrificial perforated zinc cages. All the delaminated concrete on the caps, beams and the underside of the deck was removed and left unpatched. The caps, beams and the underside of the deck were protected using sacrificial arc-sprayed zinc.

A portion of the substructure repair and rehabilitation work was monitored under C-102G for technical viability, performance and the cost of the cathodic protection systems.

The design phase was completed in January 1991, bids were solicited in June 1991, construction began on February 1992 and is still in progress.

REHABILITATION BEFORE INSTALLATION OF CP

The extent of delamination was identified during the survey conducted just prior to installing the anode. The delaminations thus identified were removed in all the members designated for cathodic protection. The delaminated areas were not patched in those sections that were designated to receive the sacrificial arc-sprayed zinc system, but were patched in all other areas with a mix specified by the FDOT as listed below:

Cement (AASHTO M-85 Type II)	722 lb.
Coarse Aggregate	None
Fine Aggregate (Florida rock)	2575 lb.
Fineness Modulus	2.20
Specific Gravity	2.62
Fly Ash (ASTM C-618)	236 lb.
Water	375 lb.
Water-cementitious Ratio	0.39

In unpatched areas the arc-sprayed zinc would have direct contact with the steel.

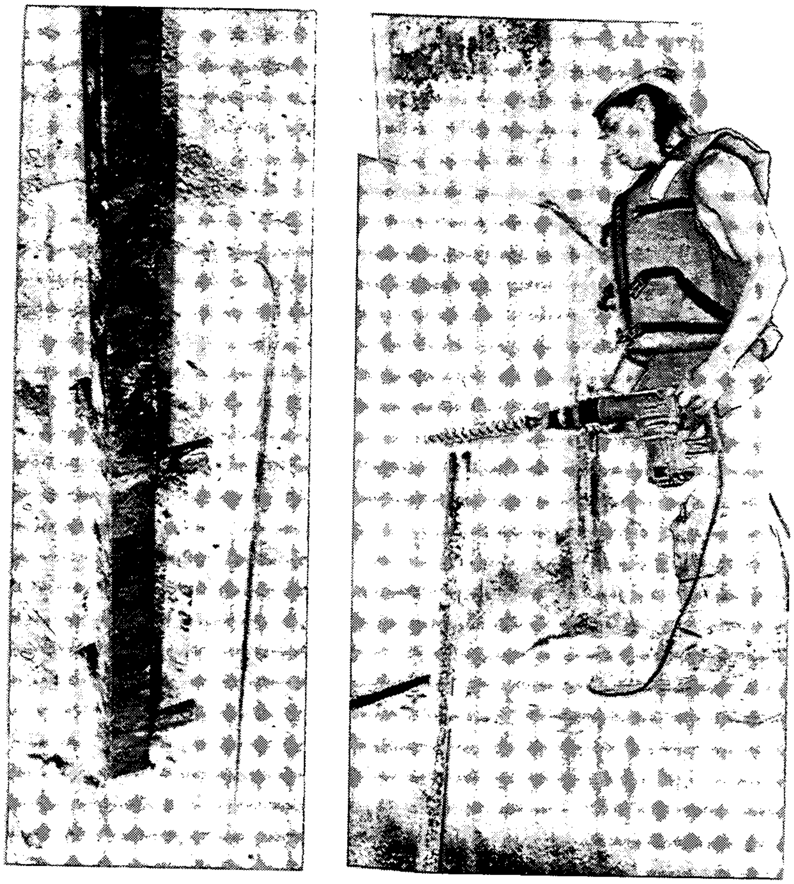
As each member (or each part of a member) was exposed to different environmental conditions; submerged in seawater, exposed to tidal variations or seawater splash, or exposed to salt laden air, an appropriate combination of the cathodic protection systems was recommended for each member. All the CP systems are the sacrificial zinc type.

THE CP SYSTEMS

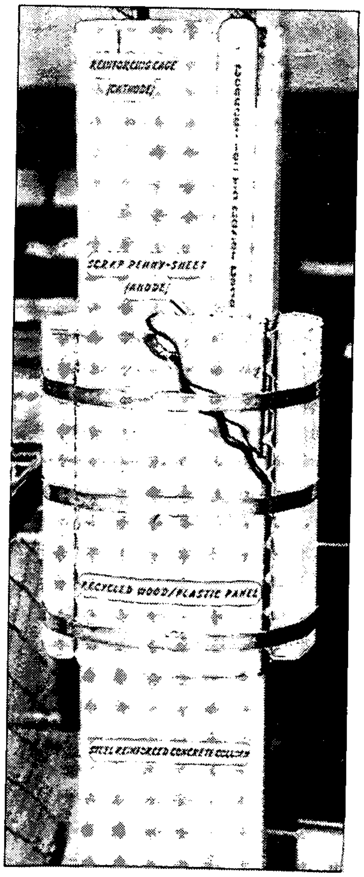
Figure 1 shows the installation and activation of different kinds of anodes.

The CP systems used here were unique and hence warranted special methods to test and activate the systems. The systems were tested indirectly by using test probes. Measurements taken using the probes were: probe to anode resistance, static half-cell potentials, anodic current versus time, depolarization and polarization potentials.

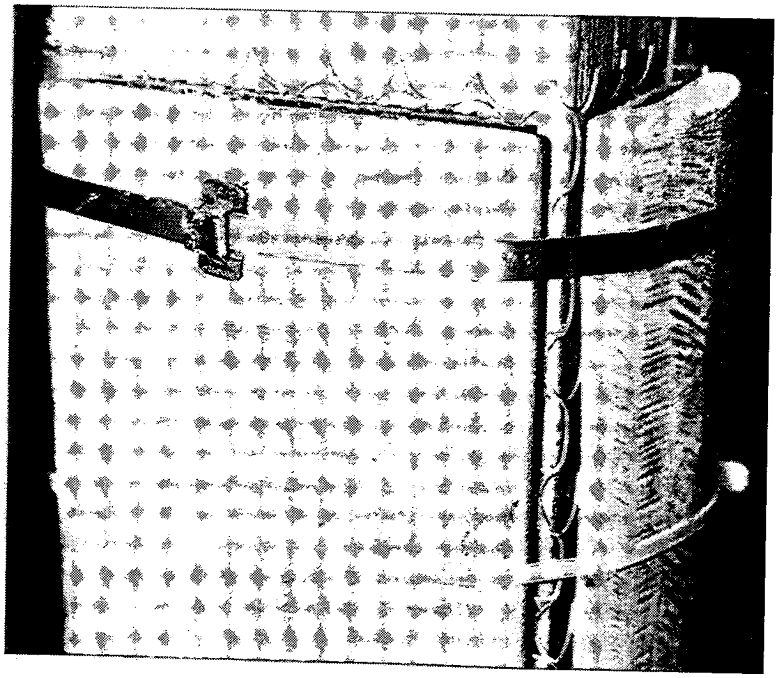
As all these CP systems are of the sacrificial type, the anodes are directly connected to the reinforcing steel. Hence, the normal method of monitoring is replaced by monitoring an embedded rebar probe. Such a monitoring probe is a rebar with exactly 2 square in. of exposed surface area and a test lead of sufficient length to be attached to the rebar. This probe is installed in a 2 in. diameter hole in the concrete member and patched with a cement-sand mortar mix using seawater. Though the chloride contents of the mortar mix around the probes could not be confirmed to be equal to or higher than the highest chloride value found in the parent concrete around the rebar, the probes exhibited very active half cell potentials after



Installation of Bulk Zinc Anode

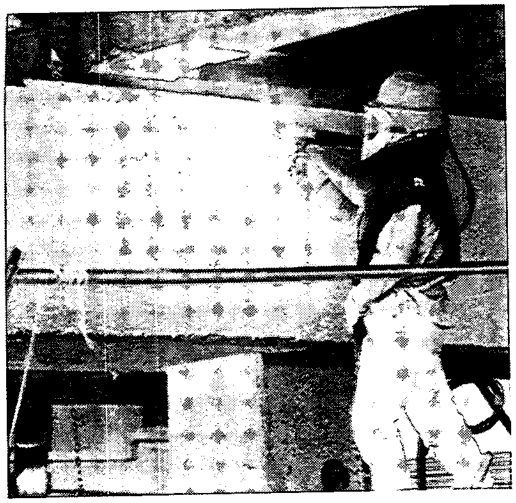


Model of Installed Perforated Zinc Sheet Anode

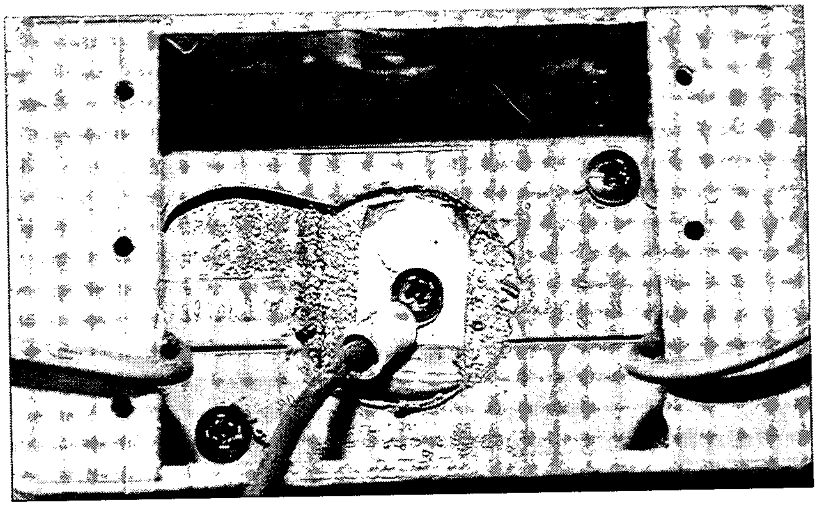


Close Up of Perforated Zinc Sheet Anode

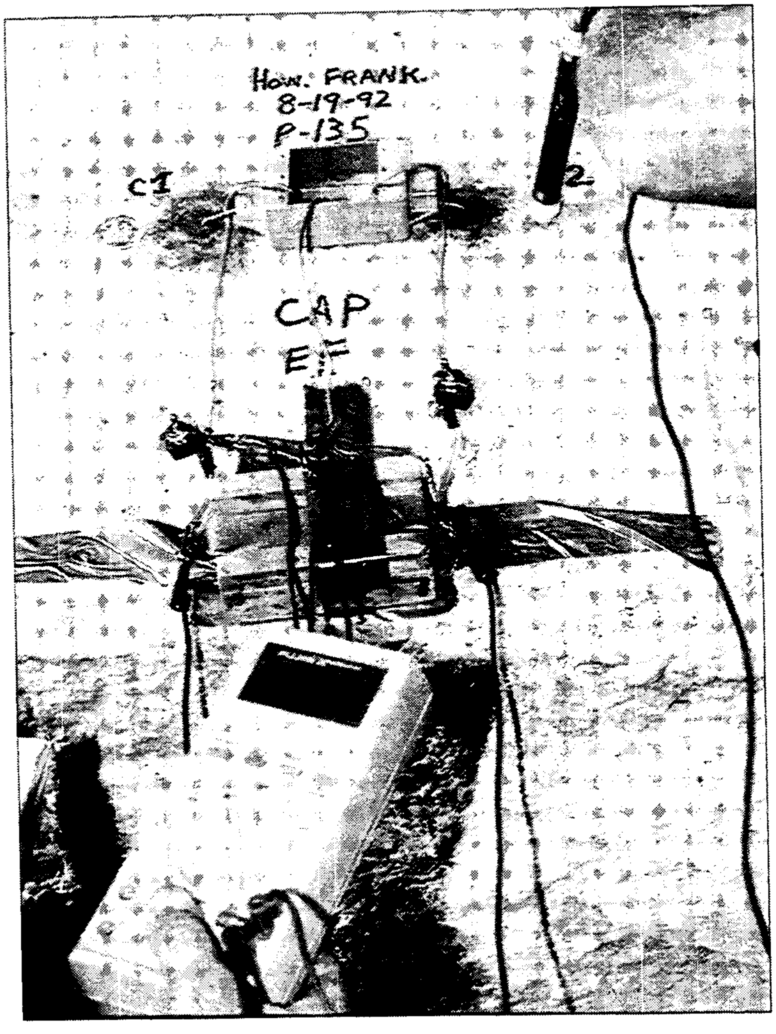
Figure 1. Installation and Activation of Anode(s)



Arc-Sprayed Zinc Anode



Connection to Arc-Sprayed Zinc Anode for Monitoring



Activation and Data Collection in Progress

Figure 1. (cont'd) Installation and Activation of Anode(s)

installation. The probes are connected to the zinc anode through a switch and a zero resistant ampmeter. The current flow to the probe is measured using the zero resistance ampmeter connected between the anode and the probe with the switch closed. The current off potential of the probe (i.e., steel) was measured using a digital multimeter connected between a reference cell and the probe with the switch open for one second. The current off potential of the anode could not be measured directly as the anode was permanently connected to the steel. If the probe showed 100 mV or more depolarization, then the steel was assumed to receive adequate protection. The current density on the probe steel was calculated by dividing the current between the anode and the probe by the exposed surface area of the probe steel.

The Bulk Zinc Anode: The portion of the footers under seawater are protected with sacrificial bulk zinc anodes. Each anode is 99 percent pure zinc and weighs about 50 lb. Two anodes are welded to the flanges (one on either side) of a 2 in. x 2 in. x 3/8 in. galvanized steel angle. The steel angle was painted with coal tar epoxy paint. This assembly was then attached to the pier using galvanized nuts and anchors. Connection to the steel was made with a 5/16 in. stainless steel all-thread rod bolted to the reinforcing steel in the pier struts. A similar procedure was used for installing the bulk anodes on the pilings.

The Perforated Zinc Sheet Anode: Though the perforated zinc sheet is yet to be installed on pilings at site, FDOT provided enough information to describe the installation procedure.

The delaminated concrete will be removed from the pile within the area to be covered by the jacket and patched to the original shape. The patching material to be used is the same as previously mentioned. The marine growth, debris and residue from the surface of the piles (at the elevations where the cathodic protection jacket is to be installed) will be removed by bush hammering.

The perforated zinc cage will be manufactured using perforated zinc sheets of 9 in. width and with perforations of approximately 0.75 in. in diameter. The center-to-center distance between perforations is 0.80 in.. The thickness of the perforated zinc sheet is 0.049 in. and weighs 0.44

lb/yd^3. The manufactured cage will be wrapped around the piling at the specified elevation and secured in place using plastic pull ties. The top 1 in. of the sheet will be bent and a 3/4-in. wide zinc band inserted into this bend and soldered to the sheet between perforations to ensure electrical continuity. The perforated zinc sheet thus installed will be compressed against the concrete surface using four grooved compression panels (made out of wood-plastic recycled material). The compression panels will then be held against the pile surface using five 3/4-in. wide stainless steel bands at 12 in. centers and permanently maintained in tension using stainless steel buckles. The anode will then be connected to the reinforcing steel.

