Case Study:

Utilization of Cathodic Protection to Extend the Service Life of Reinforced Concrete Bridges – An Overview of the Installation and Maintenance of the Cathodic Protection Systems Protecting the Howard Frankland and Crescent Beach Bridges

FHWA-HIF-22-004

Source: GPI

Crescent Beach Bridge with Control Tower

FEDERAL HIGHWAY ADMINISTRATION
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16. Abstract

Many steel reinforced concrete bridges must endure exposure to corrosive materials such as deicing salts and salt water. Unmitigated, these materials accelerate corrosion and significantly reduce the service life of bridges. While corrosion-resistant materials can be chosen during the design phase, addressing corrosion in existing structures can be more of a challenge. Some transportation departments have successfully implemented cathodic protection (CP) systems to alleviate corrosion issues with existing bridges. This case study provides an in-depth analysis of the construction, maintenance, and associated costs of the CP systems used to protect the substructures of the Howard Frankland Bridge (Tampa, FL), which is exposed to the Gulf of Mexico, and the Crescent Beach Bridge (Crescent Beach, FL), which is exposed to the Atlantic Ocean. Both bridges exhibited significant substructure corrosion in the 1980s and were fitted with CP systems. Today, more than thirty years later, both bridges remain in full-load service.

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Introduction

Corrosion is a natural process in which a metal alloy is oxidized (loses electrons) and converted into another form that is more electrochemically stable, such as steel to iron-oxide. The Association for Materials Performance and Preservation (AMPP), formerly known as the National Association of Corrosion Engineers (NACE), estimates the cost of corrosion in bridges of the United States at $13.6 billion annually and indirect costs (traffic delays, lost productivity, etc.) may be substantially higher. Examples of spalled concrete and corroded reinforcing elements are presented in Figure 1.

Source: FDOT

Source: FDOT

Figure 1. Photos. Howard Franklin prestressed hollow core bridge piles, circa 1988 (left). Fitted with additional reinforcement (right).

The Florida Department of Transportation (FDOT) reported successfully using cathodic protection systems to prevent corrosion in over 200 bridges. This case study focuses on two bridges, the Howard Frankland Bridge carrying Interstate 75 over Tampa Bay, and the Crescent Beach Bridge, carrying State Route 206 over the Intracoastal Waterway in Crescent Beach. The Howard Frankland Bridge was opened to traffic in 1960. It is a major artery in the Tampa-St. Petersburg metropolitan area and carries 8 lanes of traffic. It is a prestressed concrete stringer/multi-beam structure that is over three miles long and has an average daily traffic count of 180,000 vehicles per day. The Crescent Beach Bridge is a double-leaf bascule structure carrying two lanes over a navigable waterway, is approximately 0.5 mile long, and has an average daily traffic count of 12,000 vehicles per day. It was opened to traffic in 1975.

By the mid-1980s, in less than 30 years, both structures were experiencing significant corrosion-related concrete degradation, and it was thought that both would have to be replaced. Alternatively, FDOT decided to retrofit both bridges with cathodic protection systems to stop the corrosion of substructure components, and they remain in full service today.

