

Florida's Approach to Bridge Preservation

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Abstract

Corrosion of reinforcing steel in concrete bridges is a problem of major concern for entities responsible for the maintenance and safe operation of such structures. In the state of Florida in the United States, millions of dollars are spent yearly in the rehabilitation of structures due to corrosion deterioration. In this regard, the Florida Department of Transportation has adopted effective design and materials standards to delay corrosion development and has developed effective corrosion mitigation systems for older bridges where corrosion has already initiated. On older structures where corrosion has been identified as the source of deterioration, cathodic protection is used to stop the damaging corrosion effect as it is recognized that standard repairs provide only a short term solution.

This paper describes the newest materials and the design criteria used for corrosion prevention as well as various cathodic protection systems used on different structures in Florida.

Introduction

Reinforcing steel in concrete is considered the major cause of deterioration on reinforced concrete bridges in the United States. It has been reported that billions of dollars may be required to correct the corrosion damage to bridges and associated liabilities ⁽¹⁾ that accompany this deterioration in the United States alone. On bridges, this corrosion deterioration is typically concentrated either in the substructure or the superstructure although depending on the climate and geographical location, corrosion may be present on both.

In the state of Florida, corrosion is typically concentrated on the substructure of the bridges due to their proximity to corrosive marine environments. Experience as well as research has made it very clear that standard rehabilitation methods such as patching or application of pneumatic concrete are not adequate remedial actions as these are only

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performed as quick repairs and do not provide the long term rehabilitation needed. Furthermore, often the corrosion activity develops at higher rates due to the changed characteristics of the repaired areas. Other standard repairs such as pile jacketing or encapsulation, aggravate the condition of the structure by hiding ongoing corrosion deterioration from visual detection, thus new damage is likely to be undetected or underestimated⁽²⁾. This is of major concern due to the possible severe structural consequences (Figure 1).



Figure 1: Spalling and rebar cross-sectional loss on a bridge piling due to corrosion.

Typically, in chloride contaminated concretes, the passive steel surrounding a corroding area develops potentials that, although considered corrosion potentials (more negative than -0.350v – ASTM C876), are cathodic to the potential of the corroding area. As a result, active corrosion does not take place around the spall. In fact, the rebar at the corroding spot prevents or slows down the initiation of corrosion in the surrounding concrete. When the concrete is repaired, the new deteriorating effect of localized patching or jacketing as previously mentioned, makes the steel passive and its potential becomes less negative. The new passive potential in the repaired area now becomes cathodic to the formerly passive surrounding zones and active corrosion promptly develops in the surrounding zones leading to a “ring” or “halo” damage effect around the patch. Results of a federally (US-FHWA) funded project conducted on one of these highly contaminated bridges and on which several repair materials were evaluated, concluded that new corrosion damage was produced on repairs using all types of repair materials in less than 4.5 years⁽³⁾. The new deterioration occurred not in the repaired area, but on the original concrete adjacent to the repair.

After over twenty years of evaluation of the corrosion behavior on marine structures and vast experimentation with new materials for corrosion prevention and corrosion control, the Florida Department of Transportation (FDOT) has developed design criteria that provides an estimated corrosion free service life on these structures of over 75 years. These estimates are based primarily on chloride diffusion coefficients of the concrete and the depth of concrete cover over the reinforcement. For older structures where corrosion has already developed, the Department considers that cathodic protection is the only means to properly rehabilitate these structures and significantly increase their service life. Cathodic protection has been installed on over sixty bridge structures statewide with very successful results. The experience acquired has improved the process of matching systems to site conditions, allowed for the consideration of short and long term economic factors, and advanced the monitoring techniques of these cathodic protection systems. This paper describes the approach and criteria developed for new construction as well as some of the most implemented cathodic protection systems for marine structures.

Discussion

Corrosion Prevention

Corrosion prevention criteria have been implemented as part of the general structures design guidelines for the state. These criteria are mostly directed toward the long term durability of the structures and have been established as an independent design parameter that needs to be incorporated into the general structural design norms. All structures owned by the Florida Department of Transportation are designed following these guidelines.