The Arc-Sprayed Zinc System: All the delaminated and surrounding unsound concrete was removed and left unpatched. The exposed steel was abrasive blasted to remove mill scale, rust, oil and/or other foreign material such that a near white metal appearance was obtained. All the concrete surface designated to be metallized was thoroughly sandblasted and pieces of duct tape, about 1 in^2 , were applied to the sandblasted concrete surface to permit measurement of the applied coating thickness. Prior to metallizing, the concrete surface was air blasted to remove any sand residue and dust from the sandblasting operation. Metallizing was first started on the exposed cleaned rebars and then on the concrete surface. Metallizing was done using pure zinc (99.9 percent) in the wire form of 1/8 in. standard size. The wire was melted by the heat of the electric arc and sprayed through the nozzle by compressed air. Metallizing was done in several passes to achieve a minimum coating thickness of 15 mil. Thickness coupons were removed via the duct tape and the thickness was measured using a digital micrometer in the field. Where thickness was less than 15 mil, additional passes were made to achieve that thickness.

The adhesion strength of the zinc coating to the concrete surface was measured using a pull-off tester. Strength measurements were taken 72 hours after the zinc was sprayed. A summary of select adhesion values is given below:

Number of tests=24
Average=123 psi

Maximum=193 psi
Minimum=90 psi
Standard Deviation=29 psi

The FDOT specification required one adhesion strength test per zone done 72 hours after the zinc was sprayed. A minimum of 90 psi for 90 percent of the measurements was required.

RESULTS OF TESTING

Bulk Zinc Anode: These tests were performed with only the bulk anodes in place. Resistances between the probe, the bulk anode and the static potential (versus CSE) for each probe were measured and are given in Table 1.

It was clear that all the probes were electrically isolated from the anode assembly and hence good for future testing and monitoring. Each of the probes exhibited static potentials in the active region. A probe at one foot above the high tide level was selected for studying the polarization and depolarization characteristics. This probe was connected to the anode and a polarization of 111 mV was observed. The corresponding current density on the probe rebar was 4.46 mA/ft^2 Subsequently, a depolarization test was conducted and a total depolarization of 115 mV was obtained in 20 minutes. Table 2 summarizes polarization and depolarization data.

Arc-Sprayed Zinc Anode: A cap and a beam sprayed with zinc were selected for testing. Two probes were installed in the cap and one in the beam. Resistance between the anode assembly and the probe, and the static half-cell potential were measured and are given in Table 1.

Resistance readings showed that all the probes were electrically isolated from the anode. Also, all the probes exhibited static potentials in the active range. The probes in the cap were connected to the anode and current off potentials were measured at regular intervals until no significant change in potential or 100 mV of polarization was observed. Potential shifts of 168

Table 1: System Parameters - Howard Frankland Bridge, Tampa, Florida

Pier #	Type of member	Description	Resistance		Current density on the probe mA/ft^2
			AC Resist. Ohms	DC Volts volts	
165	Footer	Anode vs probe at high tide	*	*	*
165	Footer	Anode vs probe at 1' 0" above high tide	150	0.089	4.61**
165	Footer	Anode vs probe at 3' 0" above high tide	515	-0.222	1.008
165	Footer	Anode vs probe at 4' 0" above high tide	780	-0.258	0.734
165	Footer	Anode vs probe at 5' 0" above high tide	1200	-0.268	0.014
135	Cap	Anode vs probe 1	875	-0.183	2.880
		Anode vs probe 2	800	-0.198	2.380
135	Beam	Anode vs probe 1	1050	-0.120	1.370

Note : Current density on the probes were calculated based on 2 in^2 of the exposed surface area of the probe

* Could not measure due to defective probe; another probe was installed

** Water was 26" below the footer

Table 2: Polarization and Depolarization Data - Howard Frankland Bridge, Tampa, Florida

Pier #	Type of member	Probe location	Type of Anode	Static potential mV (CSE)	Probe curr. density mA/ft²	Polarized potential mV (CSE)	Pol. mV	Depol.* potential mV (CSE)	Depol. mV	Remarks
165	Footer	1'0" above high tide	bulk zinc	-440	0.007	-530	-90	not measured		Seawater below footer
165	Footer	1'0" above high tide	bulk zinc	-442	4.46	-553	-111	-438	115	Seawater covering 16" depth of footer
135	Cap	Middle of cap depth	Arc-spray. zinc	-458	2.88	-626	-168	-478	148	Probe is left of JB
		Middle of cap depth		-443	2.38	-613	-170	-454	159	Probe is right of JB
135	Beam	Bottom of the beam	Arc-spray. zinc	-350	1.37	-463	-113	-362	101	Probe is adj. to JB

Note :

* All depolarization values reported here were observed in less than 4 hours after disconnecting the anode

JB = Junction Box

and 170 mV were observed for probes 1 and 2 respectively. The corresponding current densities were 2.88 mA/ft^2 and 2.38 mA/ft^2. Depolarization tests, run after 24 hours of polarization, found 148 mV and 159 mV depolarization for the probes.

Perforated Zinc Sheet Anode: No data on the perforated zinc sheet anodes are available as the sheets have not yet been installed.

CONCLUSIONS

- o Polarization and depolarization of the zinc system was rapid.
- o Performance of bulk zinc anodes largely depends on the moisture content of the concrete.
- o Protection offered by bulk zinc anodes extended up to a foot above the water line.
- o The sprayed zinc system (above the tide level and splash zone) provided good polarization.

RECOMMENDATIONS

- o KCC INC findings on seawater canal structures in Saudi Arabia showed that the zinc system offered protection only a few in. above the seawater level. It is recommended that the protection offered by the bulk zinc anodes (above the water line) in Howard Frankland bridge be studied in greater detail.
- o A combination system such as the one used on piles (bulk anodes below water level, perforated zinc sheets in tidal and splash levels and arc-sprayed zinc above the tidal and splash levels) should be investigated for use on piers.

COST ANALYSIS

The following is the summary of the unit cost of the system per square foot of concrete:

Bulk zinc anodes on piles-\$11.31/ft^2
Bulk zinc anodes on piers-\$ 6.90/ft^2
Arc-sprayed sacrificial zinc anodes -\$ 3.34/ft^2
(without enclosures for collecting zinc dust)

Perforated zinc sheet anodes-\$38.50/ft^2

The cost data are detailed in Table 3.

Table 3. Cathodic Protection Cost Estimate - Howard Frankland Bridge, Tampa, Florida

Description	Labor			Material			Special Equipment		
	Man-hours	Hourly Rate	Amount	Quantity	Unit Cost	Amount	Quantity	Unit Rate	Amount
1. Concrete Repair - Remove delaminated concrete (5189 sq. ft.)									
Skilled	183.00	18.00	3294.00						
Semi-skilled	628.00	14.00	8792.00						
2. Surface Preparation									
Skilled	700.00	18.00	12,600.00	L.S.	L.S.	2,000.00	1	L.S.	6,000.00
Semi-skilled	700.00	14.00	9,800.00						
Unskilled	350.00	13.00	4,550.00						
3. Anode Installation - Arc Sprayed Zinc							1	L.S.	20,000.00
Skilled	3150.00	18.00	56,700.00	78,750.00 lb	1.01	79,537.50	1	L.S.	20,000.00
Semi-skilled	1575.00	14.00	22,050.00				1	L.S.	10,000.00
4. Instrumentation - Probes,junction boxes and conduits				Probes 350	15.00	5,250.00			
Skilled	437.5	20.00	8750.00	JBs,Conduits,					
Electrician	437.5	30.00	13125.00	Wires 175	10.00	1,750.00			
5. Pre-activation									
Technician	175.00	30.00	5250.00						
Specialist	175.00	42.00	7350.00						
6. Activation							1	L.S.	500.00
Technician	225.00	30.00	6750.00						
Specialist	225.00	42.00	9450.00						
7. Data Processing & Report							1	L.S.	260.00
Technician	175.00	30.00	5,250.00						
Specialist	650.00	42.00	27,300.00						
Total Unit Cost = 3.34/ft^2									

Total CP Area = 103,775 ft^2

Evaluation Report on The Repair and Rehabilitation of Sixth Street Bridge Over Big Sioux River, Sioux Falls, South Dakota

June, 1993

Prepared For
South Dakota Dept. of Transportation (SD DOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to interact with various state agencies to collect the technical and cost data. KCC INC would also like to thank the South Dakota Department of Transportation for their cooperation and timely assistance. State corrosion engineer, Mr. Dan Johnston, and his fellow workers and Ms. Laurie Shultz are appreciated for their assistance in collecting the data on technical performance of the titanium mesh anode encapsulated in portland cement concrete and acrylic grout.

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Evaluation Report on the Repair and Rehabilitation of Sixth Street Bridge Over Big Sioux River, Sioux Falls, South Dakota

BACKGROUND

The structure is a four-lane continuous concrete bridge (with a sidewalk on either side) over Big Sioux River in Sioux Falls, South Dakota and was built in 1975. The structure was surveyed extensively in 1989. A total delamination of 10 percent of the deck area was observed. The top mat rebar has a cover in the range of 3 to 4 in.. Summary of the results of the analysis of the chloride samples extracted from top mat rebar level is as follows:

Number of Measurements	=	12
Maximum Rebar Level Chlorides	=	11.4 lb./yd^3
Minimum Rebar Level Chlorides	=	7.9 lb./yd^3
Average Rebar Level Chlorides	=	10.2 lb./yd^3
Standard Deviation	=	1.4 lb./yd^3

The State DOT, based on the results of the condition evaluation survey, decided that CP was not only a feasible method, but also necessary to protect the deck from further corrosion damage because of the high level of chlorides at the rebar depth and beyond. A total of 16,303 ft^2 of concrete surface was designated to be protected by CP.

REHABILITATION BEFORE INSTALLATION OF CP

The extent of delamination was identified during the survey conducted just prior to installing the anode. The delaminations thus identified were removed by excavating the concrete to 1 in. below the top mat rebar and patched with South Dakota DOT class A45 concrete, is a high-quality conventional concrete. The surface of the deck was scarified so that the surface was left with a saw tooth profile for good overlay bonding. The scarification process also removed the top 0.5 in. of concrete from the deck. In all the areas where rebar were exposed, a mortar mix was used to cover the exposed metals. This ensured the electrical isolation of the anode from the steel.

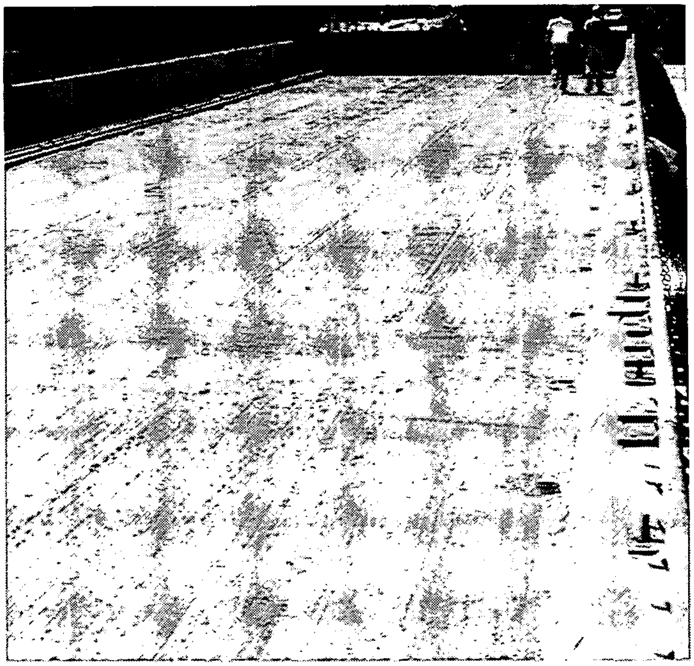
THE CP SYSTEM

Deck System

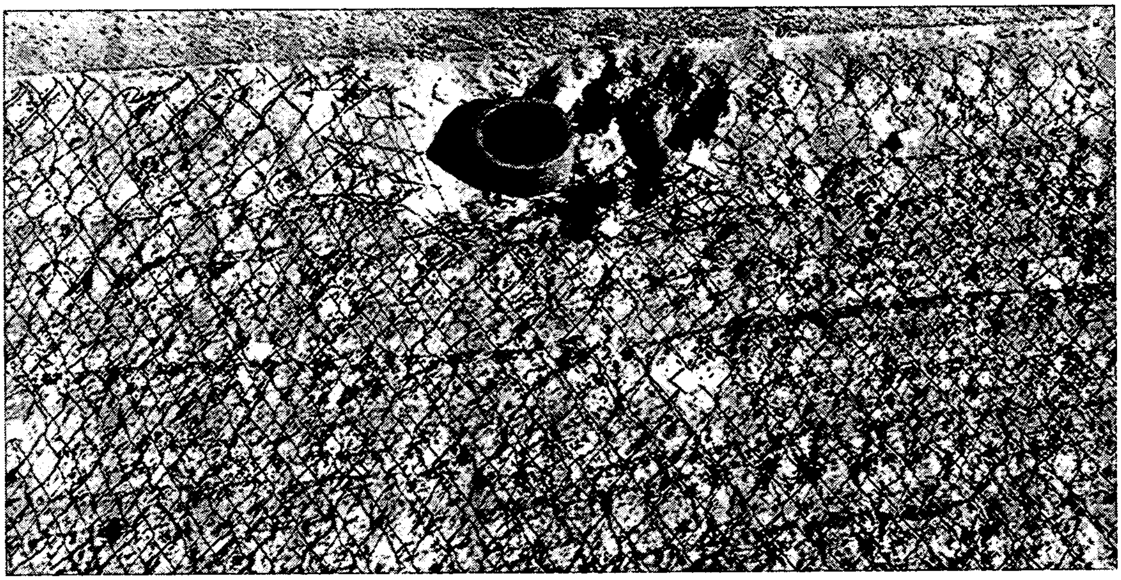
The entire deck (including the sidewalks) had noticeable amounts of delaminations and spalls and extensive build-up of chloride at the rebar level. A total of 11,100 ft^2 of the deck area was designated to be protected by CP. The scarified and patched surface was heavily sandblasted to remove dust or other foreign materials. Prior to anode installation, the concrete surface was air blasted to remove sand and dust from the sandblasting operation. Mesh anode was rolled out from one end to the other as one continuous piece. Anode rolls were supplied in 250 ft rolls with a width of 4 ft. Twelve rolls were used for the entire deck surface. A 0.5 in. x 0.04 in. titanium strip was resistant spot welded to the mesh at 3 in. intervals to make all these anode strips continuous. Figure 1 shows the anode installation process. Special prefabricated anode connectors were used at the access holes to eliminate the chances of short circuit. The anode mesh was attached to the surface of the deck with plastic fasteners at every 2 ft interval. The lead wires to the embedded half cells and probes were laid in slots cut on the deck so that they remained flush with the existing concrete surface. The anode was then encapsulated in a low slump dense concrete overlay. The mix design of the low slump dense concrete overlay was as given below (weight per cubic yard of concrete):

