18 YEARS LATER AND STILL GOING STRONG

Galvanic Cathodic Protection Extends Service Life of Ohio DOT Bridge Substructures

LONGEVITY CATEGORY

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Abstract

Ohio DOT District 7, located in Sidney Ohio, is responsible for the roads and bridges of the greater Dayton, OH metropolitan area along with Auglaize, Champaign, Clarke, Darke, Logan, Mercer, Miami, Montgomery and Shelby Counties. The District is responsible for maintaining over 4600 lane miles of interstate, federal, and state highways and 1408 bridges. Most of these bridges are small 2 or 3 span "General" bridges that were built in the 1950's through the 1970's. Maintaining this inventory of older bridges is a constant process involving assessing, planning, prioritizing, budgeting and conducting repairs or preventative maintenance.

Prior to 2005, the District's Bridge Maintenance process could be described as a 5 to 7-year repair cycle, where the areas adjacent to prior repairs failed in a somewhat predictable pattern. In 2005, the District Bridge Engineer conducted an experiment to try to get ahead of the constant repair cycle, using an abutment over-build or refacing strategy with galvanic cathodic protection. These repairs are still performing well after 18 years of service.

This demonstration included the installation of a corrosion monitoring station to allow collection of corrosion potential and galvanic current. The data from the I-75 Kirkwood Road project is presented to demonstrate the strategy has effectively extended the service life of the abutment by a factor of at least 3 times and is expected to continue to mitigate corrosion for years to come.

Synopsis

In 2005, Ohio Department of Transportation District 7 conducted an experiment with the objective of finding a method to get ahead of a seemingly constant substructure repair cycle. In this experiment, the normal process of performing substructure patch repairs was replaced with an abutment refacing strategy containing galvanic cathodic protection. Prior to employing this strategy, the District struggled to keep up with the number of bridges needing repairs because the area adjacent to the last repairs would require repair within 5 to 7 years. With 1408 bridges to maintain, they just couldn't complete enough maintenance repair projects each year to keep up with the deterioration rate. When they fell behind, the substructure would deteriorate to a point where the abutment would need to be replaced. However, the decks that had a concrete or asphalt wearing course normally had minimal distress and years of remaining service life.

Many of these older bridges carry Interstate 75 (I-75) through the District. I-75 is a major north-south highway that runs 1,786 miles from the Great Lakes to the Southeast regions of the United States. It begins at the Canadian border at Sault Ste. Marie, Michigan and ends near Miami, Florida. Maintenance of the bridges is key to keeping the flow of heavy commercial and noncommercial traffic on this important route.

It has become common on these slab bridges for the abutments to experience concrete damage and deterioration. Corrosion was the cause of failing abutments due to the deck joint being directly over the abutment. The joint seals would fail, allowing deicing salt, grit and water to enter the joint and contaminate the abutment stem wall. These typical 1950's vintage slab bridges would have a 19 to 22 inches thick slab cast into a key joint in the top of the abutment. As the deck would cool in the winter, thermal contraction would put tension on the key as it pulled the abutment stem walls toward each other. This likely initiated a crack at the base of the key that accelerated salt contamination of the stem wall reinforcing. Once corrosion started, the top of the stem wall would spall.

The options considered to fix the ailing abutments were:

- **Do nothing** – not a feasible alternative for deficient bridges on the interstate system
- **Repair bridge** – with appropriate repair, most of these bridges have remaining service life
- **Replace bridge** – Not cost-effective to remove a good slab and extremely disruptive to traffic

In 2005, The District Bridge Engineer strategized that if the entire abutment was repaired in such a manner that the repairs could last 20 years, it would allow the District to get ahead of the repair cycle, allowing the District more time to program bridge replacement. The intent of this strategy was to provide additional service life to the abutment to match or exceed the remaining service life of the deck. The solution developed was an abutment refacing strategy using self-consolidating concrete with galvanic cathodic protection to prevent reoccurring corrosion activity, allow thermal joint movement, and reestablish the slab bearing surface.

