Cathodic Protection of the Concrete Piers of Two Bridges in Virginia Using a Water-Based Conductive Coating

Gerardo G. Clemeña and Donald R. Jackson

There is a need for a simple and inexpensive anode for use in the impressed-current cathodic protection (CP) of inland concrete piers that are deteriorating because of salt-induced corrosion of rebars. In search of such an anode, a new water-based conductive coating was used recently on the cathodic protection of some concrete piers in Virginia. Further, as a possible means of eliminating the need for regular site visits to inspect and ensure that the CP is functioning properly (a disadvantage common to existing CP systems), a microprocessor-based data acquisition device that facilitates remote monitoring was tested with the system. The design, the installation, and the performance of the CP system during its first year of operation are described.

There are three strategies for the rehabilitation of concrete piers that are deteriorating because of salt-induced corrosion of rebars: (a) remove the deteriorated concrete, clean the rebars, and patch the excavated areas; (b) in addition to these procedures, replace the structurally sound concrete that is already contaminated with high amounts of deicing salt with new concrete; or (c) in addition to these procedures, apply cathodic protection (CP) to the piers.

Although the least costly, Alternative 1 eventually leads to cycles of deterioration and repair because the new concrete in the patches creates new electrochemical imbalances in the structure. Alternative 2 could prevent these cycles from occurring for probably 10 to 15 years, after which time enough salt would eventually accumulate again in the new concrete to induce corrosion of the rebars. Further, this alternative can be prohibitively expensive if some load-bearing concrete has to be replaced.

Alternative 3 is, theoretically, the ideal solution because CP eliminates the need to remove contaminated concrete, and it deals with the underlying problem directly by halting further corrosion of the rebars. In addition, the cost of a CP system is becoming relatively economical.

In the cathodic protection of any concrete substructures, the selection of a suitable anode system is critical, because the anodes are vital components of a CP system (see Figure 1). In general, anodes must be

- Electrically conductive,
- Reasonably chemically inert,
- Inexpensive,
- Easy and safe to install or apply, and
- Reasonably easy to maintain.

Small-scale testing of different anode materials on concrete piers, including conductive coatings and zinc metallized coatings, has been reported (*1–3*). It appears from these and several unpublished reports that conductive coatings have the best prospect of fulfilling these requirements. In 1988, the most extensive use of a conductive coating was made in a CP system for 93 concrete pier caps in Richmond, Virginia (*4*). The early observations made on this system confirmed that this type of anode indeed holds promise for effective use on inland concrete piers.

Conductive coatings are paints made electrically conductive by the addition of finely dispersed carbon particles; they are applied on the surface of concrete with brushes or rollers. However, in the past, their use required extreme precaution because all available conductive coatings contained organic compounds—such as xylene, propylene glycol, and monoethyl ether—which are considered potentially hazardous.

The recent introduction of a proprietary water-based conductive coating has provided a safer alternative. This coating consists of a blend of specially treated carbon dispersed in an acrylic resin with various properties that are presented in Table 1. Recent testings in a laboratory and an exposure yard have indicated that this water-based coating is as durable as the best organic-based conductive coating (*5*).

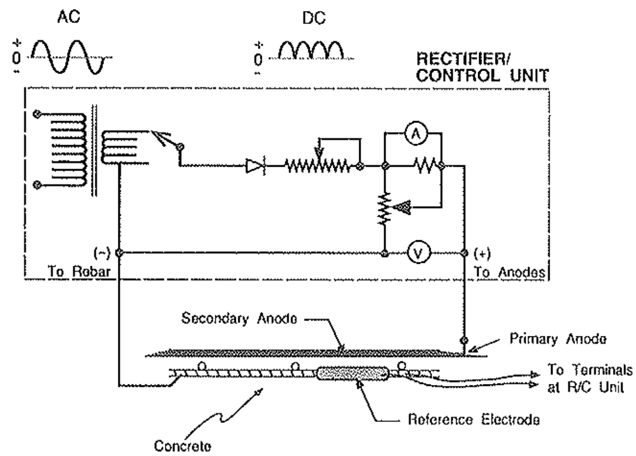

FIGURE 1 Components of a typical CP system for reinforced concrete substructures.

