Appendix K: Cathodic Protection Articles

CATHODIC PROTECTION SYSTEMS

USE OF SACRIFICIAL OR GALVANIC ANODES ON IN-SERVICE BRIDGES

NYSDOT OFFICE OF OPERATIONS
TRANSPORTATION MAINTENANCE DIVISION
BRIDGE MAINTENANCE

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INTRODUCTION

CORROSION CONTROL USING GALVANIC CATHODIC PROTECTION

> This section provides application information, design examples, and reference tables for the use of galvanic cathodic protection systems for in-service reinforced concrete structures.

An overview of the various strategies that might be considered by the Bridge Maintenance Engineer in the rehabilitation of reinforced concrete structures is provided in NCHRP Report 558 Chapter 5 "Extension of Service Life with Repair and Corrosion Mitigation Options." The strategies can be divided into two categories; <u>corrosion protection</u> and <u>corrosion control</u>.

The overview includes discussions on the methods typically used with NYSDOT. These include, reinforcing bar coatings, overlays, waterproofing membranes, and penetrating sealers. These strategies function to provide <u>corrosion protection</u> and are applicable for replacement projects or for repairs to elements with minimal levels of rebar corrosion.

In more aggressive environments, a strategy of adding <u>corrosion control</u> techniques to standard repair procedures has been proven to provide the most effective repair. Typical corrosion control materials are <u>corrosion inhibitors</u> and <u>galvanic cathodic protection</u> systems.

Corrosion inhibitors are chemical compounds either added to the repair material, applied directly to the rebar, or both. Calcium nitrite is the most commonly used corrosion inhibitor and has a long history of good performance. Nonetheless, in test patches in concrete with high levels of chloride ions "the nitrite inhibitor used in conjunction with patch repair material on field structures did not provide any benefit" (NCHRP Report page 29).

The Federal Highway Administration has stated that "cathodic protection is the only rehabilitation technique that has proven to stop corrosion in salt-contaminated bridge decks regardless of the chloride content in concrete" (NCHRP Report, page 34).

Cathodic protection can be grouped into two basic types of systems: impressed current and galvanic cathodic systems. An impressed current system is achieved by driving a low-voltage direct current (generally less than 50 volts) from a relatively inert anode material, through the concrete, to the reinforcing bars. The current is distributed to the reinforcing bars by an anodic material. This procedure is very costly and requires specialized services to design and verify the system is working properly.

Galvanic cathodic protection (also called galvanic anode system) is based on the principles of dissimilar metal corrosion and the relative position of specific metals in the galvanic series. No external power source is needed with this type of system, and much less maintenance is required. Patch-repair and plug-type anodes are examples of galvanic anodes.

As stated in NCHRP Report 558, when selecting a cathodic protection system for a given structure, several issues need to be considered:

- Long-term rehabilitation: the system is most effective for if a long-term repair (5 to 10 years) is desired.
- Electrical continuity: a closed electrical circuit is required for proper functioning of the system.
- Chloride concentrations: if the levels are in sufficient concentration to initiate corrosion, cathodic protection may be the only viable method of rehabilitation.
- Alkali-silica reaction: cathodic protection increases alkalinity at the steel-concrete interface, thereby theoretically accelerating the alkali-silica reaction, although this condition has never been reported.

Questions or comments regarding this material should be forwarded to the Bridge Maintenance Program Engineer in the Office of Operations.

References:

NCHRP Report 558 Manual on Service Life of Corrosion-Damaged Reinforced Concrete Bridge Superstructure Elements.

Vector Corrosion Technologies
www.vector-corrosion.com

The Euclid Chemical Company
www.euclidchemical.com

PRODUCTS LIST

Supplier	Product Name	Description	Contact
Vector	Galvashield XP+	“Hockey puck” with 100 grams of zinc	(813) 830-7566 www.vector-corrosion.com
	Galvashield XP	“Hockey puck” with 65 grams of zinc	
	Galvashield CC 65	Moderate steel density	
	Galvashield CC 100	High steel density	
	Galvashield CC 135	Slim fit style	
Sika Corp	Galvashield XP+	Same as Vector	1-800-933-7452 www.sikaconstruction.com
	Galvashield CC 65, 100, 135	Same as Vector	
BASF	Corrstops	Same as Vector Galvashield XP	1-800-526-1072 www.basf.com
Euclid	Sentinel-GL	“V-notch” block with 40 grams of zinc	1-800-321-7628 www.euclidchemical.com

Steel Density Ratio

The number and spacing of anodes is determined by the steel density ratio. The ratio is a calculation of the surface area of the reinforcing steel to the area of repair.

Product manufacturers supply spacing tables based on the steel density ratio for each anode type. Anodes are estimated to provide 5 to 15 years of corrosion protection.

Steel density ratios based on rebar spacing have been calculated for rebar sizes 5, 6, and 7 bars and are located in the appendix of this module. Spacing for Euclid's Sentinel-GL is based on categories of heavy, medium, and light reinforcement. The tables are color coded and grouped to facilitate this designation.

The protective current supplied by sacrificial anodes will decrease slowly with time as zinc corrosion products accumulate. The recommended anode spacing provided by the manufacturers provides a balance between desired service life and reasonable cost. Altering the anode spacing will change the service life, but the relationship between the spacing and the service life is not linear. Doubling the anode spacing (therefore halving the anode cost) will reduce the expected service life by much more than half. Halving the anode spacing will extend the expected service life by more than double, but at greatly increased cost.

Since the corrosion products of zinc occupy more volume than the original zinc, means must be provided to accommodate this expansion. Vector encapsulates the zinc in a high alkaline environment to chemically control expansion. Euclid allows for the expansion of the zinc corrosion by-products by using compressible materials within the encasement.

STEEL DENSITY TABLES

Corroded Bars

Galvashield XP+ TABLE 1.0

Steel Density Ratio	Maximum Spacing (in)
< 0.2	28
0.21 - 0.40	24
0.41 - 0.54	20
0.55 - 0.67	18
0.68 - 0.80	16
0.81 - 0.94	15
0.95 - 1.07	14
1.08 - 1.20	13

Non-Corroded Bars

Galvashield XP+

TABLE 2.0

Steel Density Ratio	Maximum Spacing (in)
< 0.3	30
0.31 - 0.6	28
0.61 - 0.9	26
0.91 - 1.2	22
1.2 - 1.5	20
1.51 - 2.0	17

Galvashield XP

TABLE 3.0

Steel Density Ratio	Maximum Spacing (in)
< 0.3	30
0.31 - 0.6	24
0.61 - 0.9	20
0.91 - 1.2	17

TABLE 4.0 Maximum Sentinel-GL Anode Spacing (in)

Steel Density Ratio	Highly Corrosive Environment[1]	Slightly Corrosive Environment[2]
< 0.50 (light)	24	30
0.50 – 1.0 (moderate)	18	24
> 1.0 (heavy)	12	18

1. Characterized by a large amount of corrosion damage. Chloride content >about 5 lbs/yd^3
2. Characterized by a small amount of corrosion damage. Chloride content <about 5 lbs/yd^3

STEPS FOR USE OF SACRIFICIAL ANODES ON IN-SERVICE BRIDGES

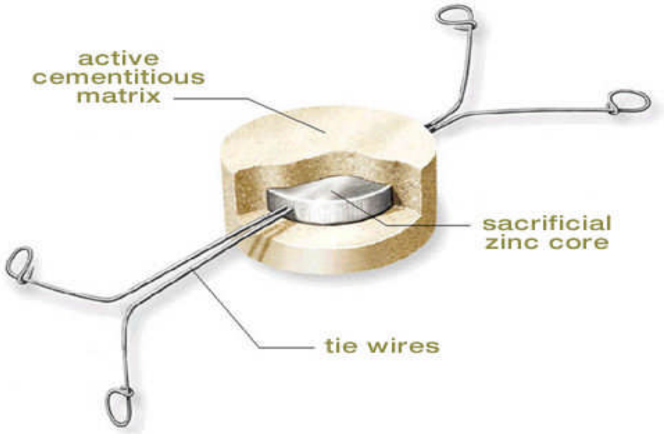
1. Determine if the use of sacrificial anodes are a cost effective strategy for the necessary repair.
2. Determine rebar types and repair material options. Galvanic anodes are not effective in materials with electrical resistivity greater than 15,000 ohm-cm.
   i. Many polymer, fly ash, and silica fume-based repair materials cannot be used in conjunction with sacrificial anodes.
   ii. Additional steps are necessary if the rebars are epoxy coated.
   iii. Low Volume Shotcrete: Repairs performed by low volume shotcrete using Dry-Pak-It methodology and materials with galvanic anodes do not exhibit improved performance over similar repairs done without the use of galvanic anodes.
3. Determine the numbers of anodes required by calculating the density of the reinforcing steel. (See attachment for sample calculation.)
4. Place the anodes accordingly as to the type of project being conducted. For pre-stressed/post-tensioned concrete structures, provide an electrical connection between the wires strands and the anodes. For top and bottom mat protection an electrical connection must be provided to the bottom mat of bridge deck reinforcing steel.

OPEN PATCHING

Galvanic protection systems utilize sacrificial anodes that naturally generate an electrical current to mitigate corrosion of the reinforcing steel. In concrete structures, zinc anodes are typically used. Galvanic protection for concrete can be classified into two categories: targeted protection for concrete repair, and distributed systems for blanket protection.

Discrete anodes are used to provide targeted protection around concrete patches, and can also be placed into drilled holes on a grid pattern in sound concrete to provide distributed protection. Galvashield® XP and Sentinel-GL embedded zinc anodes are examples of discrete zinc anodes that are used to provide targeted protection for concrete patch repair.

Discrete zinc anodes are normally intended to provide corrosion protection for only the top mat of reinforcing steel; since the top mat is usually where concrete is chloride contaminated and where corrosion takes place. In unusual cases it may be necessary to provide sufficient current to provide protection to both mats of reinforcing steel.



Galvashield® XP+ anode (above) Euclid Sentinel-GL (below)

Example Calculation for Deck Repair Using Sentinel-GL Anodes

Assumption: #5 bars (0.625” diameter) on 8” center both directions in a highly corrosive environment.

1. **Calculate top mat steel density ratio using the formula:**

$$(\pi)\ \frac{(\text{bar diameter})}{(\text{bar spacing})} = \text{ratio}$$

Top mat longitudinal bar ratio:	(π) (0.625/8) = 0.245
+ Top mat transverse bar ratio:	(π) (0.625/8) = 0.245
Total top mat steel density ratio =	**0.490**

2. **Determine anode spacing using Table 4.0:**

   From Table 4.0: for Steel Density Ratio <0.5 in Highly Corrosive Environment, **Maximum Anode Spacing = 24 in.**
   But since the ratio is very close to 0.5, a reasonable choice could be **21 in.**

Example Calculation for Column Repair Using Sentinel-GL Anodes

Assumption: #11 bars (1.375” diameter) vertical on 6” center, and #4 ties (0.500” diameter) on 12” center in a highly corrosive environment.

1. **Calculate steel density ratio using the formula:**

$$(\pi)\ \frac{(\text{bar diameter})}{(\text{bar spacing})} = \text{ratio}$$

Vertical bar steel density ratio:	(π) (1.375/6)	= 0.720
+ Tie bar steel density ratio:	(π) (0.500/12)	= 0.131
Total top mat steel density ratio =		**0.851**

2. **Determine anode spacing using Table 4.0:**

From Table 4.0: for Steel Density Ratio 0.5–1.0 in Highly Corrosive Environment, **Maximum Anode Spacing = 18 in.**

Example: Determining Number of Anodes Needed for Deck Repair using Steel Density Ratio Tables

Description of Repair: Moderately Reinforced Slab (Bridge Deck) #5 bars @ 12” x 14” spacing

Repair Dimensions: 48” (transverse) x 60” (longitudinal)

1. Determine Steel Density Ratio using tabulated values

No. 5 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	0.79	0.72	0.67	0.64	0.61	0.59	0.57	0.56	0.54	0.53	0.52	0.52	0.51	0.50	0.50	0.49	0.49	0.48	0.48	0.47	0.47
6	0.72	0.65	0.61	0.57	0.55	0.52	0.51	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.41
7	0.67	0.61	0.56	0.53	0.50	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36
8	0.64	0.57	0.53	0.49	0.46	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.32
9	0.61	0.55	0.50	0.46	0.44	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.30
10	0.59	0.52	0.48	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.29	0.28	0.28	0.27
11	0.57	0.51	0.46	0.42	0.40	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.26
12	0.56	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24
13	0.54	0.48	0.43	0.40	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23
14	0.53	0.47	0.42	0.39	0.36	0.34	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22
15	0.52	0.46	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21
16	0.52	0.45	0.40	0.37	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20
17	0.51	0.44	0.40	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19
18	0.50	0.44	0.39	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19
19	0.50	0.43	0.38	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18
20	0.49	0.43	0.38	0.34	0.32	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
21	0.49	0.42	0.37	0.34	0.31	0.29	0.27	0.26	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.17
22	0.48	0.42	0.37	0.33	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
23	0.48	0.41	0.37	0.33	0.30	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.16
24	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.25	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16
25	0.47	0.41	0.36	0.32	0.30	0.27	0.26	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.16

Tabulated values represent steel density ratios

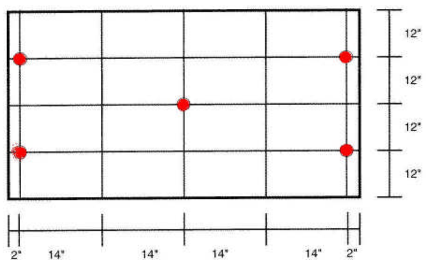
Heavy
Moderate
Light

For 12” x 14” spacing, the Steel Density Ratio is 0.30

Galvashield XP+ & Galvashield XP

From tabulated values:

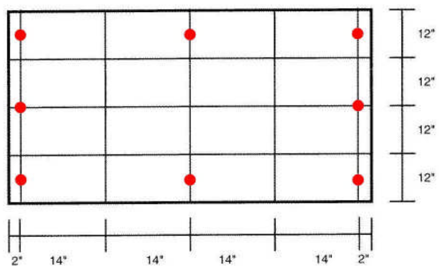
Spacing = 30 in (max.)
Number of Anodes = 5



Sentinel-GL

From tabulated values:

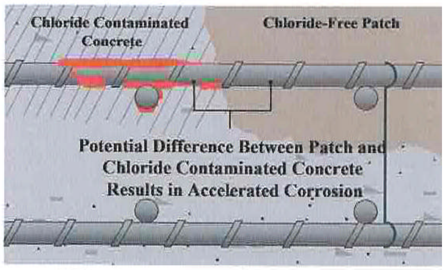
Spacing = 24 in (max.)
Number of Anodes = 9



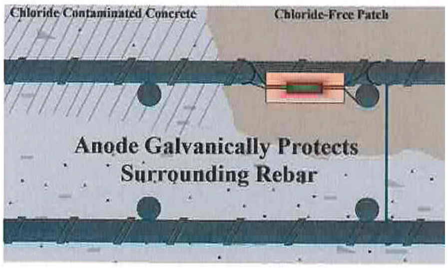
Installation Instructions

Prior to installation, the "Installation Instructions" bulletin shall be thoroughly examined for details on the placement and use of manufacturer's units. Concrete shall be removed from around and behind all corroding rebar, in accordance with good concrete repair practice (ICRI Guideline No. 03730). Securely fasten the unit to clean reinforcing steel using a suitable wire twisting tool to eliminate free movement, and to ensure a good electrical connection. Steel continuity within the patch should be verified with an appropriate meter. If discontinuous steel is present, re-establish continuity with steel tie wires. Following the unit installation, electrical connection between the unit tie wires and the clean reinforcing bar should be confirmed with an appropriate meter. The location and spacing of the units shall be as specified by the designer.