Table 1: Corrosion Classification of Soils and Water for Substructures

| | |
|----|--|
| A. | Slightly Aggressive: when all of the following conditions exist: |
| 1) | pH greater than 6.6 |
| 2) | Resistivity greater than 3,000 ohm-cm |
| 3) | Sulfates less than 150 ppm |
| 4) | Chlorides less than 500 ppm |

| | |
|----|--|
| B. | Moderately Aggressive: This classification must be used at all sites not meeting requirements for either Slightly Aggressive or Extremely Aggressive Environments. |
|----|--|

| | |
|----|--|
| C. | Extremely Aggressive: when any of the following conditions exists. |
| 1) | For concrete structures: pH less than 5.0 |
| 2) | For steel structures: pH less than 6.0 |
| 3) | Resistivity less than 500 ohm-cm |
| 4) | Sulfates greater than 1,500 ppm |
| 5) | Chlorides greater than 2,000 ppm |

The first task under the criteria is the identification of the potential for development of corrosion activity at the site where the structure is going to be built. The task consists of measuring the chloride and sulfate content, the pH, and the electrical resistivity of the water and/or soil at the site. Three corrosion classifications have been established based on these measurements: a) Slightly Aggressive b) Moderately Aggressive c) Extremely Aggressive. Requirements for a site to meet any of the classifications are based on all of the above mentioned measurements (see Table 1). Specific test procedures for the measurement of each of the above mentioned parameters have also been established.

Based on the final classification of the site, established guidelines are incorporated into the final design. This process ensures that appropriate corrosion prevention methods are used in the design.

Different parameters are given for the corrosion classification of substructures and superstructures based on the conditions that are particularly applicable to each. The parameters for the superstructure include, in addition to the above, the distance from the site to other high corrosive atmospheric environments such as pulp and fertilizer plants, or other similar industries (Table 2). Also, if the new structure is replacing an existing one, evaluation

Table 2: Corrosion Classification for Superstructures

| | |
|----|---|
| A. | Slightly Aggressive; Any superstructure situated in an environment that is not classified either Moderate or Extremely Aggressive |
| B. | Moderately Aggressive; Any superstructure located within 0.76 km (2,500 ft) of any coal burning industrial facility, pulpwood plant, fertilizer plant or any other similar industry where, in the opinion of the District Materials Engineer, a potential environmental corrosion condition exists, or any other specific conditions and/or locations described. |
| C. | Extremely Aggressive; Any superstructure situated in an area such that a combination of environmental factors indicate that significant corrosion potential exists, or with specific conditions and/or locations described. |

of the chloride contamination of the old structure is allowed to determine the final classification for the new superstructure.

For structures at sites classified as extremely aggressive, the cast-in-place concrete requirements include (in addition to standard good construction practices); a) a minimum rebar cover ranging from 76 to 114 mm (3 to 4.5 in), depending on type of component, b) the use of high performance concretes containing flyash, calcium nitrite and/or microsilica ,

Table 3: Structural Concrete Class for Specific Uses (Structures Design Guidelines) *

| CONCRETE LOCATION AND USAGE | ENVIRONMENTAL CLASSIFICATION | | |
|--|------------------------------|-----------------------------|-----------------------------|
| | Slightly Aggressive | Moderately Aggressive | Extremely Aggressive |
| <i>Superstructure</i> | <i>Concrete Class</i> | <i>Concrete Class</i> | <i>Concrete Class</i> |
| Cast-in-Place (Other Than Bridge Decks) | Class II | Class IV | Class IV |
| Cast-in-Place Bridge Decks (Including Diaphragms) | Class II (Bridge Deck) | Class IV | Class IV |
| Approach Slabs | Class II (Bridge Deck) | Class II (Bridge Deck) | Class II (Bridge Deck) |
| Precast or Prestressed Components | Class III, IV, V, or VI | Class IV, V, or VI | Class IV, V, or VI |
| <i>Substructure</i> | | | |
| Cast-in-Place (Other Than Bridge Seals) | Class II | Class IV | Class IV or V |
| Retaining Walls | Class II or III | Class IV | Class IV |
| Cast-in-Place Seals | Class III (Seal) | Class III (Seal) | Class III (Seal) |
| Precast or Prestressed (Other Than Piling) | Class III, IV, V, or VI | Class IV, V, or VI | Class IV, V, or VI |
| Cast-In-Place Columns Located Directly in the Splash Zone | Class II | Class IV | Class V |
| Piling | Class V Special | Class V Special | Class V Special |
| Drilled Shafts | Class IV (Drilled Shaft) | Class IV (Drilled Shaft) | Class IV (Drilled Shaft) |

* See Table 4 for description of the various concrete mixes.

c) a minimum elevation of the superstructure of 3.6 m (12 ft) from the water level. For structures located in slightly or moderately aggressive classifications, the requirements for the cast-in-place concretes include: a) a minimum rebar cover ranging from 76 to 102 mm (3 to 4 in), depending on type of component, b) the requirement for high performance concrete is retained, but the use of the corrosion inhibitor is relaxed.