Coarse Aggregate:	1,394 lb
Fine Aggregate:	1,394 lb
Cement:	823 lb
Water:	270 lb
Air Entrainment:	6 % by volume
Water Cement Ratio:	0.33
Maximum Slump:	1.0 in.
Water Reducing Admixture:	Per manufacturers' recommendations

Scarified Deck Being Sandblasted

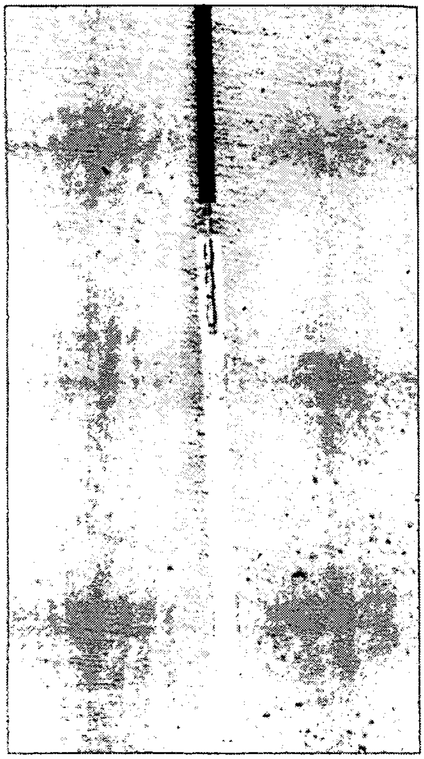


Anode Installation in Progress

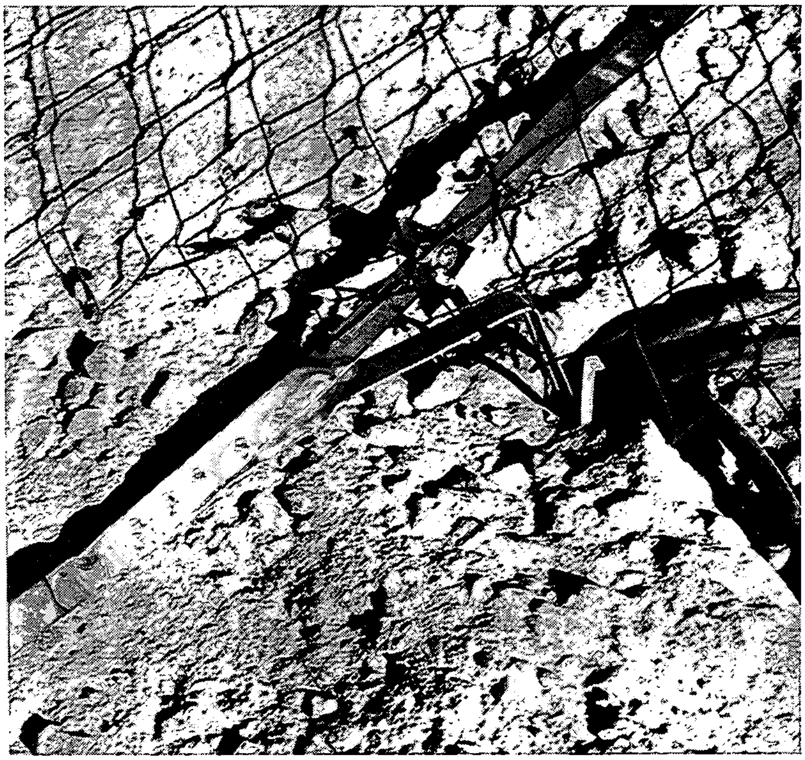


Anode Cut Around Drain Pipes to Ensure Electrical Isolation

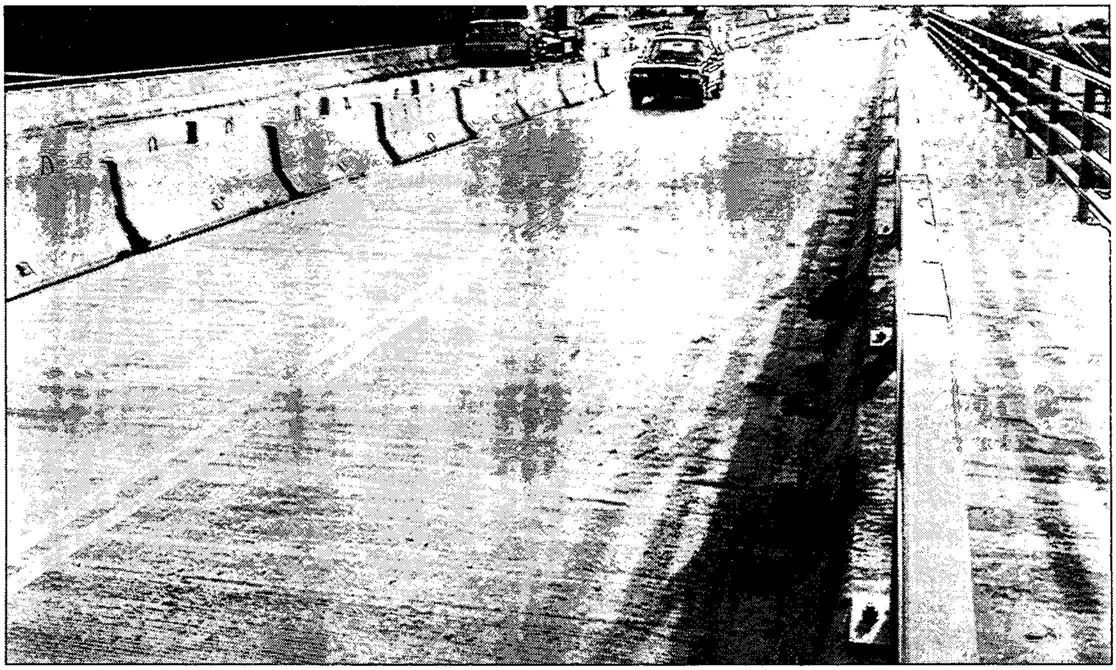
Figure 1. Surface Preparation and Anode Installation



Special Anode Connector Used at the Access Hole



Special Anode Connector Welded in Place



Structure Under Cathodic Protection in Use

Figure 1. (cont'd) Surface Preparation and Anode Installation

Sidewalk System

The procedures used for removing delaminations, preparing the concrete surface and installing the anode were similar to those used for the deck system. A total of 5,203 ft^2 of the area of sidewalk was designated to be protected by CP. However, the mesh was encapsulated in a 0.75 in. thick acrylic grout (Euco Verticoat). Euco Verticoat was mixed at the site to form a flowing mortar and applied by hand to a thickness of 0.75 in.. Delaminations of the Euco Verticoat was observed in isolated areas within a month after application. Proposed reasons for the problems observed with the Euco Verticoat were as follows:

1) The setting time was actually shorter than that specified by the manufacturer.
2) The concrete surface did not have an adequate profile.
3) The weather conditions were improper at the time of application.

The cause of the delamination of the Euco Verticoat has not yet been identified. The investigation continues. The work on the sidewalk is presently on hold and will continue once the cause of the problem has been identified.

CONCLUSIONS

- This CP installation went smoothly except for the difficulty associated with debonding of the acrylic mortar on the sidewalks. The debonding is being further investigated.

REMARKS

This project was funded by the Federal Highway Administration. The problems associated with the delamination of the acrylic grout led to postponement of further work until the problem is solved. This has prevented KCC INC from collecting technical data on the performance of the titanium mesh anode system and, hence, this report is issued without the technical information.

RECOMMENDATIONS

- Resolve the mortar debonding issue and then activate, evaluate, adjust and monitor the cathodic protection system.

COST ANALYSIS

The unit cost of the deck and sidewalk CP systems were \$9.76/ft^2 and \$11.74/ft^2 of the concrete surface respectively. The cost of CP system was estimated as a sum of labor, material, and special equipments used. The total hours of labor for each activity were obtained from field observations, contractors daily progress reports, and the payrolls. Whenever the overtime hours were reported, they were converted to equivalent regular hours as the overtime pay was 1.5 times the regular pay. It was assumed that a typical work day had 8.5 hours of work on an average. The labor rates were calculated to reflect overhead and profit (overhead and profit were taken as 100 percent of the basic labor rates). The cost of any special equipment used on the job was calculated on the basis of rental charges. The cost of labor and material for the instrumentation of the deck was taken as 2/3 of the total instrumentation cost (as the deck had 4 out of a total of 6 reference cells). Similarly the cost of rectifier and other electrical work was also taken as 2/3 of the total cost (rectifier, AC power, and electrical connections). The other third of the cost was taken as a part of the sidewalk CP cost. The cost of AC power was taken as the cost of 40 ft lead from the tapping point to the rectifier. Table 1 shows the cost of all pertinent work done as part of the CP system. The overall project cost was estimated at \$242,527 (taken from the state agency's pay estimate).

Cost of CP Related Work for the 231.25 ft x 48 ft of Deck

1.	Concrete repair and patching	9,129.30
2.	Surface preparation	4,915.70
3.	Anode installation	45,831.20
4.	Instrumentation (2/3 x 2,702.85)	1,801.90
5.	Electrical work (2/3 X 19,065.00)	12,710.00

6.	Rectifier (2/3 x 13,200.00)	8,800.00
7.	AC power (2/3 x 1000.00)	666.67
8.	Overlay	5,963.10
9.	Finishing and curing	19,212.60
	TOTAL	$108,363.77
	UNIT COST	$9.76/ft^2

Cost of CP Related Work for the 231.25 ft x 22.5 ft of Sidewalk

1.	Surface preparation	4,915.70
2.	Anode installation	23,460.86
3.	Instrumentation (1/3 x 2,702.85)	900.95
4.	Electrical work (1/3 x 19,065.00)	6,355.00
5.	Rectifier (1/3 x 13,200.00)	4,400.00
6.	Acrylic grout placement	20,735.42
7.	AC power (1/3 x 1000.00)	333.33
	TOTAL	$61,101.26
	UNIT COST	$11.74/ft^2

See Table 1 for additional detail.

Table 1. Cathodic Protection Cost Estimate
Sixth Street Bridge over Big Sioux River, Sioux Falls, South Dakota

Description	Labor			Material			Special Equipment		
	Man-hours	Rate	Amount	Quantity	Unit	Amount	Quantity	Rate	Amount
1. Concrete Repair & Patching (10% 11,100 ft^2 = 1110 ft^2)									
Driver	142.00	12.75	1810.50	10 yd^3	54 yd^3	540.00			
Labor	544.00	9.45	5140.80						
Supervisor	68.00	21.00	1428.00						
Superintendent	10.00	21.00	210.00						
			8589.30			**540.00**			
2. Surface Preparation - Deck									
Labor	306.00	9.45	2891.70				Sandblasater	1	600.00
Sand Blaster	34.00	15.00	510.00				Earth Mover	1	200.00
Supervisor	34.00	21.00	714.00						
			4115.70						**800.00**
3. Surface Preparation - Sidewalk									
Labor	306.00	9.45	2891.70				Sandblaster	1	600.00
Sand Blaster	34.00	15.00	510.00				Truck	1	200.00
Supervisor	34.00	21.00	714.00						
			4115.70						**800.00**
4. Anode Installation - Deck									
Labor	306.00	9.45	2891.70	11,100 ft^2	3.72	41,292.00	1	L.S.	500.00
Truck Operator	34.00	12.75	433.50						
Supervisor	34.00	21.00	714.00						
			4039.85			**41,292.00**			**500.00**
5. Instrumentation									
Labor	153.00	9.45	1445.85	6	150.00	900.00			
Supervisor	17.00	21.00	357.00						
			1802.85			**900.00**			
6. Anode Installation - Sidewalk									
Labor	306.00	9.45	2891.70	5203 ft^2	3.72	19,355.16	1	L.S.	500.00
Supervisor	34.00	21.00	714.00						
			3605.70			**19,355.16**			**500.00**

7. LSDC Overlay									
Labor	238.00	9.45	2249.10	40 yd^3	75.00	3000.00			
Supervisor	17.00	21.00	357.00						
Superintendent	17.00	21.00	357.00						
			2963.10			**3000.00**			
8. Finishing and Curing									
Labor	408.00	9.45	3855.60				1	L.S.	15000.00
Supervisor	17.00	21.00	357.00						
			4212.60						**15000.00**
9. Acrylic Grout Placement & Finishing									
Labor	408.00	9.45	3855.00	588 yd^2	28.10	16,522.80			
Superintendent	17.00	21.00	357.00						
			4212.60			**16,522.80**			
10. Conduit,Junction Boxes,Electrical Connection*									
Electricians	369.50	30.00	11085.00				1 Snooper	L.S.	3000.00
Labor	166.00	30.00	4980.00						
			16065.00						**3000.00**
11. Rectifier	1	L.S.	**5950.00**	1	L.S.	**7250.00**			
12. AC Power	1	L.S.	**1000.00**						
13. External Engineering Services	1	L.S.	**1500.00**						

***The unit rates were as used by the client**

Evaluation Report on The Repair and Rehabilitation of East Duffins Creek Bridge, Pickering, Ontario

June, 1993

Prepared For
Ontario Ministry of Transportation (MTO)
and
The Strategic Highway Research Program (SHRP)

Prepared by
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to interact with various state agencies to collect the technical and cost data. KCC INC would also like to thank the Ontario Ministry of Transportation (MTO) for their cooperation and timely assistance. We appreciate the assistance of MTO Rehabilitation Technician Ed Gulis in providing the data on technical performance of the coke asphalt system.

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Evaluation Report on the Repair and Rehabilitation of East Duffins Creek Bridge, Pickering, Ontario

BACKGROUND

The structure is a two-lane concrete bridge (Site No. 22-93) on Highway No. 7 over East Duffins Creek, Pickering, under the jurisdiction of the Ontario Ministry of Transportation (MTO). The bridge was built in 1973 and consists of a 7.5 in.-thick reinforced concrete slab supported by prestressed concrete beams. The total number of spans was three, each about 61 ft (18.2 m) long and 37 ft (11 m) wide. A detailed condition survey of the structure was performed by MTO in June 1989, which revealed the following information.

The concrete forming the top surface of the deck slab was generally in a fair condition, with the average compressive strength of the concrete tested being 3988 psi (27.5 MPa). The air content, specific surface and spacing factor also satisfied the MTO requirements for properly air entrained concrete in general (one sample marginally failed to satisfy the requirement) as shown below.