The anodes are typically tied on the side or beneath the exposed rebar as close as practical to the surrounding concrete making sure than enough space is left to fully encapsulate the unit in the repair. Minimum cover over the units must be 20 mm (3/4 in.). Units can be placed on a grid pattern throughout the repair to protect a second mat of steel if required. With the units in a position, complete the repair using a suitable repair material with resistivity less than 15,000 ohm-cm. If higher resistance repair materials are to be used, pack manufacturer's mortar between the unit and the substrate to provide a conductive path to the substrate, the complete repair.



"Ring Anode" (without Galvashield XP+)



Galvashield XP+ prevents "Ring Anode" Corrosion

A standard tie wire will work, if there is continuity to start with. If there is none you will need to weld either a heavy gage wire #1 or a piece of rebar between the mats.

Health and Safety

As with all cement-based materials, contact with moisture can release alkalis which may be harmful to exposed skin. Anodes should be handled with suitable gloves and other personal protective equipment in accordance with standard procedures for handling cementitious materials. Additional safety information is included in the Material Safety Data Sheet.

Installation Instructions and **Health and Safety** information can be found for each product on the manufacturer's websites.

PLUG-TYPE ANODES

Installation Instructions

The location and spacing of the Galvashield® CC units shall be on a grid pattern as specified by the engineer. Using a rebar locator, locate all existing steel within the area designated for protection and mark areas to drill unit installation holes. When possible, units should be installed a minimum of 4 in. (100 mm) from reinforcing grid.

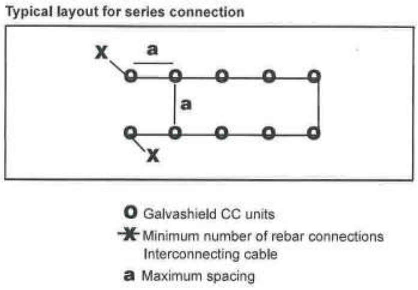
Series Connection – a single circuit shall contain no more than 10 Galvashield® CC units. Drill a minimum of two ½ in. (12 mm) rebar connection holes per string of anodes. Saw cut a single continuous groove approximately ¼ in. (6mm) wide by ½ in. (12 mm) deep into the concrete to interconnect rebar connection holes and anode connection holes.

Individual Connection – drill one rebar connection hole per unit location. Saw cut a groove approximately ¼ in. (6 mm) wide by ½ in. (12 mm) deep into the concrete to interconnect the rebar connection hole and anode connection hole.

Reinforcing steel connections should be made using the Vector Rebar Connection Kit. Place the weighted end of the connector into the drilled hole until the steel coil contacts the reinforcing steel. Feed the steel connector wire through the Vector Setting Tool and set into place by striking with a hammer.

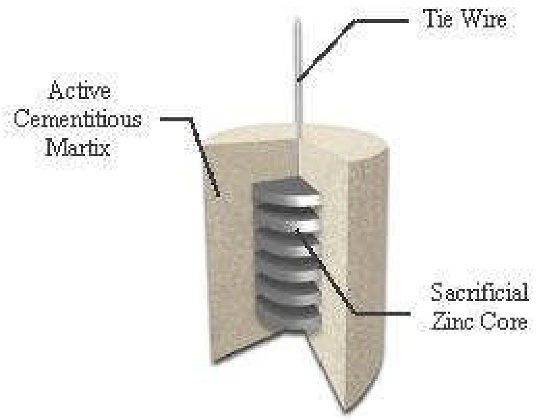
Connect the units directly to the rebar connection wire using the supplied wire connector. If installing in series, connect the units to the interconnecting cable with a wire connector (cable and wire connectors are available as the Vector Anode Connection Kit). Verify continuity between unit locations and rebar connections with a multi-meter. A resistance of 1 ohm or less is acceptable.

Typical layout for series connection

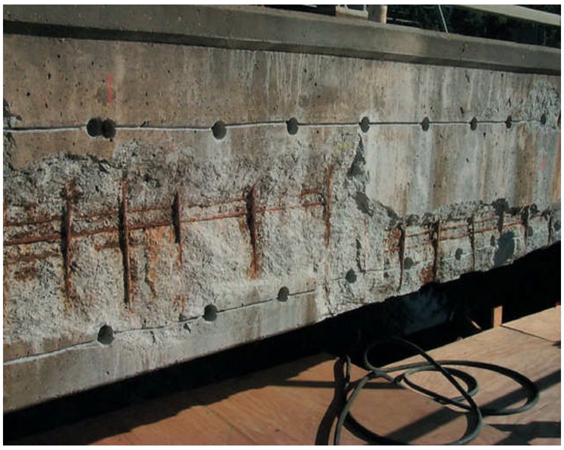


Drill holes as per the dimensions listed above to accommodate the anodes. Presoak the units for a minimum of 10 to a maximum of 30 minutes in a shallow water bath. Galvashield Embedding Mortar Embedding mortar should be wet cured or cured with a curing compound and protected from traffic for 24 hours. Place the mixed embedding mortar into the bottom ⅔ of each hole and slowly press in the unit allowing the mortar to fill the annular space ensuring there are no air voids between the unit and the parent concrete. The minimum unit cover depth shall be ¾ in. (20 mm). Place wires into grooves and top off unit holes and saw cuts flush to the concrete surface with embedding mortar.

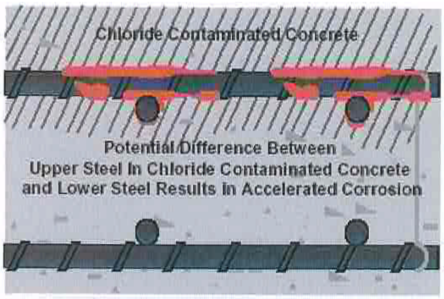
PLUG-TYPE ANODES



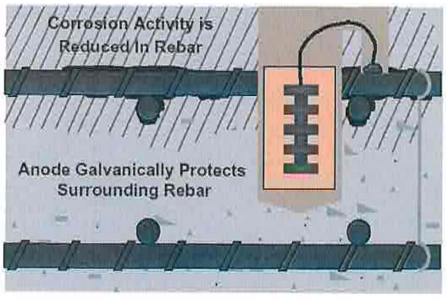
Placement of Galvashield® CC in concrete beam



A standard tie wire will work, if there is continuity to start with. If there is none you will need to weld either a heavy gage wire #1 or a piece of rebar between the mats.



Cloride contamination causes corrosion in reinforced concrete



Galvashield CC mitigates active corrosion

Tables 5.0, 6.0, 7.0

Design Criteria
Standard Units

Unit Type	Description	Unit Size diameter x length	Minimum Hole Size diameter x depth
Galvashield CC65	Standard unit for moderate steel density	1 ¾ x 2 ½ in. (46 x 62 mm)	2 x 3 ¾ in. (50 x 95 mm)
Galvashield CC100	Larger unit for higher steel density	1 ¾ x 4 in. (46 x 100 mm)	2 x 5 ⅛ in. (50 x 130 mm)
Galvashield CC135	Slim-fit for congested reinforcement	1 ⅛ x 5 ⅜ in. (29 x 135 mm)	1 ¼ x 6 ½ in. (32 x 165 mm)

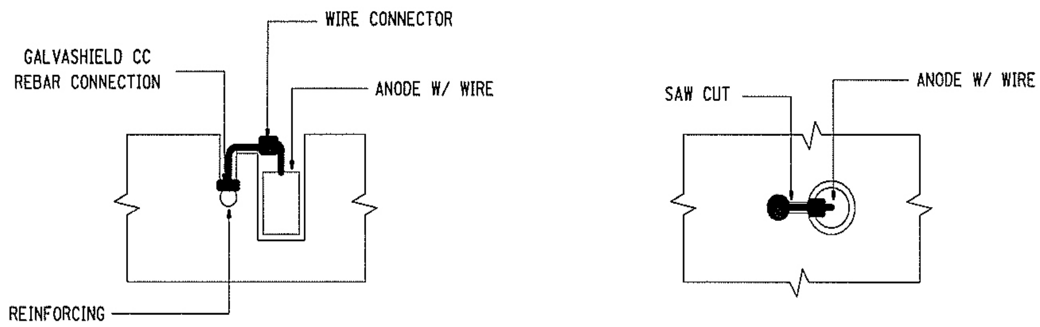
Galvashield CC65 and CC135

Steel density ratio (steel surface area/concrete surface area)	Maximum grid dimensions* in. (mm)
< 0.2	28 in. (700 mm)
0.21 - 0.4	24 in. (600 mm)
0.41 - 0.54	20 in. (500 mm)
0.55 - 0.67	18 in. (450 mm)
0.68 - 0.80	16 in. (400 mm)
0.81 - 0.94	15 in. (380 mm)
0.95 - 1.07	14 in. (355 mm)
1.08 - 1.2	13 in. (335 mm)

Galvashield CC100

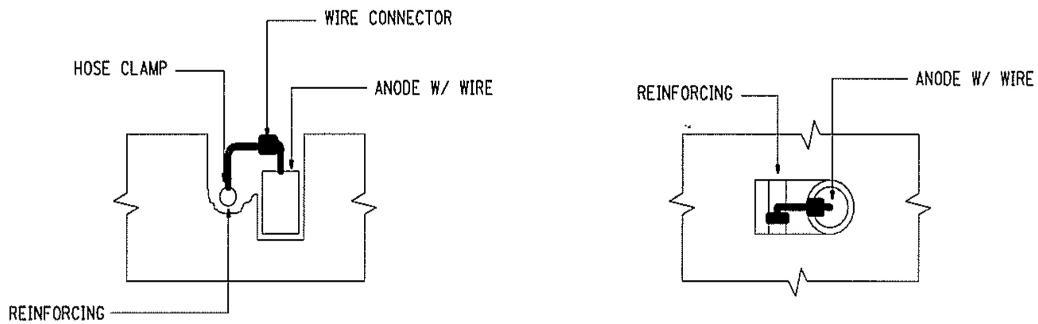
Steel density ratio (steel surface area/concrete surface area)	Maximum grid dimensions* in. (mm)
0.55 - 0.94	20 in. (500 mm)
0.95 - 1.17	18 in. (450 mm)
1.18 - 1.41	16 in. (400 mm)
1.42 - 1.64	15 in. (380 mm)
1.65 - 1.88	14 in. (355 mm)
1.89 - 2.11	13 in. (335 mm)

*Maximum grid dimensions are based on typical conditions. Spacing should be reduced as appropriate for severe environments or to extend the expected service life of the anode.



TYPICAL REINFORCING CONNECTION IN DRILLED HOLE

N.T.S.



TYPICAL REINFORCING CONNECTION IN CONCRETE EXCAVATION

N.T.S.

PRESTRESS CONCRETE REPAIR

NOTES

1. DRILL OR CHIP HOLE FOR REINFORCING CONNECTION.
2. DRILL HOLE FOR ANODE PLACEMENT. REFER TO GALVASHIELD CC DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
3. MAKE SAW CUT FOR WIRE CONNECTION AS REQUIRED.
4. CONNECT WIRE LEAD TO REINFORCING STEEL WITH HOSE CLAMP OR EXPANSION GALVASHIELD CC REBAR CONNECTION KIT.
5. ENSURE ALL CONNECTIONS OF DISSIMILAR METALS ARE COATED WITH SILICONE OR EPOXY TO PREVENT CORROSION.
6. INSTALL ANODE AND GROUT IN HOLES AND SAW CUT. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. B.I.N. COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

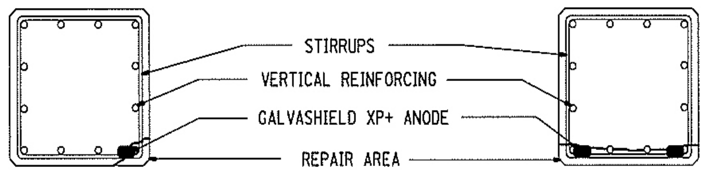
SIGNATURE DATE

GALVASHIELD CC INSTALLATION DETAILS

STATE OF NEW YORK DEPARTMENT OF TRANSPORTATION

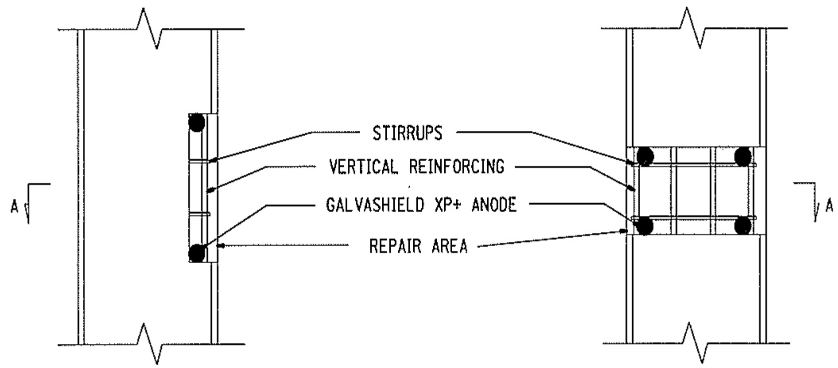
REGION DATE DRAWING NO.

DESIGN SUPERVISOR JOB MANAGER DESIGNED BY CHECKED BY ESTIMATED BY DRAFTED BY CHECKED BY



SECTION A-A - CORNER & FACE REPAIRS

N.T.S.



ELEVATION OF CORNER & FACE REPAIRS

N.T.S.

COLUMN REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH MATERIAL AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

SIGNATURE DATE

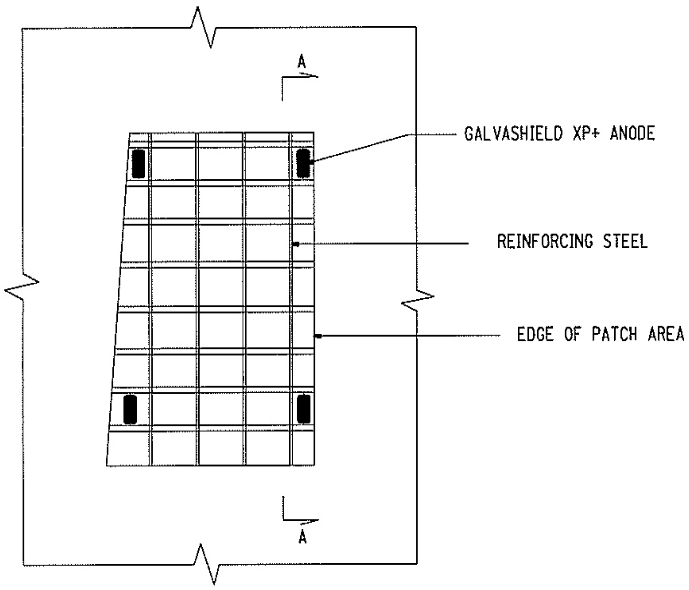
GALVASHIELD XP+
INSTALLATION COLUMN REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

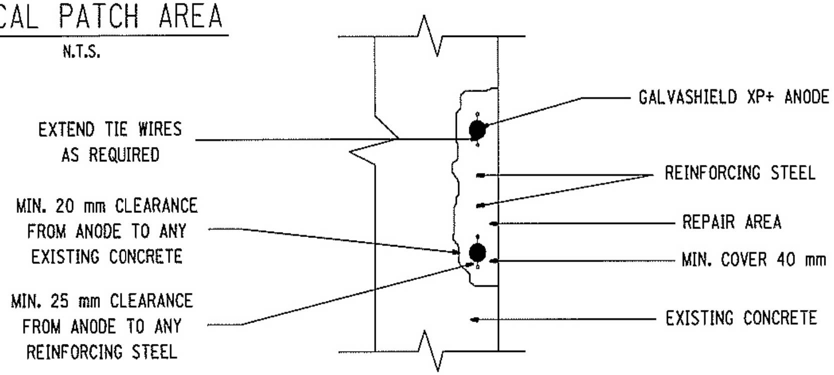
P.I.N. B.I.N. COUNTY

REGION DATE DRAWING NO.