Technology and Science

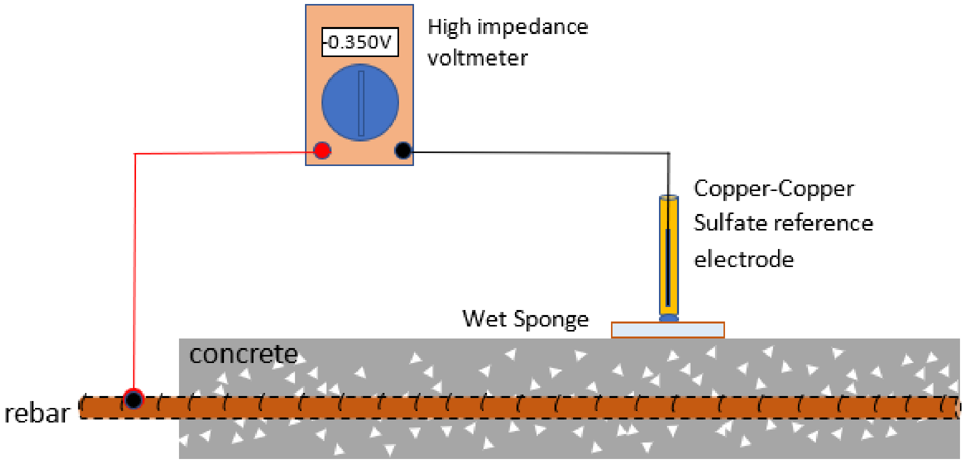
Potentials and Their Meaning

Everything that can be observed has a native potential which can be measured electrically in units of volts. A potential is the difference in voltage between two objects. To quantify potentials for corrosion measurements, a constant voltage reference electrode is used. The standard hydrogen reference electrode (SHE) has been established as a baseline and has been assigned a value of zero volts. Other reference electrodes (with varying potentials) are available and have different advantages in specific situations. However, all are designed to alter the electronic attributes of the circuit as little as possible. By far the most common used in the transportation industry are the silver-silver chloride (SSC) and the copper-copper sulfate (CSE) reference electrodes. The AMPP provides criteria based on potentials measured with reference electrodes that are used to determine whether a cathodically protected structure is satisfactorily protected from corrosion.(1,2) In addition, ASTM C876, *Standard Test Method for Corrosion Potentials of Reinforcing Steel in Concrete,* provides corrosion probabilities based on the potential measurement obtained with a copper-copper sulfate electrode at that location(3). These probabilities are shown in Table 1:

Table 1. Potential and Corrosion Probability.(1)

Potential (mV)	Probability of Corrosion
More Positive than -200	Less than 10%
-200 to -350	Uncertain
More negative than -350	Greater than 90%

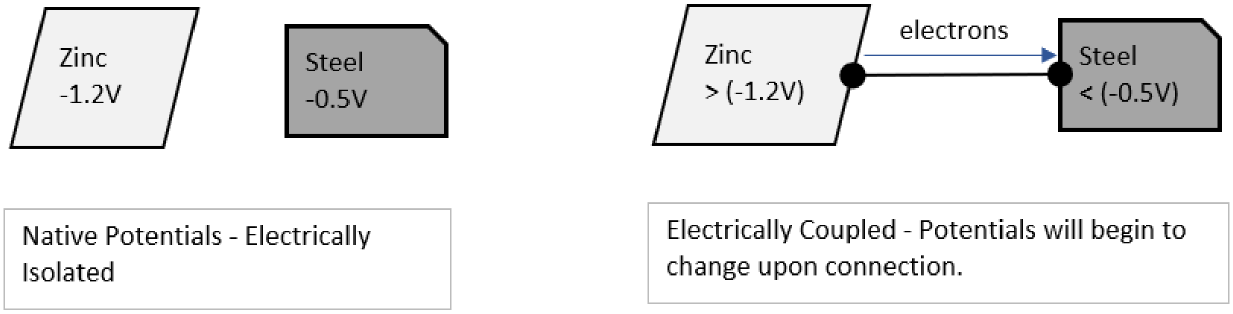
Figure 2 provides an example of a potential measurement from ASTM C876(3):



Source: GPI

Figure 2. Schematic. Example of Potential Measurement.

Cathodic protection of steel reinforcement in concrete structures is accomplished by providing an external flow of electrons to the steel. The flow of electrons is driven by a voltage difference, either between the reinforcement and an anode connected to the output voltage of a DC power supply, or the difference in voltages between the steel and the installed galvanic anode/s. The Galvanic Series for Seawater, as described in the ASM Handbook Volume 13, *Corrosion, 9th edition of Metals Handbook*(4), illustrates the voltaic relationship between zinc (a common galvanic anode) and steel. This reference provides the potential of zinc in seawater measured with respect to CSE to be approximately -1200 mV. Similarly, the corrosion potential of steel in seawater with respect to a CSE is approximately -500 mV. These potentials are representative of the propensity of the material to corrode. Since zinc has a more negative potential (greater energy) than steel, the second law of thermodynamics dictates that electrons and energy will flow from the zinc to the steel, and the steel will be protected from corrosion. The rate or flow of energy is commonly quantified in the form of electrical current (amps). The electron flow produced by coupling two metals is represented by the schematic in Figure 3.