	Sample 1	Sample 2
Air Content	5.1%	5.1%
Specific Surface	(526 in^2/in^3) 20.7 mm^2/mm^3	(635 in^2/in^3) 25.0 mm^2/mm^3
Spacing Factor	(0.0091 in) 0.23 mm	(0.0075 in) 0.19 mm

The average concrete cover to the top layer of reinforcement was 3 in. (75 mm) with a range of 2.3 to 3.5 in. (58 to 88 mm). The average soluble chloride content observed at various depths are shown below.

Depth	% Cl by Wt. of Concrete	lb./yd^3 * of Cl by Wt. of of Concrete
0 - 0.4 in (0 - 1- mm)	0.430	16.80
0.8 - 1.2 in (20 - 30 mm)	0.275	10.80
1.6 - 2 in (40 - 50 mm)	0.105	4.10
2.4 - 2.8 in (60 - 70 mm)	0.016	0.60
3.2 - 3.5 in (80 - 90 mm)	0.014	0.55

* Assumed unit weight of concrete is 3915 lb./yd^3.

The average chloride content in the top 2 in. (50 mm) of the concrete deck exceeded the corrosion threshold, though the rebar level chlorides were much less at the time the sampling was done in June 1989. Based on the results obtained from a half-cell potential survey, corrosion of the top layer of reinforcement appeared to be active over approximately 16.6 percent of the total deck area. The half-cell potential (against CSE) measurements are summarized below.

Number of measurements = 360
Average = -0.30 V
Maximum = -0.59 V
Minimum = -0.16 V
More positive than -0.20 V = 3.3%
Between -0.20 and -0.35 V = 80.1%
More negative than -0.35 V = 16.6%

Approximately 86 ft^2 (8 m^2) of delaminated and spalled concrete were observed on the deck. In addition, there was also 29 ft^2 (2.7 m^2) of patched spalls in the deck. This corresponds to a total of 1.8 percent of the deck surface. Some medium and light scaling of the concrete surface was also observed.

REHABILITATION BEFORE INSTALLATION OF CP

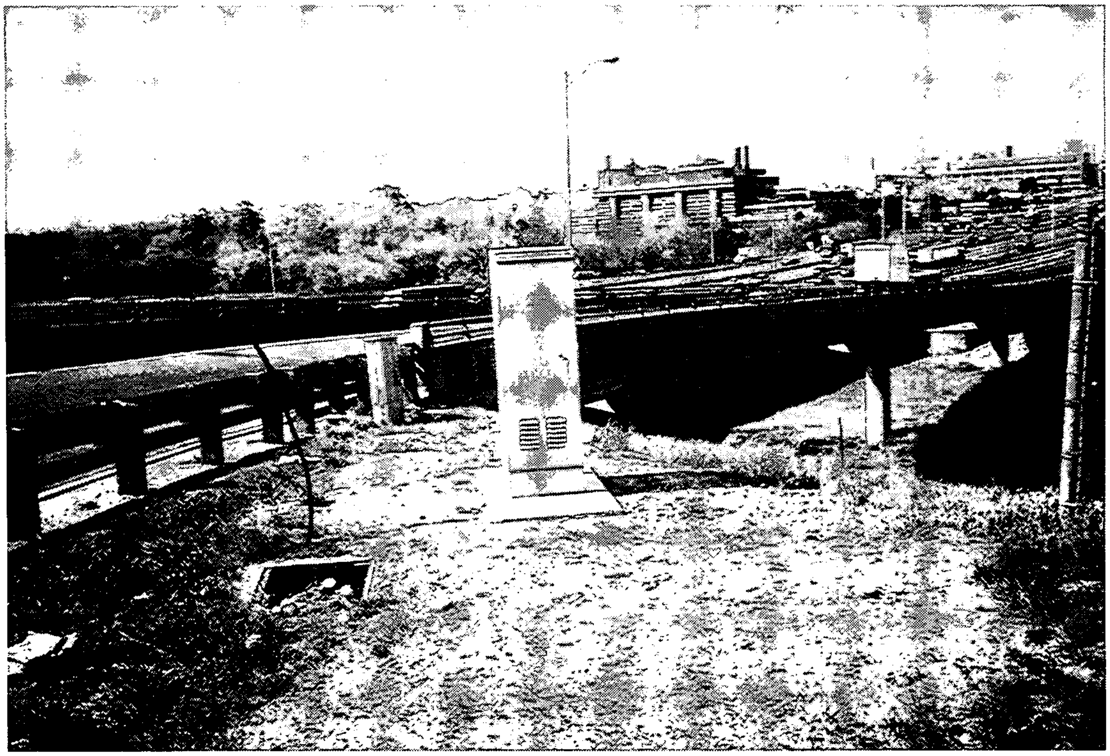
Delaminated concrete and unsound patching material was removed after making 1 in. (25 mm) deep saw cuts around the damaged areas. Scaled concrete was removed to a minimum depth of 25 mm (1 in.). The areas to be repaired were then abrasive blast cleaned and concrete was placed to the original surface. The concrete used for patching was 4350 psi (30 MPa) class conforming to OPSS 1350. Nominal maximum size of aggregate was 0.37 in. (9.5 mm).

THE CP SYSTEM

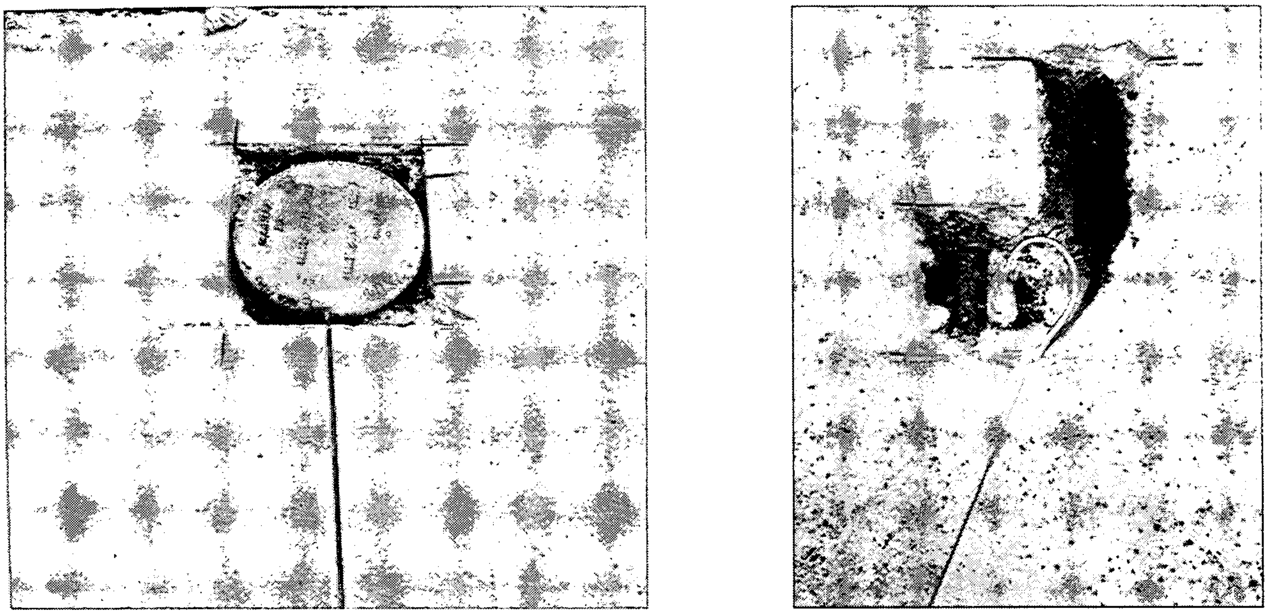
The CP system installed on this bridge deck consists of a coke asphalt system using DURCO Pancake Type I Bridge Deck Anode. The fact that the deck concrete was adequately air entrained justified the use of such a system. The total deck area under CP was about 6456 ft^2 (600 m^2). Anodes were installed in slots cut into the deck surface of size 13 in. diameter x 2 in. deep (330 mm diameter x 50 mm deep). Sixteen anodes were installed on the deck surface to supply current to the entire area. These anodes were powered by six anode buses from the rectifier, each supplying current to 2 or 3 anodes. Three graphite reference cells and four graphite voltage probes were also embedded in the deck concrete. Subsequently, the electrically conductive mix was laid to a compacted depth of 1.6 in. (40 mm) on the deck surface and then covered by another 1.6 in. (40 mm) thick asphalt wearing course of hot mix HL1. The electrically conductive mix was of the following composition:

Material	% by Mass
Coke Breeze	45
Coarse Aggregate	40
Fine Aggregate	15
Asphalt Cement (% of Aggregate Mass)	15

The asphalt wearing course (HL1) included 51.3 percent course aggregate and 48.7 percent fine aggregate. Figure 1 illustrates the installation of various components of a typical coke asphalt CP system.



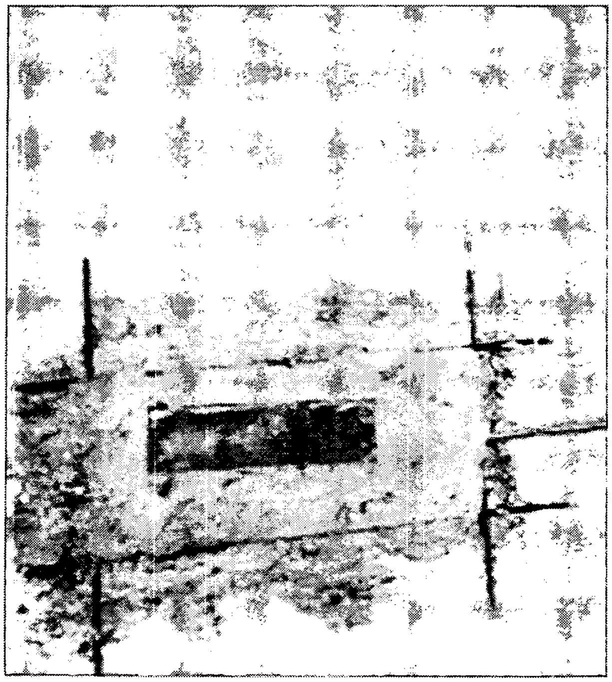
Overall View of the Structure



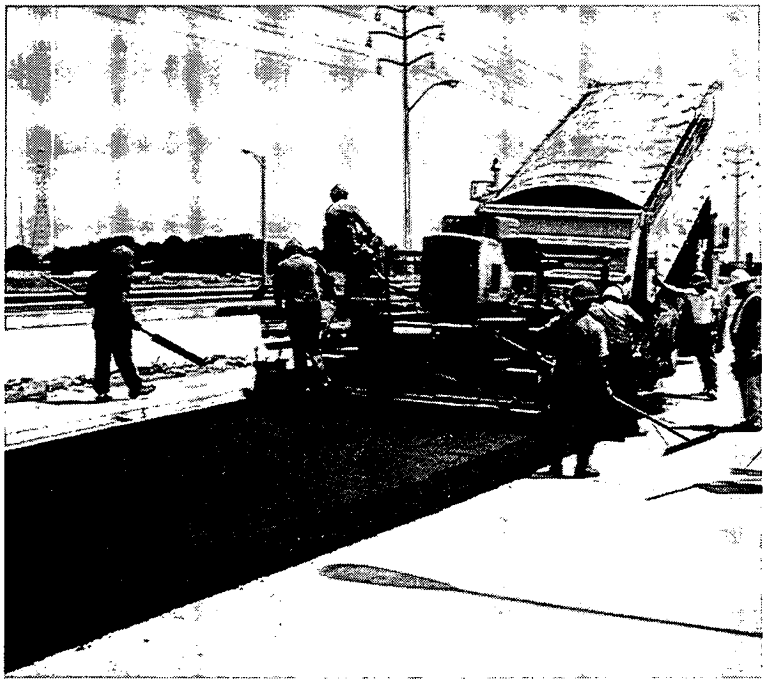
Installation of Pancake Anode

Installation of Graphite Cell and its Ground

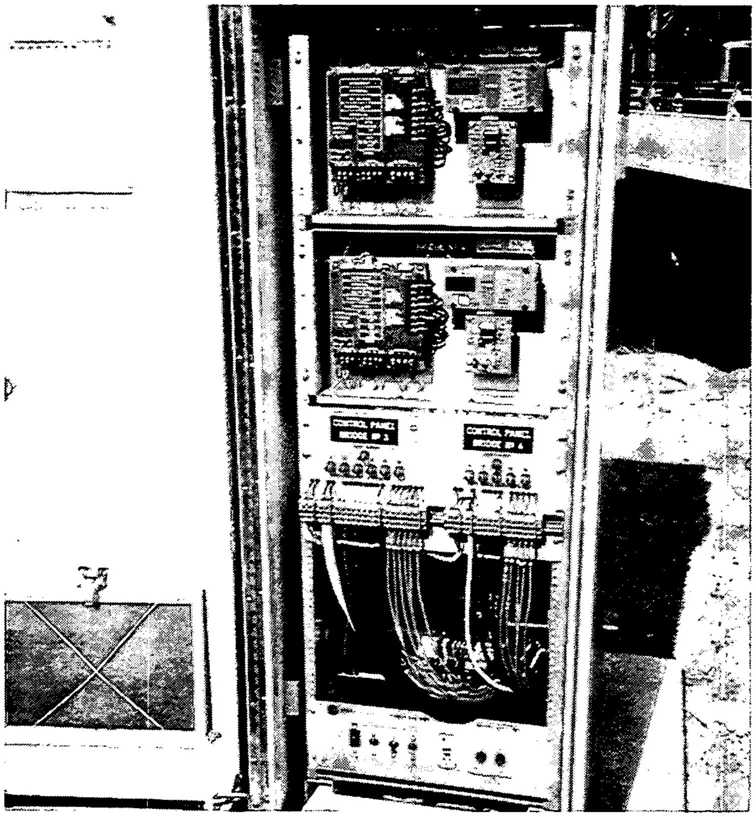
Figure 1. Installation of Coke Asphalt Anode System



Installation of Graphite Voltage Probe



Placement of Coke Asphalt Mix



Front View of the Rectifier

Figure 1. (cont'd) Installation of Coke Asphalt Anode System

The CP system was powered by a single circuit, constant DC output, full wave rectifier with an output rating of 4 A and 8 V (Goodall Model No. TPAYCA8-4GKNS). The entire deck area was powered as a single zone.

TEST PROCEDURE DESCRIPTION FOR COMMISSIONING THE SYSTEM

Activation and acceptance testing of the CP system was performed by the MTO personnel in November 1991. Tests prior to energizing involved the following:

1) Measurement of AC resistance and voltage between each reference cell ground wire and the structure current carrying ground wire in order to check the rebar continuity.

2) Measurement of AC resistance between each anode bus wire and the structure ground wire in order to check for any shorts between the anode and rebar.