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TABLE 1 PROPERTIES OF THE WATER-BASED CONDUCTIVE COATING

Pigment	specially treated non-graphite carbons
Binder	acrylic
Color	black
Carrier	water
Density	@ 1.56 g/cc (13 lbs/gal)%
Solids (by wt.)	73%
Solids (by vol.)	67
Viscosity	6,000-10,000 cps (Brookfield RVT)
pH	8.5
Flash point	none
Linear resistance	5.9-7.9 ohm/cm (15–20 ohms/in), point-to-point, at 10 mils dry film thickness
Recommended thickness	0.254-0.381 mm (10–15 mils)
Theoretical coverage	26.2 sq m/l at @ 0.025 mm thick (1072 sq ft/gal at @ 1 mil)
Actual coverage	2.44 sq m/l (100 sq ft/gal)

Obtained from manufacturer's provisional product data sheet

These developments prompted the recent experimental use of this water-based conductive coating in a CP system for the 10 concrete piers of two twin bridges in Virginia. The design and installation of the system are described and up-to-date observations on the system's performance are reported.

DESIGN OF THE CP SYSTEM

The coating was used on the concrete piers of the two bridges (Structures 2014 and 2015) that were built in 1966 to carry the northbound and southbound lanes, respectively, of Interstate 81 over Route 698 in Shenandoah County, Virginia. During an inspection in 1987, it was found that all 10 concrete piers were exhibiting all the symptoms related to salt-induced corrosion of rebars, which is a consequence of deicing salt coming through faulty deck joints located directly above the piers. By sounding the concrete, its deterioration was estimated to range from 0.1 to 18.0 percent of the surface area of the piers.

In accordance with the geometry of the piers, it was specified that a set of 6 separate PT-Nb-Cu wires of 0.79-mm diameter be installed on each pier at locations shown in Figure 2 to serve as the primary anodes. These six anode wires would provide adequate redundancy to prevent complete failure in a circuit should any of the wires become accidentally disconnected in the future. Each anode wire was taped in place with adhesive mesh tapes and then covered with a conductive anode paste (see Figure 3). Then, two coats of the conductive coating, which would serve as a secondary anode, were applied on each pier with rollers or brushes. Although not absolutely necessary, the black conductive coating was covered with a light exterior acrylic coating to ensure the durability of the conductive coating.

In order to avoid electrical interference between the piers, the six anode wires on each pier were connected to an independent circuit in a common rectifier-controller (R/C) unit; hence, the R/C unit had to have 10 independent adjustable circuits. The maximum capacity of each circuit was 10 amperes at 20 volts. The R/C unit was operated in a constant-current mode and connected to a 220-volt ac utility line.

The locations of two system ground (negative) connections, one embedded graphite reference electrode, and eight test windows that would allow for measuring the rebar potential with an external $Cu\text{-}CuSO_4$ electrode are shown in Figure 2.

In order to ensure that a CP system is functioning properly, its R/C unit has to be inspected regularly (at least once a month) by obtaining readings of the current and voltage outputs of each circuit. When many systems have to be monitored, such requirements can become a burden. Fortunately, this difficulty can be avoided by the use of remote monitoring technology to eliminate the need for bridge visitation to inspect the CP systems.

In order to test this new technology, the R/C unit was equipped with a microprocessor-based data acquisition system

