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IDEA *Innovations Deserving Exploratory Analysis Project*

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Report of Investigation

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SPRAYED ZINC GALVANIC ANODE FOR CORROSION PROTECTION OF MARINE SUBSTRUCTURE REINFORCED CONCRETE

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FOREWORD

A project sponsored by the Strategic Highway Research Program (SHRP 88-ID024) addressed Phase I of an investigation on the use of sacrificial sprayed-zinc anodes for galvanic protection of reinforcing steel in marine bridge substructures. The results of that investigation were encouraging, and the continuation project described in this report was sponsored as part of the newly established IDEA program of NCHRP under contract NCHRP-92-ID003. The objectives of this project were to conduct additional field and laboratory investigations in support of the cathodic protection concept and to develop a practical implementation manual. Part 1 of this report describes the results of the field and laboratory tests performed during the Phase II investigation. Part 2 presents the implementation manual.

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EXECUTIVE SUMMARY

Corrosion of reinforcing steel in concrete takes place in bridge substructures exposed to chloride ions from seawater. As the steel corrodes, the surrounding concrete cracks because of the volume expansion associated with rust formation. The cracks cause spalling of the concrete cover and the potential for structural damage. Corrosion control measures, such as conventional impressed-current cathodic protection, can be expensive in hard-to-reach marine locations.

This project included preparing an implementation manual and obtaining additional field experience in the performance of a novel, low-cost method for cathodic protection of marine substructure reinforced concrete. The method consists of removing the concrete cover from substructure elements where severe reinforcement corrosion has taken place, blast cleaning, and arc-spraying with zinc the exposed steel and surrounding external concrete surface. Galvanic interaction between the reinforcing steel and the surrounding zinc takes place as a result of metallic contact with the exposed steel and the presence of an adequate electrolyte (concrete in a high-humidity environment). Encouraging results were obtained earlier during an initial performance assessment of the method conducted under a Strategic Highway Research Program (SHRP) contract and published in the SHRP-S-405 report. For the present project, seven test areas of the older section of the Howard-Frankland Bridge (built in 1959) across Tampa Bay in Florida were selected for detailed examination of the substructure. As part of a major rehabilitation, the bridge contains more than 11 000 m^2 (100,000 ft^2) of arc-sprayed-zinc surface. The selected substructures included two prestressed beams, four pile caps, and a portion of a span underdeck.

The test sections were instrumented by means of cutout windows on the sprayed-zinc surface to allow direct measurement of protective current delivery and small portions of reinforcing steel (rebar probes) isolated from the rest of the rebar assembly for current delivery and polarization measurements. In addition, one entire pile cap and an underdeck portion were provided with an anode disconnection system to permit direct performance assessment. The system was monitored for 18 months.

The physical integrity of the anodes was preserved throughout the entire test period, in agreement with observations of long durability (5 years to date) at a Florida Keys location. The anode performance instrumentation techniques that were used proved to be adequate and internally consistent. After operation for more than 1 year, the sprayed anodes delivered steel current densities typically in the range of 0.11 $\mu A/cm^2$ to 1.1 $\mu A/cm^2$ (0.1 mA/ft^2 to 1 mA/ft^2). The tests with rebar probes and disconnectable anodes showed that polarization decay typically exceeded 100 mV, even with the modest current deliveries involved. The observed magnitude of the polarization decay met a commonly used criterion for acceptable cathodic protection system performance. Cumulative corrosion effects in the 30-year-old bridge at the beginning of the study were severe, even at the relatively high substructure elevations tested. Nevertheless, corrosion rates were considered to be relatively slow, based on the chloride contamination and concrete resistivity measurement results. This is consistent with the good level of polarization achieved with modest protective current densities. Experience at Florida Keys locations (documented in SHRP-S-405) showed higher current delivery by the sacrificial anodes at lower elevations where more severe corrosion took place.

The findings support earlier indications that sprayed-zinc sacrificial anodes are an attractive economic alternative to conventional spall patching in marine substructures. The implementation manual provides the user with practical guidelines for similar protection systems using commonly available equipment. Methods for controlling the quality of the application and for assessing system performance are also included.

PART 1

FIELD PERFORMANCE MONITORING OF HOWARD-FRANKLAND BRIDGE

INTRODUCTION

The substructure of marine highway bridges is exposed to an aggressive service environment. Splash and evaporation of seawater above the waterline cause high chloride ion concentrations in the concrete and subsequent corrosion of the reinforcing steel. Corrosion products cause concrete spalling and associated structural damage. Catholic protection of steel can control corrosion. Such protection can be made by means of impressed electric currents, and significant advances have been made recently in this technology (*1–3*). Impressed-current systems rely on the presence of an external power supply with associated wiring and control equipment. Because of that requirement, such systems can be costly to install and require frequent maintenance. An alternative is provided by galvanic cathodic protection systems (*4*), which deliver current that is driven by the natural difference of potential between a sacrificial anode and the structure to be protected. An efficient galvanic system is very attractive because initial costs tend to be low. Furthermore, complications and maintenance are often much less than in an impressed-current system. These advantages become greater in marine substructure applications in which access costs are high.

The sprayed-zinc galvanic anodes in this work were applied with an arc-spray gun on the previously sandblasted surface of the concrete. The anode has an average thickness of about 0.4 mm (0.016 in). Anode connection to the steel is achieved by direct spraying over the metal exposed at spalls or by means of connecting studs. Typical application costs were on the order of $\$110/m^2$ ($\$10/ft^2$).

The work performed in Phase I involved both field and laboratory investigations (*5,6*). The following summarizes the main findings of Phase I:

- Field installation of the anodes on several bridges in the Florida Keys along U.S. 1 was achieved rapidly and economically with existing technology.
- The anodes retained their physical integrity after 4.5 years of service in the harsh marine environment.
- Protective current densities in the field were typically 0.54 $\mu A/cm^2$ (0.5 mA/ft^2) after 4.5 years of service on structures containing corroding epoxy-coated rebar and about 1.1 $\mu A/cm^2$ (1 mA/ft^2) on a structure with corroding plain rebar during a 2-year service test.
- Rebar probe measurements in the field structures showed typical polarization decay values that exceeded 100 mV in as little as 1 hour.
- Laboratory experiments with anodes near the waterline in reinforced concrete columns exposed to saltwater replicated the current density values observed in the field.
- Laboratory experiments with salt-contaminated, reinforced concrete specimens exposed to environments with varying degrees of humidity revealed that anode current delivery tended to decay with time over a period of 2 years. The decay in the highest-humidity environment (85 percent relative humidity) was ascribed primarily to polarization of the anode.
- Experiments revealed that current delivery in the polarized zinc anodes could be momentarily restored by direct wetting of the anode surface with distilled water. In salt-contaminated specimens, the anode wetting had little effect on the anode-to-concrete resistance. It was speculated that anode wetting increases current delivery by a combination of increased metal area in contact with electrolyte and changes in the polarization condition of the metal.
- The successful long-term current delivery of the zinc anodes in the field was ascribed to the natural intermittent wetting of the anode surface encountered in the splash-evaporation zone in marine service.
- Impressed-current laboratory experiments revealed that anodes of 85 percent zinc and 15 percent aluminum on concrete developed service potentials about 200 mV more negative than commercially pure zinc anodes when subject to the same levels of current.

These findings supported the use of the sprayed galvanic anode technique for the splash-evaporation zone of marine substructures in service environments such as those encountered in Florida. Because of those encouraging results, the present Phase II investigation was initiated with the following objectives:

- Monitoring of the performance of sprayed-zinc anodes in a full-scale bridge rehabilitation project (rehabilitation of the Howard-Frankland Bridge on Tampa Bay, FHWA Experimental Features Project No. 92–01).
- Preparation of implementation guidelines (see Part 2).

RESEARCH APPROACH

TEST SITES

The Phase II field evaluation of the arc-sprayed-zinc sacrificial cathodic protection system was conducted at the old Howard-Frankland Bridge on Interstate 275 in Tampa, Florida. The bridge, which consists of 321 spans, has an overall length of 4838 m (15,872 ft). The structure spans Tampa Bay and was built in 1959.

The corrosion characteristics at the site are classified by the Florida Department of Transportation (FDOT) as "extremely aggressive;" the bay water chloride content is 12,600 ppm, resistivity is 30 ohms-c, and the pH value is 7.5. At the time of anode installation, the structure was undergoing major rehabilitation, which included the application of arc-sprayed zinc to approximately 11 148 m^2 (120,000 ft^2) of concrete surface on multiple corrosion-deteriorated structural elements.

For this study seven test areas (Figures 1–4) were established on selected structural members. Two prestressed beams (design comparable with current AASHTO Type 3 specifications), four pile caps, and a portion of a span underdeck (bay) were instrumented. The average elevation of the test areas on the beams was 3.0 m (9.75 ft) above high tide, 2.0 m (6.5 ft) at the pile caps, and 3.6 m (12 ft) at the underdeck.

The selected beams were located on Spans 279 and 280 and had three test areas each (Figure 1). The selected caps were located at Bents 280, 281, 293, and 307 and had three test areas each, except for Bent 293, which had only two test areas (Figures 2–4). The selected underdeck was located at Bent 293 (on Span 292), and because of its size, it only had one test area. Except for the underdeck, all the selected structural members exhibited severe corrosion deterioration (spalling).

The pile cap at Bent 293 and the underdeck on Span 292 were provided with an anode disconnection system, which allowed the electrical disconnection of the structural steel from the entire zinc anode and permitted direct measurement of anode current delivery and polarized potentials, as well as polarization decay tests. On the remaining bridge elements the anode-to-steel connection was accomplished by metallizing directly over the exposed reinforcing steel; therefore, electrical disconnection of the structural reinforcing steel was not achievable. Indirect performance measurements were performed instead, using anode cutouts and rebar probes.

ZINC ANODE APPLICATION

The zinc metallizing process melts the zinc or zinc alloy metals and rapidly propels the molten zinc particles onto the properly prepared concrete or steel surface. Application of the arc-sprayed zinc for this study was performed on the selected structural components by a contractor using specifications for application and acceptance that have been incorporated into the companion implementation guidelines. The procedure is summarized in the following paragraphs.

Before application, all delaminated concrete was removed from the element, exposing the heavily corroded reinforcing steel. No concrete restoration was performed. To prepare the concrete surface and the exposed reinforcing steel for metallizing, a light silica sand abrasive blast was used to remove any mill scale, rust, dirt, and any other foreign material from the surface to be coated. The blast also provided a lightly rough surface profile to permit a mechanical bond between the zinc and the concrete surface. The typical bond strength obtained ranged between 0.65 and 1.65 MPa (95 and 240 psi).

During sandblasting, precautions were taken to avoid removing concrete material from the back of the reinforcement (interior concrete-steel interface), which could not be reached later by the zinc spray. Metallizing was completed within 2 hours of sandblasting.

The zinc application was accomplished by employing multiple spray passes to achieve a coating thickness of 0.4 to 0.5 mm (0.015 to 0.020 in.), which was determined by measurements of the zinc deposited on test coupons placed on the concrete surface.

The metallizing equipment was an electric arc-spray gun. This system used two zinc wires (provided in spools) that were fed to the gun where they arced and melted at the tips. A compressed air jet, also at the gun, impelled the molten zinc onto the concrete or steel surface. The wire gap at the gun was automatically and continuously adjusted to maintain arcing as the zinc was blown away from the tip of the wires. The wire used was commercially pure zinc (99 percent pure) produced in 0.31-cm (1/8-in.) diameter size.

Because of the complexity of preparing the work area for the metallizing (moving and securing equipment and scaffolding), the selected elements were metallized on different dates, which are shown in Table 1.

The anode was connected to the reinforcing steel at all sites except Bent 293 and Span 292 by direct-contact spraying the metallizing zinc onto the surface of the exposed reinforcing steel. On Span 292 and Bent 293, the connection was accomplished via a copper strand wire that was mechanically attached to the rebar and the zinc surface. These connections were sealed for corrosion protection using an epoxy compound.

EVALUATION PROCEDURE

Before the instrumentation was placed, concrete resistivity readings (Table 2) and steel potentials were obtained to assist in defining the typical corrosion activity of the evaluated bridge components. Concrete core samples were obtained from beams, deck, and pile caps to measure the chloride content of the concrete (Table 3). Instrumentation of test areas included the following:

- Anode test windows consisting of metallized surfaces with an area of 0.09 m^2 (1 ft^2) electrically isolated from the remaining zinc for anode current density measurements.
- Two probes embedded at the depth of the reinforcing steel at the same elevation as the windows.
- Two unsprayed areas for placement of reference electrode for half-cell potential measurements.
- A control panel that facilitated instrumentation connection for monitoring at each area. Wiring from the test area elements was routed to terminals and switches in this control panel to facilitate monitoring operations.

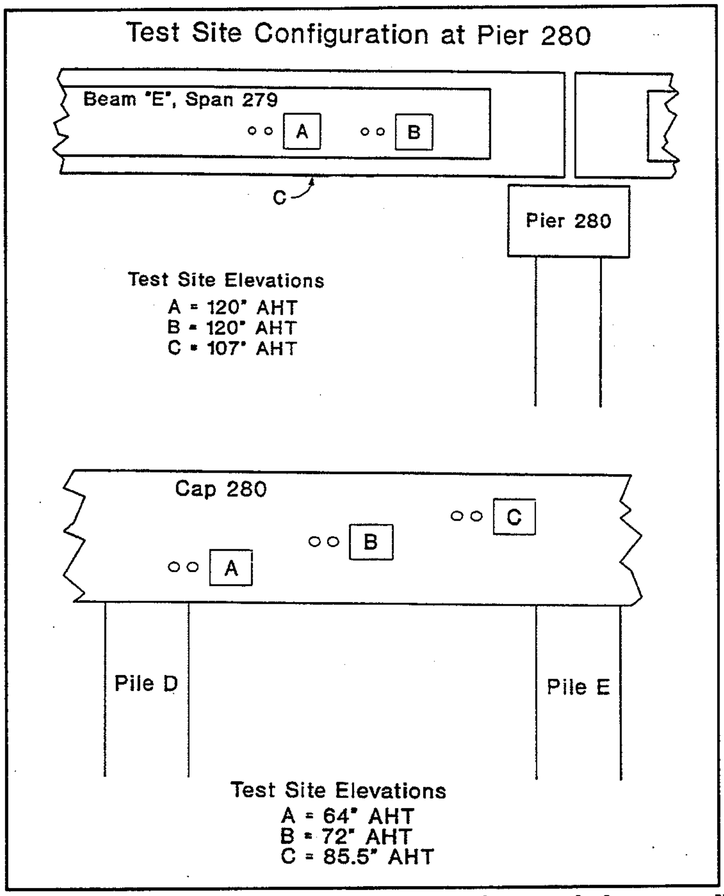

FIGURE 1 Test site configurations, Pier 280. The squares denote anode test windows; small circles denote location of the rebar test probes. Elevations indicated are above high tide (AHT) level.