For precast bridge pilings under all environment classifications, a high performance concrete containing microsilica with a minimum concrete cover of 76 mm (3 in) is required.

Several high performance concretes have been developed for different uses (Table 3). The properties of these concretes have been enhanced to provide higher structural capacities as well as extended durability. Because the major cause of corrosion in Florida is the exposure to the marine environment, the enhanced durability mostly consists of a higher resistance to chloride penetration. The compressive strength of these concretes range from 38 MPa (5,500 psi) to 59 MPa (8,500 psi). The water cement ratio is kept in the range of 0.37 to 0.41 for aggressive corrosion environments and 0.41 to 0.49 for slightly and moderately aggressive sites (Table 4).

Table 4: Characteristics of Several Concrete Classes

| | Class of Concrete | Compressive Strength MPa (psi) | Water-Cement Ratio | Min. Total Cement kg/m ³ (lb/ yd ³) | Target Slump mm (in) | Max. Chloride kg/m ³ (lb/ yd ³) |
|----------------------------|--------------------|-----------------------------------|--------------------|--|-------------------------|---|
| Standard Concretes | II (Standard) | 23 (3,400) | 0.49 | 335 (564) | 75 (3) | 0.20 (0.34) |
| | II (Bridge Deck) | 31 (4,500) | 0.44 | 365 (611) | 75 (3) | 0.20 (0.34) |
| | III (Standard) | 35 (5,000) | 0.44 | 365 (611) | 75 (3) | 0.20 (0.34) |
| | III (Seal) | 21 (3,000) | 0.52 | 365 (611) | 200 (8) | 0.20 (0.34) |
| | IV (Drilled Shaft) | 28 (4,000) | 0.41 | 390 (658) | 200 (8) | 0.20 (0.34) |
| High Performance Concretes | IV (Standard) | 38 (5,500) | 0.41 | 390 (658) | 75 (3) | 0.20 (0.34) |
| | V (Special) | 41 (6,000) | 0.37 | 445 (752) | 75 (3) | 0.20 (0.34) |
| | V (Standard) | 45 (6,500) | 0.37 | 445 (752) | 75 (3) | 0.20 (0.34) |
| | VI | 59 (8,500) | 0.37 | 445 (752) | 75 (3) | 0.20 (0.34) |

These design criteria have been in place for over fifteen years with yearly updates as materials and technology improve. Several of the older structures built under these guidelines have been evaluated and found still in a corrosion free stage.

Corrosion Control

For structures built under previous or no specific durability design guidelines, the preservation approach relies on providing adequate corrosion control such that the structure will not become structurally deficient due to corrosion damage. For most older structures,

when rehabilitation is sought, extensive corrosion damage already exists although a few (based on available budget) are provided with corrosion control as preventive maintenance. Typically, a structural analysis of the damage is performed and the corrosion control measures are implemented incorporating the necessary structural repairs such as rebar replacement and concrete restoration.

Cathodic protection is the only effective, long term corrosion control method recognized by the Florida Department of Transportation at this time. The technique of cathodic protection is based on electrically polarizing the most anodic areas present on a metallic corrosion cell (rebar) to a potential that is cathodic in relation to an anode specifically placed on or about the structure. Typically, this anode is placed externally to the structure but in some cases, anodes embedded in the concrete are also used (for CP of reinforced concrete structures). Standard NACE (National Association of Corrosion Engineers) norms based on the measurements of the potential of the rebars are used to determine the effectiveness of the cathodic protection being applied without visually inspecting the rebar for corrosion ⁽⁴⁾. These standards are used by FDOT to monitor and evaluate the performance and ensure adequate protection.

The Florida Department of Transportation has a rather vast history in the development and evaluation of cathodic protection anodes and anode systems for reinforced concrete. Several of these systems have become a standard corrosion control measure for reinforced concrete structures and are discussed below. The cathodic protection systems to be discussed include galvanic (sacrificial) anode as well as impressed current systems. The galvanic systems use a metal higher in energy than the steel to provide the cathodic protection current while the impressed current types use an external power source to produce the current.