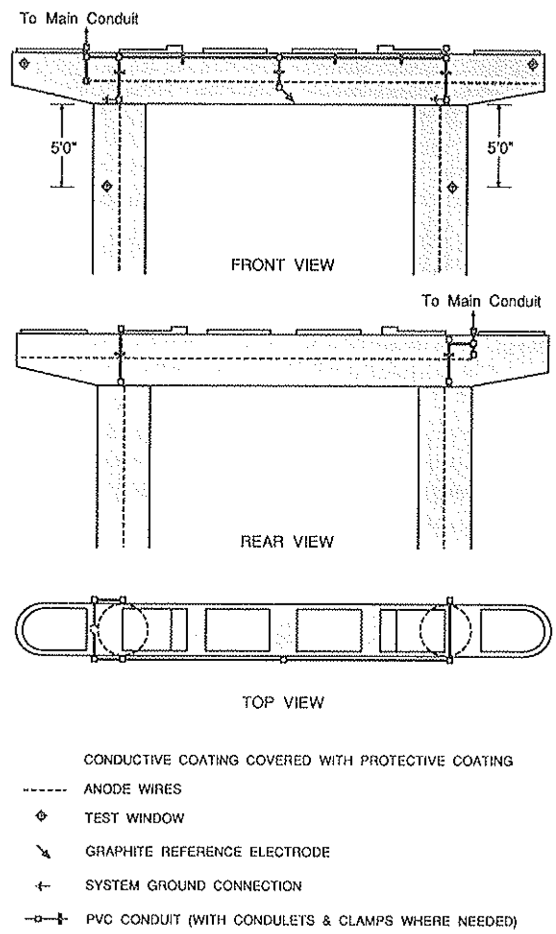

FIGURE 2 Layout of CP system components on each pier.

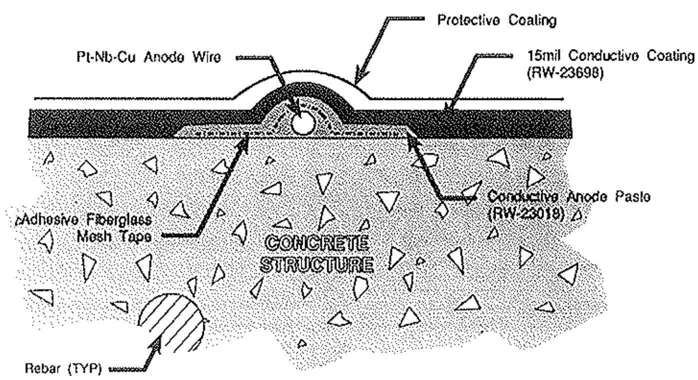

FIGURE 3 Taping of anode wire and application of anode paste, conductive coating, and protective coating.

(DAS) and a modem, which was connected to a telephone line at the bridge site to allow access to the unit from a remote office through another modem and a microcomputer. The 30-channel DAS facilitated the remote monitoring of the current output, the driving voltage of each of the 10 circuits, and the response of the rebars in each pier (i.e., the rebar potential as measured by the embedded graphite electrode).

INSTALLATION PROCEDURES AND ENERGIZATION OF THE SYSTEM

The installation procedures were as follows:

1. The deteriorated concrete was removed to 25 mm below the rebars, and the corroded rebars were sandblasted in accordance with VDOT specifications (*6*).
2. Tests were made for electrical continuity between the rebars in each pier to ensure that no rebars were electrically isolated from the rest, thus leaving them unprotected by the CP system. This important test was conducted by measuring the dc and ac resistances between the rebars at several locations (usually at the ends of the cap and at the top and bottom of the columns). Any electrically isolated rebar (identified by abnormally high resistance) was then electrically bonded to a nearby rebar by thermite welding an insulated copper wire between them.
3. All metallic appurtenances (such as drains, anchor bolts, etc.) were connected electrically to the rebars.
4. Two system ground connections and a graphite reference electrode were installed in each pier at locations shown in Figure 2.
5. The excavated areas were prepared and then patched with pneumatically applied mortar in accordance with VDOT specifications (*6*). If an excavated area was too large, it was necessary to tie a small metal mesh to the rebars to ensure that the mortar would stay in place. In such cases, only ungalvanized steel mesh was allowed, and then the contractor had to ensure that the edge of the mesh was more than 3.8 cm below the finished surface.
6. All small metal wires exposed at the surface of the concrete were masked with vinyl ester resin sealant. This important procedure had to be carried out methodically to prevent any wire (particularly chairs and tie wires at the underside of a pier cap, where the concrete cover tends to be thin) from being left exposed to come in contact with the conductive coating, thereby creating a short in the circuit.
7. Several 51- by 51-mm concrete areas in each pier had to be masked with duct tape to prevent them from being coated with the conductive coating. These areas would serve as test windows.
8. The edges of metallic appurtenances and the concrete area (to 75 mm) surrounding these appurtenances had to be masked to prevent their being coated by the conductive coating and thereby creating shorts in the circuits.
9. Six Pt-Nb-Cu primary anode wires were installed on each pier at specified locations shown in Figure 2 and covered with conductive anode paste.
10. Two coats of the conductive coating were applied to the concrete with rollers after cleaning the concrete with light sandblasting. Figure 4 shows a pier after the conductive coating was applied.
11. An acrylic coating was applied over the dried conductive coating. Figure 5 shows a pier after the completion of the top coating.
12. All wirings were routed through PVC conduits to the common R/C unit located at the south end of the bridges.

