

Galvanic Protection for Reinforced Concrete Structures: Case Studies and Performance Assessment

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SUMMARY: A range of systems are available for electrochemical corrosion mitigation including electrochemical treatments, impressed current cathodic protection and galvanic protection. Galvanic systems provide protection using dissimilar metals and operate naturally without the need for an external power source.

Galvanic systems can be used for targeted or global corrosion protection. Distributed anode systems utilized to create galvanic encasements have been used to extend the life of concrete structures in extremely corrosive environments. Monitored installations in Ohio and New York indicate that these systems can achieve a high level of protection with estimated service lives in excess of 20 years.

Keywords: Corrosion, Concrete, Electrochemical, Galvanic, Distributed Anodes, Bridge

1. INTRODUCTION

Due to its economy, constructability, and durability, reinforced concrete is a popular choice for bridge construction. One of the mechanisms that can affect the durability of reinforced concrete structures is corrosion of the reinforcing steel.

The major cause of corrosion in concrete bridges is from ingress of chloride ions from saltwater exposure or deicing chemicals through the concrete cover to the level of the reinforcing steel. When present in sufficient quantity, chloride ions break down the naturally formed passive oxide layer on the reinforcing steel.

Corrosion by-products occupy a greater volume than the original reinforcing steel. As a result, the corrosion process expansive forces that can exceed the tensile strength of concrete. This leads to concrete distress in the form of rust staining, cracking, spalling, or delamination of the concrete cover which may only be detected through sounding. Additionally, loss of reinforcing steel due to corrosion may cause structural problems. Once the corrosion process has initiated, concrete repair will be required to correct the damaged sections. Additional repairs in the future will likely be required unless protection measures are implemented.

When compared to replacing structures, rehabilitation to extend the service life of existing structures offers many potential benefits including;

- Rapid Construction compared to Replacement;
- Less Traffic Disruption and Delays;
- Less Environmental Impact;
 - Reduced Use of Raw Materials;
 - Reduction in Greenhouse Gas and Thermal Emissions;
 - Reduced Landfill of Existing Materials;
 - Environmentally Responsible Approach when all Costs are Considered;



Figure 1: Bridge Columns Damaged by Corrosion of Reinforcing Steel Due to De-icing Chemical Exposure

- Accelerated Environmental Approval Process; and
- Reduced Project Cost.

Therefore, there is a great need for bridge engineers and Departments of Transportation to provide long term and cost effective solutions to rehabilitate existing bridges which are experiencing corrosion related deterioration.

2. ELECTROCHEMICAL CORROSION PROTECTION SYSTEMS

Advancements in concrete repair methods and corrosion mitigation systems have given bridge engineers many options to repair and extend the service life of actively corroding structures. Today, most structures suffering from corrosion can benefit from some level of electrochemical corrosion protection.

Electrochemical corrosion mitigation systems for reinforced concrete structures provide direct current to embedded reinforcing steel to mitigate corrosion and fall into three general categories: Electrochemical Treatments, Impressed Current Cathodic Protection, and Galvanic Protection.

Electrochemical Treatments are processes that are intended to modify the environment around the reinforcing steel such as to provide long term corrosion mitigation. Examples of electrochemical treatments include electrochemical chloride extraction and electrochemical re-alkalization. Electrochemical chloride extraction passivates corrosion by utilizing a high level of direct current for a relatively short duration to transport chloride ions away from the reinforcing while generating substantial increase in alkalinity around the reinforcing steel. Electrochemical re-alkalization utilizes direct current to transport an alkaline solution into the concrete cover to mitigate corrosion caused by carbonation.

Impressed current cathodic protection systems are designed to provide direct current to the structure via permanently installed anodes and an external power supply. These systems typically use inert anodes to distribute the electrical current to the reinforcing steel. Through the external power supply, impressed current systems provide the user with a high level of control over the level of protection but the electrical systems must be monitored and maintained and may need to be periodically replaced.

3. GALVANIC PROTECTION SYSTEMS

Galvanic systems provide direct current through the use of dissimilar metals. Like a battery, the more anodic metal naturally corrodes relative to the more noble metal. In reinforced concrete, galvanic anodes provide sacrificial protection to the rebar and do not require external power. Galvanic systems are used to provide low-maintenance protection that can be economically tailored to protect large and small sections of the structure.