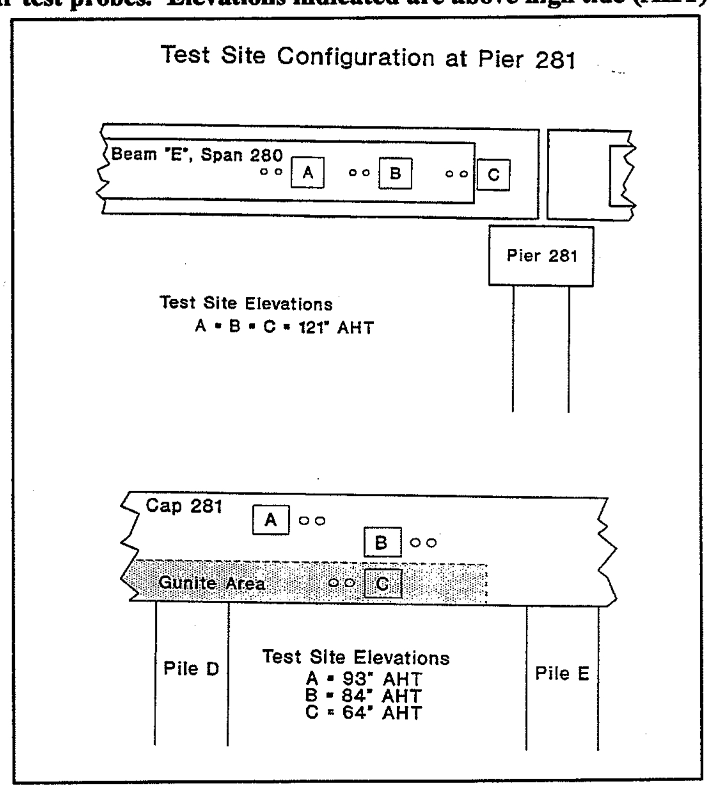

FIGURE 2 Test site configurations, Pier 281. The squares denote anode test windows; small circles denote location of rebar test probes. Elevations indicated are above high tide (AHT) level.

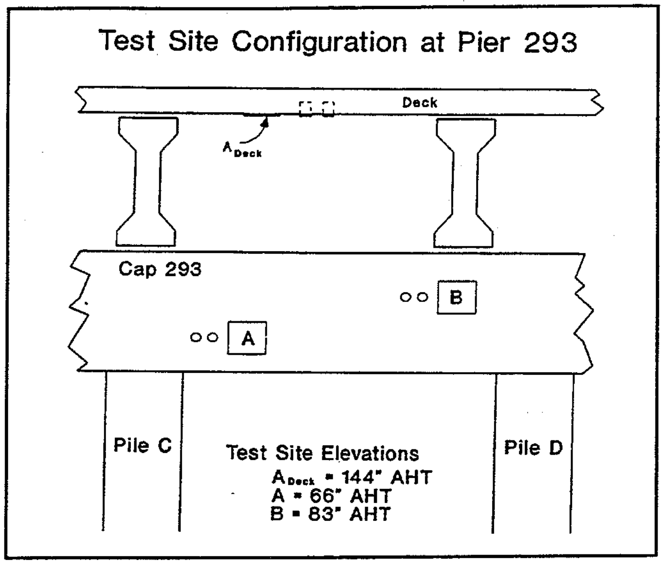

FIGURE 3 Test site configurations, Pier 293. The squares denote anode test windows; small circles denote location of rebar test probes. Elevations indicated are above high tide (AHT) level.

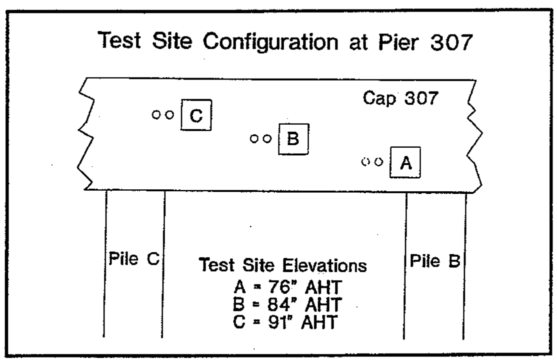

FIGURE 4 Test site configurations, Pier 307. The squares denote anode test windows; small circles denote location of rebar test probes. Elevations indicated are above high tide (AHT) level.

TABLE 1 METALLIZING DATES FOR EVALUATED BRIDGE ELEMENTS

Bridge Component	Metallizing Date
Span 279 - Beam 5	06/18/92
Span 280 - Beam 5	06/17/92
Bent 280 - Pile Cap	06/17/92
Bent 281 - Pile Cap	06/17/92
Bent 293 - Pile Cap	10/22/92
Bent 307 - Pile Cap	06/02/92
Span 292 - Underdeck	10/22/92

TABLE 2 TYPICAL CONCRETE RESISTIVITY OF BEAMS AND PILE CAPS

CAPS					
Elevation AHT	Resistivity Kohms				
	A	B	C	D	AVG.
55″	42	40	42	41	41.2
67″	32	31	60	63	46.5
79″	78	74	41	40	58.2
91″	69	97	32	35	58.2
AVG.					51.1
BEAMS					
Elevation AHT	Resistivity Kohms				
	A	B	C	D	AVG.
110″	140	141	142	127	137.5
122″	147	144	107	71	117.2
134″	177	177	54	48	115.7
146″	163	163	69	106	125.7
AVG.					124.1

TABLE 3 CHLORIDE ANALYSIS OF CONCRETE CORE SAMPLES
(all values in pounds per cubic yard)

BENT 280 - BEAM					
Core Depth	Span 279 A-1 elev. 120" Lab # 1066	Span 279 A-2 elev.120" Lab # 1067	Span 279 B-1 elev. 120 Lab # 1068	Span 279 B-2 elev. 120 Lab # 1069	
0-1	1.147	1.486	1.874	1.874	
1-2″	1.159	0.625	0.407	0.724	
BENT 307 - CAP					
Core Depth	Bent 307 A-1 elev. 76" Lab # 1074	Bent 307 A-2 elev. 76" Lab # 1070	Bent 307 B-1 elev. 84" Lab # 1071	Bent 307 C-1 elev. 91" Lab # 1072	Bent 307 C-2 elev. 91" Lab # 1073
0-1″	1.680	2.682	1.316	0.613	0.737
1-2″	1.153	0.854	0.971	0.541	0.501
2-3″	1.016	0.773	0.770	0.643	0.656
3-4″	***	0.637	0.684	0.392	0.274
SPAN 292 - DECK					
Core Depth	Bent 193 Deck A-1 Lab # 1085	Bent 193 Deck A-2 Lab # 1086			
1-2″	0.173	0.280			
2-3″	0.114	0.304			
3-4″	***	0.239			

PROBES

The probes consisted of a piece of No. 4 rebar with a precise exposed surface area of 13 cm^2 (2 $in.^2$). At one end the probes were provided with a No. 14 AWG copper strand wire that was used for electrical connection.

In the field, the probes were installed in a 5-cm (2-in.) diameter hole drilled into the existing concrete. The hole was then filled with salt-added mortar, and the probe was embedded at the reinforcing steel depth with the connection wire extending outside the concrete surface. Precautions were taken so that the probes were not in contact with or in the immediate vicinity of any reinforcing steel or any other metallic embedments in the concrete.

After the mortar had set, the static potential of the probe was measured, and the probe was then electrically connected to the metallized structure. During connection, cathodic protection current and half-cell potential change were measured. The probe was left connected so that it could stabilize at a cathodic protection level similar to that of the structure's reinforcing steel.

In this study the probes, one per test area, were allowed to stabilize for 30 days (minimum), after which the steady-state current was measured. A polarization decay test was then conducted by disconnecting the probe from the structure. Two probes were used at each test area but only one probe was energized at any time. After the depolarization test was completed, the probe was kept disconnected from the structure to allow complete polarization decay. The twin probe was then energized following the same procedure as that for the other probes.

ANODE WINDOWS

A 0.093-m^2 (1-ft^2) electrically isolated metallized area (window) was provided for each test area. The windows were installed by saw cutting around a 0.3-m-high by 0.3-m-wide (1-ft by 1-ft) square on the surface of the metallized element. The cut was approximately 0.6 cm (0.25 in.) deep to ensure that all the metallizing zinc was removed. When the saw cut was completed on all sides, electrical resistance and potential difference were measured between the window and the surrounding zinc to verify complete electrical isolation. Electrical connections to the zinc inside and outside the window were provided to allow rapid connection with, disconnection from, or both, the window and the remaining portion of the metallized component.

The test windows usually were connected to the structure to maintain the natural electrical equilibrium between the window and the remaining metallizing zinc, which was directly connected to the structure. During monitoring (typically after at least 30 days of continuous equilibrium), the steady-state current produced by the window was measured by interrupting the window-structure direct connection and allowing the current to flow through an ammeter with a resistance of 5Ω. Circuit resistance generally was high enough so that a low-resistance shunt was not needed. The ammeter usually was already in place when the direct connection was opened.

MONITORING MEASUREMENTS

Performance of the arc-sprayed zinc was monitored for approximately 13 months. During this time, five field visits were conducted at approximately 4-month intervals (1 month between the first two visits). During each monitoring visit the following measurements were obtained at each test area:

1. Window-to-structure
   a. Steady-state current
   b. Instant-off potential difference
   c. Electrical resistance
2. Window-to-probe
   a. Initial current
   b. Instant-off potential difference
   c. Electrical resistance
3. Structure-to-probe
   a. Initial current
   b. Voltage potential difference
   c. Electrical resistance
4. Probe polarization decay test conducted on the probes that had been energized since the previous visit (including steady-state current measurement).
5. Probe energizing conducted on probe that had been depolarized since the previous monitoring visit (including current measurement and half-cell potential change).
6. Structure polarization decay and reenergizing conducted on pile cap of Bent 293 and underdeck on Span 292 (including current measurements and voltage potential changes). Currents in these elements estimated from instant-off potential differences and circuit resistance, or measured with a 0.01Ω shunt.

All steady-state current measurements were obtained by placing an ammeter between the two components being measured and then interrupting the direct connection. Window-to-probe and structure-to-probe measurements were performed using the probe that had been depolarizing since the last visit.

RESULTS

CURRENT DELIVERY

Windows

Figure 5 shows the average anode window current densities for each of the pier caps as a function of time in service during the test period. The average current densities showed fluctuation (as expected from the nature of field tests) but were typically on the order of 0.33 $\mu A/cm^2$ (0.3 mA/ft^2). Figure 6 shows the average anode current densities for each of the pier beams during the same time period. These current densities were markedly smaller [on the order of 0.055 $\mu A/cm^2$ (0.05 mA/ft^2)] than those of the pier caps.

The instant-off difference of potential between window and structure immediately after window disconnection served to independently verify the current delivery measurements. Ideally, the potential difference should match the ohmic drop in the galvanic circuit, which is given by

$$\Delta V = IR_{W\text{-}S}$$

where I is the window current and $R_{W\text{-}S}$ is the window-to-structure resistance. Figure 7 shows reasonable correlation between both values extending for more than one order of magnitude, generally confirming the expected trends. There was a residual difference in that the instant-off potential values were typically somewhat larger (by about 50 percent) than the current resistance products. The deviation might be explained by the manner in which the instant-off readings were taken (after a wait of about 1 sec after disconnection). The time delay allows some polarization decay to take place, causing the observed potential to be somewhat greater than the actual initial value. The direction of the expected effect would be in agreement with the deviation observed in Figure 7.

Rebar Probes

In the substructure elements examined, the surface area of the embedded steel was comparable with the external area of the concrete. Thus, the steel current density was on the same order as the anode current density. Figure 8 compares the window current densities with those of the adjacent rebar probes for the set of measurements obtained in October 1993. Agreement to some extent between both magnitudes was expected at that time because the probes tested had been energized for about 4 months, and the overall system had been in operation for about a year. The probes tended to show, on average, current densities that were on the same order as those of the windows (disregarding the set for the Bent 280 beam data). Experimental scatter prevented determining whether the somewhat larger average values for the probes represented an actual systematic deviation. The discrepancy for the Bent 280 beam (current densities of the probes two orders of magnitude larger than those from the windows) cannot be explained at this time. Comparable discrepancies also were observed in the same three probes during previous site visits.

Bent 293

Bent 293 had provisions for disconnecting the entire anode on the cap [54 m^2 (580 ft^2)] and the entire anode on the sprayed bridge deck portion [7.7 m^2 (78 ft^2)]. The corresponding surface areas of the reinforcing steel (based on original bridge construction drawings) were 35 m^2 (380 ft^2) and 6.6 m^2 (67 ft^2). The top part of Figure 9 shows the anode current densities for both components as a function of time. Because of the low circuit resistance in these large surface area systems, current was estimated indirectly from instant-off potentials and circuit resistance projections during regular site visits. An additional site visit in January 1994 was conducted to make more accurate measurements using low-resistance shunts. Nevertheless, all current measurements for these locations are likely to underestimate to some extent the actual current delivery. The current density at the cap, measured with the entire member, was comparable with the values obtained with the test windows and probes in the same member and with the values obtained at the same elevation elsewhere in the bridge. The current at the deck segment was consistently much lower than that of the bent cap.

POLARIZATION DECAY

Rebar Probes

Figure 10 shows the polarization decay of all probes during the October 1993 test, when conditions were expected to approach those of a mature system. The probe current density is used as a parameter. Polarization decay over typical times of 20 hr exceeded 100 mV in all but one case. The results suggest some increase in the extent of polarization decay with the probe current density. The probe set with the largest average polarization decay and current densities is that of Bent 280 beam, which showed anomalous behavior in Figure 8.