Native Potentials - Electrically Isolated

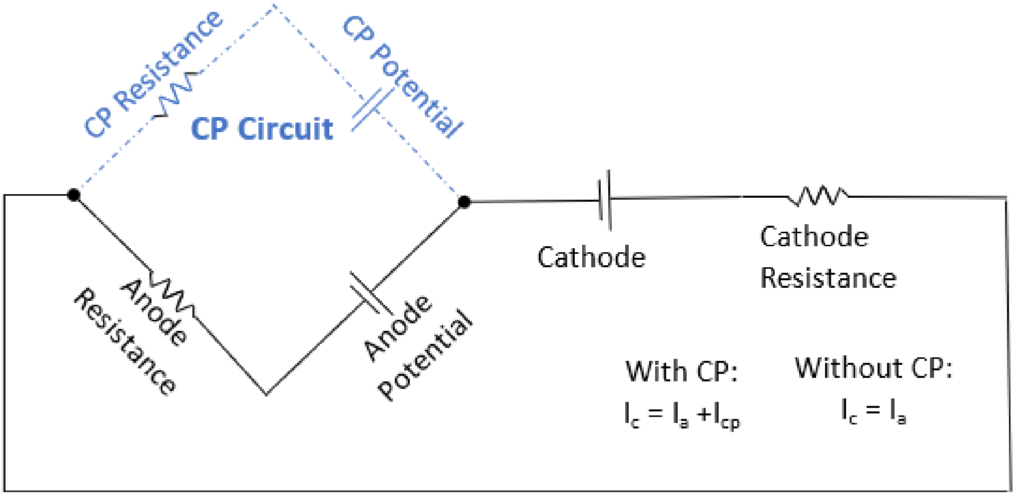
Electrically Coupled - Potentials will begin to change upon connection.

Source: GPI

Figure 3. Schematics. Examples of Galvanic Coupling. Native Potentials (left). Electrically Coupled (right).

Corrosion Cell and CP Circuitry

Identical to a battery, a corrosion cell is composed of a cell cathode, cell anode, electrolyte (ionic path), and metallic path. When implementing cathodic protection, a circuit is installed parallel to the corroding anode within the corrosion cell. The wiring diagram in Figure 4 models this arrangement electrically.



Source: GPI

Figure 4. Schematic. Electrical Model of a Corrosion Cell with Applied Cathodic Protection.

Without cathodic protection, in an unaltered corrosion cell, the current flowing through the anode is the same as the current flowing through the cathode (i.e., $I_a = I_c$). However, when CP is installed into the corrosion cell circuit, as shown above, the cell must reach a new steady state, in which the current to the cell anode (I_a = anode current = corrosion current) is reduced by the amount of the applied cathodic protection current. Cathodic protection current is supplied by either a DC power source, or a galvanic anode. By installing a suitable CP current the corrosion current is reduced, and corrosion is mitigated.

Polarization and CP criterion: Polarization is the change in potential of an object from its native potential caused by application of an external power source. For this purpose, the AMPP has provided Standard Practices SP0290, *Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*(2) and SP0216, *Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*(1). These voluntary, non-Federal standards provide several polarization criteria that when achieved are sufficient to mitigate corrosion. The most common criteria are 100 mV of polarization or depolarization at the most anodic location. It is well established through research and practical experience that corrosion will be negligible when cathodic protection systems utilized to protect concrete structures are operating in compliance with the criteria provided by these Standard Practices.(2) Therefore, it is important that once installed, these systems are also monitored to ensure that actual operating conditions remain in compliance with these criteria.

Design

Anodes

Anodes utilized in cathodic protection systems installed on the Crescent Beach and Howard Frankland Bridges fall into two categories: impressed current and galvanic. Anodes used for impressed current systems are often composed of mixed metal oxide coated titanium and are dimensionally stable over long periods of time. Impressed current anodes used on these bridges typically do not exhibit a significant volume change over time, and therefore have extended to indefinite service lives, as long as the maximum current capacity is not exceeded. In contrast, galvanic anodes used are composed of magnesium, zinc and/or aluminum alloys, and corrode (are consumed) over time and therefore provide a limited service life. When choosing which design option is most appropriate, location specific conditions should be considered. For instance, if many pile jackets are to be installed, it is typically more cost effective to install impressed current cathodic protection (ICCP) jackets rather than galvanic. Another consideration may be whether communications or power is available for impressed current installations. Table 2 below indicates options available to the designer, based on environmental exposure zone:

Table 2. Anode Usage by Environmental Exposure Zone

Environmental Exposure Zone	Galvanic	Impressed
Submerged	Bulk zinc (e.g., 50 lb.)	Titanium w/MMO coating
Tidal	Zinc mesh pile jacket	Titanium w/MMO coating
Above mean high tide	Metallizing or embedded anodes	Titanium w/MMO coating

Pile Jackets

The diagrams and photos provided in Figure 6 through Figure 12 provide a comparison of galvanic and impressed current cathodic protection pile jackets as well as typical construction photos.