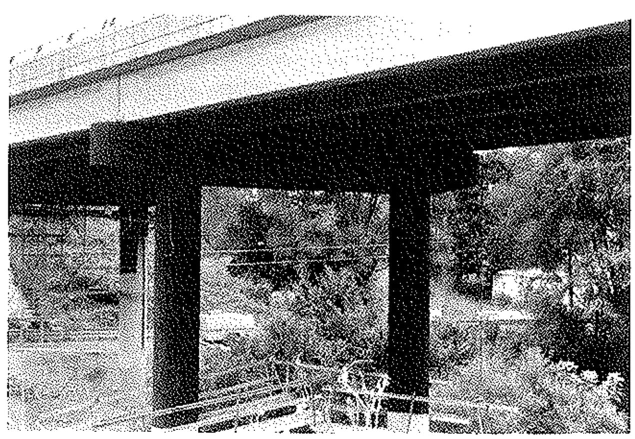

FIGURE 4 Pier 3 of Structure 2014 after application of the conductive coating.

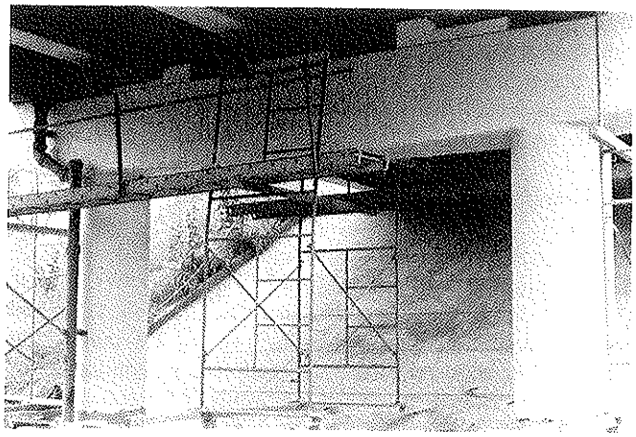

FIGURE 5 Pier 1 of Structure 2014 after the application of top coating.

After the installation, the wirings were inspected to verify that they were properly connected at the rectifier unit and in good working order. The rectifier unit was then energized and tested to determine the proper cathodic protection current required for each pier or circuit. These tests, which included measurements of the static potential of each reference electrode and of the *E* versus log *I* characteristic of each zone (circuit), will also provide data for future monitoring of the CP system. On the basis of the tests and some engineering judgment, the current level of each circuit was then adjusted and left to operate in constant-current mode for approximately 30 days. Thereafter, a depolarization test was conducted on each circuit to ascertain that its current level was providing sufficient polarization of the rebars in the pier. This test involves disconnecting the power to each circuit and recording the decay in the rebar potential (as measured with each embedded electrode). If the resulting potential decay curve shows a positive shift from the instant off value (after 4 hr of deenergization) of at least 100 mvolt, which is a criterion recommended by the National Association of Corrosion Engineers, the rebars in the pier are considered adequately protected from further corrosion.

DISCUSSION OF RESULTS

Cost of the CP System

In the three lowest bids received, the quoted total costs of the system (excluding the cost of concrete repair) ranged from \$85,546 to \$123,292. With a total concrete area of 1,040 m^2 to be protected, the lowest unit cost of the CP system came to be \$82.56/m^2. This cost was lower than that of the James River Bridge's CP system, which was approximately \$129/m^2 for a total concrete area of 7,520 m^2.

Quantities of Coatings Used

Because of the relatively high solid content of the conductive coating, which was 73 percent by weight, it required appreciable effort to apply the coating on the concrete piers. With this exception, the application process proceeded without any problem. The total quantity of the various coatings used and their respective effective coverage are presented in Table 2. The effective coverage of the anode coating was estimated to be approximately 1.96 m^2/L, which was 20 percent less than the manufacturer's original estimate of 2.45 m^2/L (Table 1). However, the manufacturer has since revised its estimate to reflect this result.