Bent 293

The steel polarization decay in the cap of Bent 293, in which disconnection of the entire assembly was possible, is shown as a function of time in the bottom part of Figure 9. The polarization decay was 106 and 245 mV (two electrode locations, 18-hr test) during the October 1993 site visit (12.4 months). Average polarization decay at the deck segment was about one-half the values for the cap. The polarization decay values for this bent have been superimposed on the probe data in Figure 10. The directly determined polarization decay values fit within the general behavior trend of the rebar probes.

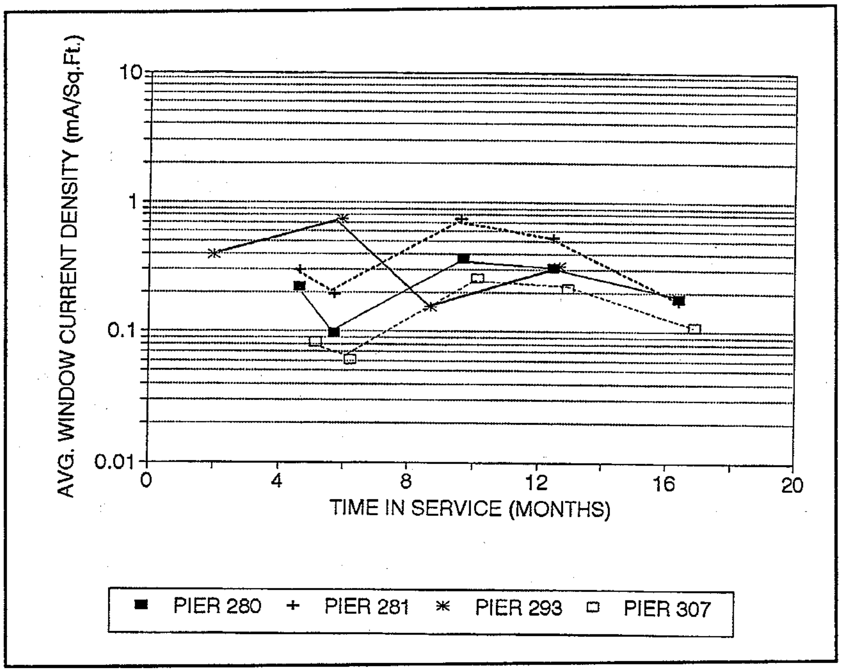

FIGURE 5 Average current densities of test windows at each pier pile cap as a function of time in service of anodes (1 mA/ft² =1.09 μA/cm²).

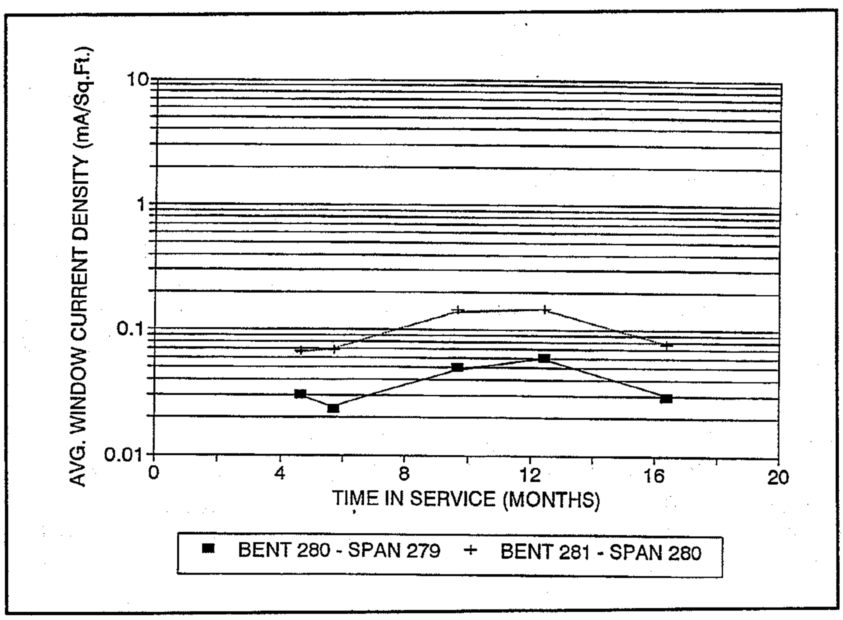

FIGURE 6 Average current densities of test windows at each pier beam as a function of time in service of anodes (1 mA/ft² =1.09 μA/cm²).

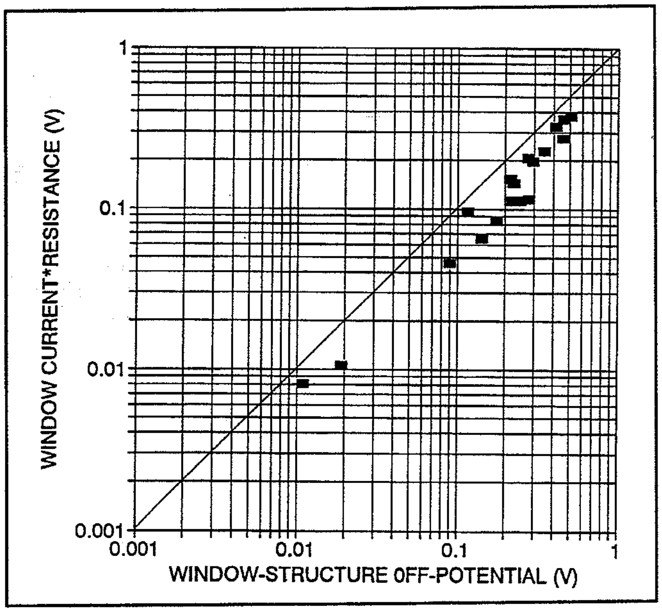

FIGURE 7 Comparison of instant-off potential difference between each zinc anode window and corresponding structural steel with the product of window current and window structural resistance. Diagonal line indicates ideal 1:1 correspondence. (Data from October 1993 field site visit.)

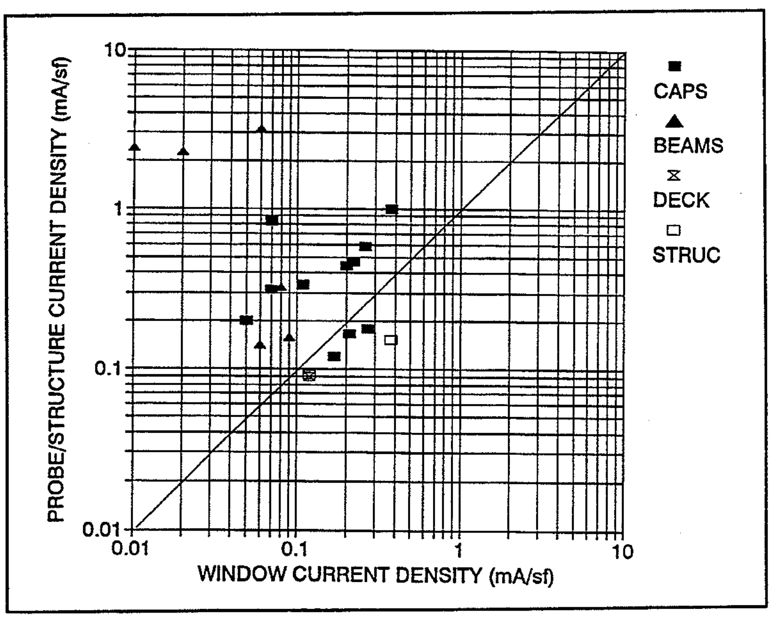

FIGURE 8 Comparison between current density of each zinc anode window and current density of corresponding adjacent rebar probe. Results for pier caps, beams, and deck locations are grouped separately. Average steel current densities for entire anode/structure locations in Bent 293 also are compared with corresponding probe current densities. Diagonal line indicates ideal 1:1 correspondence.

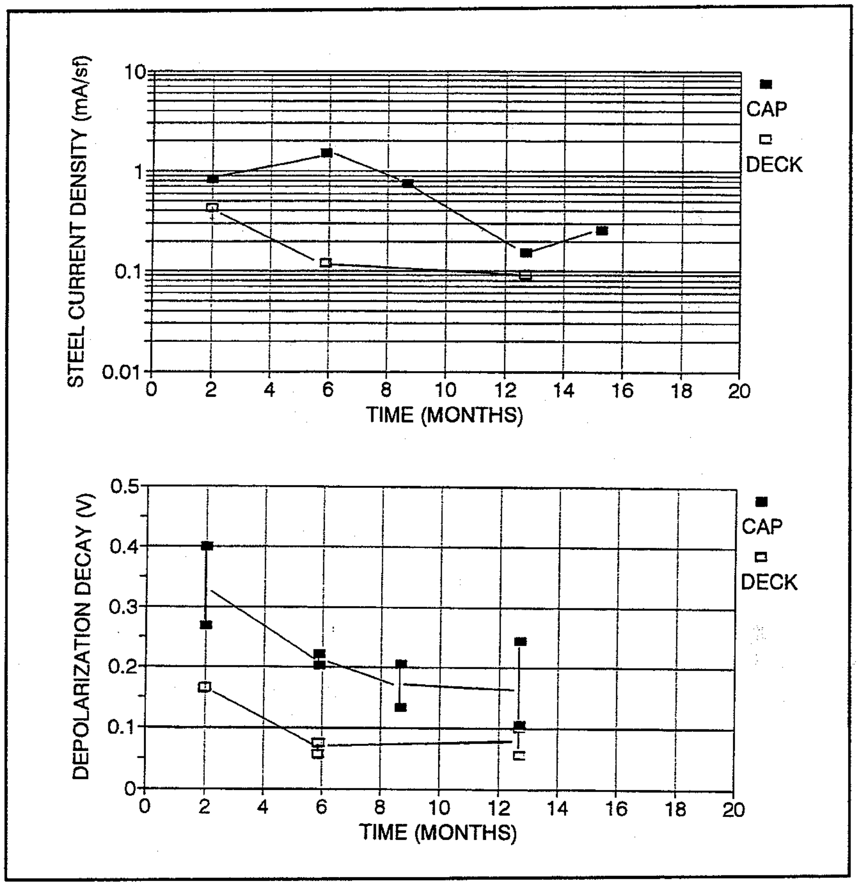

FIGURE 9 Top: Average steel current density from disconnectable anode at the pile cap and deck locations of Pier 293 as a function of time. Bottom: Polarization decay as a function of time for the same locations (1 mA/ft^2=1.09 μA/cm^2).

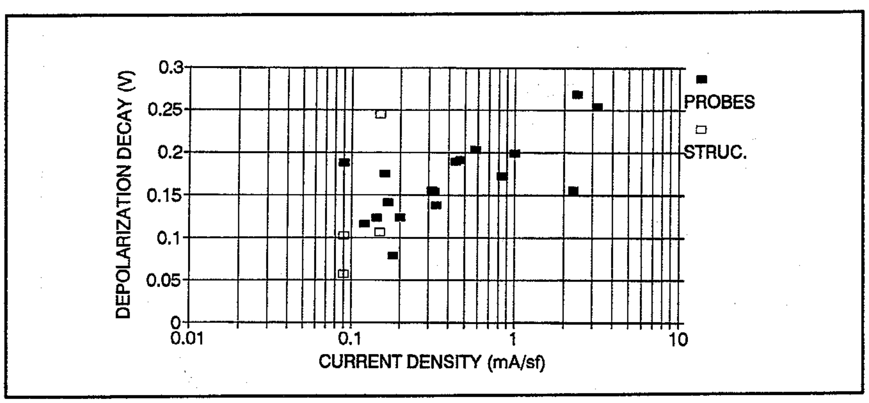

FIGURE 10 Polarization decay as a function of current density of individual rebar probes and structure locations at Pier 293. Highest current density values correspond to beam at Bent 280.

OPERATING POTENTIALS

Rebar Probes

Figure 11 illustrates typical behavior for rebar probes in one of the bridge bent caps (Probe Set 1, Bent 280 pile cap). The day after the anode had been in place for about 5 months, the probes were installed and energized. Native potentials of the probes immediately after installation were between –250 and –400 mV versus calomel standard electrode (Tables 1-10), indicative of likely active corrosion. The "on" potentials, upon initial connection to the anode, were typically several hundred millivolts more negative than the native values. Instant-off potentials, after several months of connection to the anode, tended to be in the –250 to –450 mV versus calomel standard electrode range. Figure 12 shows the probe instant-off potentials as a function of probe current density for the measurements taken during the October 1993 site visit. The results suggest a trend, as expected, of more active potential as the current density increases. If the results were fit with a straight line, its slope would be between 100 and 200 mV per decade of current density, which is on the order of the polarization slope for oxygen reduction encountered in other investigations of corrosion of steel in concrete (*7*).

Figure 13 shows the potentials for the same probes as in Figure 12, but after allowing for 20-hr polarization decay following disconnection.

Bent 293 Structure

Figures 12 and 13 also show the potential-current density locus before and after polarization decay for the Bent 293 cap and deck structure elements. The cap showed instant-off potentials that were among the most negative recorded with the probes. The depolarized cap structure potentials were well within the range of values commonly associated with active steel. In contrast, the deck showed much nobler potentials both before and after polarization decay, suggesting a generally passive condition.

Anodes

The anode potentials showed a wide range of values (Figure 14, anode potential versus window current density) for the results obtained during the October 1993 site visit. There is no clear correlation between anode potential and anode current density.

DISCUSSION

The sacrificial anode installations at the Howard-Frankland Bridge were successfully conducted with minimal difficulty by using commonly available commercial equipment. The physical integrity of the anodes was preserved throughout the 18-month test period. These installations, in addition to the other projects in the Florida Keys and elsewhere in Florida, demonstrated that the anode placement technology is well established.

The techniques for anode performance characterization were suitable for routine use and provided reasonably consistent results. As a result, these techniques were incorporated into the implementation guidelines for general user applications.

Sprayed sacrificial anodes operating without the assistance of additional components, such as submerged anodes, were installed at the Howard-Frankland Bridge only on the bent caps, beams, and portions of the deck. In those members, corrosion conditions were moderate, as evidenced by chloride concentration and high concrete resistivities. The depolarized structure potentials in Bent 293 suggested an active steel condition only for the cap, whereas the deck structure showed noble depolarized potentials associated with passive steel. The mortar surrounding the rebar probes is expected to slowly develop by diffusion a chloride-hydroxide ion ratio comparable with that of the immediately surrounding concrete. The evolution of the rebar probe potentials, initially nearing the active range, suggests that equilibration to relatively low chloride contents was approached in many cases after a few months of exposure.