TYPICAL PATCH AREA

N.T.S.



SECTION A-A

N.T.S.

SHOTCRETE REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES. ATTACH EACH END OF GALVASHIELD XP+ ANODE TO ADJACENT PARALLEL REINFORCING STEEL BARS ON EDGE TO PROVIDE MINIMUM SHADOW AREA FOR SHOTCRETING. EXTEND TIE WIRES WITH REBAR WIRE AS REQUIRED. ENSURE MINIMUM SPACING OF 25 mm BETWEEN ANODES AND ANY REINFORCING STEEL, MINIMUM SPACING OF 20 mm BETWEEN ANODES AND ANY EXISTING CONCRETE AND PROVIDE A MINIMUM OF 40 mm CONCRETE COVER.
5. POUR BACK REPAIR AREA WITH SHOTCRETE AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

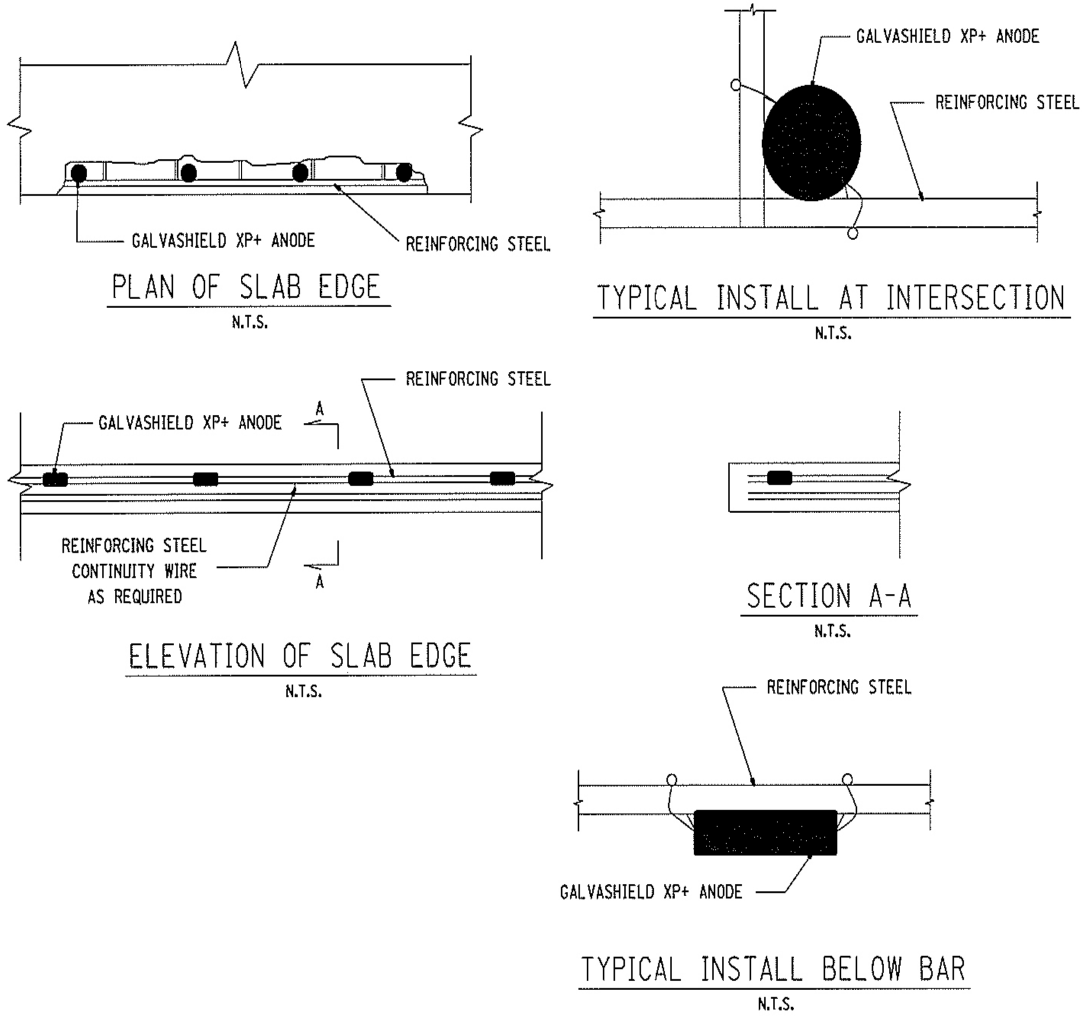
SIGNATURE | DATE

GALVASHIELD XP+
INSTALLATION SHOTCRETE REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION | DATE | DRAWING NO.

CHECKED BY | DRAFTED BY | ESTIMATED BY | CHECKED BY | DESIGNED BY | JOB MANAGER | DESIGN SUPERVISOR



SLAB EDGE REPAIR

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT SPACING OUTLINED IN CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH REPAIR MATERIAL AS PER CONTRACT SPECIFICATION. ANY REPAIR MATERIAL USED SHALL NOT BE EPOXY BASED.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

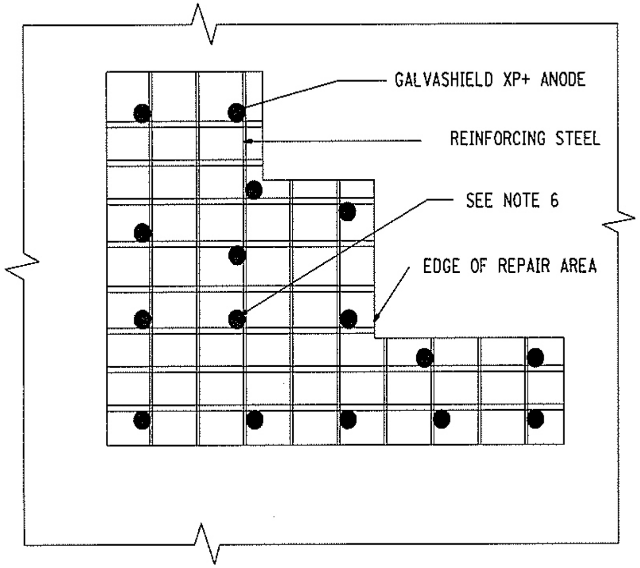
SIGNATURE | DATE

GALVASHIELD XP+
SPECIFICATION SLAB EDGE REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

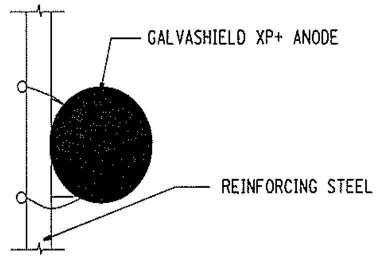
REGION | DATE | DRAWING NO.

CHECKED BY | DRAFTED BY | ESTIMATED BY | CHECKED BY | DESIGNED BY | JOB MANAGER | DESIGN SUPERVISOR



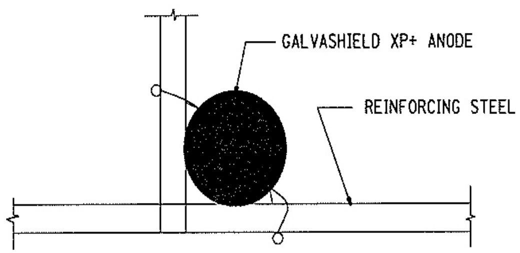
TYPICAL LAYOUT FOR SLAB REPAIR

N.T.S.



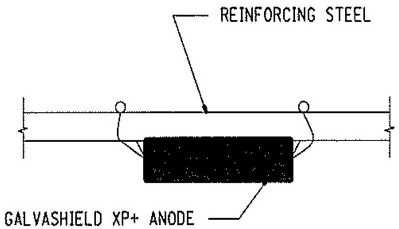
TYPICAL INSTALL BESIDE BAR

N.T.S.



TYPICAL INSTALL AT INTERSECTION

N.T.S.



TYPICAL INSTALL BELOW BAR

N.T.S.

NOTES

1. REMOVED DAMAGED CONCRETE AS WITH STANDARD REPAIR METHODS.
2. REPLACE / CLEAN CORRODED REINFORCING STEEL.
3. ENSURE ALL EXPOSED REINFORCING STEEL IS SECURELY FASTENED TOGETHER WITH TIE WIRE TO PROVIDE GOOD CONTINUITY.
4. ATTACH GALVASHIELD XP+ ANODES TO CLEAN REINFORCING STEEL AT AN EVEN SPACING WITHIN THE PATCH AREA OR AS OUTLINED IN THE CONTRACT SPECIFICATION. REFER TO GALVASHIELD XP+ DATA SHEET FOR MAXIMUM SPACING GUIDELINES.
5. POUR BACK REPAIR AREA WITH REPAIR MATERIAL AS PER CONTRACT SPECIFICATION. ANY MATERIAL USED SHALL NOT BE EPOXY BASED.
6. GALVASHIELD XP+ ANODES ARE GENERALLY ONLY INSTALLED ALONG THE PERIMETER OF THE REPAIR AREA WHERE ALL CHLORIDE CONTAMINATED CONCRETE HAS BEEN REMOVED. GALVASHIELD XP+ ANODES SHOULD BE PLACED ON A GRID PATTERN WITHIN THE INTERIOR OF THE REPAIR AREA WHEN CHLORIDE CONTAMINATED CONCRETE EXISTS IN CONTRACT WITH THE REINFORCING STEEL.

FED ROAD REG. NO.	STATE	CONTRACT NO.	SHEET NO.	TOTAL SHEETS
1	N.Y.			

P.I.N. | B.I.N. | COUNTY

ALL DIMENSIONS ARE IN m UNLESS OTHERWISE NOTED

AS BUILT REVISIONS

SIGNATURE | DATE

GALVASHIELD XP+
INSTALLATION SLAB PATCH REPAIR

STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION

REGION | DATE | DRAWING NO.

SLAB PATCH REPAIR

DESIGN SUPERVISOR | JOB MANAGER | DESIGNED BY | CHECKED BY | ESTIMATED BY | DRAFTED BY | CHECKED BY

Compatible Repair Materials

GALVANIC SYSTEMS

When incorporating galvanic corrosion protection systems into your rehabilitation plans, it is important that compatible repair materials and bonding agents be used. This list contains proprietary materials that are believed to be suitable for use with galvanic systems, it is not intended to be an exclusive list of approved materials.

Product	*Manufacturer*
C 1107 Grout	Bonsal
C 928 Repair Mortar	Bonsal
Commercial Anchor Cement	Bonsal
Fast Set Cement Mix	Bonsal
Poly-Mod Repair Mortar	Bonsal
Rapid Patch VR	Bonsal
Vinyl Concrete Patch	Bonsal
Forment	Conproco
Set	Conproco
Deep Pour EX	BASF Building Systems
LA40	BASF Building Systems
R310	BASF Building Systems
Five Star Construction Grout	Five Star Products
Five Star Grout	Five Star Products
FX 228	Fox
FX 263	Fox
FX 70-8	Fox
FX 70-8 DP	Fox
FX-225	Gemite
F80 Rocket Patch	Gemite
Control	Gemite
CP01	JE Tomes and Associates
CP02	JE Tomes and Associates
CT40	JE Tomes and Associates
CT40L	JE Tomes and Associates
Formflo CT-60	JE Tomes and Associates
Formflo X15	JE Tomes and Associates
Latex Liquid Mortar	King Package Materials
P38	King Package Materials
F.A. Concrete Repair	Sika Corporation
FA-S10	Sika Corporation
SikaSet Roadway Patch 2000	Sika Corporation
Sika Grout 212	Sika Corporation
Sika Grout 300 PT	Sika Corporation
Sika Quick 1000	Sika Corporation
Sika Quick 2500	Sika Corporation
Sika Repair 222 w/water	Sika Corporation
Sika Repair 223 w/water	Sika Corporation
Sikacrete 211	Sika Corporation
SikaShot NS	Sika Corporation
Sika Grout 328	Sika Corporation

VECTOR®

Compatible Repair Materials
for Use with Sentinel-GL Anodes

Product	Supplier
Eucocrete	Euclid Chemical Co.
Eucopatch	Euclid Chemical Co.
Form & Pour CP	Euclid Chemical Co.
ThinTop Supreme	Euclid Chemical Co.
ConcreteTop Supreme	Euclid Chemical Co.
Euco Verticoat	Euclid Chemical Co.
EucoShot-LR	Euclid Chemical Co.
Corr-Bond	Euclid Chemical Co.
Express Repair	Tamms
Spray Mortar	Tamms
SpeedCrete PM	Tamms
SpeedCrete Redline	Tamms
SikaRepair 222	Sika Corp.
SikaRepair 223	Sika Corp.
MasterFlow 713	Master Builders (BASF)
MasterFlow 928	Master Builders (BASF)
MasterPatch 230VP	Master Builders (BASF)
MasterPatch 240CR	Master Builders (BASF)
Powermix Patch	Power Crete
PowerGrout P	Power Crete
Polyfast LPL	Dayton Superior
Re-Crete 20	Dayton Superior

Appendix

Tables for determining spacing for Sentinel-GL anodes for No. 5, No. 6 and No. 7 reinforcement bars.

