# Performance of Distributed Galvanic Anode Systems on Bridges in the United States

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## ABSTRACT

Over time, concrete bridge structures exposed to de-icing chemicals and marine environments will see initiation of reinforcing steel corrosion. Visible signs of active corrosion such as cracking, rust staining, spalling, and delamination of concrete cover can occur in as little as 5 to 10 years after activation of corrosion. Left unchecked, chloride-induced corrosion of reinforced concrete structures will lead to an increased need for maintenance and repair and eventual structural issues. Many severely corroded structures have been replaced at great expense and with significant disruption to the public. However, with the proper repair strategy they can be properly rehabilitated, strengthened if necessary, and the service life can be economically extended for in a more sustainable manner than replacement.

Distributed galvanic anodes applied to existing corroding abutments, columns and beams are an effective, low maintenance galvanic cathodic protection rehabilitation option. Performance data collected from several monitored field applications indicate that distributed galvanic anode systems have the ability to deliver effective cathodic protection for 20+ years, providing an efficient, sustainable, and effective service life extension for these structures.

Key words: concrete, galvanic anodes, distributed anodes

## INTRODUCTION

Embedded galvanic anodes designed to protect reinforcing steel in chloride-contaminated concrete adjacent to concrete "patch" repairs were developed in the late 1990's.[1] The original concrete anode was puck-shaped and consisted of high purity zinc encased in a mortar formulated with high porosity and lithium hydroxide to maintain a pH greater than 14 to keep the zinc active over the life of the anode. This approach of a high pH mortar around the zinc to prevent anode passivation is commonly referred to as alkali-activation.

This generation of anode has been referred to as a discrete or point anode where individual anode units are spaced out in a linear fashion along the interface of new and existing concrete or in a grid formation if a broader area of protection is required. 20+ years of performance data from these anodes has been collected, providing a thorough understanding of the capabilities of these anodes and how they age over time.[2]

The primary advantage of galvanic anodes is their simplicity. Once the anodes are installed and connected to the steel, they operate naturally based on the difference in potential between the anode and the reinforcing steel. No other electrical components that need to be monitored or maintained such as rectifiers. However, if an owner or engineer would like to collect performance information, additional wiring and equipment can be installed to monitor galvanic anodes. Monitoring options can range from a simple system consisting of a junction box with a shunt to measure generated current to more complex systems capable of collecting current and polarization data remotely. The primary disadvantages of galvanic anodes are their fixed driving potential and anode consumption over time.

Shortly after the introduction of the discrete anode for repair, a cylindrical-shaped galvanic anode based on the same alkali-activated technology was introduced. This new configuration allowed galvanic anodes to be placed into drilled or cored holes in sound concrete. One of the earliest documented applications for the cylindrical-shaped anodes in the United States was their installation into residential building balconies along the Florida coastline.[3]

Today, these two types of embedded galvanic anode systems are described in the literature as Type 1 (discrete anodes for concrete repair) and Type 2 (discrete anodes for sound concrete). Type 1 anodes are used to extend the life of standard concrete repairs by protecting reinforcement that remains in chloride-contaminated concrete around the concrete repairs where future corrosion can occur. Type 2 anodes are installed in a grid orientation for general corrosion protection or used to target active corrosion sites as identified by a half-cell corrosion potential survey (ASTM C876). The methods of keeping the anode from passivating are generally described as alkali-activated (A) and halide-activated (H).[4]

## DISTRIBUTED GALVANIC ANODES

Another form of alkali-activated anode was introduced in 2003, distributed galvanic anodes. Distributed galvanic anodes utilize the same basic technology as discrete anodes but are different in shape and application. They can include a zinc core with paste or a porous mortar containing sufficient lithium hydroxide to prevent passivation for the expected service life of the anode. Like the Type 1A and Type 2A alkali-activated discrete anodes, the lithium hydroxide activator is corrosive to zinc but not to reinforcing steel thus meeting the requirement of concrete repair codes that prohibit repair materials from containing added constituents that are corrosive to reinforcing steel."[5]

These anodes are custom manufactured in lengths from 3 ft. to 7.5 ft with varying zinc mass and zinc surface areas. Zinc mass can be customized as required for the application. Historically, the zinc mass is generally in the range of 0.25 to 2.0 pounds of zinc per linear foot of anode. Distributed anodes may also utilize an outer layer of zinc foil and plastic mesh. Distributed galvanic anodes have been also referred to as ribbon anodes, strip anodes, rod anodes, linear anodes, distributed sacrificial anodes, and distributed anode system (DAS).