Because of the relatively mild corrosion conditions, protective current demand has been relatively low since the system achieved a mature operating regime. The rebar probes have shown polarization decay values that exceeded 100 mV in most cases—at current densities usually less than 1.1 $\mu A/cm^2$ (1 mA/ft^2) (Figure 10). As shown in Figure 8, the test windows delivered current density levels comparable with those received by the test probes. Because the ratio of structural steel to external concrete surface was about unity, the results suggest that the structural steel was receiving current densities of the same order as those of the rebar probes. Based on the chloride ion concentrations encountered and on the probe polarization decay behavior, the data suggest that the structural steel also was encountering adequate levels of cathodic protection. The arrangement of Bent 293 permitted direct verification of these expectations because the entire anode could be disconnected from the structure. Direct measurement of the protective current densities in the cap of Bent 293 showed values that were modest [about 0.16 $\mu A/cm^2$ (0.15 mA/ft^2)] but in general agreement with those obtained from the rebar probes and test windows. Nevertheless, the direct measurements in the same cap also verified that significant structural polarization decay could be obtained (100 to 250 mV) even with those modest protective current densities.

The anodes on the concrete surface tended to show relatively noble potentials when compared with those normally associated with zinc in contact with

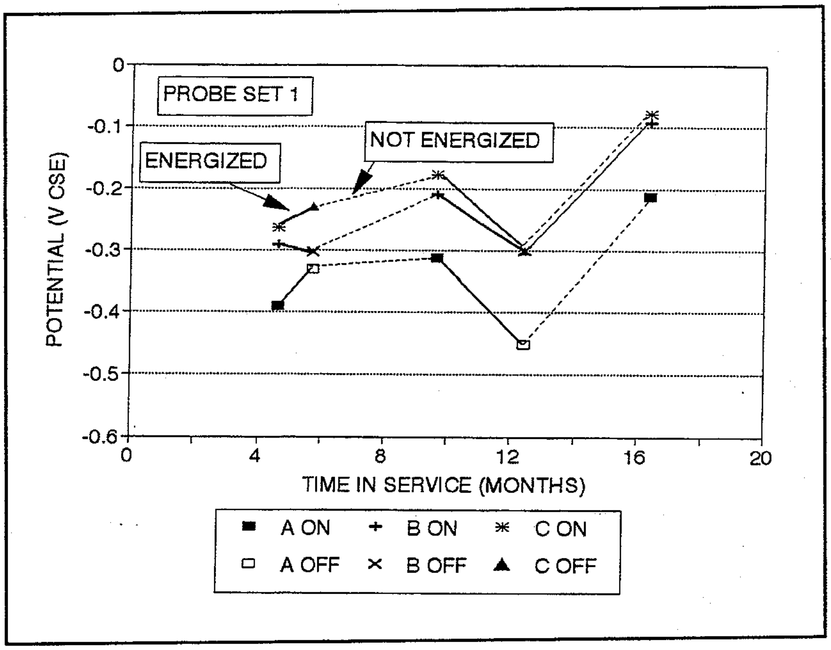

FIGURE 11 Potential of rebar probes A, B, and C of Set 1 in pile cap of Pier 280 as a function of anode service time. Potential shown is static (open-circuit) value just before beginning of periods in which probes were energized or instant-off value at end of energized period. Probe Set 1 was first energized 1 day after placement, when anode had been in service approximately 5 months.

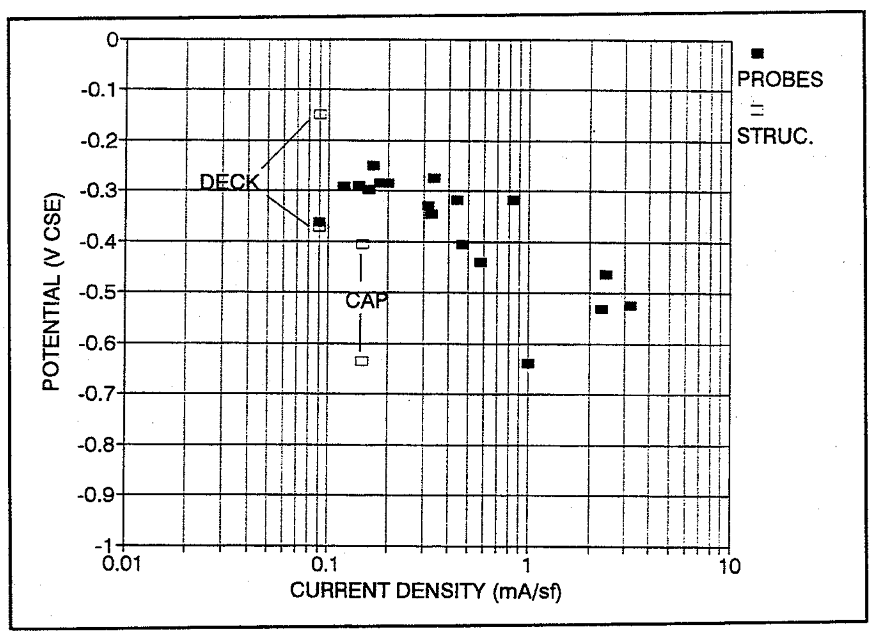

FIGURE 12 Instant-off potential of all rebar probes and structural elements at Pier 293 as a function of steel current density.

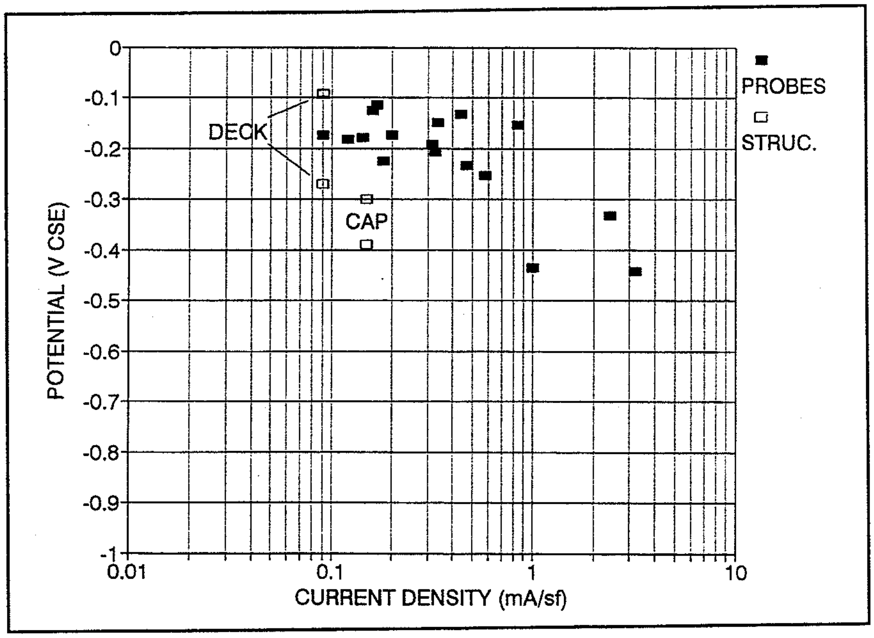

FIGURE 13 Potential of all rebar probes and structural steel elements at Pier 293 after 20-hr polarization decay as a function of steel current density just before disconnection.

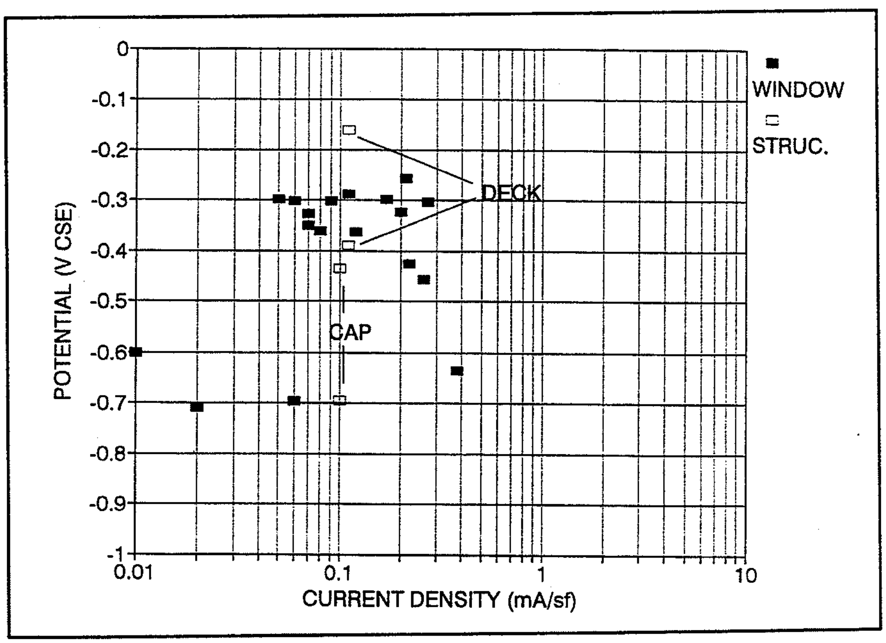

FIGURE 14 Anode potential as a function of anode current density for each test window location and for all anodes over the disconnectable structure elements at Pier 283. (Data from October 1993 field site visit [1 mA/ft^2=1.09 μA/cm^2].)

seawater. This was to be expected because of the location of the anodes relatively high above the high tide line. As found in the first phase of this investigation, intermittent wetting by saltwater or misting plays an important role in activating the anode by simultaneously lowering the operational potential and increasing current delivery. Because the extent of saltwater wetting at high elevations usually determines the severity of chloride ion contamination of the concrete, the reduced anode performance is expected to be accompanied by a reduction in corrosion severity. The results suggest that this is the case for most of the installations examined in this study. An extreme case of this behavior appears to be illustrated by the installation on the deck underside by Bent 293, where both the anode and the steel showed quite noble potentials and very little evidence of activity. Similar galvanic anodes in structural members subjected to more aggressive conditions tend to develop higher protective current delivery than the values obtained in the present study. For example, the anode current density was on the order of 1.1 $\mu A/cm^2$ (1 mA/ft^2) for the plain rebar substructure of the Bahia Honda Bridge in the Florida Keys, with an anode placed 3 to 6 ft above the high tide line.

The present investigation has provided additional experience in the placement, operation, and performance monitoring of a relatively inexpensive cathodic protection system for marine substructures. The results are consistent with expectations and previous testing, and indicate that a significant amount of corrosion protection is being achieved. The information available to date is not sufficient to determine whether the sacrificial anodes will be a long-term alternative to impressed-current systems. However, the following discussion suggests that the use of the sprayed anodes is an attractive alternative to conventional repairs using Gunite or similar patching materials.

Conventional patching in a marine substructure involves a preparation and surface pretreatment similar to that used for the galvanic anodes. Application of the Gunite finish requires portable spraying equipment, skilled operators, and finishing procedures that, in the experience of FDOT, result in costs on the order of several thousand dollars per patch for locations that require boat access. In addition, as experienced by FDOT and other transportation agencies, conventional patches in marine locations tend to develop new corrosion spalls about 2 years after application. The new spalls often develop at rebar surrounding the initial patch zone, possibly because the newly patched, chloride-free area is the site of predominantly cathodic reactions. This situation promotes the formation of a corrosion macrocell that aggravates the corrosion in the immediately surrounding anodic steel, which is still in contact with concrete with a high chloride ion concentration. Sacrificial sprayed anodes cost about the same as conventional patching or even less if no cover over the exposed spall is needed because of structural or aesthetic reasons. However, the findings of this and previous investigations indicate that, unlike the conventional patch, the sacrificial anode provides positive protection by reducing the corrosion rate of the steel. The protection also extends to the region surrounding the original spall, mitigating the possible effect of corrosion macrocells.

Experience with installations at the Florida Keys shows that sacrificial anodes have survived for up to 5 years of field service, with mostly positive results. For example, an inspection of 40 zinc-sprayed footers at the Seven Mile Bridge showed that at the end of a 3-year test period only 12 footers had experienced new spalls. Because those installations are on structures that had corroding epoxy-coated rebar, it is possible that at least some of the new spalls resulted from lack of connection, and consequent absence of protection, to electrical discontinuous elements of the rebar cage itself. Experimental conventional patch repairs at the same bridge showed new spalls within the typical time frame of 2 years. Although the South Florida installations and the Howard-Frankland Bridge test site will be subject to continued monitoring, evidence to date supports the use of the technique as an alternative to conventional repairs when limited-term corrosion protection measures are being contemplated.

Long-term protection strategies involving sacrificial anodes depend on the actual field service life of the anodes, which is not yet fully documented. The field record shows that useful service has been documented so far for up to 5 years. An upper limit of about 10 to 15 years has been estimated from anode consumption based on the amount of zinc available, typical current density demands, and expected levels of autocorrosion. The choice of galvanic versus impressed-current anodes or other strategies for specific substructure members will be dictated by economic factors, such as the required remaining service life of the entire structure, cost of replacing the galvanic anodes periodically versus a one-time impressed-current installation cost, replacement cost of the substructure member itself, and eventual obsolescence of the structure.

CONCLUSIONS

The sacrificial anode installations at the Howard-Frankland Bridge were successfully conducted with minimal difficulty by using commonly available commercial equipment. The physical integrity of the anodes was preserved throughout the 18-month test period. These and previous installations demonstrated that the anode placement technology is well established.

The following techniques for anode performance characterization were suitable for routine use and provided reasonably consistent results: (*a*) cutout anode windows for current delivery monitoring and (*b*) embedded short rebar segments (rebar probes) placed in chloride-contaminated mortar core fillings for current delivery and polarization decay tests. These techniques provided results consistent with those of custom anode installations that used entirely disconnectable anodes for direct evaluation of cathodic protection performance.

After the systems had been operational for more than 1 year, the sprayed anodes delivered steel current densities typically in the range 0.11 to 1.1 $\mu A/cm^2$ (0.1 to 1.0 mA/ft^2). Tests with rebar probes and disconnectable structures showed that polarization decays typically exceeding 100 mV were obtained, even with the modest current densities involved.

The structure elements investigated here (mostly pile caps and beams) required relatively low polarization current densities because of moderate corrosion conditions. Corrosion severity was reduced at the structure elevations considered because of low levels of chloride contamination and high concrete resistivities.