No. 5 bars

		Spacing (in)																			
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
	5	*0.79*	*0.72*	*0.67*	*0.64*	*0.61*	*0.59*	*0.57*	*0.56*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.50*	*0.50*	0.49	0.49	0.48	0.48	0.47	0.47
	6	*0.72*	*0.65*	*0.61*	*0.57*	*0.55*	*0.52*	*0.51*	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.43	0.42	0.42	0.41	0.41	0.41
	7	*0.67*	*0.61*	*0.56*	*0.53*	*0.50*	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.40	0.39	0.38	0.38	0.37	0.37	0.37	0.36	0.36
	8	*0.64*	*0.57*	*0.53*	0.49	0.46	0.44	0.42	0.41	0.40	0.39	0.38	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33	0.33	0.32
S	9	*0.61*	*0.55*	*0.50*	0.46	0.44	0.41	0.40	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31	0.30	0.30	0.30
p	10	*0.59*	*0.52*	0.48	0.44	0.41	0.39	0.37	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.29	0.28	0.28	0.27
a	11	*0.57*	*0.51*	0.46	0.42	0.40	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26	0.26	0.26
c	12	*0.56*	0.49	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25	0.25	0.24
i	13	*0.54*	0.48	0.43	0.40	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.24	0.24	0.24	0.23	0.23
n	14	*0.53*	0.47	0.42	0.39	0.36	0.34	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23	0.23	0.22	0.22
g	15	*0.52*	0.46	0.41	0.38	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.22	0.21	0.21
(in)	16	*0.52*	0.45	0.40	0.37	0.34	0.32	0.30	0.29	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22	0.21	0.21	0.20	0.20
	17	*0.51*	0.44	0.40	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.20	0.19
	18	*0.50*	0.44	0.39	0.35	0.33	0.31	0.29	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19
	19	*0.50*	0.43	0.38	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.19	0.18
	20	0.49	0.43	0.38	0.34	0.32	0.29	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18
	21	0.49	0.42	0.37	0.34	0.31	0.29	0.27	0.26	0.24	0.23	0.22	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.18	0.17
	22	0.48	0.42	0.37	0.33	0.31	0.29	0.27	0.25	0.24	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17
	23	0.48	0.41	0.37	0.33	0.30	0.28	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.17	0.16
	24	0.47	0.41	0.36	0.33	0.30	0.28	0.26	0.25	0.23	0.22	0.21	0.20	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16
	25	0.47	0.41	0.36	0.32	0.30	0.27	0.26	0.24	0.23	0.22	0.21	0.20	0.19	0.19	0.18	0.18	0.17	0.17	0.16	0.16	0.16

Tabulated values represent steel density ratios

Heavy
Moderate
Light

No. 6 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	*0.94*	*0.86*	*0.81*	*0.77*	*0.73*	*0.71*	*0.69*	*0.67*	*0.65*	*0.64*	*0.63*	*0.62*	*0.61*	*0.60*	*0.60*	*0.59*	*0.58*	*0.58*	*0.57*	*0.57*	*0.57*
6	*0.86*	*0.79*	*0.73*	*0.69*	*0.65*	*0.63*	*0.61*	*0.59*	*0.57*	*0.56*	*0.55*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.50*	*0.50*	*0.50*	0.49	0.49
7	*0.81*	*0.73*	*0.67*	*0.63*	*0.60*	*0.57*	*0.55*	*0.53*	*0.52*	*0.50*	0.49	0.48	0.48	0.47	0.46	0.45	0.45	0.44	0.44	0.43	0.43
8	*0.77*	*0.69*	*0.63*	*0.59*	*0.56*	*0.53*	*0.51*	0.49	0.48	0.46	0.45	0.44	0.43	0.43	0.42	0.41	0.41	0.40	0.40	0.39	0.39
9	*0.73*	*0.65*	*0.60*	*0.56*	*0.52*	*0.50*	0.48	0.46	0.44	0.43	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36	0.36
10	*0.71*	*0.63*	*0.57*	*0.53*	*0.50*	0.47	0.45	0.43	0.42	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34	0.33	0.33
11	*0.69*	*0.61*	*0.55*	*0.51*	0.48	0.45	0.43	0.41	0.40	0.38	0.37	0.36	0.35	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31
12	*0.67*	*0.59*	*0.53*	0.49	0.46	0.43	0.41	0.39	0.38	0.36	0.35	0.34	0.33	0.33	0.32	0.31	0.31	0.30	0.30	0.29	0.29
13	*0.65*	*0.57*	*0.52*	0.48	0.44	0.42	0.40	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.28
14	*0.64*	*0.56*	*0.50*	0.46	0.43	0.40	0.38	0.36	0.35	0.34	0.33	0.32	0.31	0.30	0.29	0.29	0.28	0.28	0.27	0.27	0.26
15	*0.63*	*0.55*	0.49	0.45	0.42	0.39	0.37	0.35	0.34	0.33	0.31	0.30	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.26	0.25
16	*0.62*	*0.54*	0.48	0.44	0.41	0.38	0.36	0.34	0.33	0.32	0.30	0.29	0.29	0.28	0.27	0.27	0.26	0.25	0.25	0.25	0.24
17	*0.61*	*0.53*	0.48	0.43	0.40	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.25	0.24	0.24	0.23
18	*0.60*	*0.52*	0.47	0.43	0.39	0.37	0.35	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.23
19	*0.60*	*0.52*	0.46	0.42	0.39	0.36	0.34	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.24	0.23	0.23	0.22	0.22
20	*0.59*	*0.51*	0.45	0.41	0.38	0.35	0.33	0.31	0.30	0.29	0.27	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.22	0.21
21	*0.58*	*0.50*	0.45	0.41	0.37	0.35	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.24	0.23	0.22	0.22	0.21	0.21	0.21
22	*0.58*	*0.50*	0.44	0.40	0.37	0.34	0.32	0.30	0.29	0.28	0.26	0.25	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.20
23	*0.57*	*0.50*	0.44	0.40	0.36	0.34	0.32	0.30	0.28	0.27	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.20
24	*0.57*	0.49	0.43	0.39	0.36	0.33	0.31	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.22	0.21	0.21	0.20	0.20	0.19
25	*0.57*	0.49	0.43	0.39	0.36	0.33	0.31	0.29	0.28	0.26	0.25	0.24	0.23	0.23	0.22	0.21	0.21	0.20	0.20	0.19	0.19

No. 7 bars

Spacing (in)	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
5	**1.10**	**1.01**	*0.94*	*0.89*	*0.86*	*0.82*	*0.80*	*0.78*	*0.76*	*0.75*	*0.73*	*0.72*	*0.71*	*0.70*	*0.69*	*0.69*	*0.68*	*0.67*	*0.67*	*0.66*	*0.66*
6	**1.01**	*0.92*	*0.85*	*0.80*	*0.76*	*0.73*	*0.71*	*0.69*	*0.67*	*0.65*	*0.64*	*0.63*	*0.62*	*0.61*	*0.60*	*0.60*	*0.59*	*0.58*	*0.58*	*0.57*	*0.57*
7	*0.94*	*0.85*	*0.79*	*0.74*	*0.70*	*0.67*	*0.64*	*0.62*	*0.60*	*0.59*	*0.58*	*0.56*	*0.55*	*0.55*	*0.54*	*0.53*	*0.52*	*0.52*	*0.51*	*0.51*	*0.50*
8	*0.89*	*0.80*	*0.74*	*0.69*	*0.65*	*0.62*	*0.59*	*0.57*	*0.56*	*0.54*	*0.53*	*0.52*	*0.51*	*0.50*	0.49	0.48	0.47	0.47	0.46	0.46	0.45
9	*0.86*	*0.76*	*0.70*	*0.65*	*0.61*	*0.58*	*0.56*	*0.53*	*0.52*	*0.50*	0.49	0.48	0.47	0.46	0.45	0.44	0.44	0.43	0.42	0.42	0.42
10	*0.82*	*0.73*	*0.67*	*0.62*	*0.58*	*0.55*	*0.52*	*0.50*	0.49	0.47	0.46	0.45	0.44	0.43	0.42	0.41	0.41	0.40	0.39	0.39	0.38
11	*0.80*	*0.71*	*0.64*	*0.59*	*0.56*	*0.52*	*0.50*	0.48	0.46	0.45	0.43	0.42	0.41	0.40	0.39	0.39	0.38	0.37	0.37	0.36	0.36
12	*0.78*	*0.69*	*0.62*	*0.57*	*0.53*	*0.50*	0.48	0.46	0.44	0.43	0.41	0.40	0.39	0.38	0.37	0.37	0.36	0.35	0.35	0.34	0.34
13	*0.76*	*0.67*	*0.60*	*0.56*	*0.52*	0.49	0.46	0.44	0.42	0.41	0.39	0.38	0.37	0.36	0.36	0.35	0.34	0.34	0.33	0.33	0.32
14	*0.75*	*0.65*	*0.59*	*0.54*	*0.50*	0.47	0.45	0.43	0.41	0.39	0.38	0.37	0.36	0.35	0.34	0.33	0.33	0.32	0.32	0.31	0.31
15	*0.73*	*0.64*	*0.58*	*0.53*	0.49	0.46	0.43	0.41	0.39	0.38	0.37	0.36	0.34	0.34	0.33	0.32	0.31	0.31	0.30	0.30	0.29
16	*0.72*	*0.63*	*0.56*	*0.52*	0.48	0.45	0.42	0.40	0.38	0.37	0.36	0.34	0.33	0.32	0.32	0.31	0.30	0.30	0.29	0.29	0.28
17	*0.71*	*0.62*	*0.55*	*0.51*	0.47	0.44	0.41	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.31	0.30	0.29	0.29	0.28	0.28	0.27
18	*0.70*	*0.61*	*0.55*	*0.50*	0.46	0.43	0.40	0.38	0.36	0.35	0.34	0.32	0.31	0.31	0.30	0.29	0.28	0.28	0.27	0.27	0.26
19	*0.69*	*0.60*	*0.54*	0.49	0.45	0.42	0.39	0.37	0.36	0.34	0.33	0.32	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.26	0.25
20	*0.69*	*0.60*	*0.53*	0.48	0.44	0.41	0.39	0.37	0.35	0.33	0.32	0.31	0.30	0.29	0.28	0.27	0.27	0.26	0.26	0.25	0.25
21	*0.68*	*0.59*	*0.52*	0.47	0.44	0.41	0.38	0.36	0.34	0.33	0.31	0.30	0.29	0.28	0.28	0.27	0.26	0.26	0.25	0.25	0.24
22	*0.67*	*0.58*	*0.52*	0.47	0.43	0.40	0.37	0.35	0.34	0.32	0.31	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23
23	*0.67*	*0.58*	*0.51*	0.46	0.42	0.39	0.37	0.35	0.33	0.32	0.30	0.29	0.28	0.27	0.26	0.26	0.25	0.24	0.24	0.23	0.23
24	*0.66*	*0.57*	*0.51*	0.46	0.42	0.39	0.36	0.34	0.33	0.31	0.30	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22
25	*0.66*	*0.57*	*0.50*	0.45	0.42	0.38	0.36	0.34	0.32	0.31	0.29	0.28	0.27	0.26	0.25	0.25	0.24	0.23	0.23	0.22	0.22

Tabulated values represent steel density ratios

Heavy
Moderate
Light

Sacrificial Cathodic Protection of Reinforced Concrete Bridges

F Jesmin[1], M. Moore[1], S Tao[1], A Beedles[1]

[1]Roads and Traffic Authority of NSW

Abstract Concrete deterioration due to reinforcement corrosion poses one of the greatest risks to the integrity of the Roads and Traffic Authority's (RTA's) bridge stock. As an alternative to Impressed Current Cathodic Protection (ICCP), the RTA is assessing the viability of Sacrificial Cathodic Protection (SCP) as a cost-effective remedial solution. Based on initial trial results, which demonstrated satisfactory corrosion protection, the RTA has implemented SCP as a full-scale rehabilitation technique on four bridges. Three different anode types have been installed. SCP would appear to offer 'installation cost' savings of up to 50%. Results to-date indicate the satisfactory performance of each system and the predicted service life would appear to be in excess of ten years, which suggests that the solution is cost effective in terms of 'whole-of-life' costs.

Introduction

The Roads and Traffic Authority (RTA) has a large number of reinforced concrete bridge structures that are located within an aggressive marine environment. Many of these structures are suffering from reinforcement corrosion that has been initiated by high levels of chloride ingress. In recent years the RTA has implemented a pro-active approach to identify concrete durability concerns at an early stage. Historically however, bridge assessments relied primarily on visual inspections to detect concrete defects, as part of a routine bridge inspection system. Unfortunately, due to the inherent nature of reinforcement corrosion, at the stage when significant visible deterioration is evident, corrosion activity is well advanced.

A recent global study of the corrosive state of the RTA's concrete bridges located within a marine environment [1] has revealed that, for the majority of bridges constructed prior to 1994, corrosion activity within the tidal and splash zones is widespread. Consequently, concrete deterioration due to reinforcement corrosion poses one of the greatest risks to the integrity of RTA's bridge stock and to main-

V. Ponnampalam, H. Madrio and E. Ancich
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tain the serviceability of these structures, long-term durability solutions are required.
Over the past several years, the RTA has primarily relied on Impressed Current Cathodic Protection (ICCP) for long-term durability rehabilitation; ICCP being the only proven technique for long-term protection regardless of the extent of chloride contamination. The RTA has installed 12 ICCP systems. However, installation costs are high and ongoing monitoring and maintenance is required. As an alternative form of corrosion control, the RTA has been assessing the viability of sacrificial cathodic protection (SCP).

Preliminary Research & Development (R&D) studies commenced in 2007 and the results were presented at the 2007 Australasian Corrosion Association (ACA) conference. More detailed studies and field trials of various anode types continued in 2008/2009 and this work was presented at the 2009 ACA conference [2].

Due to the favourable outcomes from the SCP R&D studies, the RTA has implemented this new technology as a full-scale rehabilitation solution on four bridges. This paper outlines the scope of these projects together with test data which indicates the level of corrosion protection and estimated service life.

Basic principles of Sacrificial CP

SCP utilises the effect of connecting two dissimilar metals in an electrolyte. The metal with the highest potential for corrosion will corrode in preference to the more noble metal in the galvanic series (ref Fig. 1). In concrete repair, a zinc anode will corrode in favour of reinforcing steel, thus controlling reinforcement corrosion.

Partial List of electrical Potentials

Material	Electrical Potential (V)*
Zinc	-1.10
Aluminum	-0.86
Cadmium	-0.77
Cast iron	-0.68
Carbon steel	-0.68

* All values with respect to copper-copper sulfate half-cell

Fig.1. Galvanic Series of Metals [3]

Sacrificial CP Systems Installed

The following table outlines the bridges that have been treated with SCP and the anode types that have been utilised. All bridges are located in a coastal environment and in each case corrosion of the reinforcement was initiated due to chloride attack from environmental salts (salt water splash/spray). Varying anode types were installed for the purpose of assessing their respective performance.

Table 1. Sacrificial CP Systems Installed

Bridge	Year Constructed	Location	Elements Treated	Anode Type
Boyd's Bay Bridge	1985	Tweed Heads	Pier columns	Discrete anodes
Terranora Bridge	1991	Tweed Heads	Pier columns	Strip anodes
Mororo Bridge	1935	North of Maclean	Piles	Strip anodes
Corunna Lake Bridge	1955	Narooma	Piles	Jacket anodes

Fig.2. Boyds Bay Bridge

Fig.3. Terranora Bridge

Fig.3. Mororo Bridge

Fig.5. Corunna Lake Bridge

The following figures show the various anode types installed on the above bridges.

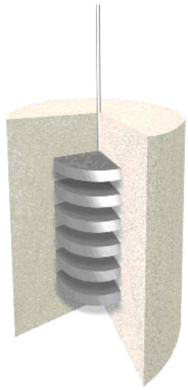

Fig.6. Discrete Anode

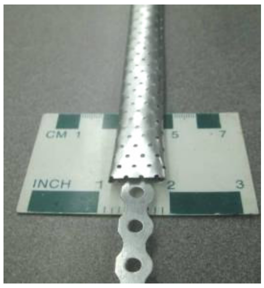

Fig.7. Strip Anode

Fig.8. Jacket Anode

The discrete anode comprises a zinc alloy contained in a highly alkaline encasement mortar. Zinc is more active in an alkaline environment and therefore the high alkalinity of the mortar aids in maintaining the zinc 'active (i.e. continues to corrode and provide protection).

The strip anode comprises a rod of zinc encapsulated in a chemical activator to maintain the zinc 'active'.

The jacket anode comprises a FRP jacket with expanded zinc mesh on the inside face. Chloride salts from the tidal saline water, which saturate the concrete 'infill' between the jacket and the structure, aid in maintaining the zinc 'active'.

Sacrificial CP Design and Anode Layout

Durability Investigation

Prior to determining the rehabilitation solution for each bridge, a detailed durability investigation was performed for the purpose of ascertaining:

- The corrosion mechanism;
- The extent of corrosion activity.

As noted above, for each bridge the corrosion mechanism was revealed to be chloride attack from environmental salts (salt water splash/spray). The extent of corrosion activity, being dependent on the severity of environmental exposure and the quality of the concrete (chloride resistance/ reinforcement cover), varied for each bridge, however for all bridges it was confined to within 2m above high-water level (HWL). The lower limit of SCP was dictated by the layout of the structure being treated; for example on Boyd's Bay and Terranora Bridge, application of SCP to the pile cap elements, located below HWL, was not considered feasible, nor necessary due to the relatively good condition of these elements.

Trial Installation

With the exception of Corunna Bridge, once SCP was identified as a likely remedial solution, a small trial system was installed for the purpose of:

- Confirming that the proposed anode type would provide adequate corrosion protection;
- Determining the appropriate anode size and spacing.