The impressed current systems consist of: 1) titanium mesh anode cast into structural concrete, 2) titanium mesh anode embedded in gunite, and, 3) titanium mesh anode cast into pile jackets. The galvanic anode systems include: 1) zinc mesh anode cast into pile jackets and, 2) sprayed zinc anodes.

The system components will be briefly described in the following subsections. Most of the systems have already been previously reported ⁽⁵⁾ and are commercially available.

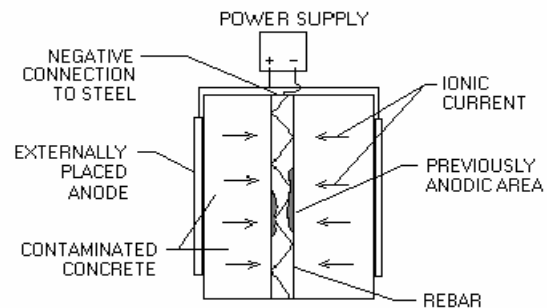


Figure 2: Protection mechanism of impressed current cathodic protection on reinforcing steel.

Titanium Mesh Anode Embedded in Gunite

The titanium anode is an expanded catalyzed titanium wire mesh with an external coating of mixed metal oxides. These anodes are capable of current outputs of up to 37.8 mA/m² (3.44 mA/ft²) of protected concrete without adversely affecting the manufacturer's specified service life of 75 years. The anode mesh is typically installed on the structure by attaching the mesh directly to the existing concrete surface at the areas to be protected using plastic fasteners (Figure 3). The mesh is provided in 1.2 m (4 ft) wide rolls which can be spliced to larger widths by resistance welding two mesh panels to a strip of flat titanium bar. A strip of the flexible titanium bar also extends outside the protected area for connection to the wires originating at the rectifier. Following installation on the existing concrete, the anode is embedded in gunite at a depth of 5.1 cm (2 in).

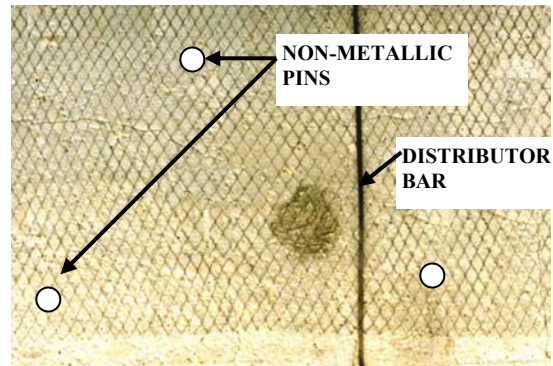


Figure 3: Titanium mesh anode installed over existing concrete surface. Mesh is then encapsulated in gunite or concrete.

The first system of this type evaluated by FDOT was installed in 1988 on a bridge pier at the Howard Frankland Bridge in Tampa, Florida. The pier is comprised of three square footer type pile caps, three rectangular columns, and two struts (Figure 4). The bottom portion of the footers come in direct contact with the tidal waters during the periods of high tide while columns and struts are frequently wetted by the splash activity. Although the system was designed as a single circuit system, reference electrodes were provided for each pier component (footers, columns, and struts) such that potentials could be monitored individually for each zone. This system was designed by the anode manufacturer who additionally provided quality control during construction.

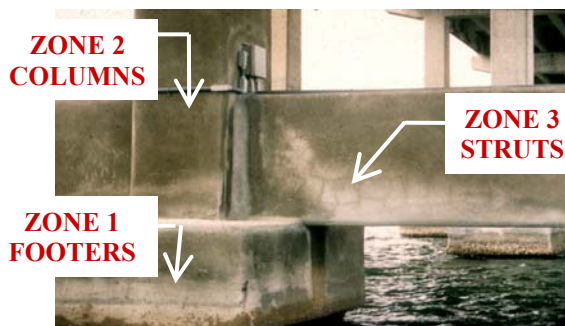


Figure 4: Titanium mesh encapsulated in gunite. Connection wires are routed outside the Gunite and directed in conduit to a rectifier.