Distributed anodes can be used in a linear orientation where they are placed end-to-end in expansion joint repairs, joint closures (Figure 1), deck widening projects, and concrete repairs. Using distributed anodes in these types of applications provide more consistent current distribution along the new/old concrete interface compared to Type 1 discrete anodes. Additionally, distributed anodes offer greater surface area and zinc mass which results in improved performance. Especially with heavily reinforced structures, distributed anodes are likely to be significantly more economical than discrete anodes.

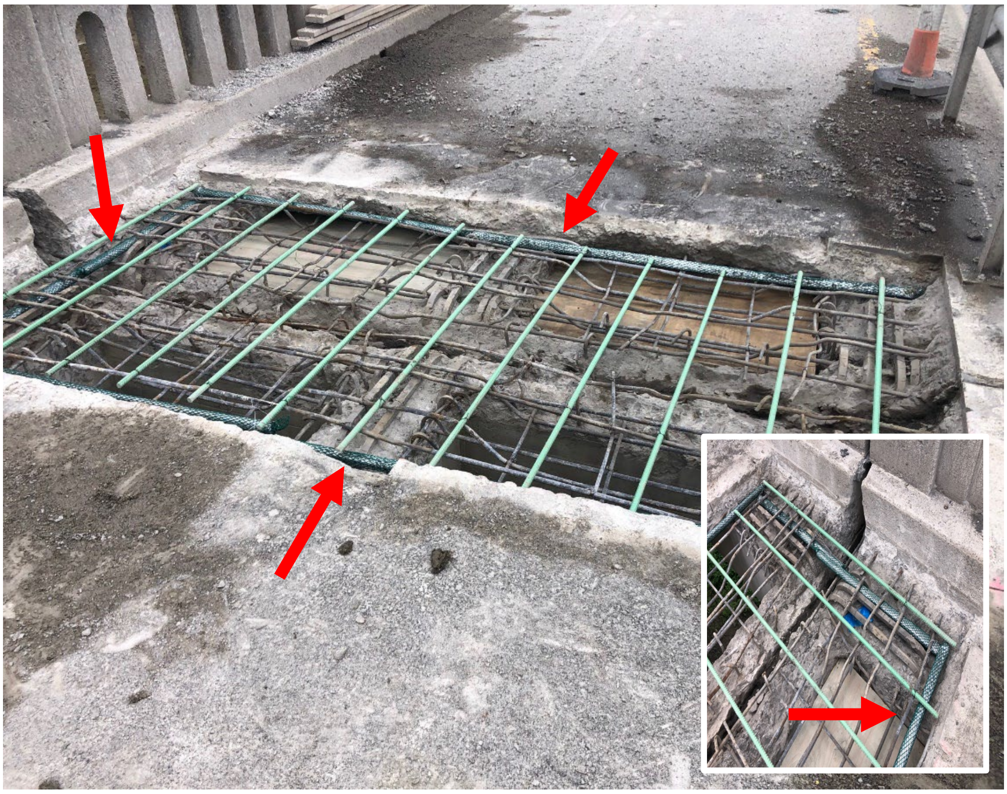

Figure 1:  Distributed Anodes in Joint Elimination, McLean County. KY

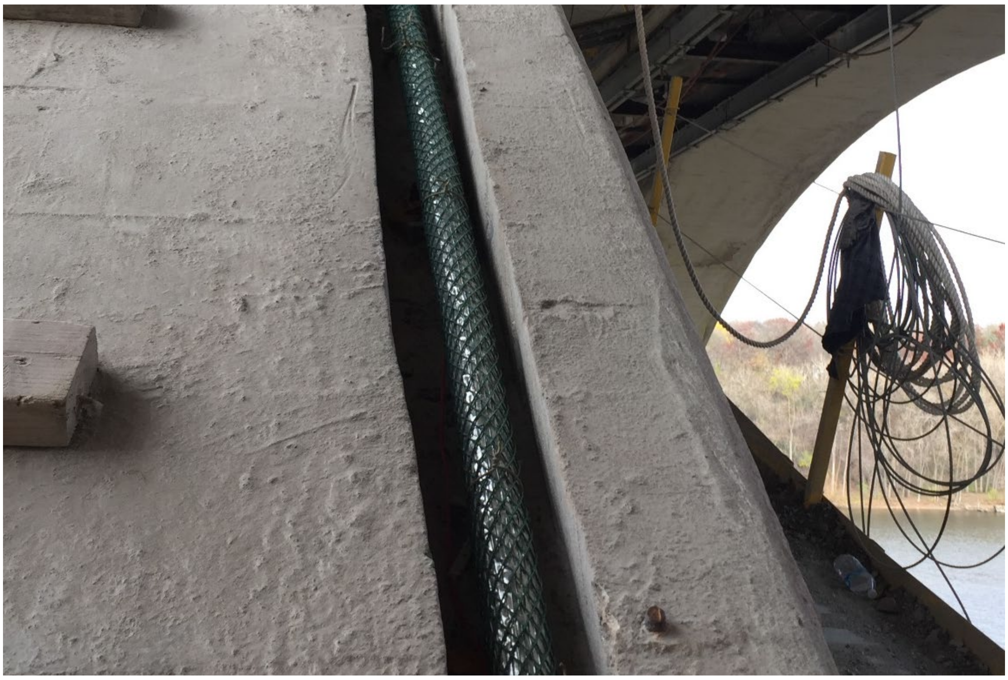

Figure 2:  Distributed Anode in Slot to Protect Concrete Arch, Minneapolis, MN

To protect larger areas, distributed anodes can be installed in a parallel orientation across the structure. They can be installed into slots (Figure 2) or more commonly covered with a concrete jacket or overlay, referred to as galvanic encasement. Prior to anode installation, the deteriorated concrete is removed, and the exposed reinforcing steel is cleaned. The anodes are attached to the reinforcing steel and covered with concrete thus competing the concrete repair and corrosion protection in a single step. Additional reinforcement can be provided with conventional reinforcing steel or noncorrosive fiberglass reinforcement in the overbuilt section.[6] If conventional steel is used, it should also be accounted for in the cathodic protection design.

**Figure 3: Galvanic Encasement of Heavily Reinforced Column with Distributed Anodes and Supplemental Reinforcing Prior to Concrete Placement, Louisville, KY**

**Figure 4: Distributed Galvanic Anodes Incorporated into Bridge Deck Overlay, Cuyahoga County, OH**

## OHIO DOT GALVANIC ENCASEMENT ABUTMENT REPAIRS

The Ohio Department of Transportation (ODOT) was experiencing an aggravating corrosion problem with their slab bridge abutments. Leaking expansion joints over the abutments were causing chloride-induced corrosion of the abutment and their repairs were only lasting 5 to 7 years.

In response, ODOT implemented a galvanic encasement repair design that utilized a built-out section with distributed galvanic anodes and additional epoxy coated reinforcing (Figure 5). The distributed anodes are connected to the existing conventional reinforcing to mitigate corrosion in the existing element that is being encased. A major advantage of this new repair detail is that the abutment is repaired, protected and strengthened while staying in service. Numerous bridges were repaired in this manner and are still in great shape a decade later.