Anodes used in galvanic protection systems can be surface applied or embedded into the concrete structure or a new overlay. For embedded systems, zinc is the most common sacrificial anode used today. When compared to metals such as aluminum and magnesium, zinc exhibits a relatively small corrosion expansion which can be managed through mortar shell formulation or by providing sufficient porosity and reinforcing within the anode unit. Embedded zinc anodes are suitable for use with conventionally reinforced, prestressed and post-tensioned concrete.

When galvanic anodes are embedded into concrete, it is important to prevent a buildup of oxides on the anode surface that will significantly restrict the performance of the anode. To combat this, an embedded anode unit will contain chemical activator that generates a soluble corrosion byproduct. Embedded anodes will either be alkali-activated in the pH 14 to pH 14.5+ range or halide- or sulphate-activated whereby salts such as chloride, bromide or sulphate are used. Because halides and sulphates are corrosive to steel and concrete, they may not be acceptable as they may not meet local codes and standards. If they are used, they should be installed such that the halide or sulphate activator is a minimum of 50 mm (2 in.) away from any reinforcing to minimize the risk of future corrosion. If sulphate activator is used, care should be taken that the sulphate does not come into contact with concrete materials which could be susceptible to damage from sulphate attack.



Figure 2: Alkali-Activated Discrete Galvanic Anode Installed For Localized Protection Around Concrete Patch Repair

3.1 Discrete Galvanic Anodes For Cathodic Prevention

The targeted corrosion mitigation approach begins with repairs completed via industry standards, such as the International Concrete Repair Institute (USA) Technical Guideline No. 310.1R–2008 *Guideline for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion*. In areas where concrete damage exists due to corrosion, this guideline calls for concrete removal to extend beyond the area of active corrosion and for concrete to be removed from the full circumference of all rebar in the repair area. This repair procedure will deal with the areas of most active corrosion.

Unless all chloride contaminated concrete is removed from the structure, chlorides will be present in the concrete adjacent to the repairs. This will create abrupt differences in corrosion potential in localized areas and creates a risk that corrosion activity will be initiated or aggravated in the existing concrete adjacent to the repair, commonly referred to as the “halo effect”. This condition can also be created when modifications are made to existing structures such as expansion joint repairs, slab replacements, and additions to structures such as bridge widening which will create an interface between new and existing concrete.

For almost a decade, embedded galvanic anodes in a discrete or “point” form have been used to provide localized corrosion prevention around concrete repairs. Embedded discrete anodes are installed around the perimeter of the concrete repair as close as practical to the patch edge. The anode spacing is dependent on the amount of steel protected but is generally in the range of 12 to 24 inches which is sufficient to provide cathodic prevention (e.g. prevent the initiation of new corrosion activity adjacent to the repairs). More recently, this type of anode has been produced in various sizes to provide more options for the engineer.

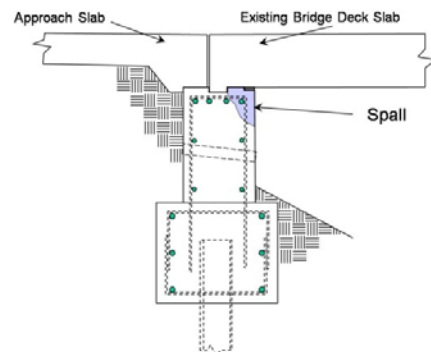


Figure 3: Discrete Anodes Used for Bridge Widening at the Interface Between Old and New Concrete

3.2 Distributed Galvanic Anodes for Corrosion Control or Cathodic Protection

In some cases, the area of chloride contamination and corrosion damage is more advanced and wide spread and a greater level of protection is required over a larger area. In these situations, discrete anodes can be installed into drilled or cored holes on a grid pattern or a distributed galvanic anode system can be utilized.

The distributed anode systems are used to provide galvanic protection over a larger area but can be easily utilized to protect small structural elements such as a single pile, column or wall. This type of system can also be referred to as a *galvanic encasement*. Galvanic encasements utilize galvanic anodes in a ribbon or strip form and are typically provided in weights between 0.15 to 3.0 kg/m (0.1 to 2.0 lb/ft) and lengths from approximately 1 to 2.3 m (3.3 to 7.5 ft). The selection of the anode size and spacing is dependent upon a number of factors including surface area of steel to be protected, exposure conditions, and desired service life.