The findings support earlier indications that sprayed-zinc sacrificial anodes are an attractive economic alternative to conventional spall patching in marine substructures.

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PART 2

IMPLEMENTATION MANUAL

INTRODUCTION

OBJECTIVE

The procedure described in this manual is intended to be used to extend the life of marine bridge and building substructure components that are experiencing damage due to the corrosion of reinforcing steel.

PRINCIPLE OF OPERATION

Reinforcing steel in concrete is initially protected from corrosion by the presence of a passive layer on the steel surface formed because of the high pH of the concrete pore water. However, if chloride ions from the external environment penetrate the concrete cover, passivity breakdown and consequent corrosion of the reinforcing steel may take place (*1*). The corrosion products are more voluminous than the consumed steel, causing cracks, concrete spalling, and consequent structural damage. In the northern United States, chloride ions from highway deicing salts are a common cause of bridge-deck corrosion (*1*). In warmer locations, substructure damage in marine bridges due to chloride ions from seawater is more common. This form of deterioration affects numerous bridges on coastal highways (*2*).

Corrosion in marine substructures is most severe approximately 60 to 180 cm (2 to 6 ft) above the high tide line. Within this zone, seawater splash and evaporation cause chloride ions to concentrate, the electrical conductivity of the concrete is high, and a significant concentration of oxygen may exist. Electrochemical coupling of the zone is possible with higher regions of the substructure not undergoing corrosion but where oxygen access is greater. This may result in the formation of corrosion macrocells that can aggravate the deterioration of the high-chloride zone. In the absence of special design procedures, externally visible signs of deterioration are observable within about 12 years of service in typical warm-weather marine substructure applications (*2*).

Current design for new substructure applications uses less-permeable concrete and increased rebar cover to achieve longer corrosion-free service times. However, many existing marine bridge substructures built to earlier specifications are in need of corrosion control and rehabilitation. Conventional repair procedures based on removal of the older concrete cover and replacement with shotcrete have not been satisfactory because external signs of corrosion tend to reappear within as little as 2 years after the repair. Other nonelectrochemical repair methods, such as incorporating corrosion inhibitors in the new cover, have been proposed. However, these methods have been aimed at deicing salt-induced damage and are still being investigated.

Cathodic protection (CP) is a promising technology for corrosion control (*3*). Polarizing the reinforcing steel in the negative direction can reduce the rate of the metal oxidation reaction to a negligible value. The desired polarization is achieved by sending an electric current into the steel. The matching ionic current travels through the concrete between the steel and another electrode, the anode. CP systems can be of the impressed-current type or the galvanic type.

In impressed-current CP systems, the anode is made of a material with an unpolarized potential that may be equal to or greater than that present initially in the steel to be protected. An external power supply is connected between the anode and the steel with the appropriate polarity and voltage to deliver the desired amount of electric current to the steel. Impressed-current CP systems have been used successfully to arrest corrosion in both bridge decks and substructures. The anode is usually embedded near the concrete surface, and the external power source is installed nearby with appropriate wiring and controls. Short circuits between the anode and rebar must be avoided. The functioning of the system should be monitored carefully. For these reasons, installation and maintenance costs of this type of system are relatively high, especially in a marine substructure application where physical access can be difficult and environmental conditions are harsh.

In galvanic CP systems, the initial, unpolarized potential of the anode material is more negative than that of the steel. The protecting electric current thus flows naturally into the steel, and protection is achieved as long as the current is large enough to create the steel polarization necessary for effective protection. If adequate current delivery is achieved, galvanic CP systems represent an attractive alternative to the impressed-current approach. In a galvanic system, protection is achieved by direct connection between the anode and the steel. No external power source is required because the anode consumption provides the necessary protecting current. Unplanned anode-steel shorts need not be eliminated. External power wiring and control instrumentation are not required.

This manual presents guidelines for implementing a low-cost galvanic anode system in reinforced concrete marine substructures; the system has been investigated in several Florida bridges and by means of laboratory experiments (*4*). It integrates features used separately in impressed-current (*5*) and experimental galvanic anodes (6) for protecting steel in concrete.

SYSTEM DESCRIPTION

The system uses metallic zinc sprayed on the external surface of the substructure component to be protected with an arc-spray gun. Surface preparation consists of dry sandblasting within an hour before metallization. Two zinc or zinc alloy wires are driven mechanically so that their tips are close to each other in front of an air spray nozzle. An electric arc (typically 300 A, 20 V) is maintained across the wire tips. The arc melts the metal, which in turn is carried away as a finely dispersed spray by the air stream. The molten metal droplets solidify on contact with the work surface, creating a deposited layer. Several metallization passes are made to obtain a typical thickness of 0.38 mm (0.015 in.), which can be deposited at a rate of several square meters per minute. The deposited metal is about 90 percent dense. A properly applied coating has a typical adherence of 0.7 to 2 MPa (100 to 300 psi) as measured by a straight pull-off paint adhesion tester.

When necessary, metallic contact with the underlying rebar can be achieved by means of a drilled and tapped connector attached to the rebar in combination with an external contact pad. However, if a corrosion-induced concrete spall has already exposed some reinforcing steel, contact may be achieved by directly spraying metal (after sandblasting) over the exposed rebar.

The extent of protection provided by the sacrificial anode depends on the degree of electrochemical coupling between the zinc anode and the steel and on the differences in electrochemical behavior between both electrodes. Field and laboratory tests have shown that sufficient electrolytic contact exists in common concrete substructures exposed to warm marine service. Testing under these conditions has also established that the sprayed anodes are active enough with respect to the steel to result in significant protection. Anode durability in the field is known to exceed 5 years and is estimated to be in the 5- to 10- year range.

Installation of the sacrificial sprayed-zinc anodes in substructures exposed to warm marine service costs several times less than conventional impressed-current systems in the same service – for example, $127/m^2 ($12/ft^2) versus $445/m^2 ($42/ft^2) in Florida Department of Transportation experience. Estimates of performance and cost indicate that sacrificial sprayed-zinc anodes in these service environments are an attractive alternative to simple patch repair of corrosion-damaged concrete. Experience is not available at this time to compare the relative long-term cost and performance of periodically replaced sacrificial anodes with a conventional impressed-current system in the type of service considered here.

STRUCTURES SUITABLE FOR IMPLEMENTATION

This protection method is applicable to marine substructure elements of bridges and other structures in warm-weather environments subject to corrosion of reinforcing steel at points where the surface of the concrete is exposed to saltwater spray or splash with intermittent evaporation. The procedure is intended for substructures that have already shown signs of corrosion-induced deterioration, including severe spalling of the concrete cover. The procedure was successfully tested with plain and epoxy-coated reinforcing steel structures that had experienced severe corrosion and on pilings in which pretressed strands were present primarily for strengthening the piles during pile driving.

The method has not been tested in structures in cold climates, structures with concrete–carbonation–related corrosion, and structural members in which prestressed steel serves as a critical structural component. Laboratory testing indicates that performance is not likely to be adequate if the anode surface is not subject to direct wetting by seawater spray (*7,8*). At the other extreme, field experience indicates that anode application is difficult and anode life is limited if the anode is completely immersed in saltwater, as in the tidal zone or at seawater pools on the horizontal surface of footers. The method can be used in conjunction with conventional repair techniques such as patching or Guniting.

ASSESSMENT OF STRUCTURES TO BE PROTECTED

In the following, the party responsible for installation of the anodes will be referred to as the contractor. The technical representative of the party commissioning the work will be called the engineer.

The structure should be visually inspected for signs of any structural deterioration due to, but not limited to, corrosion. Regions showing corrosion damage should be identified, and an inventory should be made of the presence and severity of concrete cover spalling, externally visible rust, and cracks. The surrounding concrete surfaces should be sound-tested to determine the actual dimensions of the areas to be protected and of the deteriorated concrete to be removed.

Half-cell potential readings with a copper–copper sulfate electrode should be conducted in conventional rebar (non-epoxy-coated) structures to determine the extent of the actively corroding steel zone. Emphasis should be given to determining the highest elevation above high tide for which potentials are negative enough to indicate actively corroding reinforcement. In the absence of other information, potentials more negative than -350 mV should be deemed a symptom of active corrosion.

The inventory of corrosion damage, including dimensions of the areas to be protected, should be verified by the field engineer.

Tables 4-13 provide descriptions of related data for this project.

TABLE 4 ENERGIZING PROBES: BENT 280, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Date and Service Months	Probe Set/ Probe	Static Potential (V CSE)	Condition Following Connection: Time After Connection (h)	On-Potential (V CSE)	Probe Current Density (mA/sf)
Bent 280 - West Face Of Cap					
11-5-92	*Set 1/*				
0.5	*A*	-0.390	4.0	-0.631	1.48
	B	-0.291		-0.396	1.30
	C	-0.263		-0.354	0.88
12-8-92	*Set 2/*				
1.5	*A*	-0.275	20.0	-0.525	0.48
	B	-0.378		-0.281	0.16
	C	-0.138		-0.284	0.12
4-7-93	*Set 1/*				
5.5	*A*	-0.312	22.0	-0.587	2.64
	B	-0.210		-0.509	2.36
	C	-0.178		-0.392	1.00
6-30-93	*Set 2/*				
8.0	*A*	-0.203	3.0	-0.450	2.17
	B	-0.149		-0.338	0.72
	C	-0.135		-0.295	0.72
10-27-93	*Set 1/*				
10.0	*A*	-0.212	4.0	-0.427	0.34
	B	-0.094		-0.312	0.22
	C	-0.079		-0.286	0.14
Bent 280 - South Face Beam "E"					
11-5-92	*Set 1/*				
0.5	*A*	-0.340	4.0	-0.833	18.0
	B	-0.292		-0.766	11.5
	C	-0.359		-0.771	11.1
12-8-92	*Set 2/*				
1.5	*A*	-0.184	20.0	-0.661	4.94
	B	-0.118		-0.621	4.69
	C	-0.100		-0.499	4.67
4-7-93	*Set 1/*				
5.5	*A*	-0.228	23.0	-0.788	0.42
	B	-0.260		-0.776	0.19
	C	-0.218		-0.734	1.13
6-30-93	*Set 2/*				
8.0	*A*	-0.279	2.0	-0.684	4.33
	B	-0.276		-0.678	5.77
	C	-0.249		-0.628	4.33
10-28-93	*Set 1/*				
10.0	*A*	-0.285	3.5	-0.691	2.42
	B	-0.203		-0.644	1.83
	C	-0.014		-0.594	4.54

SPRAYED-ZINC ANODE CONFIGURATION AND AREA TO BE METALLIZED

The areas to be metallized should include regions with the following characteristics:

- Spalled concrete cover;
- Deteriorated concrete to be removed;
- Concrete cover delamination, as revealed by sound testing;
- Active steel corrosion, as shown by half-cell potential surveys; and
- Points within 30 cm (1 ft) of the limits of any other region with these characteristics.

Exceptions to these include the following:

- Regions within 60 cm (2 ft) of the high tide elevation, or where physical layout promotes the formation of saltwater pools; and
- Regions where other sources of moisture, such as dripping from the superstructure above, prevent suitable surface preparation for adequate coating adhesion.

Engineering drawings should be prepared identifying the regions to be metallized and any related detailing.

TABLE 5 ENERGIZING PROBES: BENT 281, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Date and Service Months	Probe Set/ Probe	Static Potential (V CSE)	Condition Following Connection: Time After Connection (h)	On-Potential (V CSE)	Probe Current Density (mA/sf)
Bent 281 - West Face Of Cap					
11-5-92	*Set 1/*				
0.5	*A*	-0.245	4.0	-0.289	0.12
	B	-0.303		-0.340	0.24
	C	-0.273		-0.386	1.01
12-8-92	*Set 2/*				
1.5	*A*	-0.234	18.0	-0.310	0.18
	B	-0.260		-0.342	0.05
	C	-0.238		-0.282	0.56
4-7-93	*Set 1/*				
5.5	*A*	-0.325	20.0		1.37
	B	-0.297		-0.519	1.13
	C	-0.262		-0.472	1.66
6-30-93	*Set 2/*				
8.0	*A*	-0.159	1.0	-0.335	0.53
	B	-0.154		-0.302	0.30
	C	-0.127		-0.319	0.97
10-28-93	*Set1/*				
10.0	*A*	-0.219	18.0	-0.349	0.94
	B	-0.147		-0.314	1.49
	C	-0.101		-0.316	4.46
Bent 281 - South Face Beam "E"					
11-5-92	*Set 1/*				
0.5	*A*	-0.256	4.0	-0.352	0.62
	B	-0.310		-0.398	0.68
	C	-0.262		-0.288	0.08
12-8-92	*Set 2/*				
1.5	*A*	-0.286	18.0	-0.386	3.12
	B	-0.209		-0.376	0.38
	C	-0.203		-0.244	0.16
4-7-93	*Set 1/*				
5.5	*A*	-0.240	20.0	-0.543	0.49
	B	-0.262		-0.508	1.23
	C	-0.260		-0.395	0.52
6-30-93	*Set 2/*				
8.0	*A*	-0.183	1.0	-0.347	0.40
	B	-0.169		-0.396	0.81
	C	-0.132		-0.331	0.44
10-28-93	*Set 1/*				
	A	-0.144	18.0	-0.297	0.18
	B	-0.161		-0.381	0.32
	C	-0.153		-0.267	0.19

ELECTRIC CONTACTS

TYPE OF CONTACTS

For spalled concrete and exposed steel, electric contact will be achieved by direct spraying after surface preparation. If no rebar has been exposed after preparation of the concrete surface for coating, an access hole to the rebar should be core drilled in the concrete cover. The hole should be drilled and tapped to accommodate an 8-mm (5/16-in.), type 316, stainless steel all-threaded rod that extends a minimum of 6 cm (2.5 in.) from the concrete surface (Figure 1). The access hole should be sealed with sand-cement grout. Lead and steel plates should be placed after zinc spraying. Additional anchor bolts should be used to help the center bolt fasten the plates in place, as shown in Figure 1. In all cases, electric continuity between the point at which the anode is connected and the rest of the steel should be verified by previous measurements.

NUMBER OF CONTACTS

There should be at least one contact point between the sprayed zinc and the reinforcing steel for sprayed concrete areas of 10 m^2 (100 ft^2) or less. An additional, separate contact point should be provided for each additional 10 m^2 (100 ft^2) or fraction. A contact point is defined as a fastened contact or an oversprayed, exposed steel zone in which at least 15 cm (6 in.) of exposed rebar metal is in contact with the sprayed anode over at least one-third of the rebar circumference. Contact points are defined as separate when they are at least 2 m (6 ft) apart.