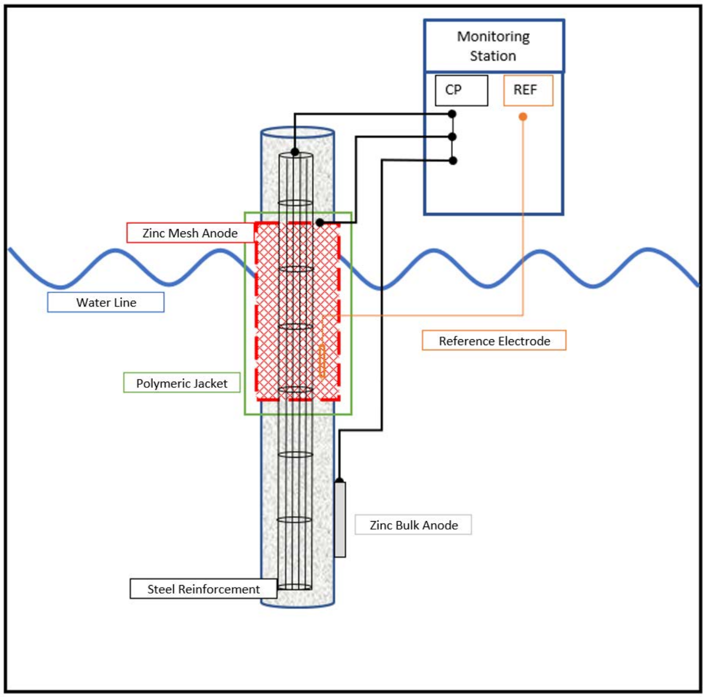


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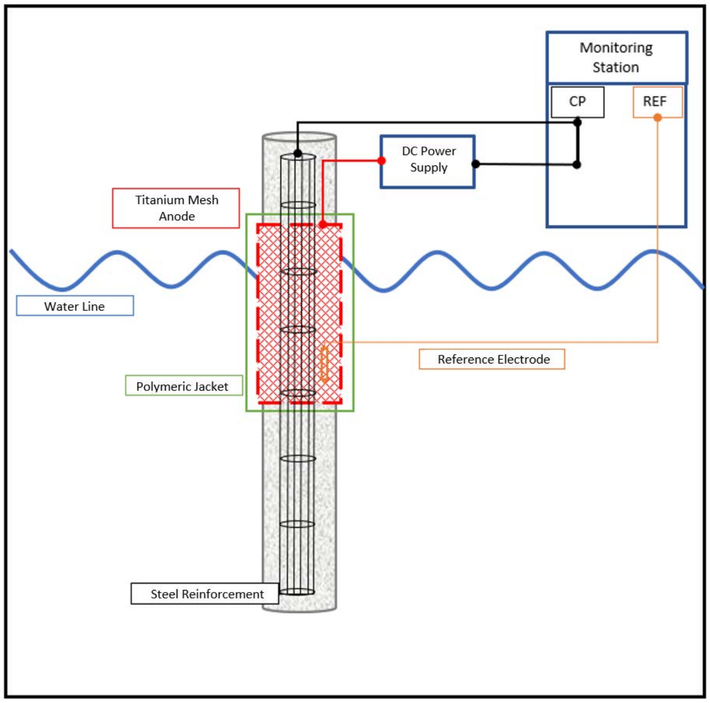
Figure 5. Schematic. Galvanic Pile Jackets.

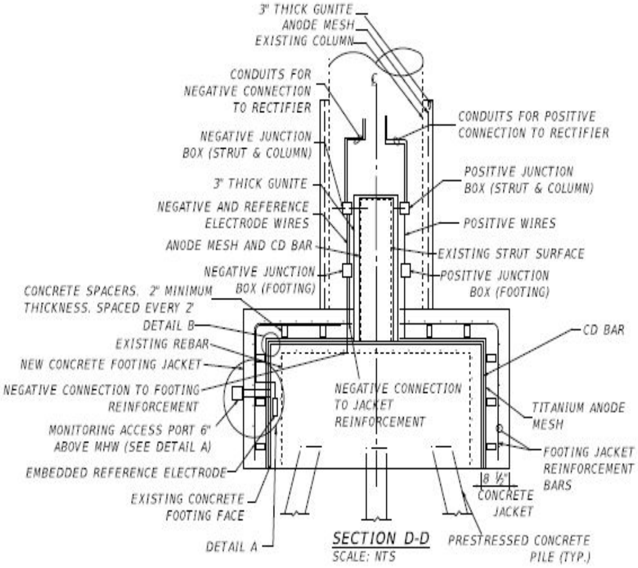


Source: GPI

Figure 6. Schematic. Impressed Current Pile Jacket.