With a galvanic encasement, the deteriorated concrete is removed and the rebar is cleaned of corrosion byproducts. The galvanic anode strips are distributed across the surface and attached to the existing reinforcing steel. Additional reinforcing is provided by placing rebar or non-corrosive fiberglass reinforcing over the anodes, then the concrete is placed such that the repairs and jacket or overlay are completed in a single step.

Figure 4: Typical Deterioration of Ohio DOT Bridge Abutment

4. DISTRIBUTED ANODE CASE STUDIES

4.1 Ohio Slab Bridges

In Ohio there are over 7,600 slab bridges (either simple span or continuous slab) that are currently in service. The decks on concrete slab bridges are generally in good condition but deterioration can be commonly found at the abutment around the key way where chloride contamination can occur from de-icing chemical leakage. Once the abutments have sufficient amounts of chloride, corrosion can commence leading to concrete cracking, spalling and delaminations.

Three options for repairing slab bridges have been identified by the Ohio Department of Transportation (ODOT):

- Do Nothing - if corrosion damage continues, there is a risk of the bridge being posted for limited vehicle weights. As many of the bridges are on major interstate routes, this would create inconvenience for the traveling public and commercial vehicles. This is not generally a feasible alternative for deficient bridges particularly on the interstate system.
- Replacement – most of the slab bridges have remaining service life and it may not be cost effective to replace the bridge.
- Repair – Historically, previous repairs would include the slab being temporarily supported during the repair and the abutment replaced. This practice requires lane closures or partial-width construction which also requires traffic maintenance during construction.

Concrete patch repair of abutments has been completed on previous structures. The typical rehabilitation cycle for chip and patch repairs in Ohio is between 4 and 7 years. ODOT developed a new repair scheme to address the short lived repairs and on-going structure maintenance. The new approach was to repair and reface the abutments with a galvanic encasement which included galvanic distributed anodes to protect the reinforcing steel that remained in chloride contaminated concrete. By incorporating galvanic protection into the repair design, ODOT expected to extend the life of the repair by at least 15 years.

During the summer of 2005, the new repair design was implemented. The initial project involved approach slab joint replacement and repair/protection of a total of ten bridge abutments on I-75 near Sidney, Ohio. The distributed anodes used were alkali-activated high purity zinc approximately 2.3 m (7.5 ft) in length with 0.9 kg/m (0.6 lb./ft) of zinc.

After the deteriorated concrete was removed and the reinforcing steel cleaned, the anodes were placed end to end in 3 or 4 rows (depending on the abutment height) across the entire width of the abutment and electrically connected to the reinforcing steel.

The new galvanic encasement was formed and self-consolidating ready mix concrete was pumped into ports installed into the face of the forms. The concrete mix was specifically selected to ensure that it exhibited normal resistivity as to not inhibit the current output of the anode system.

As part of the initial contract, ODOT required system monitoring to evaluate the performance of the system. A battery powered data logger was installed to measure current and internal concrete temperature. Periodic site visits were conducted to take additional measurements including polarization of the steel. These abutments have been monitored in excess of three years to date.

Based on data collected from the monitored anodes, it was determined that the system is achieving complete cathodic protection. Further, the estimated service life of the anodes is predicted to exceed 24 years (60% greater than the repair design life)

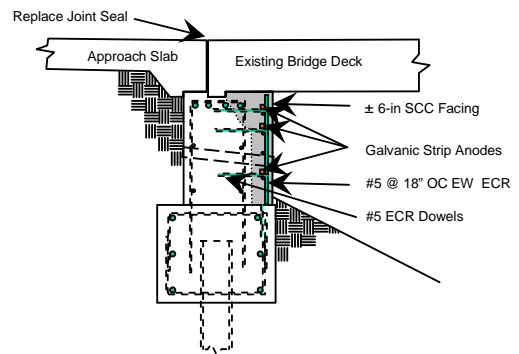


Figure 5: Ohio DOT Bridge Abutment Repair Design Galvanic Encasement using Distributed Anodes