TABLE 6 ENERGIZING PROBES: BENTS 293 AND 307, WEST FACE OF CAP

Date and Service Months	Probe Set/ Probe	Static Potential (V CSE)	Condition Following Connection: Time After Connection (h)	On-Potential (V CSE)	Probe Current Density (mA/sf)
Bent 293 - West Face Of Cap					
12-8-92	Set 2/				
0.5	A	-0.304	18.0	-0.818	8.64
	B	-0.274		-0.778	7.92
4-6-93	Set 1				
4.0	A	-0.365	4.0	-0.706	5.41
	B	-0.442		-0.630	3.48
6-30-93	Set 2/				
6.5	A	-0.296	1.0	-0.853	10.1
	B	-0.319		-0.794	8.68
10-28-93	Set 1/				
10.5	A	-0.407	18.0	-0.905	8.38
	B	-0.207		-0.802	6.18
Deck					
11-5-92	Set 1/				
0.5	A	-0.335	4.0	-0.820	2.30
12-8-92	Set 2/				
1.5	A	-0.382	18.0	-0.837	7.20
4-6-93	Set 1/				
5.5	A	-0.076	4.0	-0.217	0.40
6-30-93	Set 2/				
8.0	A	-0.224	1.0	-0.442	0.20
10-28-93	Set 1/				
10.0	A	-0.019	23.0	-0.531	6.22
Bent 307 - West Face Of Cap					
11-5-92	Set 1/				
0.5	A	-0.361	4.0	-0.383	0.39
	B	-0.378		-0.417	0.18
	C	-0.258		-0.274	0.35
12-8-92	Set 2/				
1.5	A	-0.241	3.0	-0.337	1.08
	B	-0.192		-0.285	0.20
	C	-0.215		-0.289	0.15
4-06-93	Set 1/				
5.5	A	-0.252	4.0	-0.452	1.63
	B	-0.227		-0.411	1.27
	C	-0.279		-0.454	1.76
6-30-93	Set 2/				
8.0	A	-0.144	4.0	-0.368	2.17
	B	-0.096		-0.329	1.45
	C	-0.180		-0.366	1.45
10-28-93	Set 1/				
10.0	A	-0.110	20.0	-0.323	0.63
	B	-0.128		-0.311	0.42
	C	-0.118		-0.290	0.46

SURFACE PREPARATION

SPALLED AREAS AND DETERIORATED CONCRETE

Spalled areas to be metallized do not require restoration after the unsound concrete has been removed. If structural or aesthetic reasons exist for restoration, it must be accomplished before metallization. The concrete should be thoroughly cured before metallization. Metallized surfaces should not be covered with concrete.

CLEANING AND BLASTING

All concrete surfaces and exposed steel to be metallized should be thoroughly blasted with silica sand or another suitable material before zinc application. The steel should receive an abrasive blast to remove mill scale, rust, oil, and other foreign material so that a near-white appearance is obtained. Blasting of concrete should be of sufficient duration to obtain a surface color change but without resulting in excessive coarse aggregate exposure. Blasting material must be plant packaged and maintained in a clean and dry condition at all times.

TABLE 7 PROBE DEPOLARIZATION TEST: BENT 280, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Date/ Time In Place	Probe Set/ Probe	Probe Current Density mA/sf	On Potential (V)	Instant Off Potential (V)	Depolarization Time (h)	Total Potential Decay (V)
Bent 280 - West Face Of Cap						
12-8-92	Set 1/					
1.5	A	2.75	-0.366	-0.330	20.0	0.077
	B	0.97	-0.323	-0.303		0.177
	C	0.41	-0.283	-0.229		0.103
4-7-93	Set 2/					
5.5	A	2.41	-0.590	-0.556	1.0	0.157
	B	2.07	-0.474	-0.440		0.125
	C	0.98	-0.399	-0.379		0.079
6-30-93	Set 1/					
8.0	A	0.91	-0.447	-0.451	21.0	0.222
	B	0.43	-0.310	-0.300		0.143
	C	0.26	-0.309	-0.301		0.167
10-28-93	Set 2/					
10.0	A	0.47	-0.435	-0.406	12.0	0.181
	B	0.34	-0.289	-0.276		0.139
	C	0.17	-0.257	-0.251		0.142
Bent 280 - South Face Beam "E"						
12-8-92	Set 1/					
1.5	A	7.16	-0.494	-0.464	20.0	0.264
	B	4.39	-0.445	-0.404		0.275
	C	4.20	-0.391	-0.313		0.242
4-7-93	Set 2/					
5.5	A	4.91	-0.785	-0.571	23.0	0.265
	B	6.28	-0.804	-0.600		0.312
	C	6.13	-0.710	-0.559		0.235
6-30-93	Set 1/					
8.0	A	6.49	-0.686	-0.532	21.0	0.401
	B	5.05	-0.709	-0.522		0.463
	C	5.05	-0.612	-0.520		0.477
10-28-93	Set 2/					
10.0	A	2.29	-0.710	-0.531	24.0	0.156
	B	3.21	-0.696	-0.524		0.254
	C	2.41	-0.600	-0.464		0.259

ZINC APPLICATION EQUIPMENT

POWER UNIT

For most applications appropriate for this method, the individual structural areas to be metallized are relatively small—5 to 50 m^2 (50 to 500 ft^2). Therefore, a large, high production metallizing unit may not be particularly advantageous. A moderately sized portable unit capable of spraying 50 kg (90 lb) of zinc per hour is recommended. Units corresponding to this description used successfully in field applications include (a) Eagle Arc 600 from Superior Arc Metallizing, Mobile, Alabama; and (b) Thermion 500, from Thermion Metallizing Systems, Silverdale, Washington.

For larger, easily accessible areas, a high-production unit should be considered. One high-production unit rated at 140 kg (300 lb) per hour is Powerarc 1500, available from Douglas Call Co., Inc., Virginia Beach, Virginia. Additional suppliers of metallizing equipment can be contacted via the Zinc Metallizers Task Group, P.O. Box 2664, Greenwich, Connecticut 06836.

METAL STOCK

The metallizing material should be commercially pure zinc (99.9 percent pure) produced in wire form in 3-mm (1/8-in.) standard size or other suitable gauge that can be melted and sprayed using the specified equipment. The zinc wire should be available commercially. Laboratory tests suggest that the commercial alloy Zn-15%Al provides performance comparable with that of commercially pure zinc.

TABLE 8 PROBE DEPOLARIZATION TEST: BENT 281, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Bent 281 - West Face Of Cap

Date/ Time In Place	*Probe Set/ Probe*	*Probe Current Density mA/sf*	*On Potential (V)*	*Instant Off Potential (V)*	*Depolarization Time (h)*	*Total Potential Decay (V)*
12-8-92	*Set 1/*					
1.5	*A*	0.23	-0.297	-0.289	20.0	0.123
	B	0.27	-0.316	-0.309		0.120
	C	1.43	-0.440	-0.436		0.274
4-7-93	*Set 2/*					
5.5	*A*	1.62	-0.533	-0.492	1.0	0.117
	B	1.23	-0.520	-0.487		0.110
	C	0.00	-0.487	-0.467		0.130
6-30-93	*Set 1/*					
8.0	*A*	0.33	-0.345	-0.327	21.5	0.099
	B	0.30	-0.309	-0.294		0.138
	C	0.47	-0.317	-0.308		0.163
10-28-93	*Set 2/*					
10.0	*A*	0.18	-0.304	-0.295	18.0	0.089
	B	0.12	-0.299	-0.292		0.116
	C	0.84	-0.327	-0.319		0.173
Bent 281 - South Face Beam "E"						
12-8-92	*Set 1/*					
1.5	*A*	0.77	-0.370	-0.350	20.0	0.134
	B	0.90	-0.400	-0.354		0.176
	C	0.37	-0.272	-0.250		0.076
4-7-93	*Set 2/*					
5.5	*A*	0.88	-0.442	-0.397	18.0	0.155
	B	1.51	-0.541	-0.532		0.297
	C	1.01	-0.430	-0.413		0.227
6-30--93	*Set 1/*					
8.0	*A*	0.28	-0.349	-0.337	21.5	0.181
	B	0.26	-0.390	-0.362		0.184
	C	0.31	-0.365	-0.305		0.202
10-28-93	*Set 2/*					
10.0	*A*	0.14	-0.302	-0.290	18.0	0.123
	B	0.33	-0.361	-0.347		0.154
	C	0.16	-0.301	-0.299		0.175

APPLICATION PROCEDURE

TIMING OF INITIAL SURFACE PREPARATION

All metallizing should be completed within 2 hr following sandblasting and before any visible rust bloom develops on the surface of any exposed reinforcing steel.

AIR BLASTING

Before zinc application, the concrete surface should be air blasted to remove any sand residue and dust from the sandblasting operation. The metallizing should be performed only on surfaces that have been properly prepared as previously described. The concrete must be visually dry at the time of metallizing.

TEST SECTIONS

Before commencing the arc-spraying operation, the contractor should metallize a minimum of six on-site test sections with dimensions of 0.1 m^2 (1 ft^2) each. These test sections should be used to determine the field application rate for the specified thickness, "grain size" (absence of zinc globules on the sprayed metal surface), and texture acceptability.

SPRAY PASSES AND COATING THICKNESS

The zinc application should be performed using multiple spray passes to achieve the coating thickness specified in the following section.

TABLE 9 PROBE DEPOLARIZATION TEST: BENT 293, WEST FACE OF CAP AND BAY D, AND BENT 307, EAST FACE OF CAP

Bent 293 - West Face Of Cap And Bay "D"

Date/ Time In Place	Probe Set/ Probe	Probe Current Density mA/sf	On Potential (V)	Instant Off Potential (V)	Depolarization Time (h)	Total Potential Decay (V)
Cap						
4-26-93	Set 2/					
4.0	A	4.88	-0.699	-0.645	20.0	0.232
	B	4.36	-0.632	-0.588		0.244
6-30-93	Set 1/					
6.5	A	3.14	-0.841	-0.726	18.0	0.238
	B	3.14	-0.785	-0.642		0.216
10-28-93	Set 2/					
10.5	A	1.00	-0.645	-0.639	18.0	0.199
	B	0.58	-0.457	-0.440		0.203
Deck						
12-8-92	Set 1/					
1.5	A	11.77	-0.707	-0.630	20.0	0.460
4-6-93	Set 2/					
5.5	A	0.38	-0.426	-0.419	22.0	0.124
6-30-93	Set 1/					
8.0	A	0.13	-0.202	-0.190	18.0	0.103
10-28-93	Set 2/					
10.0	A	0.09	-0.363	-0.362	23.0	0.188
Bent 307 - East Face Of Cap						
12-8-92	Set 1/					
0.5	A	0.71	-0.328	-0.317	20.0	0.097
	B	0.18	-0.252	-0.249		0.057
	C	0.15	-0.243	-0.239		0.043
4-06-93	Set 2/					
1.5	A	3.21	-0.447	-0.415	23.0	0.213
	B	2.24	-0.407	-0.387		0.141
	C	3.12	-0.448	-0.421		0.192
6-30-93	Set 1/					
5.5	A	1.47	-0.368	-0.353	18.0	0.149
	B	0.43	-0.325	-0.316		0.111
	C	0.60	-0.505	-0.493		0.290
10-28-93	Set 2/					
10.0	A	0.44	-0.323	-0.318	24.0	0.190
	B	0.31	-0.349	-0.330		0.156
	C	0.20	-0.298	-0.295		0.134

QUALITY ASSESSMENT

Coating Thickness

The zinc application should result in a coating thickness of 0.38 to 0.5 mm (0.015 to 0.020 in.). The thickness should be evaluated using small test coupons of adhesive tape (heating-duct tape) attached to the concrete surface before metallizing. After metallizing, the sprayed metal can be easily removed from the tape and the thickness can be measured directly with a micrometer. Other means of measuring coating thickness are acceptable by agreement between the contractor and engineer. A minimum of one thickness measurement should be conducted at 2.5-m^2 (25-ft^2) intervals. Measurements should be obtained and recorded by the contractor and verified by the engineer. Where coating thickness is deficient, the deficient section should receive additional coatings so that the thickness of the repaired area reaches a minimum of 0.38 mm (0.015 in.).

Coating Adherence

On test sections the coating adhesion strength is defined as the average of three pull-off tests performed following ASTM D4541 using a 0- to 4-MPa (0- to 500-psi) fixed alignment adhesion tester. Typical values are expected in the 0.7- to 1-MPa (100- to 150-psi) range. The adhesion strength should be no less than 0.7 MPa (100 psi). The engineer should verify all measurements.

TABLE 10 SOUTH FACE WINDOW ZINC ANODE TEST: BENT 280, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Bent 280 - West Face Of Cap

Date And Service Months	*Test Window*	*Window - Structure*		
		Current (mA)	*Instant-Off Potential Difference (V)*	*Resistance (Ohms)*
11-05-92 4.6	A	0.35	0.023	450
	B	0.10	0.048	1400
	C	0.22	0.065	400
12-8-92 5.7	A	0.21	0.199	1000
	B	0.02	0.126	3700
	C	0.06	0.250	2500
4-7-93 9.7	A	0.48	0.490	550
	B	0.24	0.497	1500
	C	0.37	0.479	1000
6-30--93 12.4	A	0.35	0.195	470
	B	0.22	0.377	1500
	C	0.36	0.472	1100
10-28-93 16.4	A	0.22	0.213	700
	B	0.11	0.454	2500
	C	0.21	0.510	1800
Bent 280 - South Face Beam "E"				
11-5-92 4.6	A	0.01	0.042	1300
	B	0.06	0.314	100
	C	0.03	0.022	600
12-8-92 5.7	A	0.01	0.022	2900
	B	0.05	0.073	2100
	C	0.01	0.009	1300
4-7-93 9.7	A	0.03	0.097	2000
	B	0.09	0.100	9600
	C	0.03	0.028	7900
6-30--93 12.4	A	0.05	0.096	1600
	B	0.08	0.092	1100
	C	0.05	0.021	620
10-28-93 16.4	A	0.02	0.090	2300
	B	0.06	0.116	1600
	C	0.01	0.011	810

On the work areas the contractor should conduct at least one coating-adhesion strength test on each metallized structural element or subsection specified by the engineer. Results should be recorded by the contractor and verified by the engineer. Pull-off strength should be a minimum of 90 percent of the value obtained from the preliminary on-site test areas but no less than 0.7 Mpa (100 psi). Areas not meeting the required adhesion strength should be blasted clean of all sprayed metal before respraying.