Cathodic Protection Current Outputs

On the basis of the *E* versus log *I* curves obtained during the postinstallation testing, the current output from the R/C unit to each pier was set to the level presented in Table 3, with

TABLE 2 QUANTITIES OF COATINGS USED

Coating	Quantity Used (liter)			Actual Coverage (sq m/l)
	Str. 2014	Str. 2015	Total	
Anode Coating	257	272	529	1.96
Anode Paste	23	23	46	
Top Coating	114	114	228	4.64

TABLE 3 STATIC REFERENCE ELECTRODE POTENTIAL AND INITIAL DC POWER SETTINGS ON THE RECTIFIER

Zone	Structure	Pier	11/21/89	11/22/89			
			Static Potential (v)	Current (amp)	Voltage (volt)	Potential (volt)	dE (volt)
1	2014	1	–0.134	252	3.7	–0.500	–0.366
2		2	–0.050	140	1.8	–0.417	–0.367
3		3	–0.056	176	3.8	–0.514	–0.458
4		4	–0.073	312	4.8	–0.526	–0.453
5		5	–0.040	302	5.1	–0.485	–0.445
6	2015	1	–0.101	540	5.3	–0.456	–0.357
7		2	–0.048	200	4.9	–0.494	–0.446
8		3	–0.073	80	8.5	–0.485	–0.412
9		4	–0.056	220	4.7	–0.600	–0.544
10		5	–0.142	594	6.3	–0.579	–0.437
			minimum	80	1.8		
			maximum	594	8.5		
			average	282	4.9		

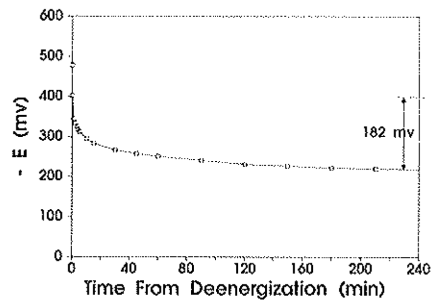

FIGURE 6 Depolarization testing of Zone 1 (Pier 1 of Structure 2014).

the goal of establishing rebar polarization of at least 100 mvolt. These current settings ranged from 80 to 594 mamp, with an average of 282 mamp. Expressed in terms of current density, these correspond to 0.7 to 5.9 mamp/m^2 of concrete area.

Depolarization Tests

After these current outputs were maintained for 27 days, a depolarization test was performed in December 1989 on each circuit to ensure that its current output was sufficient to protect the rebars. The resulting decay curve for Zone 1 (Figure 6) indicated that the potential shifted from the instant-off value of -402 to -220 mvolt after 3.5 hr, indicating that there would be a depolarization of at least 182 mvolt after 4 hr. The extent of depolarization observed in all the piers ranged from 182 to 319 mvolt, with an average of 257 mvolt (Table 4). These results indicate that, by the criterion of the National Association of Corrosion Engineers (NACE) of minimum 100-mvolt depolarization shift, the rebars in all 10 piers were more than sufficiently cathodically protected from further corrosion. These results also indicated that the current applied to several piers can be decreased to levels that may provide an optimum balance between adequate protection of the rebars and prolonged service life for the conductive coating. Therefore, the current outputs of several circuits were decreased.

After more than 4 months of operation, a second set of depolarization tests was conducted in early May 1990. These tests indicated that the extent of depolarization shifts ranged from 126 to 288 mvolt, with an average of 205 mvolt (see Table 4). The most recent depolarization tests, conducted on August 1990 after 8 months of operation, indicated depolarization shifts ranging from 67 to 259 mvolt, with an average of 191 mvolt.

With the exception of Pier 1 of Structure 2014, all piers appeared to be sufficiently polarized (see Table 4). The cathodic current for Pier 1 will be increased if the results of the next depolarization test, which is planned for December 1990, indicate again that the pier is not sufficiently polarized.