3) Documentation of the voltage potential (initial static potential) and resistance between the reference cell wire and reference cell ground wire at the control panel.

4) Documentation of voltage potentials and resistance between the voltage probe terminals and a reference cell ground wire at the control panel.

The above tests were performed to ensure that all the components of the CP system are in proper working condition and that no short circuits existed between the conductive mix and the reinforcing steel, drainage pipes or expansion joints. These tests were performed in compliance with NACE Standard RP0290-90 and AASHTO Task Force #29 Specification (Final Draft). No E-Log I tests were performed on this structure.

The CP system was then activated at 0.37 mA/ft^2 (4 mA/m^2) of the deck surface and allowed to operate for 24 hours in the constant current mode. This current density corresponds to about

0.39 mA/ft^2 of the deck rebar surface. Subsequently, the potential (both "ON" and "instant OFF") of all graphite voltage probes and reference cells connected to the control panel were measured. Based on the data obtained, output current was adjusted.

RESULTS OF TESTING

Continuity checks between each of the three reference cell grounds and structure grounds showed an AC resistance of 0.8 ohms and a high impedance voltmeter reading of 0.000 V, indicating proper continuity of the rebar network. AC resistance between anode bus wires and structure wires varied from 1.2 to 1.8 ohms, indicating no short circuits in the system. The voltage probes showed AC resistances in the range of 3 to 3.7 ohms, with all the probes showing a static potential of -158 mV. The static data collected on the reference cells and all the above data are tabulated in Table 1.

After 24 hours of operation at 0.37 mA/ft^2 (4 mA/m^2) of the deck surface, instant off potentials were measured on all the graphite voltage probes and reference cells. The operating voltage was measured to be 2.5 V. The data given in Table 1 show significant polarization of the embedded rebar during 24 hours of operation of the CP system. The average polarization indicated by half-cells varied from -208 to -779 mV with an average of -429 mV. Instant off potential of the voltage probes varied from -1640 mV to -1780 mV, with an average of -1695 mV. The output current was reduced to 0.15 mA/ft^2 (1.67 mA/m^2) after tests.

About a month after activation of the CP system, depolarization test was performed on the three embedded reference cells. The average 4 hour depolarization obtained was 323 mV with a range of 263 to 367 mV. Instant off potentials on the voltage probes varied from -1360 to -1400 mV. The CP system was operating at a current density of 0.17 mA/ft^2 (1.83 mA/m^2) at the time the depolarization test was performed. After the test, the CP system was reactivated at 0.11 mA/ft^2 (1.17 mA/m^2) of the deck surface.

In June 1992, after about 7 months of CP, instant off potentials were measured by MTO personnel on the reference cells and voltage probes. The three reference cells showed low

Table 1
Coke Asphalt CP system - Duffins Creek Bridge
Activation & Polarization Data

	A. C. Resistance, Ohms	Voltages		
		Static, mV	24 hr. Instant Off Potential, mV	24 hr. Polarization, mV
Reference Cell Grounds				
1	0.8	0		
2	0.8	0		
3	0.8	0		
Reference Cells				
1	230	-30	-809	-779
2	1500	-30	-238	-208
3	240	-64	-363	-299
Voltage Probes				
1	3.4	-158	-1780	
2	3.0	-158	-1680	
3	3.1	-158	-1680	
4	3.7	-158	-1640	
Anode Buses				
1	1.5			
2	1.3			
3	1.8			
4	1.4			
5	1.2			
6	1.8			
Total	0.9			

Note: CP system powered at 4 mA/sq. m. (0.37 mA/sq. ft.) of deck surface.

instant off potentials in general (-114, -232 and +192 mV). The low potentials are difficult to interpret. Experience has shown that graphite cells are not reliable for measuring absolute potential to a universal reference over time. They drift. Thus, they are normally used for short-term shift (i.e., 7 days or less) data only. Voltage probe potentials ranged from -490 to -890 mV with only one probe reading less than -800 mV. The CP system was operating at a current density of 0.11 mA/ft^2 (1.17 mA/m^2) of the deck surface at this time and the operating voltage was 1 V.

The installation and initial testing of this coke asphalt CP system were performed in accordance with the recommendations given in NACE Standard RP0290-90, AASHTO Task Force #29 Specifications (Final Draft), MTO Directive B-198 - "Start-up, Monitoring and Maintenance of Bridge Deck Cathodic Protection Systems" and MTO Special Provision 999504. All the AC resistance and voltage readings on reference cells, anode buses and voltage probes were within allowable limits, except for reference cell #2, which showed an AC resistance of 1500 Ohms, exceeding the maximum limit of 1000 Ohms.

The polarized potential measured using voltage probes and the 4 hour depolarization data indicate that the CP system provided adequate protection to the embedded rebar network when powered at 1.83 mA/m^2 (0.17 mA/ft^2) of the deck area. The primary CP criterion that is being used by the MTO is a polarized potential between -0.80 to -1.25 V at all voltage probe locations. The 4 hour depolarization tests are carried out for information purposes and are used only when the voltage probes are unreliable due to high resistance, as discussed in MTO Report 50-92-05, page 30. As a result, currents were further reduced to 1.17 mA/m^2 (0.11 mA/ft^2) since the polarized potentials of the voltage probes were all more negative than -1.25 V. Data collected in June 1992 at the above current level showed that one of the four voltage probes did not satisfy the CP criterion. The reference cells also showed low polarization, indicating that the steel may not be adequately protected at this current level.

CONCLUSIONS

- The coke asphalt CP system performed well (based on data collected up to June 1992).
- Adequate protection was achieved at a current density of 0.17 mA/ft^2 of the concrete surface.
- The 100 mV depolarization criterion was satisfied at the operating current density of 0.17 mA/ft^2 of the concrete surface.
- Adequate protection may not have been achieved when the system was powered at a current density of 0.11 mA/ft^2 of the concrete surface.

RECOMMENDATIONS

- Since the current density at which the CP system was operating in June 1992 may not have been adequate, retests should be performed, and the rectifier output current adjusted, if necessary, such that the 100 mV depolarization criterion is met on all reference cells.

COST ANALYSIS

KCC INC contacted the Ontario Ministry of Transportation for cost information. Per MTO direction, the Contractor was contacted for the cost information. No cost information was received.

Evaluation Report on the Repair and Rehabilitation of I-64 Bridge, Charleston, West Virginia

June, 1993

Prepared for
West Virginia Department of Transportation (WVA DOT)
and
The Strategic Highway Research Program (SHRP)

Prepared by
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, Virginia 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to collect the technical and cost data. KCC INC would also like to thank Mr. Marty Laylor of SHRP for his timely assistance in receiving approval from SHRP to monitor the non-overlay slot system built in 1984-1985.

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Evaluation Report on the Repair and Rehabilitation of I-64 Bridge
Charleston, West Virginia

BACKGROUND

KCC INC was involved in this project as a consultant and hence most of the information required for C-102G was readily available. The available cost information were 1983 figures, therefore these figures were converted to 1992 equivalent using the Federal Highway Administration (FHWA) document on price trends for Federal-Aid Highway Construction.

This structure is a bridge-viaduct located on Interstate 64 at milepost 53.28 in Kanawha County, West Virginia. Both northbound and southbound bridge decks were designated to receive cathodic protection. The work on the westbound deck was analyzed under C-102G for performance and cost of the cathodic protection system.

The structure was extensively surveyed in 1982 to determine the extent of damage due to corrosion of reinforcement. A total of 99,000 ft^2 of deck surface was tested for delamination and spalling. The area surveyed includes a portion of the westbound and a portion of the eastbound deck. Only about 1 percent of the deck area surveyed exhibited spalling and/or delamination. Though the chloride content at 0 to 1 in. level was in excess of 7 lb/yd^3, the chloride content at 2 to 3 in. level was lower than the chloride threshold limit. The clear cover over the reinforcement was measured using the R-meter. A total of 21 measurements were taken, of which only one indicated a steel depth of less than 2 in.. However, it should be noted that this location exhibited spalling.

With the surface level chlorides in excess of 7 lb/yd^3, a method of protection against corrosion was necessary. With minimal delaminations and spalls and clear cover over reinforcement in excess of 2 in., non-overlay slot anode cathodic protection system was considered to be the most suitable and hence was selected to protect this structure.

REHABILITATION BEFORE INSTALLATION OF CP

No formal repair method was specified.

THE CP SYSTEM

The cathodic protection system was a non-overlay slotted anode system. This system consists of primary anodes of platinized niobium wire placed in slots longitudinally and secondary anodes of carbon strands (30,000 filaments with a resistance per foot of 0.055 ohms) placed in transverse slots. The slots were 1/2 in. wide and 3/4 in. deep. The transverse slots were cut at 1 ft intervals. The slots, after anode placement, were filled with FHWA conductive polymer grout. The conductive polymer specified for use was required to satisfy the following requirements:

1. Compressive strength in excess of 4000 psi at 4 hours
2. Electrical resistivity not exceeding 10 ohm-cm
3. 24-hour water absorption not exceeding 0.5 percent.

The rectifier was a full wave, unfiltered rectifier and had three modes of operation: constant current, constant voltage and automatic structure potential control. Each circuit had 16 A, 24 V capacity. E-Log I was performed by applying a known amount of current and measuring the instant off potential. The westbound deck had 23 zones (named A thru. W) with a total surface area of 140,614 ft^2. The steel to concrete area ratio was estimated as 0.43 and the anode to concrete area ratio was estimated as 0.27. A significant aspect of this work was that all work was performed (at night) with no daytime traffic closures.

TEST PROCEDURE DESCRIPTION FOR COMMISSIONING THE SYSTEM

Various tests including continuity, system resistance, E-Log I and current off potentials were done to determine the performance of the CP system. Continuity tests were performed to ensure that all rebars within a zone were continuous. Continuity between rebars were measured by AC resistance, DC resistance and DC voltage. System resistance was measured between the anode and the system negative using a Nilsson soil resistance meter.

For E-Log I testing, anode was connected to the positive of the rectifier and the steel to the negative of the rectifier. The current was increased in steps at regular intervals. The system was allowed to polarize for three minutes before measuring the current off potentials. The current off potential of the steel was measured at each current increment. The potential thus measured, along with the corresponding current level, was used to determine the polarization characteristics, the appropriate cathodic protection current and the corresponding current density on the steel. No anode potentials were measured.

RESULTS OF TESTING

Table 1 gives the system resistance for each zone. System resistance was measured by AC resistance and DC resistance methods. AC resistances were measured using the Nilsson soil resistance meter (model 400) and the DC resistance using a digital multimeter. AC resistance values ranged from 0.51 ohms to 1.20 ohms and the DC resistances ranged from 30 ohms to 1900 ohms. Half cell potentials (both IR free and static) of the steel were measured using the embedded silver-silver chloride reference cell. The potentials thus measured were converted to copper-copper sulfate reference by adding -132 mV. Static potentials in most zones were in the active range.

E-Log I test was performed by the contractor on all zones using the embedded half-cells and the portable surface reference cells. All the E-Log I data were obtained from the KCC INC files. KCC INC files were created with data as received from the contractor. Table 2 summarizes the E-Log I data for each zone. It provides information such as concrete surface areas, corrosion currents, protection currents, potentials corresponding to corrosion and protection currents, the potential shifts (from corrosion to protection level), concrete current density, steel current density and anode current density based on protection currents obtained from E-Log I tests. Concrete current density ranged from 0.909 mA/ft^2 to 1.618 mA/ft^2, the steel current density ranged from 2.114 mA/ft^2 to 3.762 mA/ft^2, and the anode current density ranged from 3.367 mA/ft^2 to 5.991 mA/ft^2. Shift in IR free potential ranged from 70 mV to 390 mV. The CP system in each zone was activated at the current level determined by the

Table 1. Anode to Steel System Resistance - I-64 West Bound Bridge, Charleston, West Virginia

Zone #	System Resistance	
	AC Resist.	DC Resist.
A	0.51	95
B	0.53	122
C	0.67	145
D	0.55	153
E	0.95	182
F	0.62	165
G	0.66	178
H	1.00	30
I	0.89	30
J	0.76	1400
K	0.53	122
L	1.20	121
M	0.81	131
N	0.95	138
O	0.84	103
P	1.10	1100
Q	0.76	1600
R	0.85	139
S	0.71	1900
T	1.10	96
U	0.76	153
V	0.75	121
W	0.64	130

Table 2. E-Log I Data Summary - I 64 West Bound Bridge, Charleston, West Virginia

Zone #	Concrete Surface Area, sq. ft.	Corrosion Current Amps	Protection Current Amps	Potential of Steel @		Potential Shift mV	Protection Current Density mA/sq. ft.		
				Icorrosion mV	Iprotection mV		Concrete	Steel	Anode
A	6004	2.60	7.40	-312	-532	220	1.233	2.866	4.565
B	7713	4.30	7.04	-482	-589	107	0.913	2.123	3.381
C	7280	3.00	7.50	-362	-602	240	1.030	2.396	3.816
D	7700	3.80	7.00	-502	-642	140	0.909	2.114	3.367
E	5052	2.00	6.40	-267	-657	390	1.267	2.946	4.692
F	5682	2.10	8.20	-367	-612	245	1.443	3.356	5.345
G	7981	2.50	7.50	-387	-547	160	0.940	2.185	3.480
H	5255	3.60	8.50	-372	-752	380	1.618	3.762	5.991
I	4884	3.40	7.20	-392	-712	320	1.474	3.428	5.460
J	6404	2.50	7.00	-457	-707	250	1.093	2.542	4.048
K	7543	2.50	10.00	-332	-432	100	1.326	3.083	4.910
L	5162	2.90	7.50	-357	-557	200	1.453	3.379	5.381
M	6835	1.80	7.00	-382	-512	130	1.024	2.382	3.793
N	4604	1.30	4.50	-407	-592	185	0.977	2.273	3.620
O	6096	2.30	6.40	-532	-617	85	1.050	2.442	3.888
P	5247	1.10	7.00	-312	-632	320	1.334	3.103	4.941
Q	6876	2.40	6.50	-507	-647	140	0.945	2.198	3.501
R	4861	2.00	6.50	-332	-567	235	1.337	3.110	4.952
S	6358	1.90	7.50	-422	-587	165	1.180	2.743	4.369
T	4318	1.70	4.50	-452	-812	360	1.042	2.424	3.860
U	5694	3.00	8.00	-552	-622	70	1.405	3.267	5.204
V	5584	2.70	6.50	-482	-742	260	1.164	2.707	4.311
W	7481	3.80	8.60	-582	-737	155	1.150	2.673	4.258

* Estimated steel to concrete area ratio = 0.43

** Estimated anode to concrete area ratio = 0.27

Total concrete surface area = 140,614 sq. ft.