Figure 6: Distributed Galvanic Anodes (Red) Installed Prior to Concrete Placement

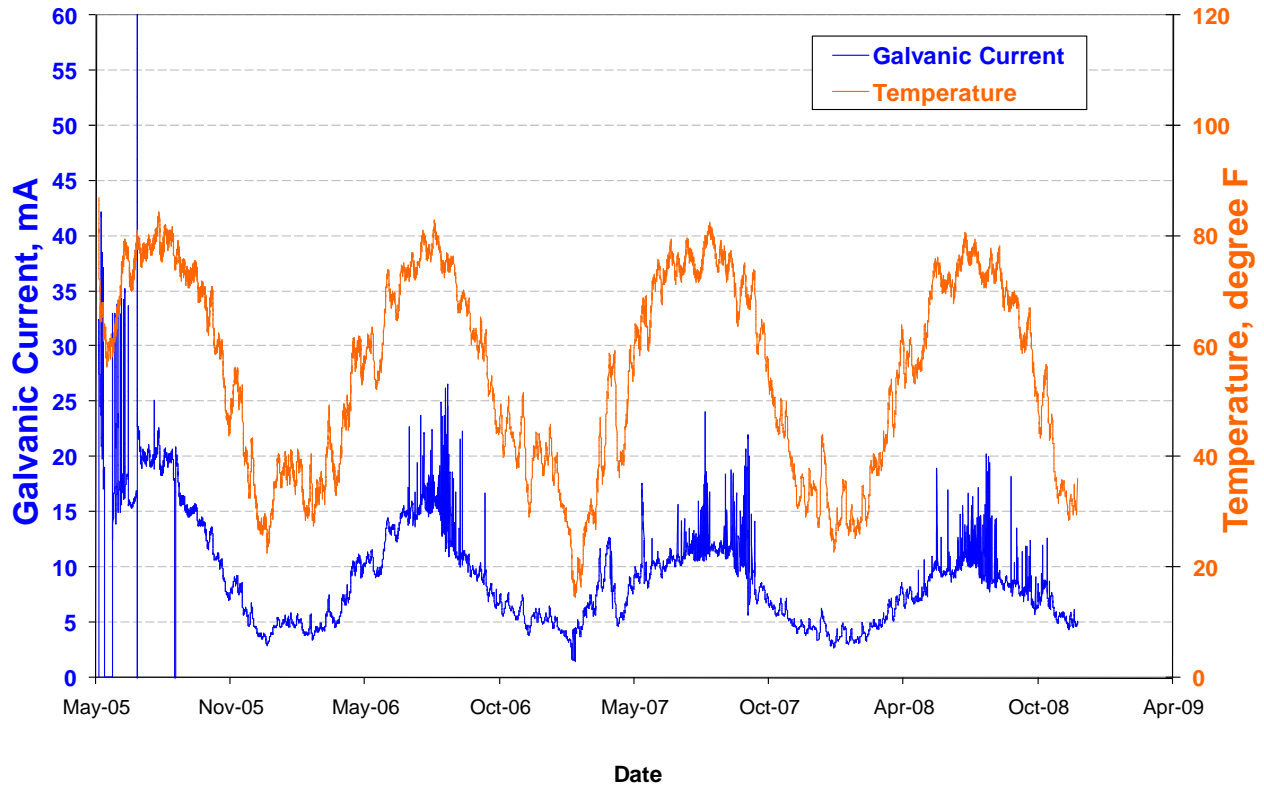


Figure 7: Monitored Distributed Anodes Current vs. Internal Concrete Temperature for Ohio DOT Galvanic Encasement

Date	Temperature C (F)	Current Density mA/m ² (mA/ft ²)	Instant Off (mV)	Polarization (mV)
5/6/05		37.7 (3.5)	-654	
7/20/05		13.9 (1.3)	-1000	346
8/16/05	31 (87)	12.9 (1.2)	-987	333
10/26/05	12 (54)	5.4 (0.5)	-1048	394
12/7/05	11 (51)	3.2 (0.3)	-993	339
5/1/06	14 (57)	7.5 (0.7)	-989	335
12/20/06	4 (40)	4.3 (0.4)	-1154	500
5/30/07	26 (79)	7.5 (0.7)	-1100	446
9/20/07	24 (75)	9.7 (0.9)	-1138	484
12/19/08	4 (40)	3.2 (0.3)	-1124	470
7/9/09	23 (74)	3.2 (0.3)	-1129	475