Visual Appearance

The surfaces of the zinc-coated sections should be uniform in appearance and free from visible coating defects such as cracking, burning, blistering, and uncoated areas or other defects that will affect the function of the coating. If a deficient area is found, the correction should be performed in the same way as for deficient thickness. Sandblasting of the defective area will be required as directed by the engineer.

General Criteria

Unless otherwise approved by the engineer, the method or combination of measurement methods used to assess the coating should be performed on test areas representative of the actual surface of the structure to be protected.

TABLE 11 SOUTH FACE WINDOW ZINC ANODE TEST: BENT 281, WEST FACE OF CAP AND SOUTH FACE OF BEAM E

Date And Service Months	Test Window	Window - Structure Current (mA)	Instant-Off Potential Difference (V)	Resistance (Ohms)
Bent 281 - West Face Of Cap				
11-05-92 4.6	A	0.65	0.238	560
	B	0.20	0.084	500
	C	0.05	0.002	1500
12-08-92 5.7	A	0.47	0.352	570
	B	0.09	0.129	570
	C	0.02	0.007	160
4-07-93 9.7	A	1.27	0.443	311
	B	0.71	0.356	370
	C	0.25	0.048	140
6-30-93 12.4	A	0.60	0.455	620
	B	0.49	0.346	495
	C	0.52	0.188	120
10-28-93 16.4	A	0.27	0.412	1200
	B	0.17	0.223	660
	C	0.07	0.019	150
Bent 281 - South Face Beam "E"				
11-05-92 4.6	A	0.07	0.092	1200
	B	0.07	0.138	1600
	C	0.06	0.025	1500
12-08-92 5.7	A	0.07	0.139	1200
	B	0.06	0.158	1700
	C	0.07	0.243	2100
4-07-93 9.7	A	0.10	0.189	1100
	B	0.14	0.267	1400
	C	0.19	0.342	1300
6-30-93 12.4	A	0.12	0.165	1050
	B	0.15	0.235	1250
	C	0.17	0.293	1950
10-28-93 16.4	A	0.06	0.177	1400
	B	0.08	0.224	1800
	C	0.09	0.298	2200

PERFORMANCE MONITORING AND MAINTENANCE

REBAR PROBES

Rebar probes should be prepared with a 5-cm (2-in.) length of No. 4 [12-mm (0.5 in.)] as-received rebar fitted with a plastic-insulated 12-gauge copper wire connection at one end. Both rebar ends should be covered with thick epoxy, leaving an exposed rebar metal area of 12 cm^2 (2 $in.^2$). At positions specified by the engineer, probes should be positioned in triplicate separated by a distance of 30 cm (1 ft). For each probe, a 5-cm (2-in.) core hole should be drilled, intersecting no existing rebar. The hole depth should be equal to the concrete rebar cover. The rebar probe should be inserted into the end of the core hole, with the wire extending 30 cm (1 ft) outside the concrete surface. The core hole should be filled with sand-cement grout containing chloride additives specified by the engineer to approximately match the chloride ion content of the surrounding concrete. The concrete surface should be metallized after the grout is set. A junction box and zinc connection must be made (Figure 2). A 5- by 5-cm (2- by 2-in.) uncoated area adjacent to the probe hole should be left for future corrosion monitoring.

In each triplicate set of probes, one should be left normally connected to the zinc by means of the probe wire and zinc connection. Another probe should be normally disconnected as an unprotected control. The third

TABLE 12 SOUTH FACE WINDOW ZINC ANODE TEST: BENT 293, WEST FACE OF CAP AND BAY D, AND BENT 307, WEST FACE OF CAP

Bent 293 - West Face Of Cap & Bay "D"

Date And Service Months	*Test Window*	*Window - Structure Current (mA)*	*Instant-Off Potential Difference (V)*	*Resistance (Ohms)*
Cap				
11-05-92	A	N/A	N/A	N/A
0.9	B	N/A	N/A	NA
12-08-92	A	0.45	0.212	380
2.0	B	0.33	0.352	740
4-06-92	A	0.86	0.269	270
5.9	B	0.64	0.416	570
6-30-93	A	0.12	0.046	380
8.7	B	0.19	0.177	780
10-28-93	A	0.38	0.275	550
12.7	B	0.26	0.459	1400
1-18-94	A	0.10	0.103	640
15.6	B	0.24	0.369	1025
Deck				
0.9	A	0.40	0.252	960
2.0	A	0.36	0.446	1020
5.9	A	0.27	0.476	1300
8.7	A	0.29	0.434	1200
12.7	A	0.12	0.348	1900

Bent 307 - West Face Of Cap

Date And Service Months	*Test Window*	*Current (mA)*	*Instant-Off Potential Difference (V)*	*Resistance (Ohms)*
11-05-92	A	0.17	0.014	490
5.1	B	0.03	0.018	900
	C	0.05	0.026	1300
12-08-92	A	0.03	0.039	780
6.2	B	0.08	0.197	1600
	C	0.07	0.256	2000
4-06-93	A	0.39	0.283	460
10.1	B	0.19	0.313	970
	C	0.19	0.352	1100
6-30-93	A	0.17	0.283	460
12.9	B	0.33	0.437	740
	C	0.14	0.298	1100
10-28-93	A	0.20	0.248	560
16.9	B	0.07	0.143	930
	C	0.05	0.279	2300

probe should be alternatively connected and disconnected in successive monitoring periods for the purpose of estimating the reenergizing capability of the anode. At periodic intervals the following steps should be performed with the normally connected probe:

1. Measure "on" potential, the potential difference between the probe wire and a copper–copper sulfate half cell in contact with the uncoated concrete patch next to the probe.
2. Measure probe current by disconnecting the probe zinc wire, connecting a low-input resistance (100 ohms or less) ammeter between the probe wire and the zinc, and reading the probe current with 1-μA resolution. Dividing the probe current by probe steel area provides the estimate of current density. Properly operating systems provide current densities typically above 0.11 $\mu A/cm^2$ (0.1 mA/ft^2) (*2*).
3. Measure polarization decay by measuring the probe to half-cell potential immediately after disconnection between probe and anode, leaving the probe disconnected and measuring the half-cell potential 4 hr later. The final minus initial potential is the 4-hr polarization decay. Values exceeding 100 mV usually indicate adequate system performance (*2*).
4. Reconnect the probe.

The half-cell potential of the normally disconnected probe should be measured to establish whether corrosive behavior still prevails in the unprotected condition.

TABLE 13 STRUCTURE DEPOLARIZATION TEST

Bent 293 - West Face Of Cap

Date/ Service Months	Reference Electrode Position	On Potential (V CSE)	Instant Off Potential (V CSE)	Decay Time (hr)	Total Decay (V)	Anode Current Density (mA/sf)	Steel Current Density (mA/sf)
Cap							
12-08-92	A	-0.714	-0.613	18.0	0.399	0.52	0.84
2.0	B	-0.574	-0.439		0.269		
4-26-93	A	-0.702	-0.480	18.0	0.222	0.95	1.52
5.9	B	-0.626	-0.459		0.203		
6-30-93	A	-0.566	-0.543	20.0	0.206	0.48	0.76
8.7	B	-0.464	-0.456		0.134		
10-28-93	A	-0.695	-0.635	23.0	0.245	0.10	0.15
12.7	B	-0.436	-0.406		0.106		
1-18-94	A	-0.874	-0.710	*Not Tested*		0.16	0.26
12.5	B	-0.605	-0.530				
Deck							
12-08-92	A	-0.300	-0.280	18.0	0.166	0.51	0.44
2.0	B	N/A					
4-06-93	A	-0.196	-0.186	18.0	0.058	0.14	0.12
5.9	B	-0.367	-0.345		0.076		
6-30-93	A	N/A		*Not Tested*			
8.7	B	N/A					
10-28-93	A	-0.161	-0.150	24.0	0.057	0.11	0.09
12.7	B	-0.389	-0.372		0.102		

The alternatively connected and disconnected probe should be left disconnected until the 30-day inspection, when it should be connected and the probe current and on potentials determined after 10 min of connection. The probe should be left connected until the next inspection. At the next inspection, the probe should be subjected to on potential, probe current, and probe polarization decay measurements but left disconnected afterward until the following inspection period, when reconnection is made again. Testing proceeds thereafter in the same cyclical manner.

TEST WINDOWS

Square regions 30 by 30 cm (1 by 1 ft) should be identified at metallized locations selected by the engineer. A concrete saw with an abrasive blade 6 mm (0.25 in.) thick should be used to cut the outline of each region to isolate a square section ("window") of coating. Connections to both the window and the immediately surrounding zinc should be prepared by installing a connecting wire. It is recommended that the connections be covered by a plastic connection box, silicone sealant, or other means of protecting the connection from corrosion.

At regular intervals the window-zinc connection should be opened. A low-input resistance ammeter (10 ohms or less, a more stringent requirement than for probe current measurement) should be inserted between the window and the zinc. Properly operating systems provide current densities typically above 0.11 $\mu A/cm^2$ (0.1 mA/ft^2) (*2*). The window should be reconnected after the test.

MONITORING SCHEDULE

It is recommended that the rebar probe and test window measurements be performed immediately after anode installation and 24 hr, 30 days, 90 days, and 180 days afterward, followed by yearly tests.

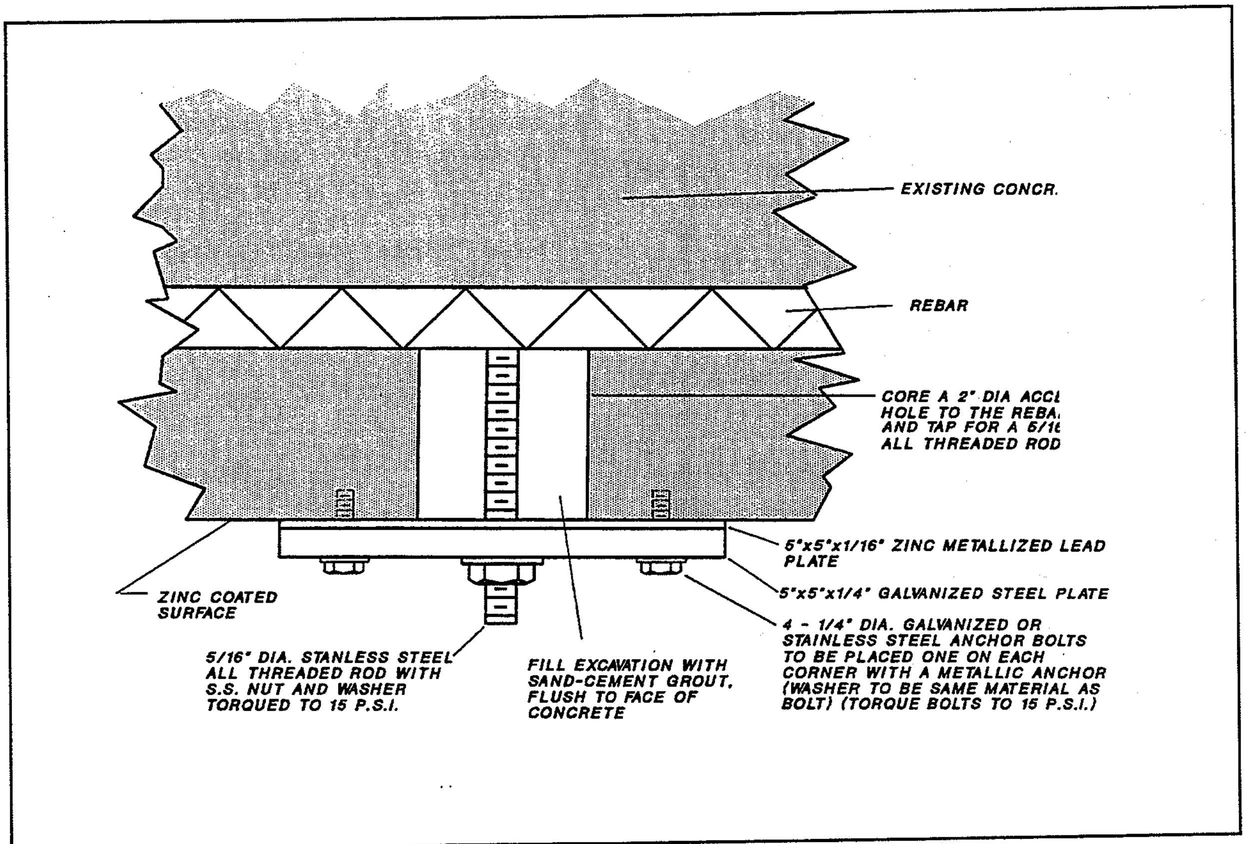

FIGURE 1 Rebar connection detail.