E-Log I test. The system was allowed to polarize for 20 hours before measuring the rectifier output current and voltage and IR free potentials. The potential shift due to 20 hour polarization was calculated and reported. Table 3 gives data such as system resistance, rectifier output, static and IR free potentials and the potential shifts.

CONCLUSIONS

- The CP system has performed satisfactorily except for select zones in which rectifier operation problems occurred.
- Concrete surface current density varied from 0.909 mA/ft^2 to 1.618 mA/ft^2.
- At the end of the 20-hour polarization period all but two of the 23 zones showed IR free potential shifts equal to or greater than 100 mV.

RECOMMENDATIONS

- Measure IR free anode potentials (when the system is activated after 24-hour depolarization).
- The performance of the CP system should be checked by measuring the depolarization twice a year and any appropriate current adjustments should be made. Any remaining rectifier operation problems should be corrected.

COST ANALYSIS

The 1992 equivalent cost of the slotted cathodic protection system was calculated as \$7.00/ft^2 of concrete surface area. The cost of the CP system was estimated as a sum of labor, material and special equipment used. The total hours of labor, skill level and the hourly rate for each skill level were obtained from the KCC INC files. The summary of total man-hours of each skill level for each CP related activity was defined. The cost of any special equipment used on the job was calculated on the basis of rental charges.

Table 3. Activation Data Summary - I 64 West Bound Bridge, Charleston, West Virginia

Zone #	System Resistance		Rectifier Output		Refer. Cells Readings*		Polarization shift mV
	AC Resist. Ohms	DC Resist. Ohms	Voltage Volts	Current Amps	Static mV	IR free** mV	
A	0.51	95	7.10	8.50	-306	-611	-305
B	0.53	122	6.20	8.00	-477	-702	-225
C	0.67	145	7.90	9.00	-345	-668	-323
D	0.55	153	6.80	9.00	-501	-789	-288
E	0.95	182	9.50	8.00	-262	-911	-649
F	0.62	165	7.90	9.00	-360	-797	-437
G	0.66	178	7.70	9.00	-395	-583	-188
H	1.00	30	11.10	9.00	-356	-968	-612
I	0.89	30	9.70	8.00	-380	-998	-618
J	0.76	1400	8.00	8.00	-455	-832	-377
K	0.53	122	8.30	12.00	-328	-622	-294
L	1.20	121	8.30	8.00	-378	-694	-316
M	0.81	131	8.60	9.00	-372	-573	-201
N	0.95	138	8.60	7.00	-419	-674	-255
O	0.84	103	9.80	10.00	-532	-800	-268
P	1.10	1100	7.70	7.50	-311	-588	-277
Q	0.76	1600	7.00	8.00	-509	-662	-153
R	0.85	139	6.70	7.00	-223	-706	-483
S	0.71	1900	6.20	9.50	-423	-582	-159
T	1.10	96	8.60	6.00	-453	-898	-445
U	0.76	153	8.00	10.00	-554	-664	-110
V	0.75	121	8.10	8.50	-476	-896	-420
W	0.64	130	7.20	10.50	-577	-890	-313

* Values given here are with respect to copper copper sulfate reference cell

** The CP system was energized at values determined from E-Log I test and left on for about 20 hours before measuring the IR free potentials

The original 1983 cost figure was $5.50 per square foot of concrete surface area. This cost figure was converted to 1992 equivalent using FHWA document on price trends for Federal-Aid Highway Construction. The Composite Index calculated for all federal-aid highway construction (using 1987 as the base year) showed that the Indices for 1983 and 1990 were 87.6 and 108.5. Thus an increase of about 21 percent in 7 years or an increase of approximately 3.00 percent per year. Using the same annual percentage increase for 1991 and 1992, cost figures based on 1983 values were increased by 27 percent to yield 1992 equivalents.

Evaluation Report on The Repair and Rehabilitation of Brooklyn Battery Tunnel, New York, New York

June, 1993

Prepared For
New York Department of Transportation (NY DOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, VA 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to interact with various state agencies to collect the technical and cost data. KCC INC would also like to thank the New York Department of Transportation for their cooperation and assistance. Department engineer, Mr. Lin Nathan, and his fellow workers are appreciated for their assistance in collecting the data on technical performance of the titanium mesh anode encapsulated in shotcrete and the cost of installing this system.

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Evaluation Report on The Repair and Rehabilitation of Brooklyn Battery Tunnel, New York, New York

BACKGROUND

The Brooklyn Battery Tunnel consists of two parallel tubes, 15 ft apart and 9,117 ft long between the entrance and exit portals. It is the longest continuous underwater vehicular tunnel in North America. It has four ventilation towers constructed along its length to move as much as 6,152,000 ft^3 of air per minute through the tunnel. It took approximately 10 years to complete the project. The tunnel was opened to traffic in 1950. Each tube is 31 ft in diameter and has three levels; the fresh air duct as the first level, the roadway as the second level, and the exhaust duct as the third level. The fresh air duct is separated from the roadway by the roadway floor slab and the exhaust duct is separated from the roadway by the roadway ceiling slab. The roadway floor slab was rehabilitated and hence was monitored under C-102G.

The roadway slab is 14 in. thick and was constructed with a 4000 psi concrete. The concrete surface was paved with 4-in. thick asphalt. A survey done in 1990 revealed many pot holes, humps, and delaminations in the asphalt paving course. At the locations where asphalt was damaged, it was removed and the concrete beneath was observed to be in poor condition. Many areas of spalled concrete cover were discovered and the reinforcing steel underneath was severely corroded. The top flanges of the encased steel beams had no concrete cover in many cases. The areas which were not spalled, were delaminated and the delaminations appeared to extend outside the boundaries of the asphalt which was removed. The cores removed from the roadway slab almost always fractured at the depths of rebar. However, some of them were the result of core removal. The chloride contents in the cores were found to be generally above the threshold level. The chloride contents in the cores with delaminations tended to be higher in the top half of the cores relative to undelaminated cores. The petrographic analysis of the cores indicated that the concrete had a water cement ratio in the range of 0.45 to 0.50 and had no entrained air.

The high level of chlorides coupled with the presence of moisture seemed to be the cause of deterioration of the top concrete surface, corrosion of rebars, and the presence of pot holes in the asphalt roadway paving. It was recommended that the roadway slab be repaired and protected by appropriate protective measures.

REHABILITATION BEFORE INSTALLATION OF CP

All of the delaminated concrete was removed. All of the reinforcing steel with significant loss of cross section was identified and replaced with fusion-bonded epoxy coated reinforcing steel of comparable size. The epoxy coated rebars were tied into existing reinforcement by welding.

THE CP SYSTEM

This titanium mesh and shotcrete CP system is being installed on the underside of the roadway slab. All the unsound concrete was identified and removed. The concrete surface and the exposed steel were sandblasted to remove all loose material, rust stains, or other coatings. A continuity test was performed after the completion of surface preparation, but prior to shotcreting, to identify any areas of discontinuity. Discontinuity between the steel was confirmed by the following:

a. Resistances that changed more than 0.3 ohms when the ohmmeter leads are reversed,

b. Resistances that changed more than 0.3 ohms in 15 seconds,

c. Resistances greater than 1.0 ohm.

Any discontinuous steel observed was welded to the continuous mat to make it continuous.

The mixed metal oxide mesh anode was secured on to the prepared concrete surface using plastic fasteners. The titanium strip of 0.5 in. by 0.04 in. was resistant spot welded to the mesh at every three in.. The electrical isolation of the mesh from the steel was checked and ensured.

The anode mesh was encapsulated in 3500 psi shotcrete. Figure 1 shows the anode installation process and E-Log I testing. The total concrete area under cathodic protection was 111,212 ft^2. There were a total of 42 zones. The total anode surface area was 33,364 ft^2.

INSTRUMENTATION

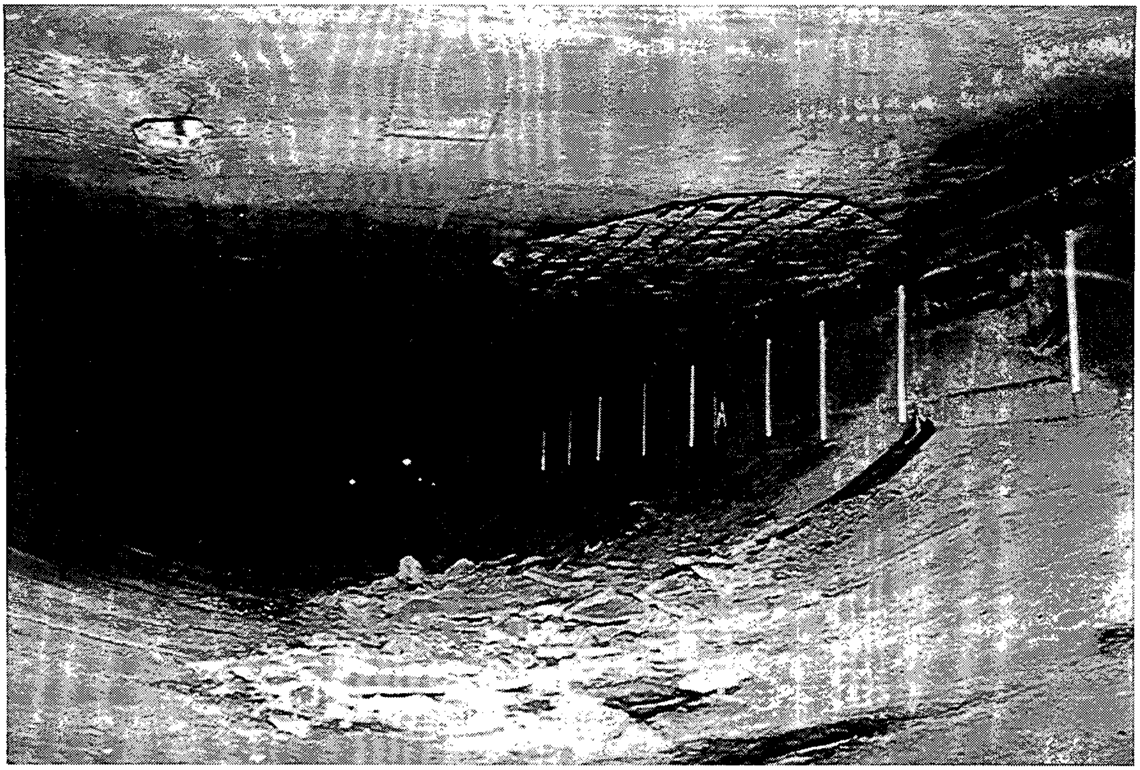
The reinforcing bars for the rebar probes were of ASTM A615, grade 60 bare rebar. The probes were placed in sawcut slots. The concrete used for filling the slots was air entrained Type IIA Portland Cement concrete with a 0.5 water cement ratio and sufficient admixed sodium chloride to yield 15 lbs./yd^3. The reference electrodes were molded dense electro-graphite rods of 1 inch diameter and 6 in. long.

The rectifier is a silicon controlled, air cooled, constant current filtered DC output rectifier. Each rectifier had four circuits and each circuit had a 16 A, 30 V capacity. Each rectifier was designed to operate from 208 V, 3 phase, 60 Hz AC power and be compatible with a remote monitoring unit.

TEST PROCEDURE DESCRIPTION FOR COMMISSIONING THE SYSTEM

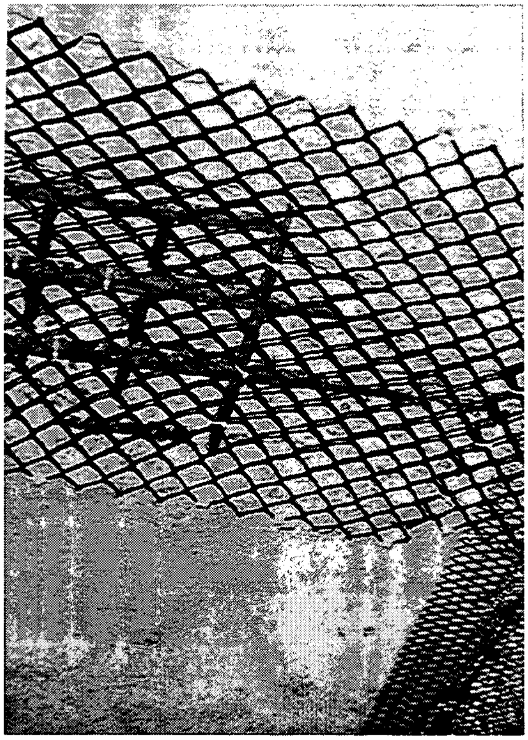
Various tests including system resistance, E-log I, IR free potential, and depolarization were done to determine the feasibility and the performance of the CP system. The system resistance (i.e., the resistance between the anode and the steel) was measured to identify the electrical shorts, if any, and eliminate them.

The E-log I was performed by connecting the anode to the positive terminal of the rectifier and the steel to the negative terminal of the rectifier. The current was increased in steps and at each increment, current off potential of the steel and the anode were measured by manually switching off the rectifier for one second in every one minute. The IR free potential thus measured were plotted against the corresponding current for both the steel and the anode to determine the polarization characteristics, the appropriate cathodic protection current, and the corresponding current density on the anode and steel.