Notes:

- a) mV Ag/AgCl = potential with respect to copper-copper sulfate reference electrode
- b) Polarization > 100 mV at all times
- c) Instant off Potential < -850 mV

Figure 8: Current and Polarization Data for Ohio DOT Galvanic Encasement

After completion of the project, ODOT determined the galvanic encasement repair, a one-step repair and protection solution, had minimal impact on traffic. On-going system monitoring provided comfort to ODOT that the galvanic encasement exceeded the project objectives. Since the initial abutment project, the galvanic encasement repair continues to be utilized to protect ODOT abutment. Additionally, over 5,500 m² of concrete deck surface has been protected with distributed galvanic anode systems embedded in overlays.



Figure 9: Distributed Anodes Installed on Ohio ODT Bridge Deck



Figure 10: Concrete Overlay Placement over Distributed Galvanic Anodes on Ohio DOT Bridge Deck

4.2 New York State DOT Pile Protection

The Robert Moses Causeway is part of the north-south corridor from Sunken Meadow State Park in Kings Park to Robert Moses State Park at the western tip of Fire Island. The causeway was built over a 10 year period from 1954 to 1964. In 2005, the New York State DOT (NYSDOT) embarked on a major project to rehabilitate the superstructure and repair and protect the 61 cm (24 in) square precast concrete piles exposed to saltwater environment.

The scope of work for the pile protection included the removal of existing steel jackets and the installation of a galvanic pile protection system. NYSDOT specified that alkali-activated distributed anode strips be used in conjunction with stay-in-place fiberglass reinforced polymer (FRP) jackets filled with a standard flowable concrete mix.



Figure 11: Distributed Anodes Placed Around NYSDOT Reinforced Concrete Pile Prior to Encasement

The galvanic jackets consisted of a 1.8 m (6 ft) high FRP jacket, FRP bottom form and 8 alkali-activated distributed anode strips (two per face). Each distributed anode was 1.67 m (5.5 ft) long with 3.0 kg/m (2.0 lb/ft) of zinc. During 2006, the system was installed to protect the tidal zone on 764 precast concrete piles.

The initial design of the pile protection system was to achieve a 35 year service life. Representative samples of the piles were monitored using by a battery powered data logger and periodic site visits by a technician. The system was monitored over a one year period to take in consideration seasonal temperature affects.

Based on this information, the system is providing full cathodic protection. Additionally, the average anode service life is estimated in excess of 50 years, well beyond the initial design criteria.



Figure 12: Completed Pile Repair (Galvanic Encasement with FRP Jacket) for New York State DOT