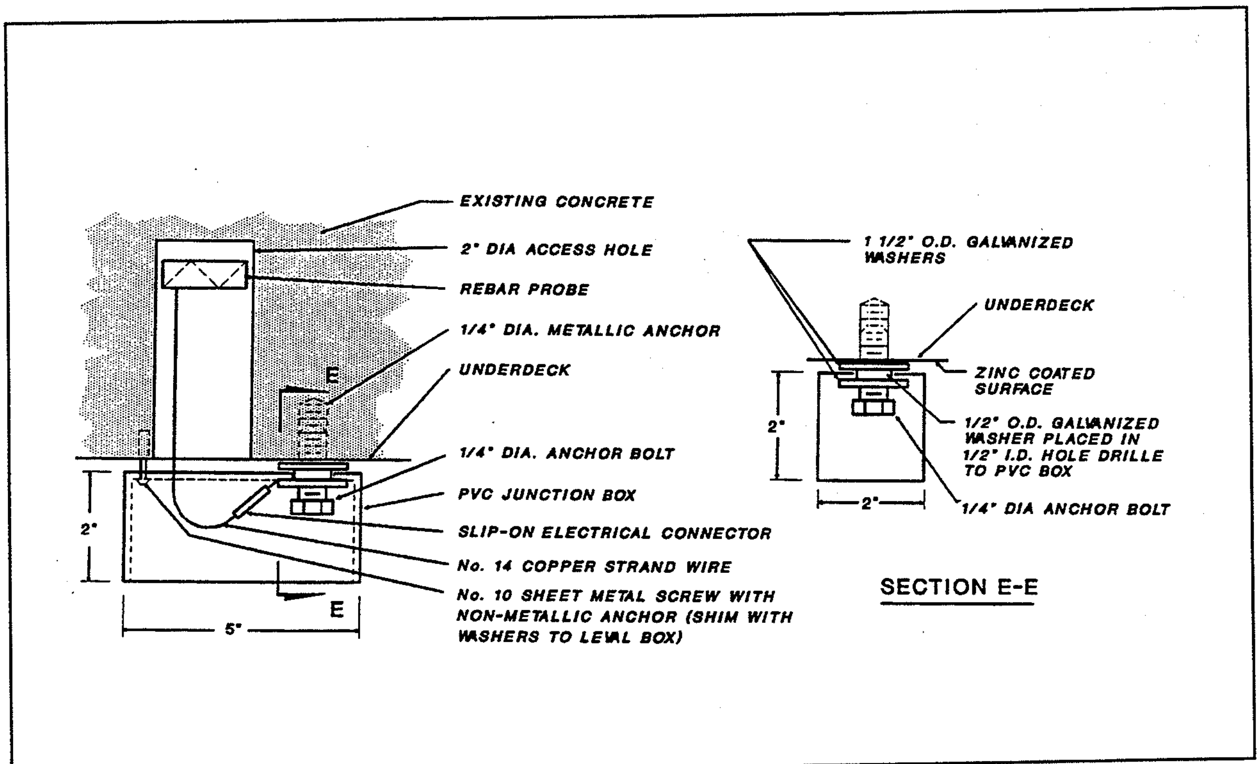

FIGURE 2 Rebar probe detail.

MAINTENANCE

Coincident with performance monitoring tests, the anode and contact condition should be visually inspected, and repairs to the contacts should be made and tested. Premature physical deterioration of the anodes may be indicative of unexpected wastage factors, such as accumulation of seawater on horizontal surfaces, strong tidal or wave action, or previously undetected concrete deterioration. The engineer should determine whether anode reapplication is in order or whether service conditions are inappropriate for this protection method.

SERVICE LIFE ESTIMATE

On the basis of field experience, laboratory determinations, and computations of environmental corrosion, it is estimated that properly applied anodes will last 5 years and can be in place by as many as 10 years before anode wastage is severe. If performance is determined to be satisfactory during a 5- to 10- year service interval, anodes that become visibly wasted can be removed by blasting, and a new sprayed anode can be put in service at the same location.

REFERENCES

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APPENDIX: EXAMPLE OF TYPICAL CONTRACT SPECIFICATIONS

A set of specifications prepared for a recent anode installation job follows. (Only specifications for arc-sprayed zinc are considered.)

EXAMPLE

TECHNICAL SPECIAL PROVISIONS

BRIDGES XXXXX-XXXX, XXXXX-XXXX AND XXXXX-XXXX

HILLSBOROUGH & PINELLAS COUNTY

Note: *This example is a photocopy of a draft contract specification, provided for illustration purposes only. Specific instructions may vary from those suggested in the Implementation Manual.*

SECTION CP 400-22
CATHODIC PROTECTION

CP 400-22.1 INTENT AND SCOPE

The work included under this specification consists of supplying and installing a sacrificial zinc anode cathodic protection (CP) system to selected structure elements of the Howard Frankland Bridge in Tampa, Florida.

The work also includes the installation of current monitoring rebar probes with its respective connections to the zinc at selected locations as shown in the construction plans. Such probes shall be supplied to the Contractor by the Department (Materials Office). Probes will be used to evaluate the galvanic performance of the system.

Three basic types of cathodic protection systems will be used in this project. Such systems are: a) Bulk zinc anode system, b) perforated zinc sheet system and c) arc-sprayed zinc system. A combination of these systems will be used as follows:

1. Bulk zinc anode and perforated zinc sheets system at selected bridge pilings.
2. Bulk zinc anode, perforated zinc sheets and arc-sprayed system at selected bridge pilings.
3. Bulk zinc anode at selected bridge piers and selected footer pilings.
4. Arc-sprayed zinc at selected caps, beams and underdeck (bay) areas.

400-22.4 ARC-SPRAYED ZINC SYSTEM

The installation of this system requires the application of zinc (anode) to the selected structure elements. The application shall be performed by thermal spraying (metalizing) the concrete and all exposed steel with the required surface preparation to provide a good bond between the zinc and the sprayed surface. A good bond is essential to provide an efficient system.

The work shall be performed from a barge or a suitable boat. Location of equipment on the roadway over the bridge will not be permitted.

The Contractor shall locate and inspect all the deteriorated areas indicated in the plans. The surrounding concrete surfaces shall be sound tested by the Contractor to determine the actual dimensions of the areas to be metalized and the deteriorated concrete to be removed. Dimensions and locations of the areas to be metalized as well as dimensions of the spalled areas shall be recorded by the Contractor and verified by the Engineer.

Spalled areas that are to be metalized do not require restoration after unsound concrete is removed. All concrete surfaces and exposed steel to be metalized shall be thoroughly blasted with silica sand or other suitable material prior to zinc application. The steel shall receive an abrasive blast to remove mill scale, rust, oil and/or other foreign material to the extent that a near white appearance is obtained.

Blasting material must be plant packaged and maintained in a clean and dry condition at all times.

Prior to commencing the arc-spraying operation, the Contractor shall metalize a minimum of six on-site test sections with dimensions of one square foot each. These test sections shall be used to determine the field application rate for the specified thickness and the grain size and texture acceptability.

The Contractor shall measure the adhesion strength on all test sections to determine if sufficient bond is achieved between the concrete surface and the zinc coating. A bonding strength of 100 to 150 psi is expected as determined by ASTM D4581-85 method. The Engineer shall verify all measurements.

The metalizing material shall be essentially pure zinc (99.9% pure) produced in wire form of 1/8 inch standard size which can be molten and sprayed using the specified equipment. The zinc wire shall be available commercially.

Prior to zinc application the concrete surface shall be air blasted to remove any sand residue and dust from the sandblasting operation. The metalizing shall only be performed on surfaces which have been properly prepared as described in this specification. All metalizing shall be completed within two hours following sandblasting and before any visible rust bloom develops. The concrete must be visually dry at the time of metalizing.

The zinc application shall be performed employing multiple spray passes to achieve a coating thickness of 15 to 20 mils as determined by thickness measurements on test coupons or other means acceptable to the Engineer. A minimum of one thickness measurement shall be obtained at 25 square feet intervals. Measurements shall be obtained and recorded by the Contractor and verified by the Engineer. Where deficient coat thickness values are found, the deficient section shall receive additional coating so that the coat thickness of the repaired area reaches a minimum of 15 mils.

The Contractor shall conduct a minimum of one coating adhesion strength test (pull-off test) on each metalized section. Results shall be recorded by the Contractor and verified by the Engineer. Pull-off test shall be conducted using a 0 to 500 psi fixed alignment adhesion tester as per ASTM D 4541-85. Pull-off strength shall be a minimum of 90% of the values obtained from the preliminary on-site test areas. Areas not meeting the required bonding strength shall be blasted clean of all sprayed metal prior to respraying.

Surface of zinc coated sections shall be uniform in appearance, free of visible coating defects such as cracking, burning and uncoated areas and/or other defects that well affect the function of the coating. If a deficient coated area is found, the correction shall be performed the same as for deficient thickness. Sandblasting of the defective area may be required as directed by the Engineer.

Unless otherwise approved by the Engineer, all measurements shall be taken horizontally and vertically. The method or combination of methods of measurements shall be those which will reflect with reasonable accuracy the actual surface area of finished metalized work as determined by the Engineer.

The metalizing unit shall be a portable, electric arc type system capable of depositing zinc coatings of controllable weights as Eagle Arc 600 manufactured by Fern Industries, Inc. for Superior Arc Metalizing Co. of Mobile, Alabama (telephone 205/473-8500) or approved equal.

Payment under this section shall be at the unit price and shall be made based on actual area (square foot) of metalized concrete surface approved satisfactory by the Engineer.

No separate payment shall be made for probes or negative connections installation. Such work and materials shall be considered as incidental to the arc-sprayed zinc system.

Pay Item No. 400-142-3 - Cathodic Protection System Zinc Spray - per square foot.

GENERAL NOTES

ZINC COATING CAPS AND GIRDERS (SEE TABLES II-III FOR LOCATIONS)

1. AFTER PREPARATION OF CONCRETE SURFACE FOR COATING, IF NO REBAR HAS BEEN EXPOSED, AN ACCESS HOLE TO THE CAP REBAR SHALL BE CORE DRILLED AT THE LOCATIONS SHOWN IN DETAIL "E", SHEET R-17.
2. THE ABOVE HOLE SHALL ACCOMMODATE A 5/16" 316 S.S. ALL-THREADED ROD WHICH SHALL EXTEND A MINIMUM OF 2.5" OUT OF CONCRETE SURFACE. SEE DETAIL "G", SHEET R-18.
3. SEAL ACCESS HOLE WITH SAND-CEMENT GROUT CONTAINING CHLORIDE ADDITIVES AS DIRECTED BY THE ENGINEER. INSTALL LEAD AND STEEL PLATES AS SHOWN IN DETAIL "G". APPLY TWO COATS OF AN APPROVED APPROVED EPOXY PAINT TO PLATES AND HARDWARE AFTER INSTALLATION.
4. AT LOCATIONS WHERE STEEL IS EXPOSED IT SHALL BE CLEANED BY SANDBLASTING TO A NEAR-WHITE CONDITION AND SHALL REMAIN EXPOSED EXCEPT FOR THE ZINC COATING. WHERE THIS CONDITION EXISTS THE ABOVE DRILLED CONNECTIONS MAY BE OMITTED.
5. REBAR PROBE INSTALLATION. AT 6 LOCATIONS AS SPECIFIED BY THE ENGINEER, A 2" CORE HOLE SHALL BE DRILLED. NO REBAR SHALL BE VISIBLE IN THE HOLE. USE A REBAR LOCATOR TO LOCATE THE STEEL. SEE DETAIL "E".
6. FILL THE 2" HOLES WITH SAND-CEMENT GROUT CONTAINING CHLORIDE ADDITIVES AS SPECIFIED BY THE ENGINEER. THE PROBE HOLE DEPTH SHALL BE THE SAME DEPTH AS THE REBAR. FINISH GROUT TO MATCH EXISTING SURFACE.
7. METALIZE CONCRETE SURFACE AFTER GROUT IS SET. INSTALL A JUNCTION BOX AND ZINC CONNECTION AS SHOWN IN DETAIL "H", SHEET R-18.
8. LEAVE A 2" X 2" UNCOATED AREA ADJACENT TO THE PROBE HOLE FOR FUTURE CORROSION MONITORING. SEE DETAIL "H".
9. METALIZING: ALL UNSOUND CONCRETE, INCLUDING THOSE AREAS WITH CLASS 3 AND LARGER CRACKS SHALL BE REMOVED AND REPAIRED AS SPECIFIED IN THESE PLANS.
10. AFTER CLEANING THE REBAR SOME CONCRETE RESTORATION MAY BE NECESSARY TO AVOID LEAVING AREAS WHERE WATER WILL REMAIN STANDING. USE PORTLAND CEMENT-SAND GROUT AS APPROVED BY THE ENGINEER.
11. CONCRETE SURFACES SHALL BE SANDBLASTED AND FREE OF MOISTURE AND ANY OTHER DELETERIOUS MATERIAL PRIOR TO METALIZING, AS APPROVED BY THE ENGINEER.
12. ZINC COATING SHALL BE APPLIED ON ALL VERTICAL FACES AND BOTTOM OF THE CAPS AND GIRDERS UNLESS OTHERWISE DIRECTED. THE THICKNESS SHALL BE 15 TO 20 MILS.

ZINC COATING BOTTOM OF DECK (SEE TABLE IV FOR LOCATIONS)

1. WHERE REBAR IS NOT EXPOSED A STEEL-ZINC CONNECTION SHALL BE INSTALLED AS DESCRIBED ABOVE IN CAP NOTES 1 THRU 3. LOCATION FOR THESE CONNECTIONS SHALL BE AS SPECIFIED BY THE ENGINEER. SEE DETAIL "F", SHEET R-17.
2. REBAR PROBES SHALL BE INSTALLED AS SHOWN IN DETAIL "H", AT NO MORE THAN 3 LOCATIONS AS SPECIFIED BY THE ENGINEER. SEE SECTION D-D OF DETAIL "F".
3. THE AREA TO BE COATED SHALL BE LIMITED TO THE BAY IN WHICH THE SPALL OCCURS. CONCRETE SURFACE SHALL BE THOROUGHLY CLEANED AS DESCRIBED ABOVE. SEE SECTION "D-D", SHEET R-17.
4. SURFACE SHALL BE METALIZED AS SPECIFIED IN THE ABOVE SECTION, 15 TO 20 MILS THICKNESS.

B. PAINT BEARING ASSEMBLIES

1. SEE TABLE V, SHEET R-15, FOR A LISTING OF BEARING ASSEMBLIES TO BE PAINTED.
2. ORIGINAL PAINT SYSTEM FOR BEARINGS CONSISTED OF TWO COATS OF ZINC-CHROMATE FOLLOWED BY A THIRD COAT OF CODE B-8 AND LASTLY, A FINISH COAT OF ALUMINUM CODE B-A.
3. THE BEARINGS SHALL BE CLEANED AND PAINTED IN STRICT ACCORDANCE WITH SECTION 561 OF THE FDOT STANDARD SPECIFICATIONS 1986 EDITION, 3 COAT SYSTEM. COLOR SHALL BE FEDERAL STANDARD NO. 595A, #36622, LIGHT GRAY.
4. PAYMENT FOR THIS WORK SHALL BE INCLUDED UNDER PAY ITEM NUMBER 560-1.

CATHODIC PROTECTION - NOTES (SHEET 2 OF 2)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

BRIDGE (REHAB)

REVISIONS	ROAD NO.	COUNTY	PROJECT NO.
		PINELLAS & HILLSBOROUGH	

	Name	Date
Designed by	RP	4/91
Checked by	TV	4/91
	—	—
Checked by	—	—
Supervised by	CDO	

Approved by: C. [signature]