To measure the level of corrosion protection being provided by the anodes, Ag/AgCl/0.6M KCl reference electrodes were installed within the trial areas. Details of the trial installation are provided in the following figures. The reference electrodes are shown as solid rectangles within the figures.

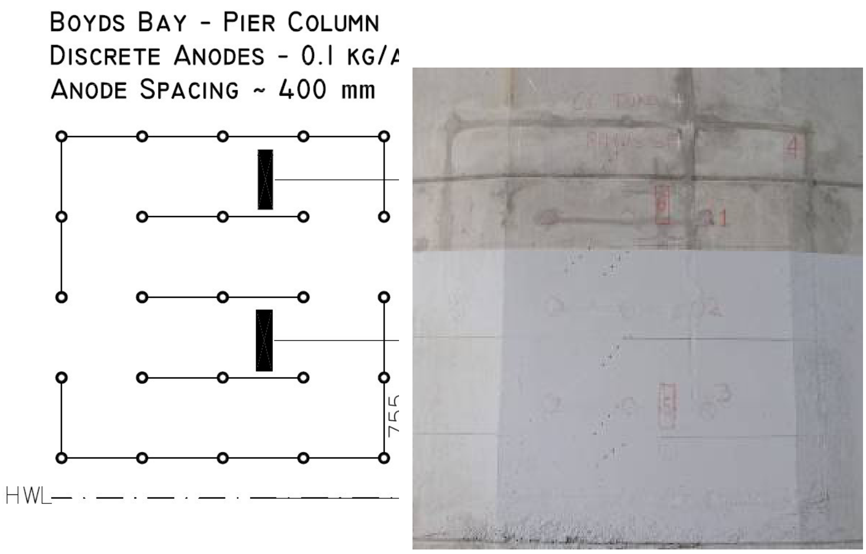

Fig.9. Boyds Bay Discrete Anode Trial

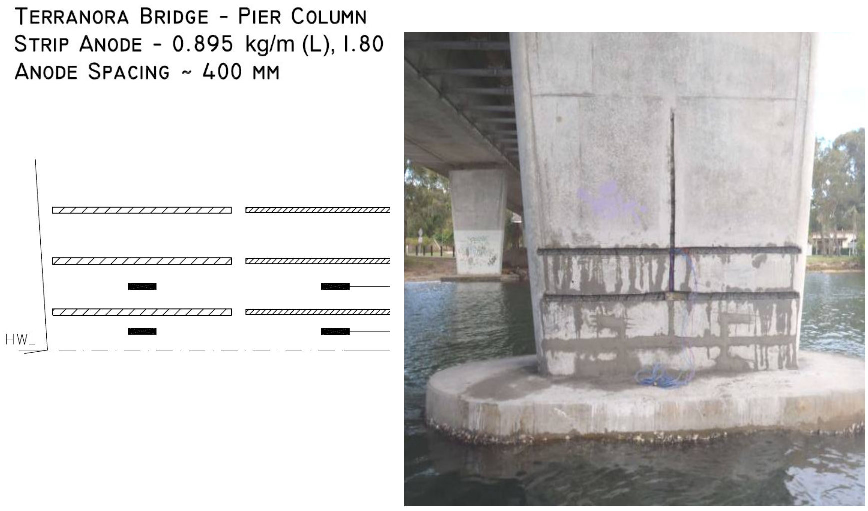

Fig.10. Terranora Bridge Strip Anode Trial

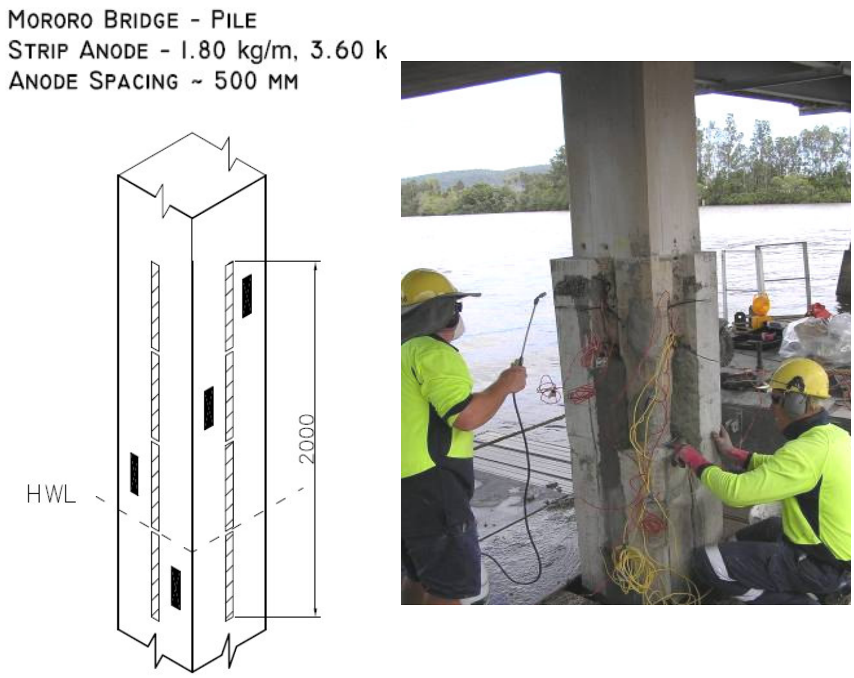

Fig.11. Mororo Bridge Strip Anode Trial

Anode Layout

Following on from successful outcomes from the trials, SCP designs were prepared for each bridge. The following figures provide details of the anode size, orientation and spacing for each bridge. Also noted, is the steel reinforcement density for each element being protected, expressed as surface area of reinforcement per concrete surface area.

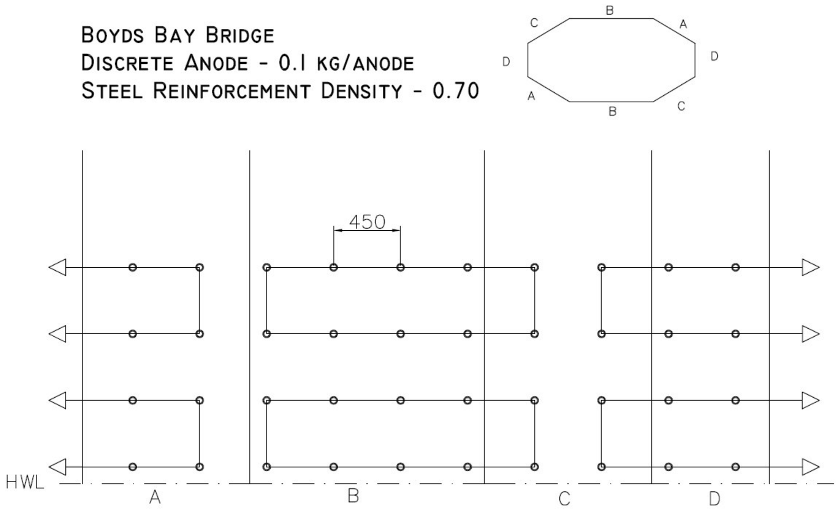

Fig.12. Boyds Bay Discrete Anode Layout

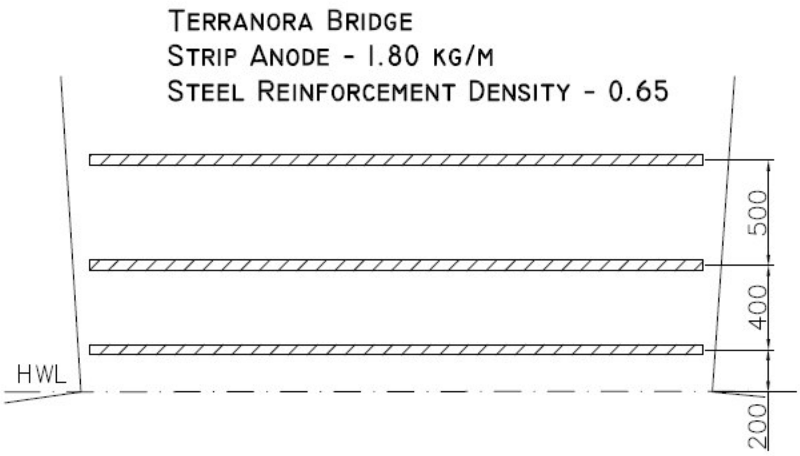

Fig.13. Terranora Bridge Strip Anode Layout

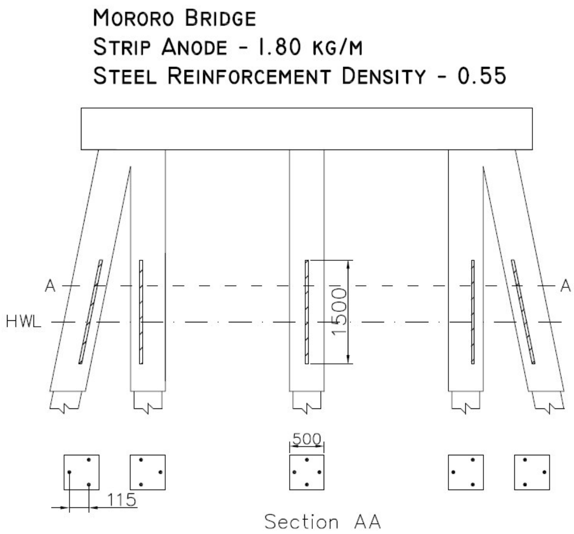

Fig.14. Mororo Bridge Strip Anode Layout

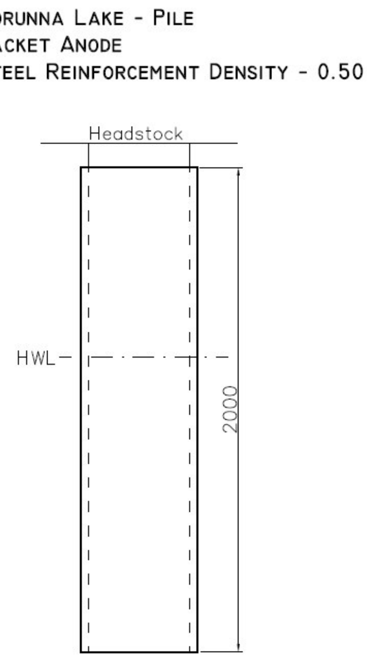

Fig.15. Corunna Lake Bridge Jacket Anode Layout

SCP System Performance Monitoring

As part of each SCP system, a number of Monitoring Zones (typically 3-4 per bridge) were installed for the purpose of measuring the performance of the SCP system at these select locations. These zones are similar to the trial areas, which were left in-place to act as an additional monitoring zone. Within each monitoring zone the performance of the system is assessed through measurements of potential (voltage) and current. Potential measurements provide an assessment of the level of corrosion protection that is being provided. Current measurements provide an assessment of the service life of the SCP system.

Potential Measurements

Within each monitoring zone a number of Ag/AgCl reference electrodes (typically 2-3 per zone) were installed for the measurement of the electro-chemical potential of the reinforcement, to assess the level of corrosion protection. Reference electrodes were located at various Reduced Levels (RLs), since the level of corrosion activity varies significantly with height, typically decreasing with height above water level. To facilitate the measurement of potentials, the reference electrodes, anodes and reinforcement were all connected via an external Switch Box with multi-meter connectivity.

Base (natural) potentials, Instant-off potentials and 24/48 hr-off potentials were all recorded in accordance with the Australian Standard for the cathodic protection of steel reinforcement in concrete structures [4]. Base potentials provide a measure of the initial corrosive-state of the reinforcement. The Instant-off potentials and 24/48 hr-off potentials provide a measure of the Potential Decay, which is calculated as the difference between these two values. The Potential Decay Criterion, as outlined within the Australian Standard, is the primary criterion that has been used to assess the level of corrosion protection. The Australian Standard states that a Potential Decay value of 100 mV or greater indicates that cathodic protection is being achieved.

Current Measurements

Within the monitoring zones, anodes located at different RLs were electrically isolated for the purpose of measuring individual currents from these anodes. As noted above, the level of corrosion activity varies significantly with height as does the ambient moisture and temperature conditions. Therefore anodes at different RLs are expected to discharge varying currents to reflect this. To facilitate the measurement of individual currents, anodes at different RLs were connected to separate channels of the Switch Box.

Monitoring Results

The monitoring results (potential and current measurements) for the SCP systems on each bridge are presented in the following tables. Note that the SCP systems have been installed for several months, with the exception of Terranora Bridge, where only data from the trial is available at this stage. Also note that longer-term data is available from each of the Trials since they were installed some months before each of the full-scale SCP systems, with the exception of Corunna Bridge, where no trial was installed. As indicated by the associated RL, all reference electrodes and anodes (e.g. 1-3) are numbered 'top to bottom' within each zone. "HWL" within each table refers to High Water Level.

Potential Readings

Ta**ble 2**. Boyds Bay Bridge – Discrete Anode SCP to Piers

Monitoring Zone	Reference Electrode	RL above HWL (m)	Base Potential (mV)	Potential Decays (mV)Table .					
				2 mths	7 mths	12 mths	20 mths	30 mths	36 mths
Trial	1	1.60	-340	238	231	200	136	112	124
	2	0.75	-393	228	222	200	145	120	123
1	1	0.60	-126	223	121	206	106	99	
	2	0.14	-272	50	37	46	23	23	
2	1	0.65	-213	95	73	72	52	53	
	2	0.30	-218	169	131	182	124	101	

The majority of the decay values exceed 100 mV indicating that cathodic protection is generally being provided. The high decay values for the Trial are particularly encouraging, considering the corrosive state of the reinforcement (very negative base potentials indicating a high level of corrosion activity) and the age of the system (3 yrs). For the reference cells that did not record >100 mV, the majority of these recorded >50 mV, which suggests that some level of corrosion control is being provided by the anodes.

Table 3. Terranora Bridge – Strip Anode SCP to Piers

Monitoring Zone	Reference Electrode	RL above HWL (m)	Base Potential (mV)	Potential Decays (mV)				
				0.5 mths	1.5 mths	2.5 mths	8 mths	11.5 mths
Trial	1	0.15	-66	136	108	126	223	136
	2	0.50	-134	49	40	49	84	47

Reference Electrode 1 has consistently recorded >100mV decay values, which is not surprising considering the 'less-corrosive' nature of the reinforcement (-66 mV base potential). By comparison, Reference Electrode 2, located in a more corrosive environment, has consistently recorded lower decay values. These lower decay values (~ 50mV), whilst not achieving the 100mV CP criteria, indicate that some level of corrosion control is being provided. The lower decay values for Reference Electrode 2 are also likely due to the fact that the bottom-most anode (located ~ 300mm above the pile cap – ref. Fig. 10) is 'protecting' a large area of steel reinforcement within both the base of the column and the pile cap. To improve the level of corrosion protection being provided at this location, the anode layout for the full-scale installation was modified by moving the bottom-most anode closer to the pile cap (300 mm spacing reduced to 200 mm – ref. Fig. 13).

Table 4. Mororo Bridge – Strip Anode SCP to Piles

Monitoring Zone	Reference Electrode	RL above HWL (m)	Base Potential (mV)	Potential Decays (mV)			
				1 mth	5 mths	7 mths	12 mths
Trial	1	0.70	481	1055	400		440
	2	0.18	141	590	436		351
	3	-0.35	-319	181	745		267
	4	-0.87	-475	130	171		167
1	1	0.75	-201			332	
	2	0.25	-296			325	
	3	-0.25	-395			114	
2	1	0.75	-205			381	
	2	0.25	-269			350	
	3	-0.25	-238			90	
3	1	0.75	-245			283	
	2	0.25	-301			225	
	3	-0.25	-395				

All potential decay results, with the exception of one reading, are > 100mV, indicating that cathodic protection is being provided. The one result < 100 mV (Zone 2, Reference Electrode 3), being 90 mV, indicates a very high level of corrosion control.