These "experimental" repairs are still performing well after 18 years of service. Satisfied with the performance of the galvanic cathodic protection system, ODOT District 7 continued to use this strategy on numerous abutment repairs and use galvanic cathodic protection on slab bridge deck widening or guard rail replacement projects. With 250 slab bridges in the District's inventory, the common sentiment in 2005 was "We never seem to get ahead of the repairs" now this strategy has been successfully used to extend the service life of dozens of bridges.

Repair Process

The ODOT District 7 Abutment Repair Process:

1. Excavate soil to expose and clean the pile cap
2. Remove all unsound concrete behind reinforcing
3. Abrasive blast the reinforcing to remove rust and residual concrete
4. Drill and install epoxy-coated dowels and form anchors in sound concrete
5. Connect alkali-activated distributed galvanic anodes to existing reinforcement
6. Install monitoring instrumentation when specified
7. Install new layer of epoxy-coated reinforcing and extend weep holes
8. Pressure wash to moisten and remove loose concrete, and deleterious material
9. Install forms and seal seams
10. Pump concrete into forms from bottom up, plug top of form as concrete fills formwork
11. Remove forms after 72 hours
12. Abrasive blast surface
13. Coat abutment with low viscosity penetrating epoxy primer with an aliphatic urethane topcoat

In addition to the abutment stem wall overbuild, deck joint glands were typically removed and replaced. A lane was closed during concrete operations to minimize vibration, and the abutment refacing was conducted in two phases. Traffic was shifted from the side where concrete was cast to minimize vibration, and forms were left in place to promote curing. Use of a curing agent was not allowed prior to coating.

The enclosed application made it difficult to use conventional concrete placement and internal vibration techniques. An innovation for ODOT was the decision to use self-consolidating concrete (SCC) for this project. At the time SCC was gaining recognition as a viable material that many concrete producers were experimenting with and offered. Today SCC is commonly used in large volume form and pump repair applications.

Figure 1 shows the condition of the abutment prior to concrete removal. Figures 2 and 3 illustrate the repair strategy. Figure 6 shows the formwork just prior to casting, and Figure 7 shows the completed repair.