After installation, the system was energized using the E Log I criterion (NACE Criterion) which determined the amount of current needed for cathodic protection. Voltage potential data gathered during the entire evaluation period indicated satisfactory cathodic protection levels even though after the first six months, the gunite placed at the elevation in direct contact with the water, partially delaminated from the original concrete surface. The delamination was attributed to the physical properties of the gunite material which could not provide a

good bond to the existing concrete surface in moisture saturated conditions. It was determined

however, that even though partial delamination of the gunite occurred, protection current was being discharged through the salt water and the reinforcement potentials maintained cathodic protection values. The delamination problem was corrected for later installations by identifying a more suitable gunite material. After 14 years of service, the system is still in operation and no further corrosion has been detected.

Routine testing of this cathodic protection system includes depolarization tests which typically produce average polarization decays ranging from 132 to 214 mV. At this time, this type of system is recommended for bridge components (typically mass concrete components) not in direct contact with tidal waters. Similar systems were installed on the substructures of the Banana River Bridge in 1996 and the Sebastian Inlet Bridge in 2002, both located on the East coast of Florida.

Titanium Mesh Anode Cast Into Structural Concrete

The anode used for this system is the catalyzed expanded titanium mesh anode identical to that described in the previous section. This system is typically used on bridge mass concrete components which require structural rehabilitation due to degradation related to inadequate reinforcement, settlement, and/or corrosion of the original rebar. This system combines structural rehabilitation with corrosion control. Installation of the system requires the removal of all existing delaminated concrete and cleaning of the remaining concrete surface and exposed reinforcing steel. If present, remaining cracks in sound concrete are filled with mortar grout and the catalyzed titanium mesh anode is installed over the concrete surface similar to the gunite encapsulation system. Reinforcing steel encasement is then placed around the component being rehabilitated as dictated by the required structural repair (Figure 5). Forms for the new structural jacket are placed and the concrete is cast around the deteriorated component encapsulating the anode and the new steel. Electrical isolation between the existing and the new reinforcing steel is maintained such that the two steel systems may be energized at different current levels since the older steel will exhibit a higher level of corrosion activity due to its' surrounding concrete.



Figure 5: Titanium mesh anode installed over original concrete to be encapsulated in structural concrete.

The first of these systems was installed at Verle Allen Pope Bridge in Crescent Beach, Florida. The system was installed on eight pier footers which had experienced structural deterioration as a result of inadequate reinforcement volume. The resulting cracks allowed the intrusion of salt water into the concrete which consequently produced severe reinforcement corrosion and subsequent concrete spalling. The system design provided one constant-current/constant-voltage rectifier per pier (two footers). Connection wires to the steel were

provided such that new and existing steel could be energized separately. Only the existing steel was energized initially, while the corrosion level on the new steel was periodically monitored for connection to the system when needed.

When installation was completed, the system was energized by FDOT personnel using the E Log I criterion and performance was closely monitored. Reflective cracking in the newly placed concrete developed soon after the repairs were completed allowing salt water intrusion to the new reinforcement. After three years the footer was replaced due to structural concerns, the cathodic protection system maintained the reinforcing steel in a corrosion free condition even at the locations where the cracks intersected the rebar. This was verified by visual inspection of the reinforcement when the footer was demolished for replacement and the rebars extracted.

Following the success on this bridge, this system was incorporated to repairs on other bridges of similar configuration. On these bridges, the system was combined with structural repairs requiring structural jackets with post-tensioning. In all cases, the system has proven very effective in controlling corrosion.

Impressed Current CP Pile Jacket System

This system is specifically designed for corrosion control on bridge piles. Similar to the previously discussed systems, it is of the impressed current type and requires an external power supply to provide the cathodic protection current. The anode utilized by this system is the expanded titanium mesh anode which, in this case, is mechanically suspended on the inside face of a standard fiberglass stay-in-place form (Figure 6). The anode is positioned such that it will be located equidistant from the pile and the jacket form.



Figure 6: Titanium mesh pile jacket installed at splash zone elevation. The anode is pre-installed in the fiberglass form then placed around the pile and filled with mortar/concrete.

The concept was developed by the Florida Department of Transportation and the first system was installed on forty-four piles at the Ribault River Bridge in Jacksonville, Florida. On this project the jackets were 1.2 m (4 ft) tall and were vertically centered at high tide elevation. The system included four rectifiers installed at different locations along the length of the bridge with the ability to provide individual current output adjustment to each pile bent. Installation of the jackets consisted of removing all delaminated concrete and cleaning the remaining concrete surface and exposed steel of all marine growth or debris. Because the jackets were later filled with mortar, no concrete restoration was required. The anode jackets were installed and filled as specified, and a

conduit-wiring system was installed to provide the steel and anode connections from every pile to the rectifiers.