The higher decay results for this system, compared with Terranora Bridge (both systems comprising 1.8 kg/m strip anodes) is likely due to the piles of Mororo Bridge being less resistive (i.e. lower concrete resistivity) since they are more exposed to 'wetting' (splash/spray) compared with the piers at Terranora Bridge.

Table 5. Corunna Bridge – Jacket Anode SCP to Piles

Monitoring Zone	Reference Electrode	RL above HWL (m)	Base Potential (mV)	Potential Decays (mV)		
				1.5 mths	**6 mths**	**10.5 mths**
1	1	0.65	-198	62	77	90
	2	-0.12	-368	147	86	84
	3	-0.43	-613	93		88
2	1	0.70	-197	33	59	27
	2	-0.10	-261	101	72	91
	3	-0.40	-558	102	57	69
3	1	0.60	-234	56	17	16
	2	-0.05	-417	102	134	85
	3	-0.45	-499	101	97	110

The majority of the reference electrodes have consistently recorded decay values > 70 mV, which, whilst not achieving the 100mV CP criteria, indicates that a high level of corrosion control is being provided.

The notable exception to the above is the upper-most reference electrodes for Zones 2 and 3 (Reference Electrode 1), where the recorded decay values were significantly lower, with four results < 35 mV. These low results are likely due to the fact that the jacket anodes require environmental salts (tidal water) to maintain the zinc anode 'active' and the top reference electrodes are well above high water level (HWL). However, as evidenced by the base potential readings for these reference electrodes, the level of reinforcement corrosion is less and therefore the lower protection levels are less critical.

Current Readings

As noted above, anodes at various RLs are expected to output differing currents to reflect the variations in corrosion activity, moisture content and temperature. All anodes (e.g. 1-3) are numbered ‘top to bottom’ within each zone.

Table 6. Boyds Bay Bridge – Discrete Anode SCP to Piers

Monitoring Zone	Anode String (3 no. discrete anodes)	RL above HWL (m)	Current Output (mA)					
			2 mths	7 mths	12 mths	20 mths	30$^{(i)}$ mths	36 mths
Trial	1	1.40	3.5	2.0	3.2	1.6	0.9	1.4
	2	1.00	3.3	1.9	3.0	1.2	0.7	1.1
	3	0.60	3.9	2.2	3.6	1.9	1.1	1.8
1	1	1.25	2.2	1.0	1.2	0.7	0.5	
	2	0.85	1.7	1.0	1.2	0.8	0.6	
	3	0.45	4.7	2.1	2.5	1.5	1.0	
2	1	1.25	2.7	1.2	1.1	0.5	<0.1	
	2	0.85	2.5	1.0	1.1	0.5	<0.1	
	3	0.45	3.0	1.4	1.5	0.7	<0.1	

(i) Uncertainty in accuracy of readings – multimeter readout unstable

Table 7. Terranora Bridge – Strip Anode SCP to Piers

Monitoring Zone	Anode (1500 mm long horizontal anode)	RL above HWL (m)	Current Output (mA)			
			0.5 mths	2.5 mths	8$^{(i)}$ mths	11.5$^{(ii)}$ mths
Trial	1	1.10	2.1	2.7	2.8	<0.1
	2	0.70	2.6	3.3	4.4	<0.1
	3	0.30	2.9	3.0	19.3	<0.1

(i) High current readings likely due to recent floodwaters
(ii) Uncertainty in accuracy of readings – multimeter readout unstable

Table 8. Mororo Bridge **–** Strip Anode SCP to Piles

Monitoring Zone	Anode String (3-4 no. 500 mm long vertical anodes)	RL above HWL (m)	Current Output (mA)			
			1 mth	**5 mths**	**7 mths[(i)]**	**12 mths[(i)]**
Trial	1	0.70	3.6	7.2		<0.1
	2	0.18	5.0	6.3		0.1
	3	-0.35	17.2	8.1		0.1
	4	-0.87	20.0	9.3		0.1
1	1	0.75			<0.1	
	2	0.25			0.1	
	3	-0.25			0.1	
2	1	0.75			<0.1	
	2	0.25			0.2	
	3	-0.25			<0.1	
3	1	0.75			<0.1	
	2	0.25			<0.1	
	3	-0.25			0.1	

(i) Uncertainty in accuracy of readings – multimeter readout unstable

Table 9. Corunna Bridge – Jacket Anode SCP to Piles

Monitoring Zone	Anode (600 mm long section of jacket anode)	RL above HWL (m)	Current Output (mA)		
			1.5 mths	**6 mths**	**10.5 mths**
1	1	0.75	0.0	0.0	<0.1
	2	0.00	2.9	2.0	1.5
	3	-0.75	4.3	3.5	2
2	1	0.75	0	0	0
	2	0.00	3.4	2.9	1.9
	3	-0.75	4.9	3.4	2.2

For each bridge it is evident that, during the early stages of the system (initial 6-12 mths) there is generally more current output from the lower anodes. This is most likely attributable to the lower resistivity of the concrete that is closer to the water and more exposed to 'wetting' (splash/spray).

Of most interest, after the early stages (initial 6-12 mths), currents typically reduce to less than 2-3 mA per anode (or anode string). This suggests that the consumption of the anodes should be reasonably slow. Anode service-life can be estimated utilising a modified version of Faradays Equation. The following table estimates anode service life for each project based on conservative (upper limit) assumptions of current output and the assumption that the anode will remain active to consume the vast majority (at least 70%) of the zinc mass.

Table 10. Anode Service-Life Estimates

Project	**Anode Type**	**Anode density (m^2zinc/m^2concrete)**	**Assumed current output (mA)**	**Estimated Service-Life (yrs)**
Boyds Bay Br.	Discrete	0.5	2	~15
Terranora Br.	Strip	4.5	4	>20
Mororo Br	Strip	3.6	10$^{(i)}$	~12
Corunna Lake Br.	Jacket	8	4	>20

(i) This current is expected to reduce further with time

It should be noted however that more long-term and continuous current output data is required before service lives can be predicted with any degree of certainty. RTA is currently investigating the use of data-loggers and remote control units to facilitate these measurements.

Conclusions

- Of the three sacrificial anode types that have been installed by RTA, the Strip anodes (ref. Fig. 7) have demonstrated the best performance in terms of the level of corrosion protection being provided (refer Potential Decay results - Tables 3 & 4).
- The Strip anodes also appear to offer a reasonable service, based on early-age performance data. (ref. Table 10).
- From a practical perspective, Strip anodes cast within cut-chases appears to offer the simplest solution in terms of ease-of-installation, however as contractors gain more experience in the installation of SCP systems, alternate systems or installation techniques may prove to be more cost-effective.
- Overall, SCP would appear to offer significant cost advantages compared with impressed current CP. At this early stage, with only a few SCP projects completed, it is difficult to accurately compare installation costs, however it is estimated that cost savings of up to 50% may be realised. SCP would appear to be particularly cost-effective on smaller projects or where the extent of CP application is confined to a relatively small area.

Reference

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[3] Poner, (1991) Zinc Handbook

[4] Standards Australia (2008) AS 2832.5-2008 Cathodic protection of metals Part 5: Steel in concrete structure, Sydney

Galvanic Cathodic Protection of Corroded Reinforced Concrete Structures

David Whitmore, P.Eng., FACI, FICRI, FCSCE, NACE CP4
Vector Corrosion Technologies Ltd.
474 Dovercourt Drive
Winnipeg, MB Canada R3Y 1G4
DavidW@Vector-Corrosion.com

J. Chris Ball
Vector Corrosion Services, Inc.
102-3822 Turman Loop
Wesley Chapel, FL 33544

ABSTRACT

Reinforced concrete structures can be designed and maintained to achieve long service lives, even in aggressive chloride environments. Unfortunately, many structures, such as bridges, piers, and wharves, show signs of active corrosion (e.g. rust staining, concrete spalling, etc.) in as little as 5 to 10 years. Left unchecked, chloride induced corrosion can lead to a major structural problems. Many severely corroded structures have been replaced at great expense and with significant disruption to the public. As an alternative to demolition and replacement, a viable option is to repair and protect the severely deteriorated structures utilizing a galvanic encasement that both structurally upgrades and cathodically protects the structure. This approach can provide an effective, low maintenance galvanic cathodic protection solution for deteriorated concrete structures.

A galvanic encasement consists of distributed galvanic anodes embedded in a concrete overlay or concrete jacket. The galvanic encasement may include additional reinforcing steel to create a one-step structural repair and protection system. This paper presents case studies on the use of galvanic encasements to repair and protect reinforced concrete structures. Long term monitoring of field projects over more than 10 years indicates that effective cathodic protection can be provided for 20 to 40+ years.

INTRODUCTION

Chloride induced corrosion of reinforcing steel in concrete is a major problem worldwide. Chlorides can be introduced into the concrete via de-icing chemicals, seawater, or in certain cases as contaminants or additives in the initial concrete mix. This leads to localized breakdown of the normally passive steel reinforcement in the form of pitting corrosion (Figure 1).

Figure 1: Chloride-induced Pitting Corrosion on Concrete Reinforcement

Corrosion leads to concrete deterioration and local patch repairs are often performed to address this concrete damage. Patch repairs are completed by removing the cracked or spalled concrete, cleaning the steel locally and filling the cavity with fresh repair mortar or concrete (Figure 2[A]). Unless all chloride-contaminated concrete around the patch is removed, however, the repair process can lead to the formation of incipient anodes (Figure 2[A]), new corrosion sites just outside the repaired area driven by the difference in potential between the steel in the chloride contaminated and chloride-free sections [1,2].

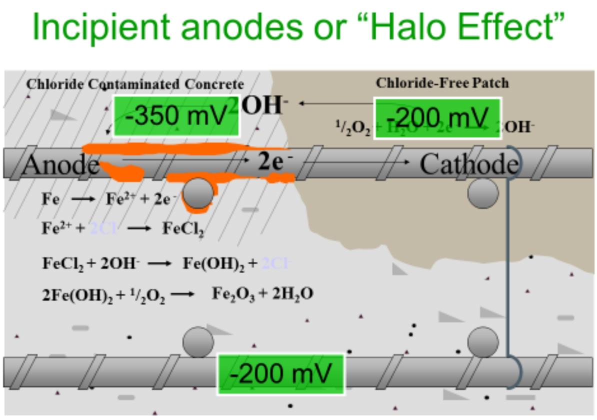

Figure 2[A]: Illustration of Corrosion around Concrete Patch Repair

Further repairs will be required and often, the whole repair process will need to be repeated several times over the remaining service life of the structure.

Installed Galvanic Anode

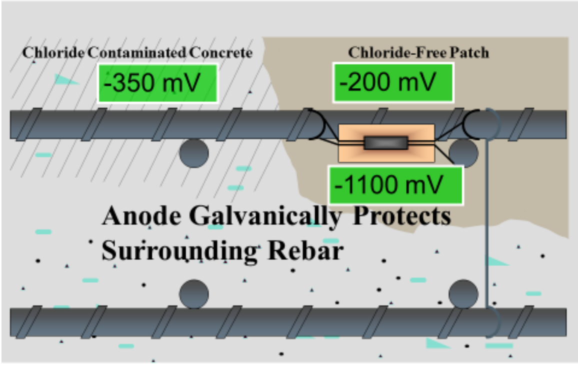

Figure 2[B]: – Illustration of Localized Galvanic Protection Protecting the Remaining Concrete Adjacent to Concrete Repair

This ‘localized’ problem has been eradicated by placement of discrete galvanic anodes around the perimeter of patch repairs (Figure 2[B]) which control incipient anode formation and avoid corrosion initiation [3,4]. One of the oldest monitored projects where such anodes were used has been monitored for over 16 years and is showing no signs of failure. The anodes are continuing to produce sufficient galvanic current to avoid corrosion initiation in the vicinity of the repairs, a phenomenon termed cathodic or corrosion prevention [5,6].

Similar galvanic anodes have been used in either a grid configuration or as elongated chains parallel to the main steel reinforcement to control low level steel corrosion in yet undamaged reinforced concrete elements which were shown to be at risk of corrosion or where incipient anode formation was considered to be a risk. This application is known as corrosion control where corrosion cannot initiate at new locations and locations where corrosion is already occurring is gradually reduced. These have also shown consistently good performance [7].

Continuous monitoring of field projects and further laboratory investigation has led to a better understanding of the performance and capability of galvanic anodes in a variety of environments. It is now recognised, for example, that chlorides are repelled away from the steel concrete interface owing to the negative charge which is imposed on the steel. This is aided by the cathodic reaction (1) and the migration of the alkali cations Na^+, K^+ & Ca^{++} to the steel which enhances the alkalinity around the steel. As a result, the chloride to hydroxide ratio [Cl^-/OH^-], the primary parameter that determines the corrosivity of the electrolyte, decreases substantially, the passive film is reinstated and steel corrosion subsequently ceases.

$$\tfrac{1}{2} O_2 + H_2O + 2e^- \rightarrow 2OH^- \qquad (1)$$

PERFORMANCE OF GALVANIC ANODES

Specially designed galvanic anodes were first installed in the late 1990’s to provide cathodic prevention (corrosion prevention) in concrete patch repairs. One of the first monitored installations was on a pier cap of a bridge in the UK (Figure 3).

Figure 3: Embedded Galvanic Anode Installation on a Bridge Pier Cap

A total of 12 anodes were installed at approximately 600mm centres along the perimeter of the repairs. The pier cap suffered from corrosion due to chloride contamination of up to 2% Cl^- by weight of cement at the depth of the steel. The galvanic anodes were connected to the steel via a junction box allowing monitoring of the current. Figure 4 summarises the mean current density delivered by the anodes to the steel. The range is comfortably within the 0.2-2.0 mA/m^2 current density suggested for cathodic prevention over the entire 15-year period (Figure 4). More importantly, there is no evidence of corrosion initiation either within or around the periphery of the patch repair. Removal and examination of two anodes showed that over half the zinc mass was still available for continued protection such that the service life of the anodes is likely to be 25 to 35 years.

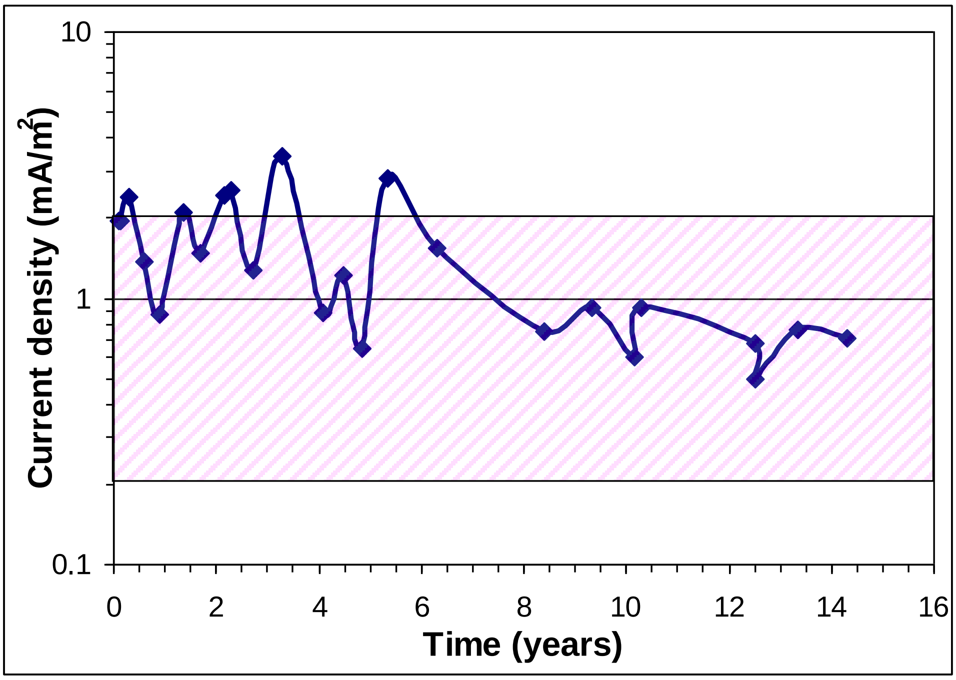

Figure 4: Current density to the reinforcing steel (mA/m^2) plotted vs time. Shaded area indicates current density for cathodic prevention (corrosion prevention) as per EN12696 (0.2 to 2.0 mA/m^2)

GALVANIC CATHODIC PROTECTION

Historically, cathodic protection systems required an impressed current power supply to provide sufficient current to the reinforcing steel. This is no longer the case as properly designed galvanic encasements using high output, long life distributed galvanic anodes can provide sufficient current density to polarize the reinforcing steel and meet all NACE Cathodic Protection (CP) criteria.