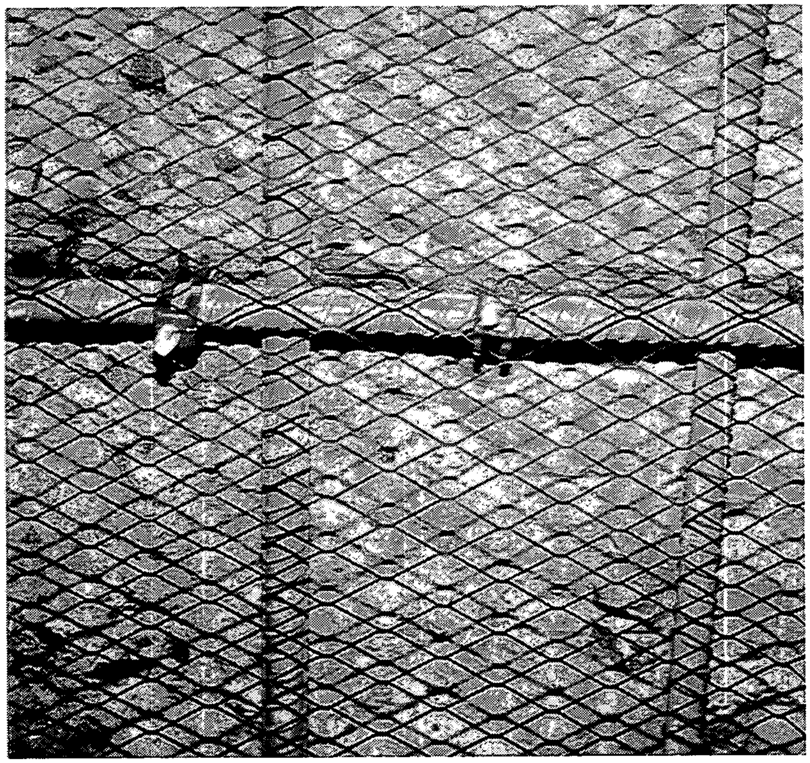
Overall View of the Roadway Underside

Graphite Half Cell and Rebar Probe in Place

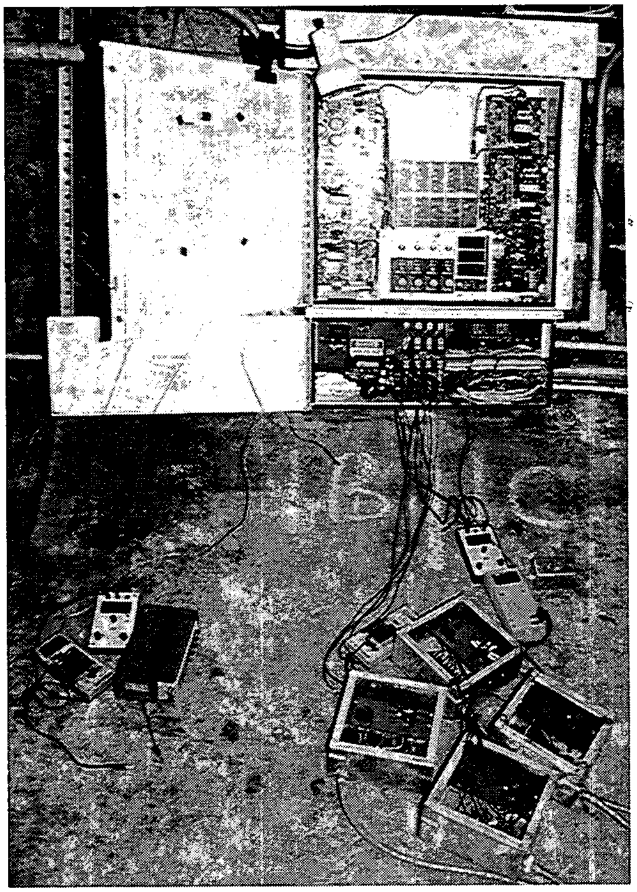


Plastic Mesh to Electrically Isolate Anode and Steel

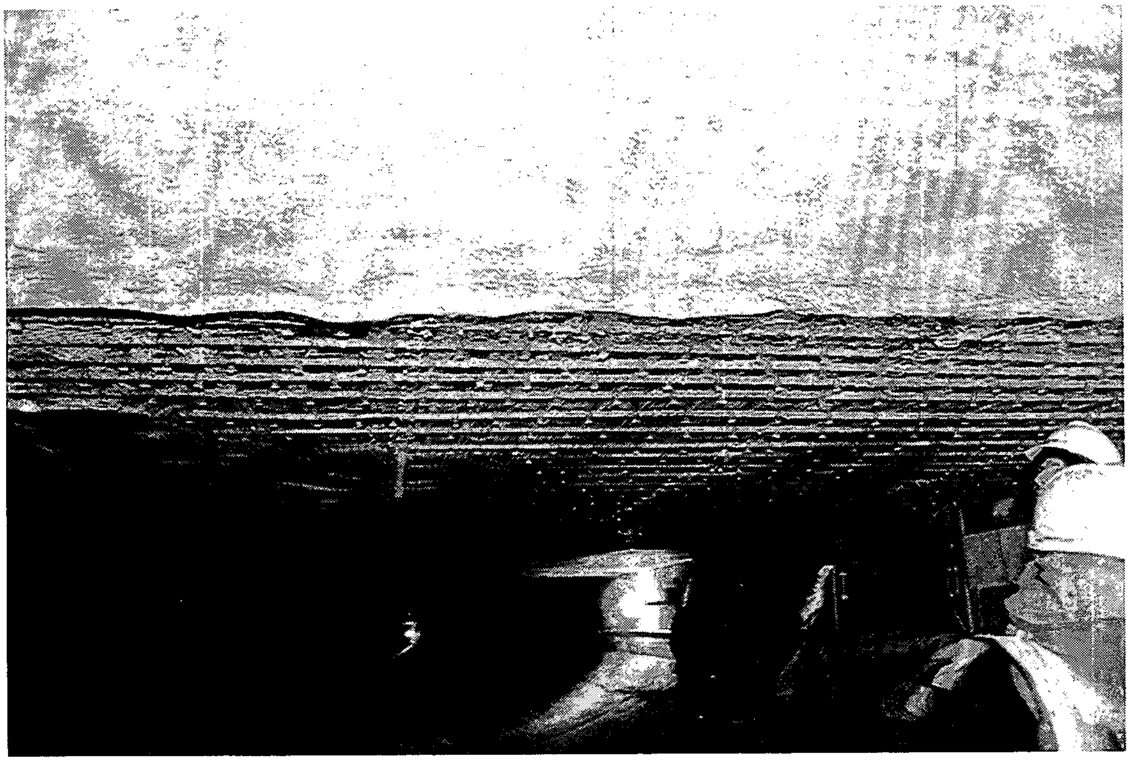
Figure 1. Installation and Activation of Anode Mesh



Anode Mesh Secured in Place



Activation in Progress



Mesh Ready for Shotcreting (Finished shotcreted surface in the Foreground

Figure 1. (cont'd) Installation and Activation of Mesh Anode

Depolarization of steel was measured after allowing the steel to be polarized for approximately one month. At the end of this period the rectifier was switched off and the potential of the steel was monitored at least over a period of 4 hours. The 4-hour depolarization was calculated and based on the depolarization value and the current was adjusted such that the NACE Standard RP0290-90 depolarization criteria was satisfied.

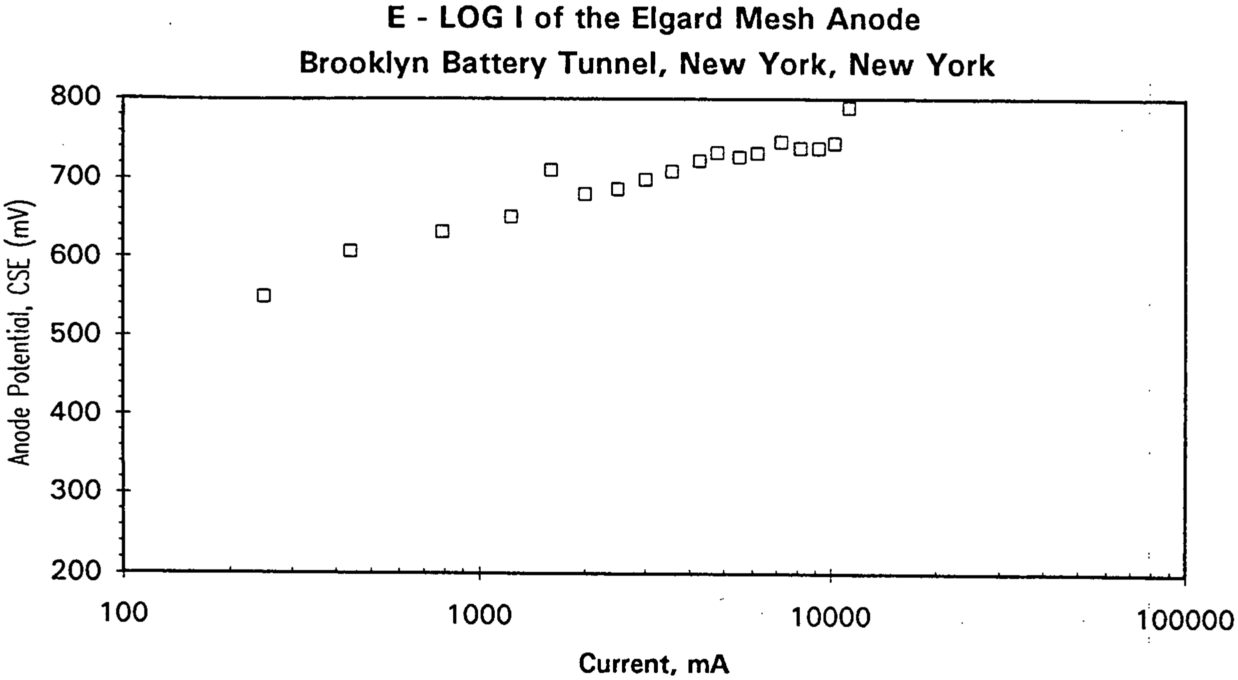
RESULTS OF TESTING

Electrical continuity between the anode and the steel was checked by measuring the system resistance by AC resistance, DC volts, and the DC ohms methods. The AC resistances were measured using the Nilsson soil resistance meter, whereas DC volts and DC ohms were measured using a digital multimeter. Table 1 gives the system resistance for each zone. The AC resistance value ranged from 0.08 ohms to 0.41 ohms, whereas DC volts and DC ohms ranged from 374 mV to 634 mV and 547 ohms to 1040 ohms respectively. Although AC resistance values were all less than 1 ohm, DC volts and DC ohms values showed that the anode is electrically isolated from steel. In addition, static half-cell potentials of the anode and steel were measured using the embedded graphite reference cells and are given in Table 1. The static potential values again reinforce the electrical isolation of anode and steel. E-log I of the anode and the steel for one of the zone, W1B with a concrete surface area of 2664 ft^2, is included in this report. The polarization curves of the anode, top steel, and bottom steel of zone W1B is given in Figure 2. The current output was adjusted by adjusting the potentiostat for current control. At each current increment the anode and the steel were allowed to polarize for two minutes before measuring the current off potential. The current off potential was measured by shutting the rectifier off manually.

The polarization curves of both the top and bottom steel showed an abnormal trend at lower current levels (i.e., the potential shifted more positive with the increase in cathodic current). However, the normal trend (i.e., the potential shift to more negative potential with the increase in cathodic current) was observed at higher current levels. The reason for this behavior is not known. The polarization curve for the top and bottom steel had three distinct regions as shown in Figure 2 and the start of the third region was identified as the protection level. The current

Table 1. Resistance Measurements - Brooklyn Battery Tunnel, New York, New York

Circuit #	Resistance				Static Potential	
	AC Resist.	DC Resistance mV drop		DC Ohms	Anode	Steel
	Ohms	Forward	Reverse	Ohms	mV vs CSE	mV vs CSE
System Resistance (Between Anode and Rebar Ground)						
W1A	0.23	634	-654	1040	463	-165
W1B	0.08	374	-378	547	222	-164
W1C	0.14	494	-492	756	177	-322
W1D	0.17	443	-437	673	250	-205
W2A	0.18	462		700	142	-327
W2B	0.23	415		622	292	-154
W2C	0.41	387		566	310	-84



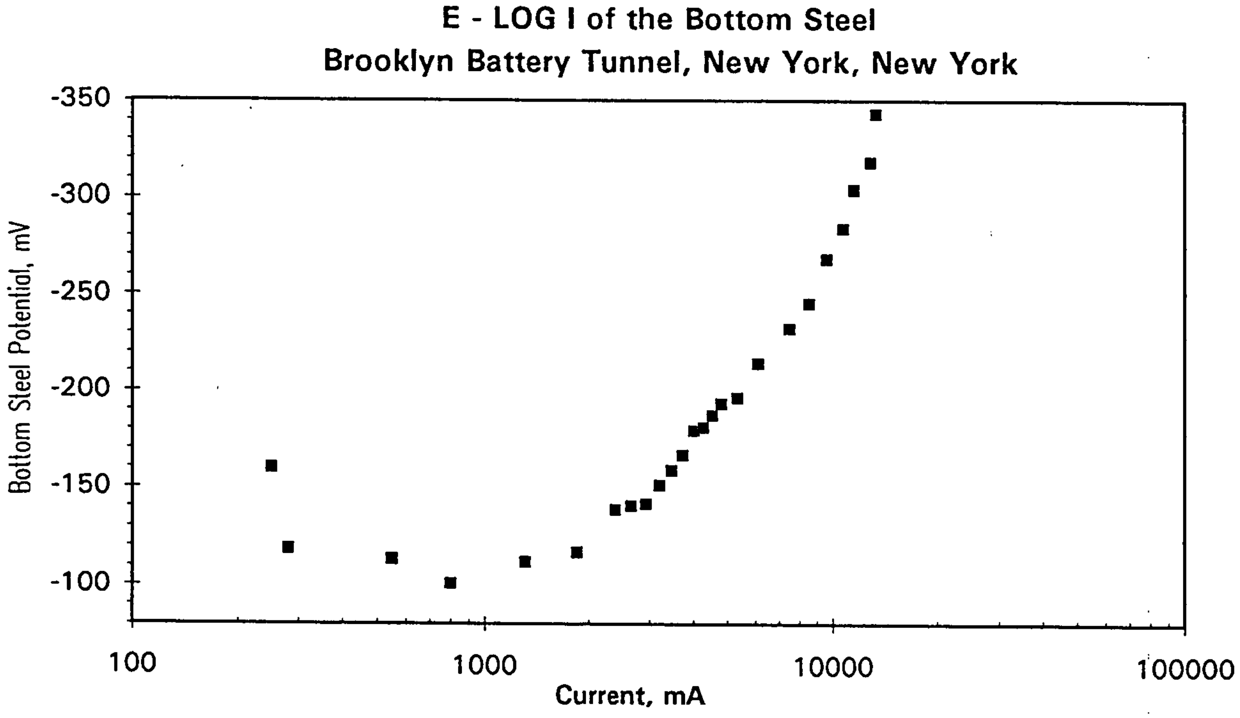


Figure 2. E-Log I of Anode and Top and Bottom Steel

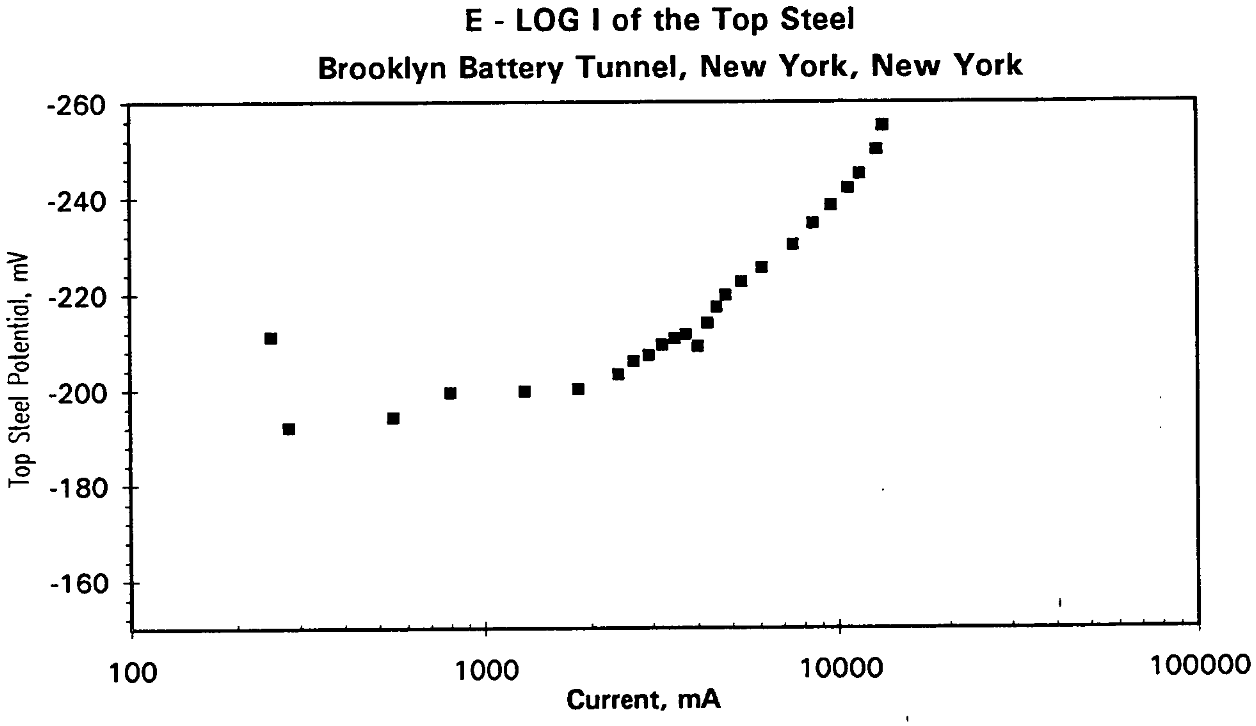


Figure 2. (cont.)

corresponding to this level of protection was about 8 amperes and a current density of 3.0 mA/ft^2 of concrete surface area.