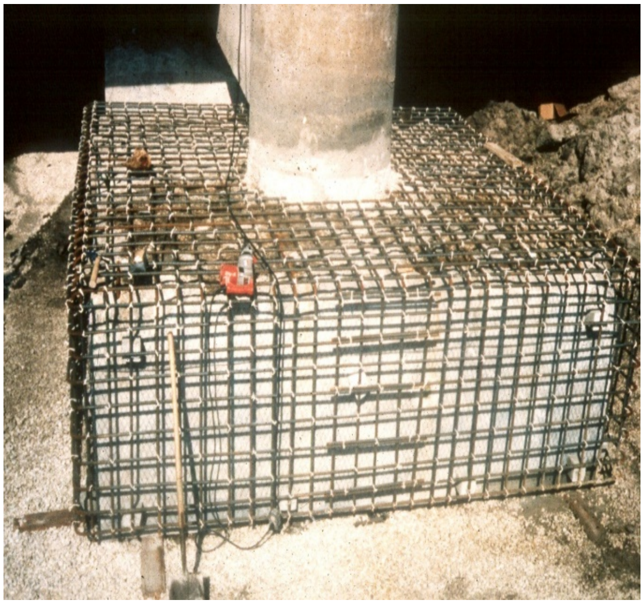
Source: FDOT

Figure 7. Photo. Crescent Beach pier footing prior to rehabilitation, circa 1986.



Source: GPI

Figure 8. Schematic. Crescent Beach pier footing CP design.



Source: FDOT

Figure 9. Photo. Crescent Beach pier footing CP construction.

Source: GPI

Figure 10. Photo. Crescent Beach pile jackets under construction. ICCP bent cap complete and ready for wiring.

Source: GPI

Figure 11. Photo. Crescent Beach ICCP: Finished pier footings.

Source: GPI

Figure 12. Photo. Howard Frankland CP pile jacket ready for connection. ICCP bent cap also ready for wiring.

Construction

Pile Jackets

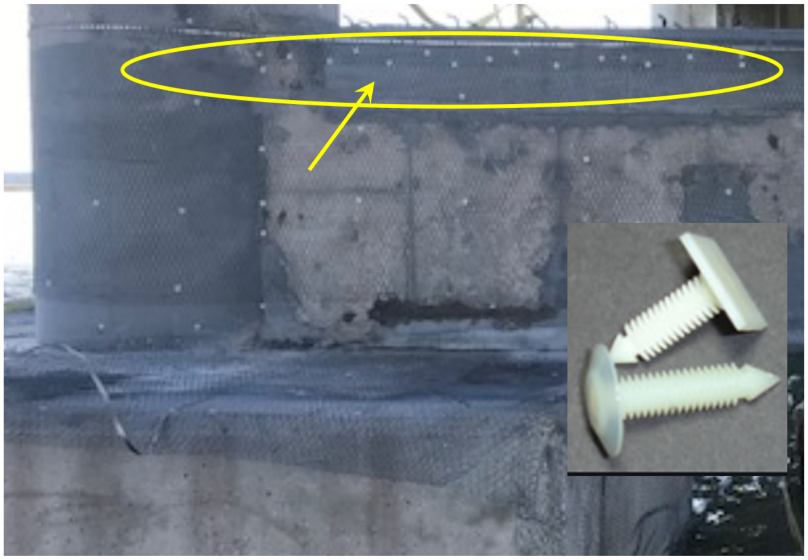
The construction sequence begins with removal of unsound concrete. Compromised concrete is located using sounding, or other suitable techniques, and should be indicated in the plans. Corrosion of the steel reinforcement typically progresses during the period between design and construction, causing an increase in the actual square footage of compromised concrete. Once the unsound concrete is removed, electrical continuity between reinforcing elements is either verified or established. If a structural pile jacket is being constructed, additional reinforcement is added at this time by doweling Glass Fiber Reinforced Polymeric (GFRP) L-Bars (see Figure 14) into the existing concrete and then tying-in any additional reinforcement. Doweling the GFRP L-Bars creates a physical bond that, when added to the chemical bond, strengthens the overall adhesion of the new concrete to the old.