Figure 1 – Abutment condition prior to repair, May 2005

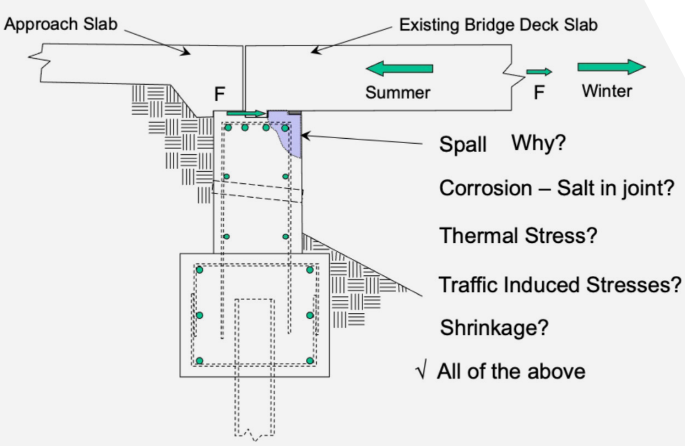

Figure 2 – Original 1950's stem wall detail

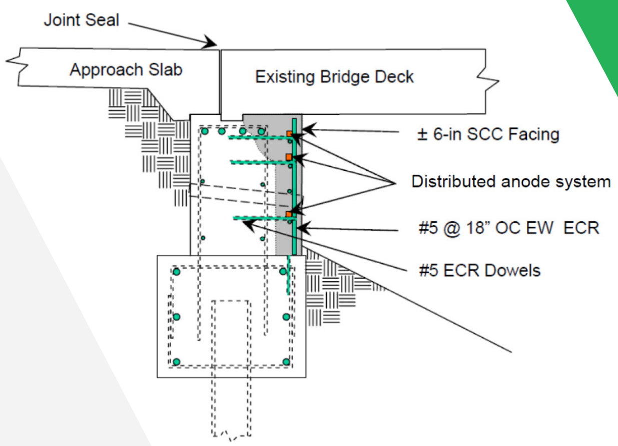

Figure 3 – Galvanic encasement rehabilitation detail

Figure 4 – Spall removal

Figure 5 – Dowels and anodes installed

Figure 6 – Formwork and monitoring station prior to pumping SCC

Figure 7 – Abutment of I-75 Bridge over Kirkwood Road (mm 87), July 2005

Cathodic Protection

One of the keys to longevity was the use of galvanic anodes in the repairs. The rod-shaped distributed anode system, commonly referred to using the acronym D.A.S., is an alkali-activated zinc anode encased in a mortar shell. The anodes were sized to protect the existing reinforcing under the joint for a minimum of 20-years of service life. The alkali-activated galvanic anode technology was commercialized in the late ‘90s. At the time, this larger elongated anode shape was being introduced to provide global (entire element) cathodic protection. Previously, embedded galvanic anodes were being used around the perimeter of patch repairs and drilled-in anodes were used for localized corrosion control in sound concrete.

The galvanic D.A.S. anodes were designed to deliver an initial cathodic current density of 2 mA/ft^2 (~20 mA/m^2) based on the reinforcing steel surface area. This initial current density was selected to polarize the reinforcement upon energizing. (Polarization is the shifting of the reinforcing potential (V) toward the anode potential.) Once polarized, the galvanic current stabilizes to an equilibrium value that depends on the corrosion rate. Normal reinforced concrete contaminated with chloride from deicing salt or marine environments tend to stabilize around 1 mA/ft^2, (~10 mA/m^2). Once the galvanic anodes stabilize, the amount of current produced is a function of moisture and temperature. This self-regulating process makes galvanic systems essentially maintenance free.

ACE) cathodic protection (CP) criteria

AMPP (NACE) cathodic protection (CP) criteria for atmospheric exposed concrete can be summarized as:

1. **Passivity** – If the potential of the structure with the CP current interrupted is more positive than -200 mV versus a copper sulphate reference electrode at 25 C (77 F) no corrosion is taking place, so no cathodic protection is needed.
2. **Polarization Development or Decay** – If the reinforcing potential shifts 100 mV or more in the electronegative direction after the initial exposure to cathodic protection current, or if an electropositive potential shift in 24 hours after interrupting the cathodic protection current is 100 mV or more, then full cathodic protection is achieved.
3. **Polarized Potential** – If the potential of the structure is more electronegative than -850 mV versus a saturated copper sulfate electrode within 1 second after the circuit is interrupted, full cathodic protection is achieved.

Performance

Over the last 18 years the bridges included in the ODOT refacing experiment have performed remarkably well. The joint seals have failed and were replaced, but the abutments are still in good shape. There are signs of water seepage as evidenced by the calcified deposits in Figure 8. This strategy has now eliminated two full 7-year repair cycles and it appears that the repaired abutment has many more years of service.

Table 1 shows the manual data collected indicating the galvanic cathodic protection system is meeting AMPP/NACE performance criteria. Figure 9 shows the cathodic protection data collected over the years indicating the galvanic anodes are providing full cathodic protection. The data from Figure 9 was collected using battery powered data loggers. Over time these failed due to nearby lighting strikes, or depleted batteries. The data clearly shows the galvanic output of the anodes is influenced by temperature and that the galvanic current generally decreases over time. This decrease is related to three phenomena: 1) galvanic anode consumption reducing the anode surface area, 2) deposition of zinc corrosion products around the anode inside the mortar shell, and 3) development of a passive oxide on the reinforcing due to the cathodic current. The deposition of zinc corrosion products in the encasement mortar and a growing steel passive oxide layer gradually increases the galvanic circuit resistance, which throttles back the galvanic current.