The system was energized using the E Log I criterion on four bents, and the -850 mV criterion on the remaining portions⁽⁶⁾. Effective cathodic protection was achieved as demonstrated by periodic potential depolarization tests, which indicate an average minimum polarization of 150 mV on each bent. This system was later installed on other bridges and likewise exhibited excellent performance. This system has become one of the FDOT standard bridge pile rehabilitation methods and today it has been used to provide corrosion control on over 500 piles statewide.

Sacrificial Cathodic Protection Pile Jacket

Similar to the impressed current pile jacket described above, this sacrificial anode cathodic protection system was developed jointly by the Florida Department of Transportation and a manufacturer of zinc products¹ to provide corrosion protection to bridge pilings where concrete restoration due to corrosion deterioration is required. The system protects the submerged portion of the piling, the splash area, and the area immediately above. The system consists of a standard pile jacket provided with an internally placed expanded zinc mesh anode, an additional bulk zinc anode installed at an elevation of 0.6 m (2 ft) below low tide, and a connection to the reinforcement (Figure 7). The bulk anode is used to minimize current demand on the zinc mesh anode by the reinforcement in submerged portion of the pile. If necessary, sprayed zinc can be applied to the areas above the jacket to control any corrosion activity at this elevation. The jacket is a two piece, stay-in place fiberglass form provided with the expanded zinc mesh anode pre-installed on the inside face of the form.

Being of the sacrificial type, this system does not require an external power source and the anode is connected directly to the reinforcement to establish the cathodic protection circuit.

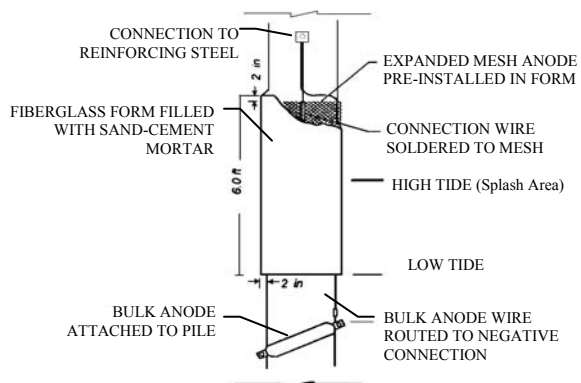


Figure 7: Schematic of sacrificial cathodic protection pile jacket with submerged bulk anode.

Installation consists of removing all delaminated concrete from the pile and clean-up of the remaining concrete as well as the exposed steel. The jacket is then placed around the pile from low water elevation upward providing a 5.1 cm (2 in) annular space between the pile surface and the fiberglass form. The bulk anode is installed below water level at the

¹ Alltrista Zinc Products, Greenville, Tennessee, USA
U.S. Patent No. 5,714,045 – Feb. 1998

specified elevation and the connection cable is routed upward inside the jacket to the anode steel connection location. The jacket is then mortar filled and the zinc mesh and bulk zinc anodes are connected to the reinforcing steel. The filling material is a portland cement-sand grout with a minimum cement content of 558 kg/m³ (940 lb/yd³) of grout although, concrete is sometimes used for structural applications.

Initial field evaluation was conducted by providing two standard reinforcement, pre-cast concrete piles at the Broward River Bridge in Jacksonville, Florida with the system. The piles were provided with instrumentation to measure system current and the voltage potential of the reinforcing steel. The NACE 100 mV polarization and polarization decay criterion was used to evaluate the cathodic protection performance. A polarization decay test conducted on each pile after 400 days of operation. At that time, the measured potential indicated an average polarization of 140 mV.

The cost of this system compares favorably with the cost of standard (No-CP) pile jackets when considering the added benefits of the corrosion control anode. When compared to impressed current systems, this system has the advantage of requiring only minimal monitoring and maintenance since external power supplies are not required. It is also expected that the minimum effective service life of the system will be 45 years based on the consumption rate of the anodes. This system is commercially available for various pile sizes.

At this time this system is also considered another standard rehabilitation method for bridge pilings in direct contact with salt water and has been installed on several bridges protecting over 900 piles.