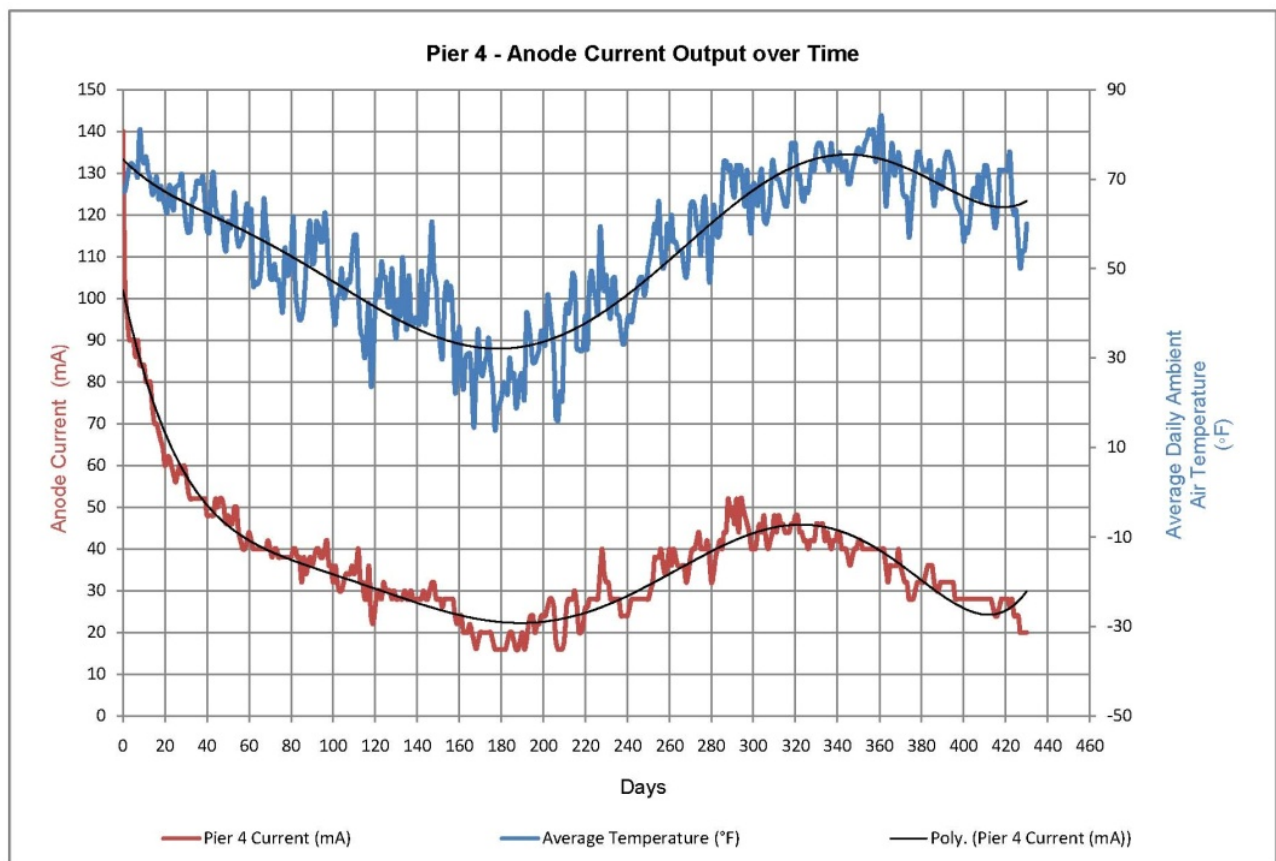


Figure 13: Robert Moses Causeway Anode Current vs. Temperature

Date	On Potential (mV)	Instant Off Potential (mV)	Off Potential (mV)	Polarization (mV)
9/06/06	-1260	-1174	-1046 (3 hrs)	128
4/10/07	-1335	-1167	-869 (20 hrs)	297
10/16/07	-1135	-1012	-820 (4 hrs)	192

Notes:

- a) mV Ag/AgCl = potential with respect to silver-silver chloride reference electrode
- b) Polarization > 100 mV at all times
- c) Instant off Potential < -850 mV

Figure 14: Robert Moses Causeway Testing Results Indicating High Level of Protection for Concrete Piles

5. CONCLUSIONS

Galvanic protection systems for reinforced concrete structures provide engineers and owners with a low maintenance option for corrosion mitigation. This approach can be attractive to owners with structures with corrosion issues that desire more than traditional “patch repair” but do not have the personnel, budget or desire for long term system monitoring and maintenance.

Discrete or “point” anodes have been used to provide localized protection around concrete repairs. For structures where global protection is desired for specific structural elements, embedded distributed galvanic protection systems can be an economical and effective approach.

Case studies on galvanic protection using embedded distributed anodes for the repair and protection of reinforced bridge elements subject to both marine and non-marine exposure conditions were presented. Long term monitoring of distributed anode systems indicates a high level of performance with service lives in excess of 20 years.

5. AUTHOR DETAILS



J. Christopher Ball is Vice President Vector Corrosion Technologies based in Tampa, Florida (USA). Chris has over 15 years of construction industry experience with a specialty in concrete rehabilitation and corrosion protection systems. He previously held the positions of Senior Market Development Manager and Concrete Repair Product Manager for Master Builders, Inc. and Concrete Repair Product Manager for Fosroc Inc. Chris is a member of the International Concrete Repair Institute, American Concrete Institute and the National Association of Corrosion Engineers.



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