Figure 8 – Abutment of I-75 Bridge over Kirkwood Road (mm 87) in 2022
(Note efflorescence from leaking joint and weep holes)

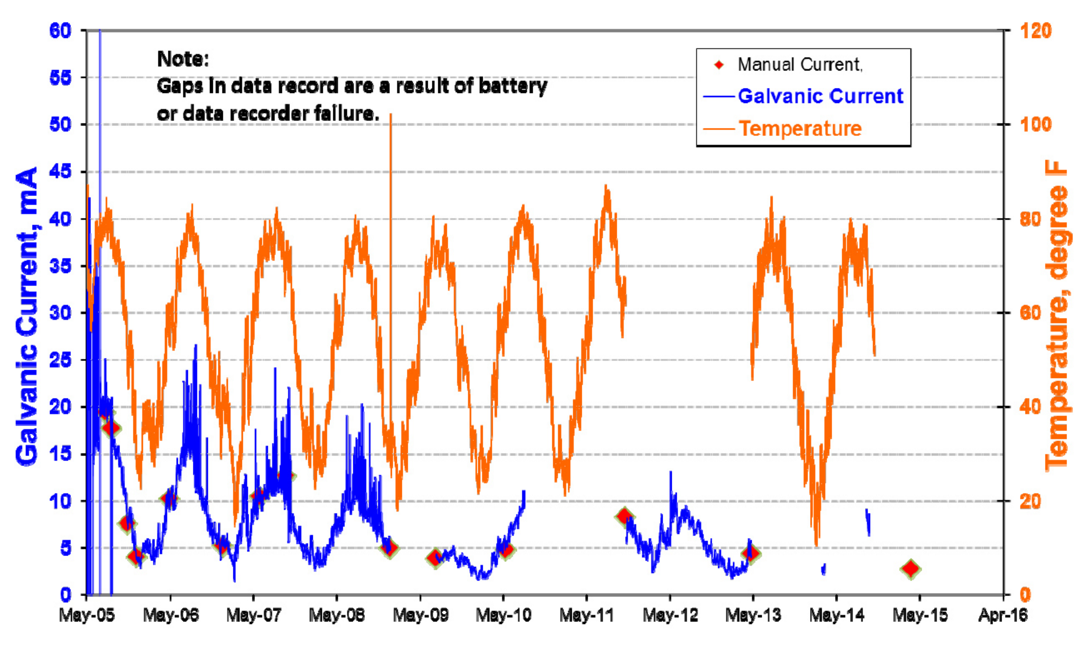

Figure 9 – Initial cathodic protection performance data

Date	Temperature, degree C	On Potential E_{ON}, mV	Instant Off E_{IOFF}, mV	Current Density Icp, mA/m^2	Polarization, Epol, mV
5/6/2005	(*Native*)		*-654*	37.7	
7/20/2005		-1061	-990	14.0	346
8/16/2005	30.6	-1136	-998	12.7	344
10/26/2005	12.2	-1082	-1023	5.4	369
12/7/2005	10.6	-982	-964	2.9	310
5/1/2006	13.9	-1051	-967	7.3	313
12/20/2006	4.6	-1176	-1113	3.7	459
5/30/2007	26.3	-1212	-1104	7.5	450
9/20/2007	23.9	-1238	-1136	9.1	482
12/19/2008	4.4	-1174	-1105	3.5	451
7/9/2009	23.3	-1146	-1125	2.8	471
5/11/2010	12.2	-1160	-1139	3.4	485
10/16/2011	22.2	-1193	-1142	5.9	488
4/22/2013	21.1	-1113	-1079	3.1	425
3/24/2015	1.7	-1060	-1035	2.0	381
9/17/2018	25.6	-1044	-1007	5.3	353
9/9/2020	26.7	-1036	-1005	3.6	351
8/23/2022	26.7	-1008	-986	2.0	332

Table 1 – Galvanic Manual Cathodic Protection Performance Data for Bridge SHE-75-0152

Project Evaluation

- **The project had minimal impact on interstate traffic.**
- **The selected system provided a one-step repair with galvanic protection**
- **Cost Comparison**
  - Rehabilitation with anodes -$319,000
  - Abutment Replacement / Temporary Shoring -$427,000
  - Replacement of structures -$4,500,000
- **Success continues to be tracked through monitoring.**