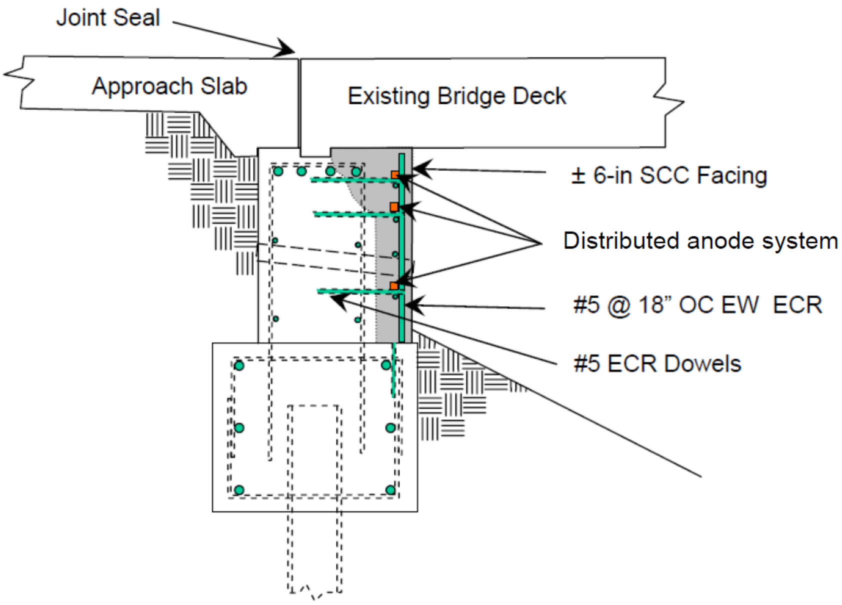

**Figure 5: Galvanic Encasement of Abutment Utilizing Distributed Galvanic Anodes**

A bridge abutment on Interstate 75 near Sydney, Ohio was repaired using the ODOT galvanic encasement technique in July 2005 (Figure 6). The abutment is approximately 52 ft wide by 4 ft high. One zone of distributed anodes were installed with the ability to monitor the anode performance as part of an ODOT technology evaluation program (Figure 7).

**Figure 6: Galvanic Encasement of Abutment, Sidney, OH**

**Figure 7: Distributed Anode System Monitoring Cabinet**

On the south abutment of the southbound bridge, three six-foot-long anodes with 1.5 lb. zinc per anode were installed to provide cathodic protection and wired so that they could be monitored. The remaining anodes installed on the abutment were directly connected to the reinforcing steel. Current and temperature data was being collected by battery-powered dataloggers and downloaded manually on a periodic basis. Manual measurements of the entire abutment surface were obtained periodically.

The anodes have been installed and monitored for over 17 years. A visual inspection in 2022 showed that the condition of the repaired abutment is still very good. The system performance data (Table 1) indicates that the galvanic cathodic protection system installed is performing excellently with instant off potentials more negative than -850 mV CSE and polarization shifts exceeding 100 mV.

Concrete cathodic protection criteria have been established by NACE International, British, and European standards organizations. The relevant NACE publication that provides guidance regarding cathodic protection criteria is *NACE SP0216 Sacrificial Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*. NACE SP0216 defines the criteria for cathodic protection as:

- The potential of the steel in concrete is more negative than -720 mV versus a copper/copper sulfate reference electrode (CS) with the sacrificial anode disconnected.
- A minimum of 100 mV of polarization should be achieved at the most anodic location, typically in each 50 m$^2$ (500 ft$^2$) area or zone, or at artificially constructed anodic sites, provided its corrosion potential, or decayed off-potential is more negative than -200 mV versus a copper/copper sulfate reference electrode (CSE). If the corrosion potential or decayed off-potential is less negative than -200 mV CSE, then the steel is passivated, and no minimum polarization is required.

**Table 1: Galvanic Cathodic Protection System Performance Summary**

| 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 |

Using the anode current data and initial zinc mass, the estimated anode life can be estimated using Faraday's Equation. The anode life for the Sydney, Ohio bridge is estimated at 35 years, substantially exceeding the original 15-year design. This calculation includes an anode utilization factor of 0.8 and an anode efficiency factor of 0.9.

## FLORIDA DOT JACKETING WITH DISTRIBUTED ANODES

The Lake Avenue Bridge over the Intercoastal Waterway in Lake Worth, Florida is comprised of two bridges, an eastbound and a westbound structure. The Lake Avenue Bridge's substructure is comprised of flattened oval-shaped reinforced concrete columns supported on footers and piles. The columns measure 4 feet wide by 7 feet long, with 3 feet of flat section in the center and 2 feet of curved sections on each end.

Each of the bridges have 20 piers with a single column at each pier. These Florida DOT marine bridges were suffering from corrosion due to chloride contamination from storm surges and atmospheric exposure. Due to the corrosion deterioration of the columns, galvanic cathodic protection jackets with alkali-activated distributed anodes were installed in 2015 on a total of 36 columns.

The scope of work included the removal of existing 7-foot-high structural steel jackets (Figure 8), removal of deteriorated concrete, and installation of the new cathodic protection jackets of the same height (Figure 9).