Next, the concrete and exposed reinforcement surfaces are blast cleaned with abrasives to remove all marine growth, corrosion and scaling to provide the proper surface profile needed to promote bonding of the new concrete. Surfaces below the water line are cleaned using power tools. Commercially available pile jackets are then placed and supported with temporary hard backing to maintain the shape of the jacket during grout or concrete placement. New concrete is specified to be placed within 72 hours of surface cleaning completion due to the quick recontamination experienced in marine environments. Jackets have a series of ports, and concrete is pumped into the jacket from the bottom up. Concrete will displace the water in the jacket, and water will flow first from the port followed by concrete. Once a good concrete flow is observed from the port, it is capped and the concrete continues to fill the void between the jacket and existing surface and will rise to the next port. This is repeated until all water is displaced, and concrete flows out of the top of the jacket. Consolidation/vibration is performed only after all concrete is placed and only on the exterior of the hard-backing to ensure that salt water is not mixed with the new concrete being placed.

For galvanic pile jackets, bulk anodes should be placed prior to placement of the jacket so that wiring can be installed beneath the jacket and up to the junction box. Fiberglass pile jackets are commercially available in which the mesh anode (Zn or titanium) is preinstalled. For zinc/galvanic jackets, the mesh is affixed to the inside fiberglass surface. This allows more water flow and oxygen availability which helps prevent anode passivation. Bulk anodes are not needed with impressed current pile jackets and titanium mesh or titanium ribbon may be placed in the annulus between the jacket and the existing concrete. Portland cement grout containing at least 940 lbs. of cement and a minimum 28-day compressive strength of 5,500 psi is used to fill both structural and non-structural jackets. Sometimes instead of neat cement grout, a concrete made with small aggregate (less than 3/8 in. nom. max. aggregate size) is used for structural jackets. Fly ash, slag, or silica fume should not be used in grouts used for jackets due to their effect on the electrical resistance of the grout.

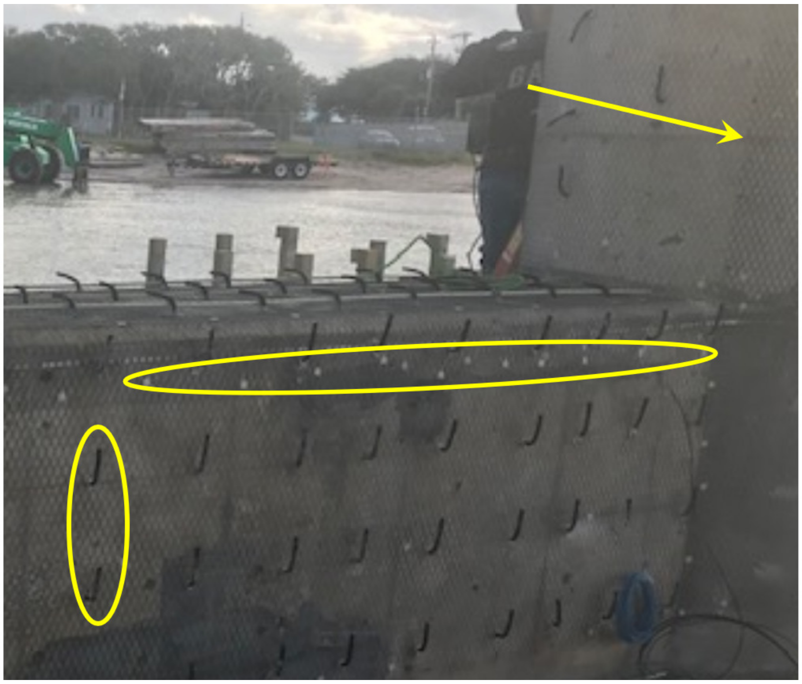
Pier Caps and Pile Bents

The construction process is analogous to the sequence above for pile jackets. However, for drier structural components like pier caps and pile bents, impressed current cathodic protection typically is used. Dry concrete exhibits a much higher electrical resistance than wet concrete, and the current provided by galvanic anodes may be insufficient to polarize reinforcing steel at higher elevations unless this is taken into consideration in the design. All surfaces are cleaned, and ICCP system titanium mesh or titanium ribbon anodes are placed directly against the existing concrete using plastic Christmas tree fasteners (see Figure 13). Examples are presented in Figure 13 to Figure 17. Just like with pile jackets, for structural enhancement, GFRP L-bars are doweled into the existing concrete and tied to the new reinforcement. If site-specific logistics allow, temporary forms can be used, and concrete is pumped into the formwork. If not, shotcrete can be used. Concrete similar to that of structural jackets should meet a minimum compressive strength of 5,500 psi at 28 days, a slump of 7 to 9 inches, and should not contain slag, fly ash, or silica fume. Approved admixtures (for air entrainment or workability) may be incorporated.