Arc-Sprayed Zinc Anode System

This system is of the sacrificial anode group and it also uses zinc as the anode to provide the cathodic protection current. The potential of the zinc anode is around -1.1 volts while the potential of corroding steel is typically around -0.450 volts (Cu/CuSO₄). The installation consists of removing all the deteriorated concrete from the structure and sandblasting clean the surrounding concrete surface and exposed steel. The zinc is



Figure 8: Arc-sprayed zinc applied to the concrete surface to produce the cathodic protection current.

applied over the concrete surface as well as the exposed reinforcement. Spraying over the reinforcement provides the electrical connection between the zinc and the steel. In this manner, the zinc directly protects the exposed steel while the steel within the concrete receives cathodic protection current through the concrete itself (Figures 8-9).

The application process for the zinc anode is made similar to that of spray painting. A hand held gun creates an electric arc between two direct current charged zinc wires fed through the gun. The zinc melts at this point and is sprayed onto the concrete surface by an air nozzle provided at the gun. The zinc coating is applied to a thickness ranging from 0.4 to 0.5 mm (15 to 20 mils). The typical zinc to concrete bond strength is around 1,034 kPa (150 psi). This system has the ability of functioning as a sacrificial or impressed current system (no direct contact to the steel if used as impressed current), although the FDOT has only used it in sacrificial mode.

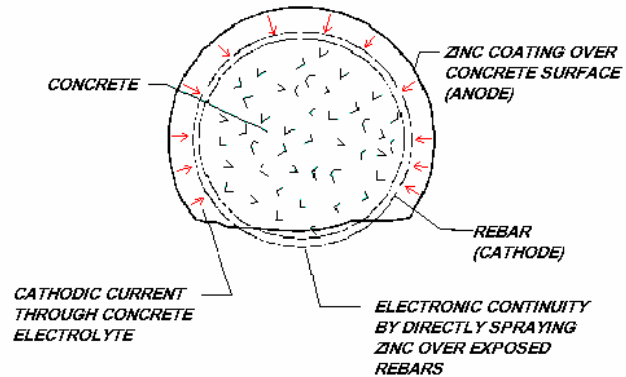


Figure 9: Current transfer mechanism of the arc-sprayed zinc system.

Initial evaluation of this system was conducted on five circular columns at the Niles Channel Bridge in the Florida Keys in 1989. The columns were 0.9 m (3 ft) in diameter and were built using epoxy-coated rebar. All of the columns exhibited advanced stages of corrosion development with significant spalling. Three of the columns were metalized and further visually evaluated and sound tested periodically to observe any corrosion progression. The other two columns were instrumented prior to metalizing such that current flow and polarization could be measured. Polarization measurements in excess of 100 mV were observed at all elevations within the metalized area on both instrumented columns. After five years, only one of the exposed bars in one of the columns exhibited some degree of corrosion progression.

The estimated service life of the anode is between five to eight years in severe environments, at which time re-metalizing is required. This system is recommended for applications not in direct contact with the water since this accelerates the consumption rate of the anode, and significantly decreases the anode service life. Additional evaluation has been performed on structures containing standard (uncoated) rebar. At this time FDOT has used this system ten bridges comprising over 32,500 m² (350,000 ft²) of metalized concrete. In typical applications, the sprayed zinc anode has prevented further corrosion deterioration for more than five years on 95% of the protected components provided with this approach. In a few instances, premature consumption of the zinc was observed resulting from frequent direct exposure to salt water. Direct exposure to the water generates accelerated atmospheric corrosion of the zinc which combined with the cathodic protection consumption, rapidly depletes the zinc.

Conclusions

- a. It is clear that for new construction in extremely corrosive environments, a proactive approach to prevent corrosion development provides a long term economic advantage. However, to obtain this advantage, it is necessary to correctly identify the environment prior to the design phase such that the proactive investment on higher quality materials and design practices are adequately used.
- b. After more than 15 years of implementing corrosion prevention measures on new bridge structures in aggressive corrosion environments, the Florida Department of Transportation recognizes the effectiveness of these measures based on actual experience. It is recognized that the use of denser concretes significantly reduces the amount of chloride penetration, therefore delaying the onset of corrosion.
- c. The Department also recognizes that the use of standard repairs in chloride contaminated concretes are only temporary remedies as new deterioration soon develops on the old concrete adjacent to new repair.
- d. Because of the previous, only cathodic protection is recognized as an effective means of producing long term rehabilitation of chloride contaminated concrete structures in marine environments. Successful results have been achieved with sacrificial as well as with impressed current cathodic protection systems. Some of these systems have been in place for over 16 years and no significant corrosion has reappeared on the protected components.

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