Figure 8: Concrete Damage Revealed After Removal of Structural Steel Jackets

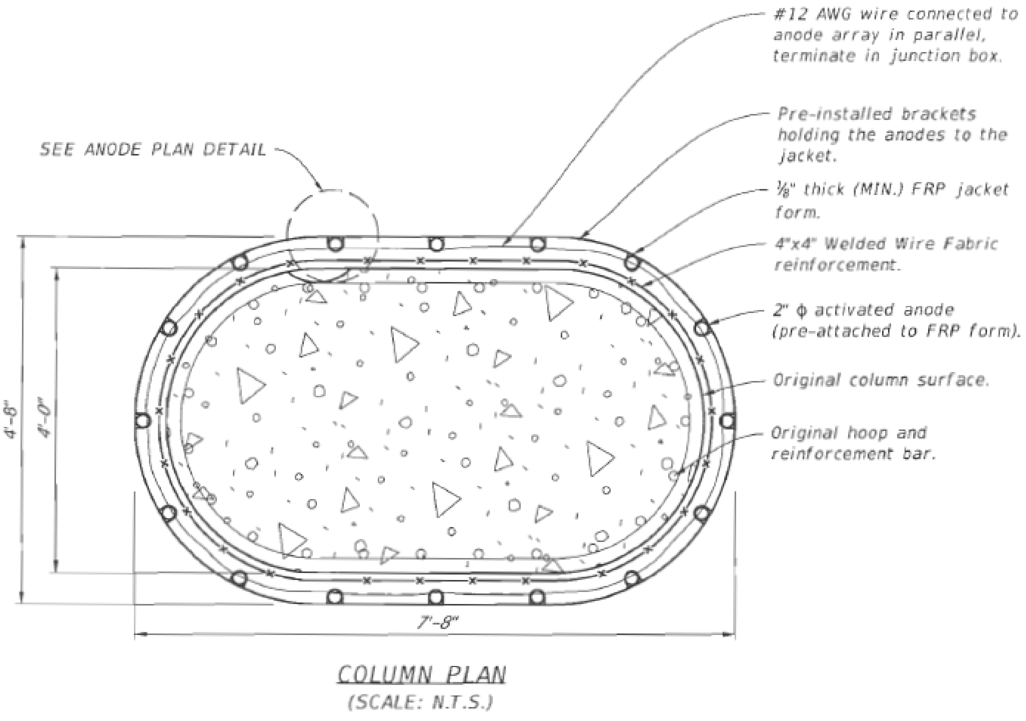

Figure 9: Cross Section of Lake Worth Galvanic Jackets

Florida DOT typically uses cathodic protection jackets with bulk anodes for concrete pile protection. In this case, the base of the columns are not normally submerged in the seawater, so a different approach was taken. The FDOT specification required that the activated distributed anodes be pre-attached the fiberglass forms at a spacing of 12 inches (Figure 10). Welded wire fabric was also installed in the 4-inch annular space of each jacket between the pre-attached anodes and the concrete surface. After the concrete fill cured, a potential monitoring access port was installed in each jacket (Figure 11).

Figure 10:  Curved Jacket Sections with Pre-Attached Distributed Anodes

Figure 11:  New Cathodic Protection Jackets Installed

In May 2022, the cathodic protection jackets were evaluated after 7 years of continuous operation (Table 2).  The conclusion of the evaluation is that the alkali-activated distributed anodes are performing as intended with the anodes providing sufficient current to polarize the steel rebars, meet the NACE cathodic protection standard, and mitigate active corrosion.