Source: GPI

Figure 13. Photo. Crescent Beach unsound concrete has been removed and replaced. Christmas tree fasteners are holding titanium mesh to a strut and column.



Source: GPI

Figure 14. Photo. Crescent Beach strut with concrete replacement, titanium mesh indicated by arrow. Christmas tree fasteners and GFRP dowels installed.

Source: GPI

Figure 15. Photo. Crescent Beach excavation for titanium ribbon installation.

Source: GPI

Figure 16. Photo. Crescent Beach concrete repairs completed, titanium mesh and reinforcement in-place, prior to forming and concrete placement.

Source: GPI

Figure 17. Photo. Crescent Beach two galvanic pile jackets and an impressed current pile bent cap.

The Howard Frankland Bridge

As a result of significant corrosion to the substructure, the first cathodic protection system contract was let in 1987 for approximately $397,000 and included impressed current systems for pier footings. Over the years, a total of 21 contracts have been progressively executed to install or maintain cathodic protection systems with a cumulative value of approximately $15 million. Several contracts were let that involved multiple bridge structures, and the cost to install and maintain cathodic protection systems associated with the Howard Frankland Bridge are known to include work performed on other bridges. For these contracts, total contract value was utilized, and the cathodic protection system construction and maintenance cost estimate is knowingly higher than reality. CP installations and maintenance funds were tabulated by the FDOT as shown in Table 3.

Table 3. Summary of Cathodic Protection System Installation and Maintenance – Howard Frankland

Year	System	Description	Unit Cost	Total Cost
1987	ICCP	Impressed current/Titanium Mesh Gunite Encapsulation CP on Footers with Remote Monitoring.	$25/ft^2	$396,792
1992	Metalizing	Sacrificial/ Zinc sprayed anode on piles above tidal area and on selected pile caps/ Approximately 126,189 ft^2 of concrete protected.	$12/ft^2	$1,514,268
1992	Galvanic	Sacrificial/ Zinc Sheet, Bulk Zinc Anode CP on Pre-Stressed Pilings; Rehabilitation of 62 piles. Approximately 1,984 ft^2 of concrete protected. Cost per ft^2 includes cost of additional bulk anode per pile plus zinc sheet anode.	$42/ft^2	$1,514,268

2001	Galvanic	Sacrificial cathodic protection pile jackets with submerged bulk anodes. 35 piles protected. Some of the new jackets replaced the old zinc sheet anode installed in 1992.	\$2,800/pile	\$98,000
2001	Metalizing	Sacrificial/ Zinc sprayed anode on selected pile caps; Approximately 40,000 ft^2 of concrete. Metalizing applied to new deteriorated caps and 2,000 ft^2 of re-metalizing localized spalls on previously metalized caps.	\$32/ ft^2	\$1,280,000
2004	Metalizing	Sacrificial/ Zinc sprayed anode on selected pile caps/ Approximately 35,000 ft^2 of concrete protected. Metalizing applied to deteriorated caps and 2,000 ft^2 of re-metalizing localized spalls on previous metalized caps.	\$41/ft^2	\$1,435,000
2004	Galvanic	Sacrificial cathodic protection pile jackets with submerged bulk anodes. 30 piles protected. Some of the new jackets replace the old zinc sheet anode installed in 1992. (8 CP Jackets, 122 Structural CP Jackets)	\$6,684/pile	\$200,520
2006	Metalizing	Sacrificial/ Zinc sprayed anode on selected pile caps/ Approximately 105,000 ft^2 of concrete protected. Metalizing applied to deteriorated caps and 50,000 ft^2 of re-metalizing localized spalls on previously (1990) metalized caps.	\$12/ ft^2	\$1,260,000
2009	ICCP	Approximately 11,628 square feet of titanium mesh impressed current system (between the Gandy and Howard Frankland) encapsulated in structural concrete for selected footers. Second zone consisting of Ti mesh encapsulated in Gunite for selected columns and struts. Installation costs include conduit, wiring, AC power source, rectifiers, and remote monitoring.	\$161.50 ft^2	\$1,877,922
2009	Galvanic	Sacrificial cathodic protection pile jackets with submerged bulk anodes.; 96 piles protected (between the Gandy & Howard Frankland) with both structural and non-structural jackets of varying lengths (6 ft. to 10.5 ft.). Some of the new jackets replace the old zinc sheet anode installed in 1992.	Struct Jkt. ≈\$1,540/LF or ≈ \$12,187/pile N-Struct Jkt ≈\$1,055/LF or ≈\$6,825/pile	\$912,576
2009	Metalizing	Sacrificial/ Zinc sprayed anode on selected pile caps/ Approximately 16,000 ft^2 of concrete protected. Metalizing applied to deteriorated caps and 12,717 ft^2 of re-metalizing localized spalls on previous 1990 metalized caps.	\$22.23/ft^2	\$638,379
2011	Galvanic	168 ft non-structural sacrificial jacket, 509 ft Structural sacrificial jacket, 66,642 ft^2 metalizing, 66 bulk anodes. (54 Structural CP Jackets) NOTE - 535 LF Non-CP Structural jackets also installed on this contract.	Struct Jkt. \$1,402/ft. N-Struct Jkt. \$1,286/ft. Metalizing \$15/ft^2 Bulk Anodes \$676	\$1,962,649