This portion of the paper describes four projects where long term cathodic protection has been provided galvanically to bridge abutments, decks and columns.

a) Ohio DOT Bridge Substructure
b) Ontario Ministry of Transportation Bridge Deck
c) New York State DOT Marine Columns (Tidal / Splash Zone)
d) Florida DOT Marine Substructures (Above Tidal Zone)

Ohio DOT Substructure

This bridge was repaired in July, 2005 with a galvanic encasement. The ODOT bridge substructure repair included re-facing the abutments of multiple bridges with distributed embedded galvanic anodes designed to provide cathodic protection (Figures 5 & 6[A]) for the steel in the entire abutment. The bridge has been monitored as part of an ODOT technology evaluation program since May, 2005. (Figure 6[B]).

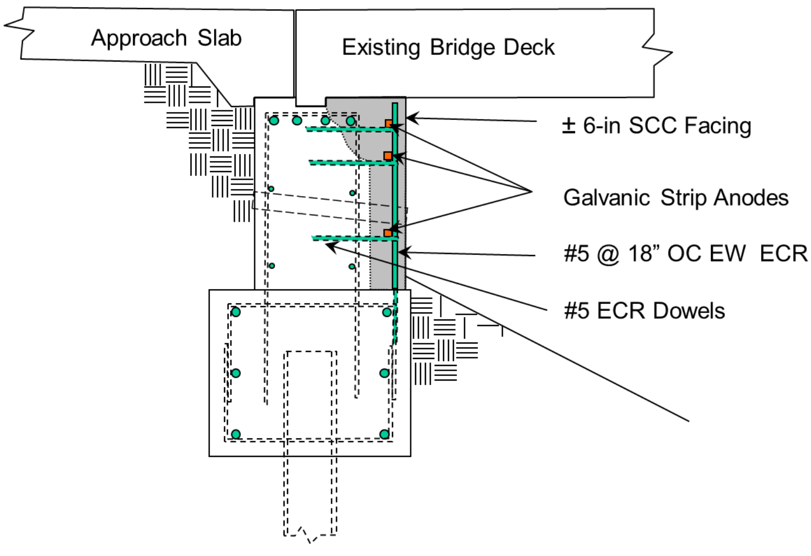

Figure 5: Galvanic Encasement of Abutment

Figure 6[A] –Galvanic Distributed Anodes Installed Across Face of Abutment

Figure 6[B]: Distributed Anode System Monitoring Cabinet

The monitoring program included the installation of dataloggers to monitor the current flowing from the galvanic anodes to the reinforcing steel as well as the temperature of the concrete itself (Figure 7). In addition to the dataloggers, current, potentials and polarization was measured manually when personnel visited the project site (Figure 8).

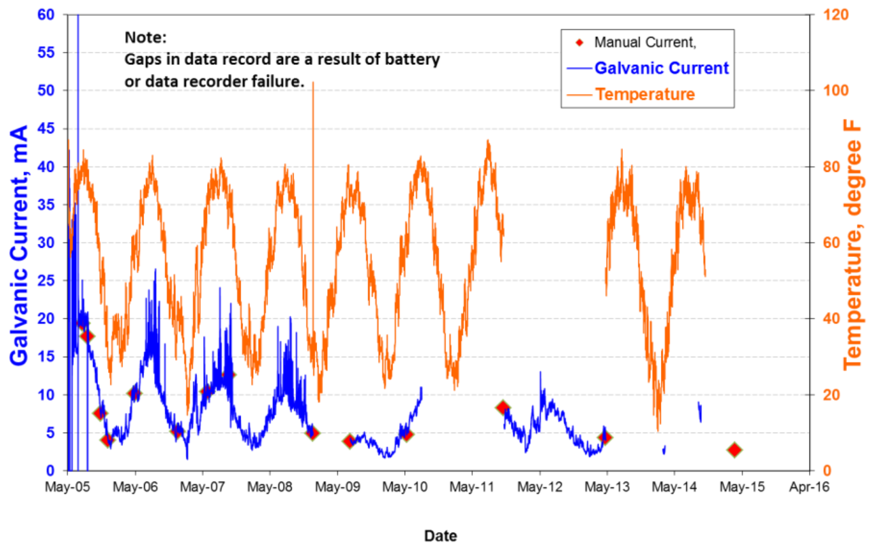

Figure 7: Ohio DOT Galvanic Current and Temperature History

Galvanic current data collected at regular intervals can be integrated to precisely calculate the consumption of the galvanic anodes. The calculated anode life is approximately 35 years. This calculation includes an anode utilization factor of 0.8 and an anode efficiency factor of 0.9.

Ohio DOT: Galvanic CP Data

Date	Temp	mA/m2	Polarization
5/6/05	(C)	37.7	(mV)
8/16/05	31	12.9	333
12/7/05	11	3.2	339
5/1/06	14	7.5	335
5/30/07	26	7.5	446
12/09/08	4	3.3	470
5/11/2010	12	3.3	485
10/16/2011	22	6.6	488
4/22/2013	21	3.3	425
3/24/2015	2	2.2	381

Figure 8: Ohio DOT Galvanic CP Polarization Data

The performance data indicates that the installed galvanic cathodic protection system is performing well. The following cathodic protection criteria are satisfied:

- Cathodic polarization shift exceeds 100 mV,
- the polarized instant-off potential has generally been more negative than -850 mV vs CSE, and
- Polarization of the reinforcing steel is requiring less current density over time. Calculated service life is now more than double the design service life as the average current density has been significantly less than the design current density.

The abutment is in very good condition 10 years after the galvanic encasement was completed. Prior to completing this galvanic encasement, this type of abutment was being repaired every 5 to 7 years.

The performance of this galvanic encasement installation verifies the system has been providing galvanic cathodic protection for over 10 years. Service life calculations indicate there is sufficient zinc for the system to provide corrosion protection for 35 years.

Ontario Ministry of Transportation (MTO) Bridge Deck Overlay

Due to long-term exposure to de-icing chemicals the bridge deck of the North Otter Creek Bridge (MTO) was chloride contaminated and required repair. In 2003, the Ontario Ministry of Transportation (MTO) decided to place a galvanic cathodic protection overlay on the bridge deck.

Figure 9: Bridge Deck after Milling

The bridge deck was prepared by milling off a portion of the existing concrete cover. As a result the majority of the existing reinforcing steel was to remain in chloride contaiminated concrete. A ‘distributed’ galvanic cathodic protection system consisting of elongated galvanic anodes placed in rows and connected to the existing reinforcing steel was installed. The galvanic anodes consisted of a zinc core encased in a low resistivity alkali-activated mortar shell and were prefabricated to fit the dimensions of the deck. (Figure 10)

A carbon fiber grid was installed to reduce shrinkage and minimize cracking of the 2.5 inch (60 mm) thick silica fume deck overlay (Figure 10).

Figure 10: Installation of Distributed Galvanic Anodes and Carbon Fiber Grid prior to Concrete Overlay

MTO Galvanic CP Bridge Deck Overlay

Date	Temp C / F	Current (mA)	Current/m2 (mA/m2)	Polarization (mV)
Oct. 3, 2003	7 / 45	169	6.5	273
May 10, 2004	20 / 68	99	3.8	271
Jan. 18, 2005	-20 / -4	14	0.55	142
July 27, 2005	20 / 68	47	1.8	313
Nov. 17, 2005	0 / 32	30	1.1	276
Apr. 19, 2006	10 / 50	38	1.4	330
July 26, 2006	25 / 76	43	1.6	353
Apr. 11, 2007	-3 / 27	27	1.0	201
Aug. 23, 2007	22 / 71	41	1.5	501
Jan. 10, 2008	0 / 32	29	1.1	322
May 12, 2009	21 / 70	38	1.4	285
Sept. 25, 2010	19 / 66	35	1.3	305
June 7, 2012	22 / 71	46	1.8	278
Nov. 7, 2013	4 / 39	29	1.13	388
Oct. 6, 2015	13 / 55	28	1.1	423

Figure 11: MTO Galvanic CP Bridge Deck Overlay Performance Data

The bridge deck has been monitored since 2003 and remains in good physical condition. The galvanic cathodic protection overlay is providing over 100 mV polarization and is meeting the NACE cathodic protection standard for cathodic protection (Figure 11) even though the anodes are in a dry environment beneath the silica fume concrete overlay and bridge deck waterproofing system installed on top.

New York State DOT Marine Columns (Splash Zone)

In 2006, New York State DOT completed a project on the Robert Moses Causeway to Long Island, NY (Figure 12[A]). The project included installation of galvanic cathodic protection jackets to protect the tidal and splash zone of 764 columns (Figure 12[B]).

Figure 12[A]: Alkali-activated Distributed Galvanic Anodes for Pile Protection on the Robert Moses Causeway

Figure 12: FRP Concrete Placement and Jacket Elevation at High Tide

Monitored jackets have met cathodic protection criteria by providing greater than 100 mV polarization. NYSDOT specified a 35 year design service life for the column jackets. Service life calculations based on data from monitored jackets predicts that the system contains enough zinc to last over 70 years.

Florida DOT Marine Columns (Above Splash Zone)

These Florida DOT marine bridges located in south Florida and the Florida Keys were suffering from corrosion due to chloride contamination from storm surges and atmospheric exposure (Figure 13).

Figure 13: Deteriorated Columns and Removal of Damaged Concrete

Florida DOT has utilized other corrosion protection options such as arc-sprayed zinc and zinc mesh jackets on this type of structure in the past with limited success. These projects utilized distributed alkali activated galvanic anodes installed inside stay-in-place forms (Figure 14).

Figure 14: Installation of Alkali-Activated Galvanic Anodes and Jacket

The stay-in-place form can be fiberglass or PVC with PVC having the advantage of being modular and providing greatly improved durability and bonding with the concrete column.

Figure 15: Installed PVC Galvanic Cathodic Protection Jacket with Monitoring Station

As with all FDOT projects, monitoring provisions were provided when the column jackets were installed such that the long-term performance and effectiveness in providing cathodic protection could be verified (Figure 15).

FDOT has used zinc mesh galvanic jackets to protect reinforcing steel in the splash zone. Research has shown these jackets to be effective if they are kept wet but the zinc mesh will become more passive and generate less protective current for each foot of elevation above the high tide line. Since these columns are fully above the high tide line activated zinc anodes were specified and installed (Figure 16).

Figure 16: Installed Above-Water Alkali-Activated Galvanic Cathodic Protection Jackets

The alkali-activated galvanic cathodic protection jackets are installed and are being monitored by FDOT. Monitoring parameters include potentials, current, polarization and service life. Due to the number of monitored columns, the raw data is too voluminous to present herein. Since the first columns were completed in 2012, the jacketed columns have met or exceeded the NACE cathodic protection criteria by polarizing the reinforcing steel more than 100mV.

	mA	On (mV)	Off (mV)	Pol. (mV)	Notes
Static/native		-458			
On	725				
16 hrs	228	-997	-825	-367	vs static
20 days	98	-931	-652	-238	4 hours
90 days	72	-912	-657	-293	21 hours
118 days	n/a	-905	-667	-205	vs static
270 days	54	-867	-664	-236	2 hours
594 days	67	-924	-679	-330	14 hours

Figure 17: Long Term Monitoring of Alkali-Activated Galvanic Cathodic Protection Jacket in the Florida Keys

CONCLUSIONS

- Alkali-activated discrete galvanic anodes installed in the 1990's remain active and have provided Corrosion Prevention (Cathodic Prevention) current densities to reinforcing steel adjacent to patch repairs for over 15 years. Examination of anodes verify there is sufficient zinc remaining to last 25 to 30 years. As such, alkali-activated discrete galvanic anodes in patch repairs provide a low cost and simple to monitor approach which can significantly extend the service life of localized concrete repairs.

- Galvanic anode systems can be designed to meet cathodic protection criteria by polarizing the reinforcing steel by 100mV or greater.

- Galvanic cathodic protection systems can be designed to provide low maintenance cathodic protection for 20 to 40+ years.

- Current densities required to polarize the reinforcing steel typically decrease over time as hydroxide ions are generated at the steel / concrete interface and the steel becomes more passive. As a result, actual service life may be greater than the calculated design service life since the average current density may be less than the design current density.

- Galvanic cathodic protection systems can be designed to provide long-term cathodic protection to structural concrete components in a range of environments including:
  - Bridge substructures in temperate, de-icing salt environments,
  - Bridge decks in temperate, de-icing salt environments,
  - Bridge piles in marine tidal / splash zones, and
  - Bridge columns in tropical, marine environments above the tidal zone.

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OTEC 2007 - Bridge Innovation

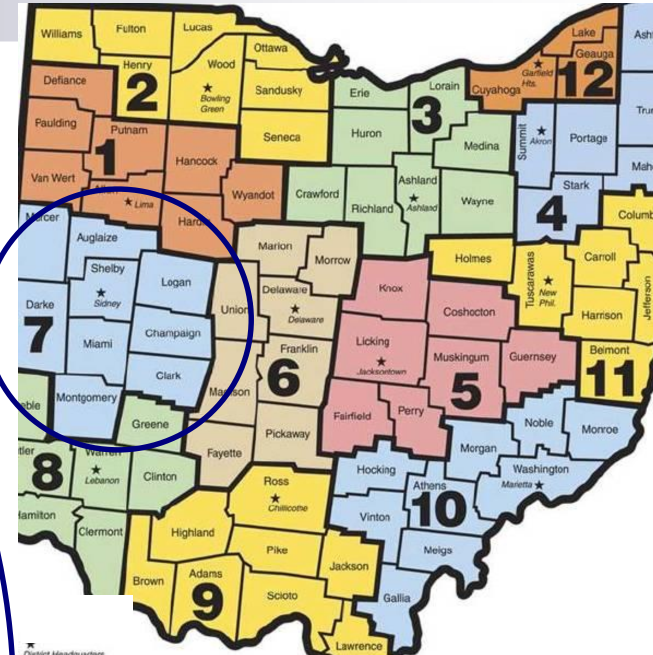
Performance of Distributed Anode System for Slab Bridge on I-75

Brad Lightle, P.E.