**Table 2: Performance of Alkali-Activated Distributed Anodes on Marine Columns Above the Tidal Zone**

| Bridge | Column | Current (mA) | Native at Constructoin 4/2015 (mV vs CSE) | Instant Off Potential (mV vs CSE) | Depolarization Potential 68 hrs (mV vs CSE) | Polarization after 68 hrs of Decay (mV) | Polarization Compared to Native (mV) | Does the Pile Meet CP Criteria per NACE SP0408? |
|---|---|---|---|---|---|---|---|---|
| **WB** | **1** | 149 | -268 | -760 | -691 | 69 | 492 | Yes |
| **WB** | **2** | 180 | -202 | -570 | -380 | 190 | 368 | Yes |
| **WB** | **3** | 140 | -203 | -550 | -460 | 90 | 347 | Yes |
| **WB** | **4** | 145 | -202 | -710 | -520 | 190 | 508 | Yes |
| **WB** | **5** | 70 | -260 | -622 | -590 | 32 | 362 | Yes |
| **WB** | **6** | 126 | -285 | -830 | -630 | 200 | 545 | Yes |
| **WB** | **7** | 60 | -309 | -1064 | -815 | 249 | 755 | Yes |
| **WB** | **8** | 45 | -304 | -955 | -560 | 395 | 651 | Yes |
| **WB** | **9** | 50 | -349 | -630 | -506 | 124 | 281 | Yes |
| **WB** | **12** | 124 | -320 | -770 | -480 | 290 | 450 | Yes |
| **WB** | **13** | 85 | -298 | -1043 | -739 | 304 | 745 | Yes |
| **WB** | **14** | 55 | -392 | -959 | -760 | 199 | 567 | Yes |
| **WB** | **15** | 133 | -260 | -618 | -496 | 122 | 358 | Yes |
| **WB** | **16** | 90 | -399 | -870 | -775 | 95 | 471 | Yes |
| **WB** | **17** | 122 | -388 | -882 | -720 | 162 | 494 | Yes |
| **WB** | **18** | 110 | -382 | -1069 | -774 | 295 | 687 | Yes |
| **WB** | **19** | 95 | -355 | -1045 | -730 | 315 | 690 | Yes |
| **WB** | **20** | 114 | -276 | -698 | -430 | 268 | 422 | Yes |
| **EB** | **1** | 150 | -266 | -748 | -530 | 218 | 482 | Yes |
| **EB** | **2** | 179 | -328 | -755 | -580 | 175 | 427 | Yes |
| **EB** | **3** | 120 | -200 | -563 | -430 | 133 | 363 | Yes |
| **EB** | **4** | 122 | -285 | -883 | -630 | 253 | 598 | Yes |
| **EB** | **5** | 40 | -237 | -609 | -560 | 49 | 372 | Yes |
| **EB** | **6** | 154 | -329 | -654 | -527 | 127 | 325 | Yes |
| **EB** | **7** | 55 | -330 | -802 | -650 | 152 | 472 | Yes |
| **EB** | **8** | 59 | -356 | -808 | -499 | 309 | 452 | Yes |
| **EB** | **9** | 45 | -343 | -603 | -466 | 137 | 260 | Yes |
| **EB** | **12** | 32 | -363 | -681 | -524 | 157 | 318 | Yes |
| **EB** | **13** | 51 | -319 | -827 | -670 | 157 | 508 | Yes |
| **EB** | **14** | 65 | -282 | -990 | -782 | 208 | 708 | Yes |
| **EB** | **15** | 55 | -365 | -991 | -780 | 211 | 626 | Yes |
| **EB** | **16** | 60 | -371 | -929 | -724 | 205 | 558 | Yes |
| **EB** | **17** | 145 | -388 | -949 | -739 | 210 | 561 | Yes |
| **EB** | **18** | 100 | -358 | -1039 | -780 | 259 | 681 | Yes |
| **EB** | **19** | 89 | -330 | -996 | -660 | 336 | 666 | Yes |
| **EB** | **20** | 99 | -218 | -600 | -419 | 181 | 382 | Yes |
| 100 | mV - NACE cathodic protection polarization criterion achieved | | | | | | | |
| -200 | mV vs CSE - NACE cathodic protection passivation criterion achieved | | | | | | | |
| -850 | mV vs CSE - NACE Instant Off potential criterion achieved | | | | | | | |
| Note 1: Only one of the NACE criterion needs to be achieved to pass SP0408 for a protected structure | | | | | | | | |

## KENTUCKY TRANSPORTATION CABINET SURFACED MOUNTED DISTRIBUTED ANODES

More recently, a field study demonstration of a new surface mounted distributed anode system was installed on a beam in the summer of 2022 in Louisville, Kentucky. The selected beam was chloride-contaminated from de-icing contaminated water leaking though the deck joint above the beam. The beam exhibited characteristics of very active corrosion as determined by a corrosion potential survey and concrete chloride content testing.

Different sizes of alkali-activated surface mounted galvanic anodes were installed on the concrete surface. After the concrete surface was prepared, the individual anode units were installed in parallel horizontal rows across the beam face. A conductive cementitious mortar was used to bond the anodes to the concrete and create an ionic connection to the beam. The anode units were further secured with mechanical anchors (Figure 12). A remote monitoring system was installed to measure the galvanic current output of the anodes, ambient temperature, and potential of the reinforcing steel using an embedded reference electrode.

The preliminary results are very encouraging. After almost 5 months of monitoring, the data show that the anodes are producing sufficient galvanic current to provide corrosion mitigation, the current fluctuates with temperature and rain events (Figure 13), and the current density is sufficient to polarize actively corroding reinforcing steel to meet or exceed the NACE 100mV polarization criteria (Figure 14).