Operational Characteristics of the System

Since it started operation 12 months ago, the system has been monitored remotely with the aid of a desktop computer and a modem. The use of a remote monitoring device completely eliminated the need for on-site reading of the rectifier outputs; although difficult to estimate, the resulting savings in labor could be substantial. In addition, the device will also substantially reduce the downtime of the system if there is a

TABLE 4 DEPOLARIZATION TESTS

Structure	Pier	Depolarization Shift (mv) 12/19/89	05/02/90	08/21/90
2014	1	182	126	67
	2	206	201	176
	3	236	189	178
	4	265	194	209
	5	262	226	190
2015	6	248	214	254
	7	297	209	214
	8	268	227	181
	9	319	288	259
	10	286	179	182
minimum		182	126	67
maximum		319	288	259
average		257	205	191

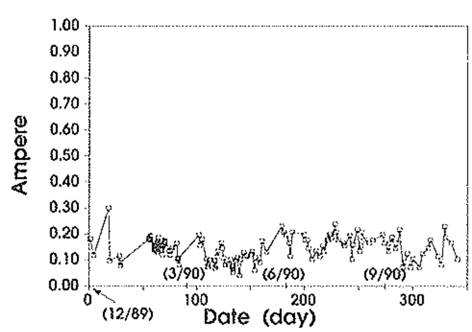

FIGURE 7 Circuit current of Zone 9 (Pier 4 of Structure 2015) from Day 1.

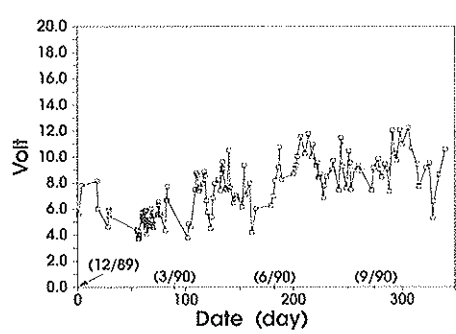

FIGURE 8 Circuit voltage of Zone 9 (Pier 4 of Structure 2015) from Day 1.

malfunction because it allows such a situation to be brought to the attention of the user automatically.

Figures 7–9 show what the cathodic current, the driving voltage, and the rebar potential, respectively, for Zone 9 (Pier 4 of Structure 2015) were during that period. Figure 7 shows that the R/C unit maintained an average current of approximately 0.14 amp for that pier. Responding to the varying resistance of the concrete in the pier, the driving voltage fluctuated between 3.7 and 12.2 volts—with an average of approximately 7.3 volts (see Figure 9). Figure 9 shows the response of the rebars to the cathodic current, as manifested in the recorded rebar potentials. These illustrations reflect the general behavior of the other nine zones. Table 5 presents the 10 average characteristics of the system during the first 11 months of operation.

The circuit resistances of the various anode coatings that have been tested or used on concrete piers in Virginia are presented in Table 6. Caution must be exercised when comparing these data, because those of the zinc spray and the polymer spray were obtained from testing only one concrete pier per type of coating. In contrast, the data for the organic-based coatings were obtained from 93 pier caps, and those for the water-based coating were derived from 10 piers. The water-based coating exhibited higher circuit resistances than the other coatings. Nevertheless, it appeared that zinc spray offered the lowest resistance. However, zinc is likely to degrade faster than carbon, which is the component that makes the other coatings conductive. It is not certain whether there is any difference between the resistances of the polymer spray and the organic-based coating. Consistent with relatively higher linear resistance quoted by its manufacturer (see Table 1), the water-based coating yielded higher circuit resistance. Although this resistance should not present any problem, adjustment must be made in the design of any future CP system that will use the water-based coating to counterbalance it.

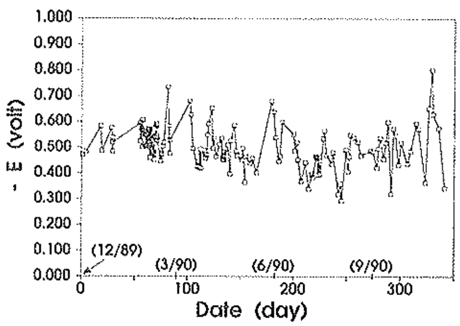

FIGURE 9 Concrete-to-rebar potential measured by graphite electrode embedded in Zone 9.

Visual Inspection of the Coating

Visual examination of the coating after 12 months of operation did not reveal general deterioration. However, some localized carbonization of the protective coating was observed beside two of the four steel drain pipes that are attached to the piers (see Figure 10).