2013	Galvanic	CP Jackets, 185 LF structural and non. 293 LF jackets.	$1,651/ft struct, $1,183/LF	$652,054
2013	Metalizing	Sacrificial/Zinc sprayed anode, pile caps, and girders 62,000 ft^2.	$\$20/\text{ft}^2$	1,240,000
2016	Metalizing	Beam and strut repair, Sacrificial/Zinc sprayed anode, 11,221 ft^2.	$22/\text{ft}^2$	$245,852
			Total Value	**$15,123,260**

The Crescent Beach Bridge

Two contracts were let to install and maintain cathodic protection systems on the Crescent Beach Bridge. The first contract was let in 1988 for $45,892 and executed to install ICCP systems on 8 pier caps. From 2017 to 2019, a two-year construction project was completed at a cost of $3.8M, which included 45 galvanic pile jackets, 14 ICCP bent caps, 2 ICCP pier caps, four ICCP struts, and 8 ICCP columns. Maintenance to the existing CP systems, by re-wiring and replacing conduit was also included in this contract. It is estimated that the FDOT has invested $3.9 million to mitigate corrosion of the substructure of the Crescent Beach Bridge. A summary of CP installations and maintenance is presented in Table 4.

Table 4. Summary of Cathodic Protection System Installation and Maintenance – Crescent Beach

Year	System	Description	Unit Cost	Total Cost
1988	ICCP	Impressed current /Titanium Mesh Anode Structural Encapsulation CP with Remote Monitoring/ Rehabilitation of 8 footers with severe structural damage. C.P. Installed in addition to the structural repairs.	$\$15.40/\text{ft}^2$	$45,892
2017	Galvanic	Concrete repairs, spot paint and install CP on 21 piles		$560,582
2018	Galvanic	Cathodic protection Integral Pile Jacket, Non-Structural, 16.1 to 30 in. Cathodic Protection Integral Pile Jacket, Structural, 16.1 to 30 in.		$3,258,818
2018	ICCP	ICCP System, Titanium Mesh		
			Total Value	**$3,865,292**

Conclusion

Cathodic protection is a viable, cost-effective preservation strategy that increases the service life of reinforced concrete structures that are exposed to deicing chemicals, salt water, or other corrosion accelerating environments.(5) Both the Howard Frankland and Crescent Beach structures exhibited significant corrosion in their early life. By investing less than $20 million (2021 Value = Appx. $47 million), FDOT successfully increased the service life of both structures by over 40 years. In contrast, to address capacity, FDOT is replacing the old Howard Frankland Bridge with a new structure at a construction cost of $865 million.(6,7)

Resources

The resources utilized for this case study are provided below.

1. Association for Materials Protection and Performance. *Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*. NACE Standard SP0216-2016-SG. Houston, TX: AMPP, 2016.
2. Association for Materials Protection and Performance. *Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*. NACE Standard SP0290-2019. Houston, TX: AMPP, 2019.
3. American Society for Testing and Materials. *Standard Test Method for Corrosion Potentials of Reinforcing Steel in Concrete*. ASTM C876. West Conshohocken, PA: ASTM International, 2015.
4. ASM International. *Metals Handbook Volume 13: Corrosion*, 9th edition. Materials Park, OH: 1987.
5. NCHRP. *Synthesis 398. Cathodic Protection for Life Extension of Existing Reinforced Concrete Bridge Elements. A Synthesis of Highway Practice.* Washington, DC: Transportation Research Board, 2019.
6. Tampa Bay Times. *Contract to Build New Howard Frankland Bridge is Record $814M*. St. Petersburg, FL: Times Publishing Company, 2018.
7. ABC Action News. *Construction Ramps Up on $865M Howard Frankland Bridge Redesign*. Tampa, FL: Scripps Media, Inc, 2021.

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