**Figure 12: Surface Mounted Distributed Anode Field Study, Louisville, KY**

**Figure 13: Current and Temperature Data for Surface Mounted Anode Study**

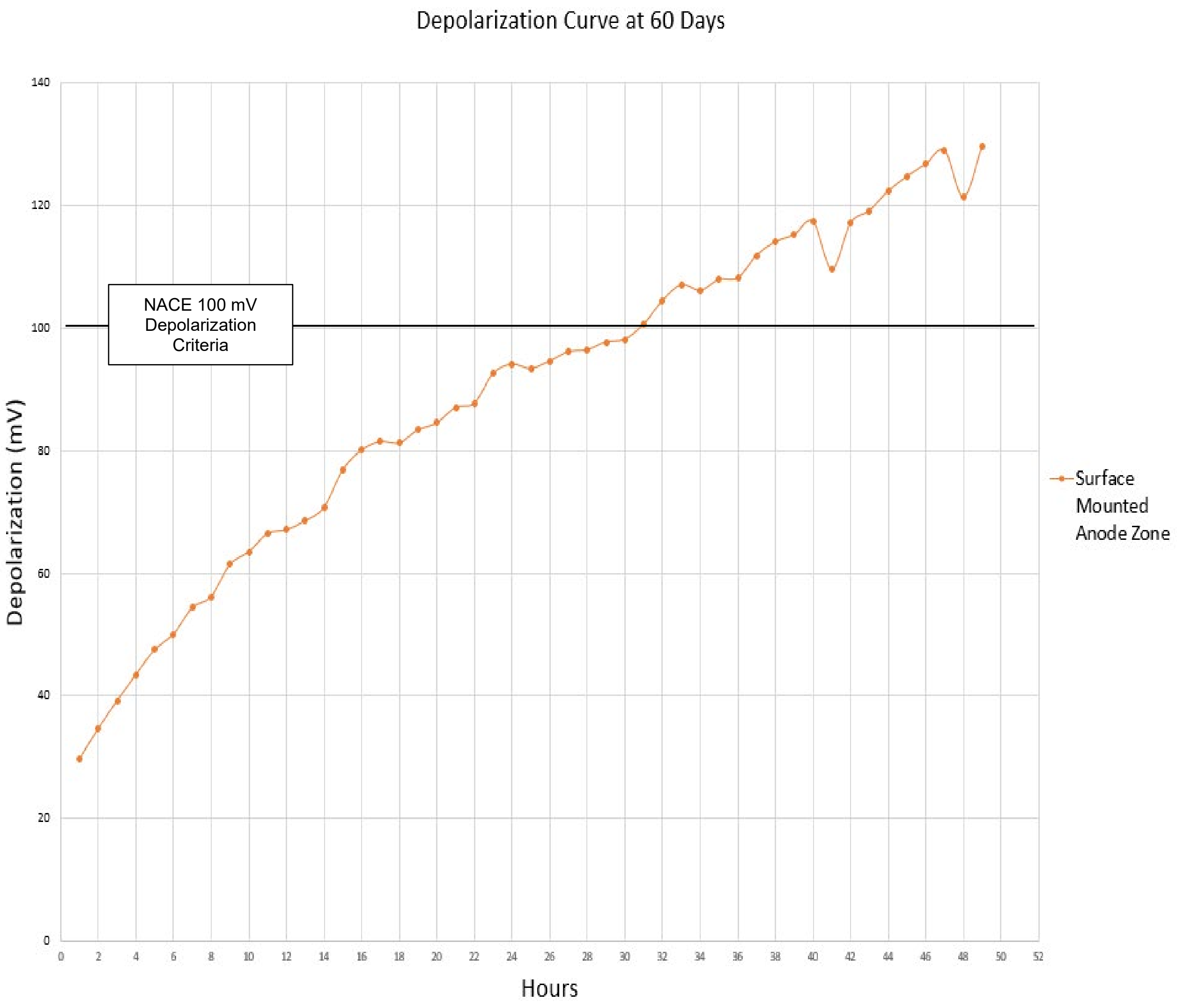

**Figure 14: Depolarization Curve 60 Days After Energizing**

## SUMMARY

Alkali-activated distributed anodes have been used on reinforced concrete bridges throughout the United States for almost 20 years. The anodes have been used in a variety of environments ranging from northern states with corrosive de-icing salts to marine exposure in southern states with tropical climates. Long term monitoring has demonstrated that the anode systems can be designed to satisfy NACE cathodic protection criteria while providing low maintenance cathodic protection for up to 35 years.

## ACKNOWLEDGMENTS

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