This carbonization was indirectly the result of cracks that were found at the elbow sections of these two pipes, which allowed excessive leakage of rainwater on the nearby protective coating. This caused some temporary localized discharge of the direct current from the nearby primary anode to the protective coating, which led to the carbonization of the latter. This conclusion is supported by the fact that the other two drain pipes were in good condition and the surrounding coating did not show any carbonization. This problem can be avoided by proper maintenance of the drain pipes and the

TABLE 5 AVERAGE OPERATIONAL CHARACTERISTICS OF THE CP SYSTEM

Zone	Structure	Pier	Current (amp)	Voltage (volt)	Current Density (ma/sq m)**
1	2014	1	0.233	6.07	2.9
2		2	0.228	5.88	2.3
3		3	0.174	5.88	1.7
4		4	0.232	9.07	2.3
5		5	0.194	9.68	2.0
6	2015	1	0.272	6.55	3.2
7		2	0.133	8.84	1.1
8		3	0.256	8.71	2.1
9		4	0.143	7.28	1.2
10		5	0.213	5.75	1.9
minimum			0.133	5.75	1.1
maximum			0.272	9.68	3.2
average			0.208	7.37	2.1

* for the first 11 months of operation
** per concrete area

TABLE 6 CIRCUIT RESISTANCES OF VARIOUS ANODE COATINGS INSTALLED IN VIRGINIA

Coating System	Resistance Low	(ohm) High	Time of Observation
Zinc Spray (Norfolk, Va.)	3.4	8.0	During first 8 months
Polymer Spray (Norfolk, Va.)	6.7	19.0	During first 8 months
Organic-Based Coating (Richmond, Va.)	1.4 0.6	38.6 45.6	At start of operation After 12 months
Water-Based Coating (Shenandoah County, Va.)	18.2 26.9	70.7 77.5	At start of operation After 11 months

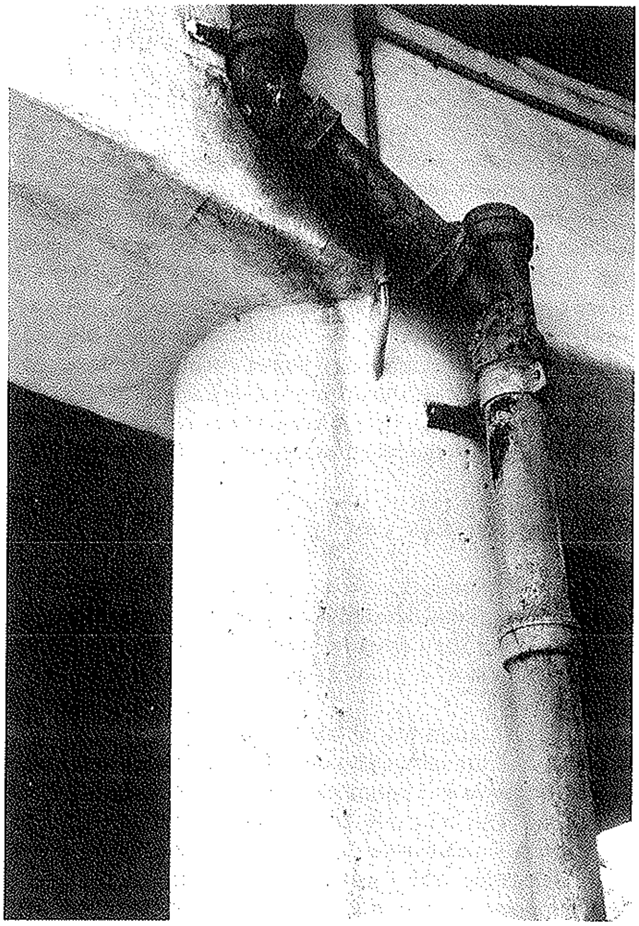

FIGURE 10 Carbonization of protective coating beside a leaky drain pipe.

placement of the primary anodes away from the vicinity of a pipe.

CONCLUSION

On the basis of the observations made so far, the water-based coating still holds promise as an effective alternative anode coating for cathodic protection of inland concrete piers. Its relative ease of application and the fact that it is free from the health hazards that the other anode coatings present during application make the anode coating an attractive alternative.

As expected, the remote monitoring device allows convenient monitoring of the conditions of the electrical components of the CP system from anywhere a phone, a modem, and a personal computer are available.

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