Figure 2 also gives the polarization curve for the mesh anode. The anode potential seemed to stabilize at higher current levels and operated at 740 mV at the identified protection level. The corresponding current density on the anode was 10.00 mA/ft^2 which was only 50 percent of the anode current discharge capacity.

A conservative analysis of the E-Log I plot yielded a protection current of 8 A as described. A more rigorous analysis of the E-Log I plot indicated a protection current in the range of 5 A.

The rectifier operated at 50 percent of its capacity for the proposed protection level. The rectifier seemed to introduce spikes in the signal when it was either switched off or switched on. Using the manual interrupter on line or the circuit switch. These spikes seem to influence the measurement of current off potential of the steel and the anode. However, when the rectifier breaker was used, no spikes were apparently observed (i.e., no increase in current immediately after the rectifier was switched off). Hence, it was decided to measure the current off potential of the anode by using the rectifier breaker. The polarization curve of the anode shown in Figure 2 was obtained this way. It is important to note that the current off potential of the anode fluctuated so much that it made it difficult to plot polarization trends for anodes in the other zones.

Prior to doing E-log I, the CP system of zone W1B was activated at 6.66 A and left at that current level for the system to polarize for about a month. The current off potential was measured at the end of this period and the rectifier was switched off to measure the depolarization of top and bottom steel. The top and bottom steel showed a 4 hour depolarization of 44 mV and 122 mV respectively and a 24-hour depolarization of 118 mV and 211 mV respectively. Although the E-log I data showed a protection current level in the range of 5 to 8 A, the depolarization test seem to indicate that about 6 A of current should satisfy the NACE criteria for CP systems. The E-Log I of the virgin CP system could not be obtained because of the contractual requirements that depolarization testing be done before E-Log I.

Hollow sounding areas have been identified in certain areas of the shotcreted section in early January '93. Investigation is in progress to identify the factors that cause the delamination of the shotcrete.

CONCLUSIONS

- o The CP system as installed performed satisfactorily in that the bottom reinforcing steel exhibited depolarization in excess of 100 mV. However, the depolarizations on the top reinforcing are less than 100 mV, indicating the possibility of only partial protection.

- o The IR free potentials of steel are more positive than the hydrogen evolving potentials.

- o Use of the circuit switch to measure the IR free potential introduces spikes in the signal which appears to influence the IR free potential measurement.

RECOMMENDATIONS

- o The influence of spike on current off potential values should be quantified and the source of the spike must be identified and removed to facilitate measurement of current off potential by remote monitoring method.

COST ANALYSIS

The cost of the CP system was calculated as $11.10 per square foot of the concrete surface. Table 2 lists the cost of all pertinent work related to the CP system. Only those activities directly related to CP were considered for calculating the cost of the CP system.

A total of 111,212 ft^2 of concrete surface is to be protected by CP. A portion of the structure to be monitored under C102G was identified. A total of 15,762 ft^2 (six zones) out of 111,292 (42 zones) was monitored under C102G (i.e. 14 percent of the total CP area was monitored under C102G). The cost of the CP system was obtained as a sum of labor, material and special equipment used. The total hours of labor, skill level, and the hourly rate for each activity was taken from the daily reports and field observations. Where data were not available, estimates were made based on the field observation and prior experience of KCC INC with other C-102G projects. The labor rates were calculated to reflect the overhead and profit (overhead and profits were assumed as 100 percent of the basic labor rates). A summary of the total man-hours of each skill level for each CP-related activity was made using the daily reports and direct field observations. The cost of any special equipment used on the job was calculated on the basis of rental charges.

Cathodic Protection Cost

1. Surface Preparation	$15,920.00
2. Checking for Continuity	600.00
3. Instrumentation	3,300.00
4. Anode Installation	88,350.00
5. Shotcrete Overlay	21,090.00
6. Rectifier	7,410.00
7. Remote Monitoring	8,550.00
8. Electrical Wiring	26,198.00
9. Activation	3,400.00

Total Cost = $174,818.00

Unit Cost = $174,818.00/15,762 = $11.10/ft^2

Table 2. Cathodic Protection Cost Estimate - Brooklyn Battery Tunnel, New York, NY

Description	Labor			Material			Special Equipment		
	Man-hours	Rate	Amount	Quantity	Unit Price	Amount	Quantity	Rate	Amount
1. Surface preparation	1	L.S.	15,920.00						
Subtotal $15,920.00			**15,920.00**						
2. Checking for Continuity									
Engineer	10	40.00	400.00						
Technician	10	20.00	200.00						
Subtotal $600.00			**600.00**						
3. Instrumentation				10 probes	100.00	1000.00			
Technician	40	20.00	800.00	10 cells	150.00	1500.00			
Subtotal $3300.00			**800.00**			**2500.00**			
4. Anode Installation									
Laborers	320	20.00	6400.00	15,762.00 ft²	5.00	78,810.00	1 welder	L.S.	500.00
Foreman	40	26.00	1040.00						
Field Engineer	40	40.00	1600.00						
Subtotal $88,350.00			**9040.00**			**78,810.00**			**500.00**
5. Shotcrete Overlay							1 compressor	L.S.	1500.00
Skilled	80.00	30.00	2400.00	95 yd³	90.00	8550.00	1 pickup	L.S.	600.00
Skilled	240.00	25.00	6000.00				1 dump truck	L.S.	1000.00
Supervisor	40.00	26.00	1040.00						
Subtotal $21,090.00			**9440.00**			**8550.00**			**3100.00**
6. Rectifier									
Electrician	8.0	30.00	240.00	6 circuits	1000.00	6000.00			
Technician	8.0	20.00	160.00	1 case	L.S.	1010.00			
Subtotal $7410.00			**400.00**			**7010.00**			

7. Remote Monitoring				2 1000 ft	625.00 0.80	1250.00 800.00	Computer Initialize	L.S. L.S.	3000.00 3500.00
Subtotal $8550.00						**2050.00**			**6500.00**
8. Electrical Wiring Electrician Asst.Electrician Superintendent	 160 160 80	 30.00 25.00 26.00	 4800.00 4000.00 2080.00	 1	 L.S.	 15,318.00			
Subtotal $26,198.00			**10,880.00**			**15,318.00**			
9. Activation Engineer Technician	 40.00 40.00	 40.00 20.00	 1600.00 800.00				Instruments	L.S.	1000.00
Subtotal $3400.00			**2400.00**						**1000.00**
Total Amount = $174,818.00									

Total concrete surface area = 15,762 ft²

Unit rate = 174,818/15,762 = $11.10/ft²

Evaluation Report on the Repair and Rehabilitation of Yaquina Bay Bridge, Newport, Oregon

June, 1993

Prepared For
Oregon Department of Transportation (OR DOT)
and
The Strategic Highway Research Program (SHRP)

Prepared By
Kenneth C. Clear, Inc.
6407 Sperryville Pike
Boston, VA 22713

Acknowledgements

KCC INC would like to thank SHRP for funding this effort and setting the stage for KCC INC to interact with various state agencies to collect the technical and cost data. KCC INC would also like to thank the Oregon Department of Transportation for their cooperation and assistance. Department Engineer, Mr. Walter Eager, and his fellow workers are appreciated for their assistance in collecting the technical information on sprayed zinc anode systems.

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Evaluation Report on the Repair and Rehabilitation of Yaquina Bay Bridge, Newport, Oregon

BACKGROUND

The structure is a two-lane bridge and was built in 1934. The structure was surveyed in 1989 for the extent of damage due to corrosion of reinforcing steel. A total of at least 14,003 ft^2 of delaminations was identified. Chlorides from the marine atmosphere have penetrated the concrete and accumulated in sufficient concentration at the steel interface to induce corrosion. In many locations on the Yaquina Bay Bridge there are severely corroded reinforcing bars, the strength of which has been decreased by the reduction in the cross section area.

REHABILITATION BEFORE INSTALLATION OF CP

All the concrete surface to which zinc anodes will be applied will be inspected to identify all the delaminations and exposed and/or near surface metallic objects. The identified delaminations will be removed such that the depth of underdeck excavations does not exceed 3 in..

All the exposed metal pieces (i.e., metallic form ties, tie wires, reinforcement supports, nails, and other unessential metallic objects) that are less than 1/2 in. from the concrete surface will be removed. The importance of this is accentuated by the fact that the thermally sprayed zinc easily penetrates into the concrete through the pores (as much as 1/4 in. deep) and establishes contact with the reinforcing steel causing system shorts.

All the cracks on the concrete surface to be cathodically protected will be identified and cleaned with compressed air. These cracks will then be sealed by injecting epoxy through the ports set along the cracks.

Severely corroded rebars will be identified and left in place. However, a new bar of the same size will be lap welded to compensate for the loss of structural stability.

Existing patches of low strength or of resistivities greater than 50,000 ohm-cm will be removed. All the excavations will be patched with the pneumatically applied mortar with a compressive strength of 3000 psi. The mix design for the pneumatically applied mortar is one part of cement (Type I or Type II) and 3.5 parts of dry loose sand by volume. The moisture content of the sand should be between 3 percent to 6 percent by weight. Sodium Chloride will be used as an admixture at the rate of 4 lb/yd^3 of pneumatically applied mortar. During application, the nozzle should be held at right angles to the shooting surface at a distance of 2.5 to 3.5 ft. The pneumatic mortar thus applied will be cured for at least seven days using a pigmented curing compound.

INSTRUMENTATION

Two permanent reference cells will be installed in each zone; one graphite reference cell and one silver/silver chloride reference cell to monitor the performance of the CP system.

A permanent graphite reference cell will be installed at a non-spalled and non-delaminated location in each zone with the most negative rebar potential. The second permanent reference cell in each zone is a silver/silver chloride and will be located in the next most negative potential which is at least 10 ft away from the first reference cell.

The slots for the reference cells will be excavated by saw-cutting to the rebar depth and then chipping out the concrete. The reference cells will be encapsulated in a non-epoxy grout with sodium chloride at the rate of 0.35 percent by weight of grout. A layer of grout will be placed on all sides of the reference cell before placing it in the excavation such that the reference cell does not come in contact with the rebar or cathodic protection system component. The reference cell slot will then be filled flush with the existing concrete surface by hand packing. The reference cells will be checked by measuring the resistance between reference cells and the rebar and accepted based on the following:

1) graphite permanent reference cell to rebar resistance is less than 500 ohms.

2) silver/silver chloride permanent reference cell to rebar resistance is less than 5000 ohms.

THE CP SYSTEM

The CP system consists of a 2.5 in. diameter and 1/8 in. thick brass plate (primary anode) and thermally sprayed zinc of thickness 20 ± 2 mil. The sprayed zinc is specified to have the following properties:

1) Thickness between 18 to 22 mil

2) Average adhesion strength of 150 psi with a minimum of 50 psi

A minimum of 3 measurements per zone is required to be performed for both the thickness and the adhesion strength tests.

The primary anode plate has a 1 in. long bolt brazed to the plate. The primary anode plates will be attached to the concrete surface using Concresive epoxy adhesive. Two primary anode plates will be provided per zone, separated by at least 4 ft. The exposed surface of the plate will be flush with the concrete surface, but no portion of the plate will be in direct contact with the concrete surface. The brass plate will be roughened by sandblasting to enhance adhesion to the epoxy.

The concrete surface to be sprayed with zinc will be cleaned by abrasive blasting with non-metallic grit such that 30 percent to 60 percent of the concrete surface is exposed as coarse and fine aggregate. Zinc spraying will be performed only when the air temperature is between 70 and 90°F and the relative humidity is between 20 percent and 60 percent adjacent to and surrounding the entire current work surface.

Current EPA regulation necessitates the containment of zinc as it was classified as hazardous. The CP specification for the Yaquina Bay Bridge calls for containment and proper disposal of the zinc dust. During all phases of the delamination repair and CP system installation, the enclosure will be in operation.

The enclosure is a vertical structure which surrounds the work area and provides a seal against the underside of the deck. Heated and filtered air will be circulated over the work surfaces through at least a partially open grate enclosure. Exhaust air will be taken from the area where the work is being performed and filtered before it is exhausted to the exterior atmosphere or recirculated to the enclosure. The air cleaning system is specified to provide a cleaning efficiency of at least 99 percent for particulate diameters above 0.1 micrometers at rated air flow. Air delivered to the work area or exhausted to the surrounding atmosphere should contain less than 2 grains per thousand cubic feet (2 gr./1000 ft^3) of particulate. This enclosure specification is expected to provide a good atmosphere to achieve excellent adhesion strength between the thermally sprayed zinc and the concrete surface to which it is applied.

CONCLUDING REMARKS

Installation of the anode was postponed for several reasons including problems with electrical shorts. Hence KCC INC could neither obtain technical data nor collect cost information before the contract C-102G reporting deadline.

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John Apostolos
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Robert J. Girard
Missouri Highway and Transportation Department

Richard Kessler
Florida Department of Transportation

Carl E. Locke, Jr.
University of Kansas

David G. Manning
Ontario Ministry of Transportation

Paul Virmani
Federal Highway Administration

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