ODOT - District 7, Planning

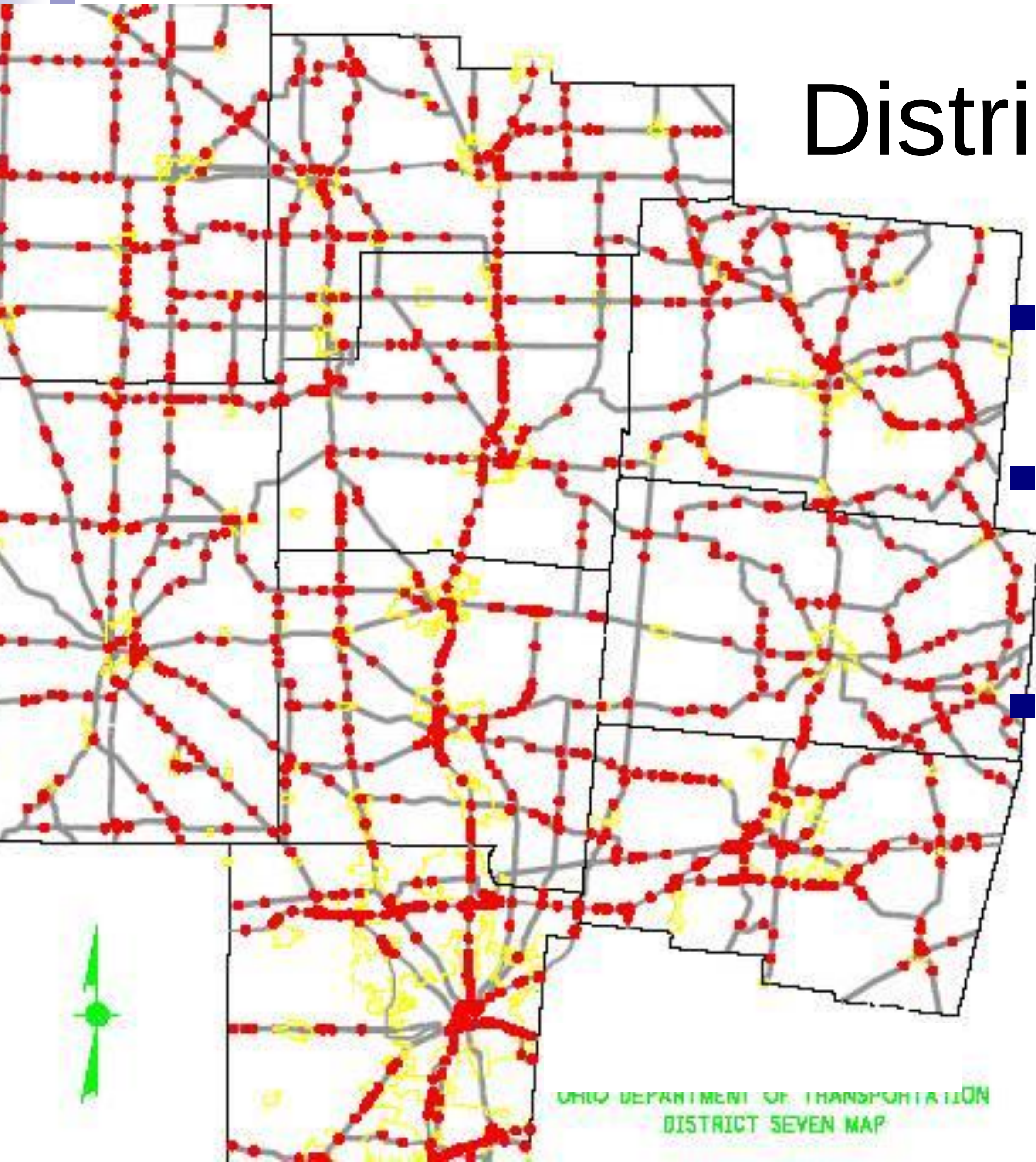
Chris Ball

Vector Corrosion Technologies



ODOT District 7

District 7 Bridges

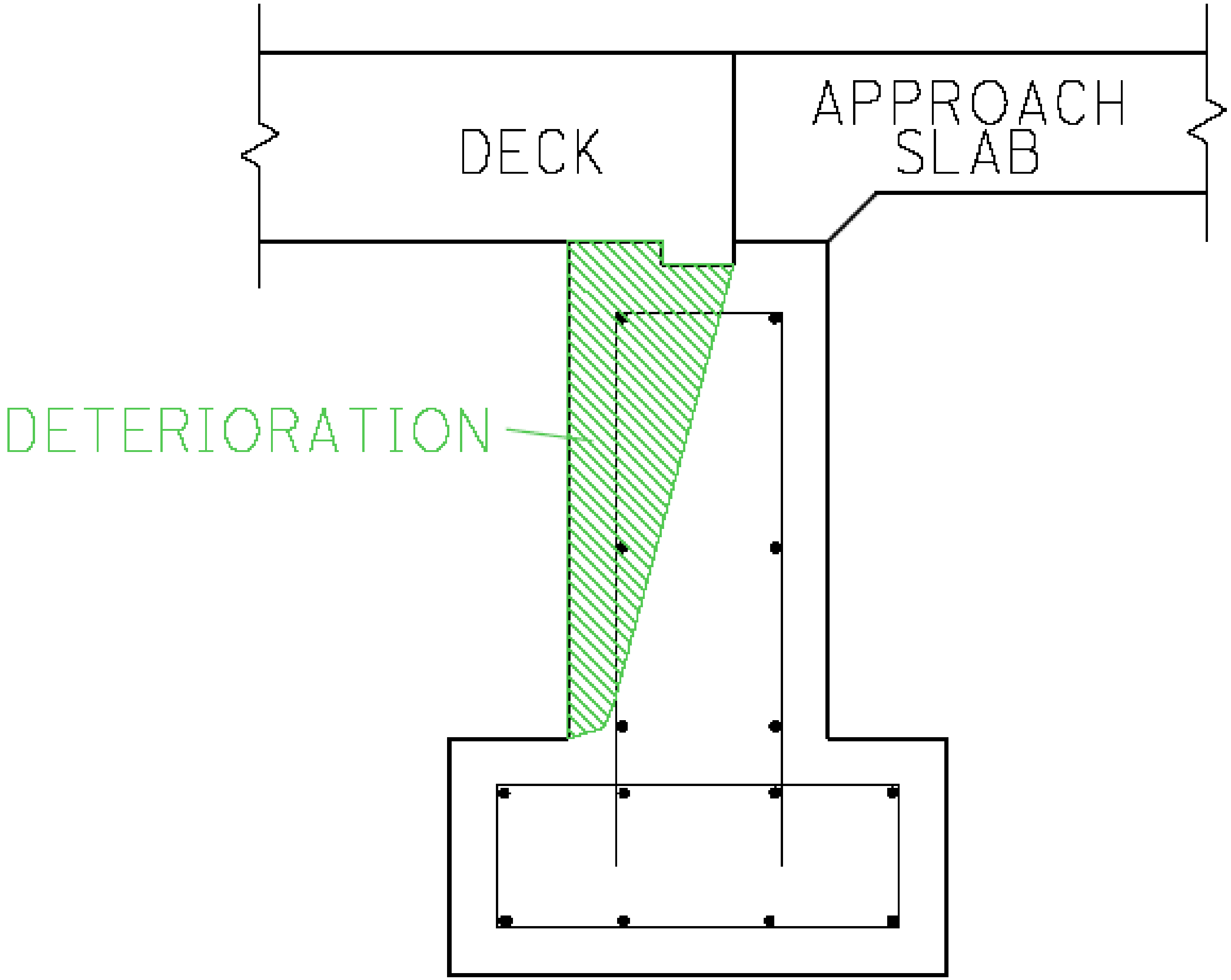


- 1408 Bridges
- 250 Continuous Slab Bridges
- Of 250 Continuous Slab Bridges, 225 have abutments rated 2,3, or 4

On Many Slab Bridges…

- Slabs are in good condition
- Deterioration at abutment around the key way

Cross-Section of Slab / Stub Abutment



Options

- 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

Past Practice for Repairs

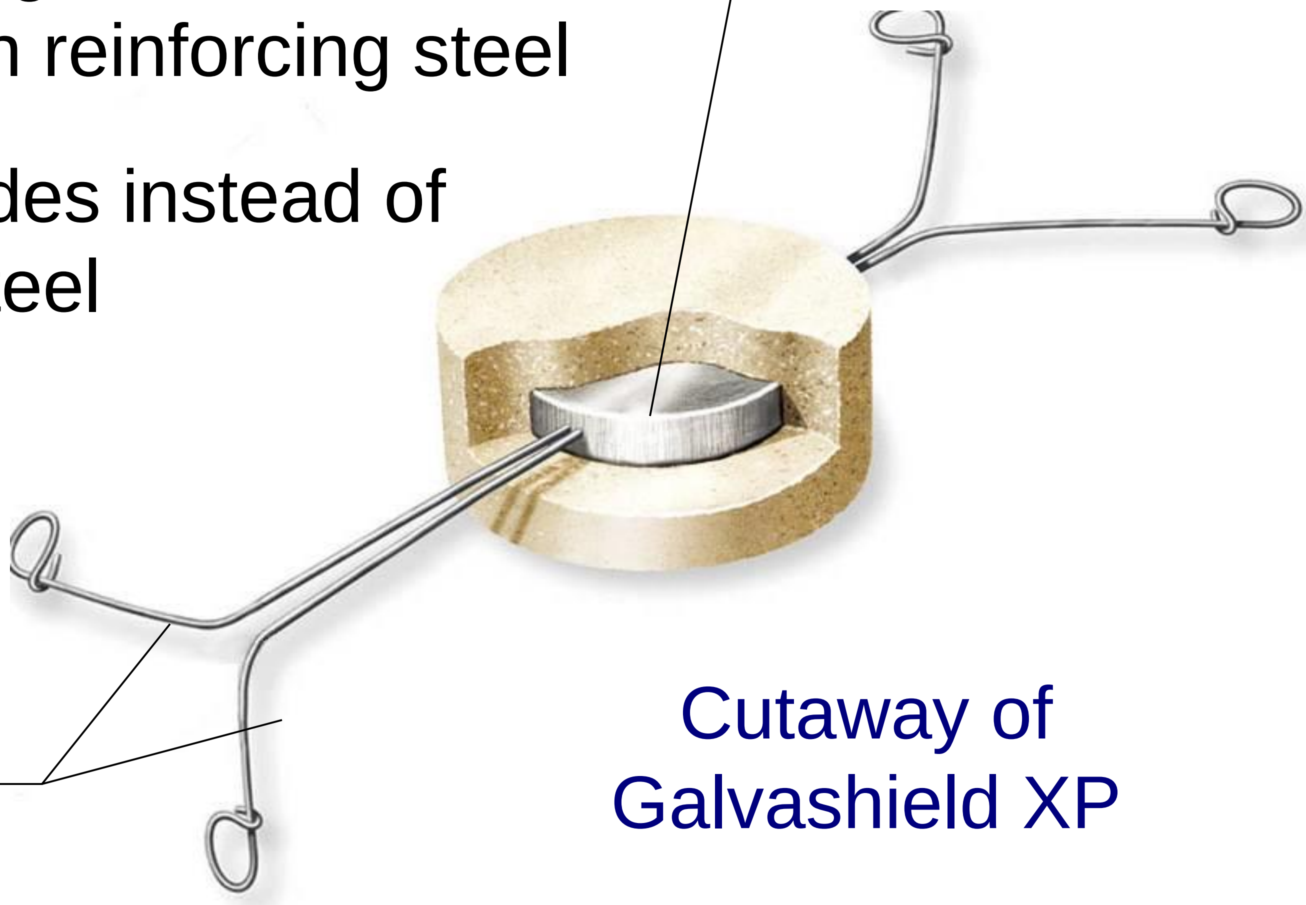
- Slab would be temporarily supported
- Abutments would be replaced
- Requires closure or part-width construction

Maintenance of Traffic

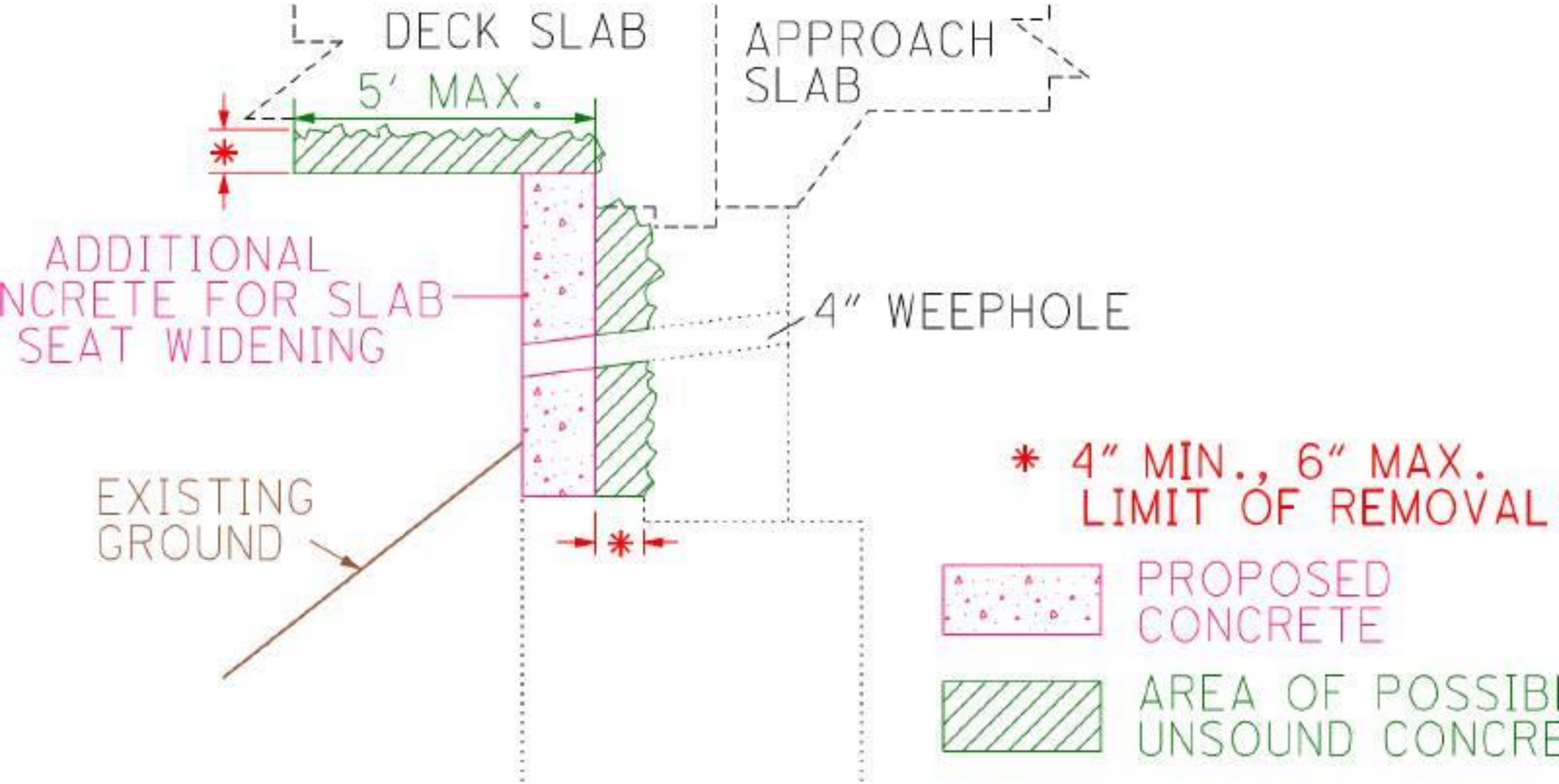

7 14:24

What Anode Is and How It Works

- Anode has higher corrosion potential than reinforcing steel
- Anode corrodes instead of reinforcing steel



Cutaway of Galvashield XP



SECTION A–A

CONCRETE REMOVAL AND REPLACEMENT

Concrete Removal

- Remove less than 6”
- If more than 6”, contractor to perform structural assessment
- Temporary shoring may be needed

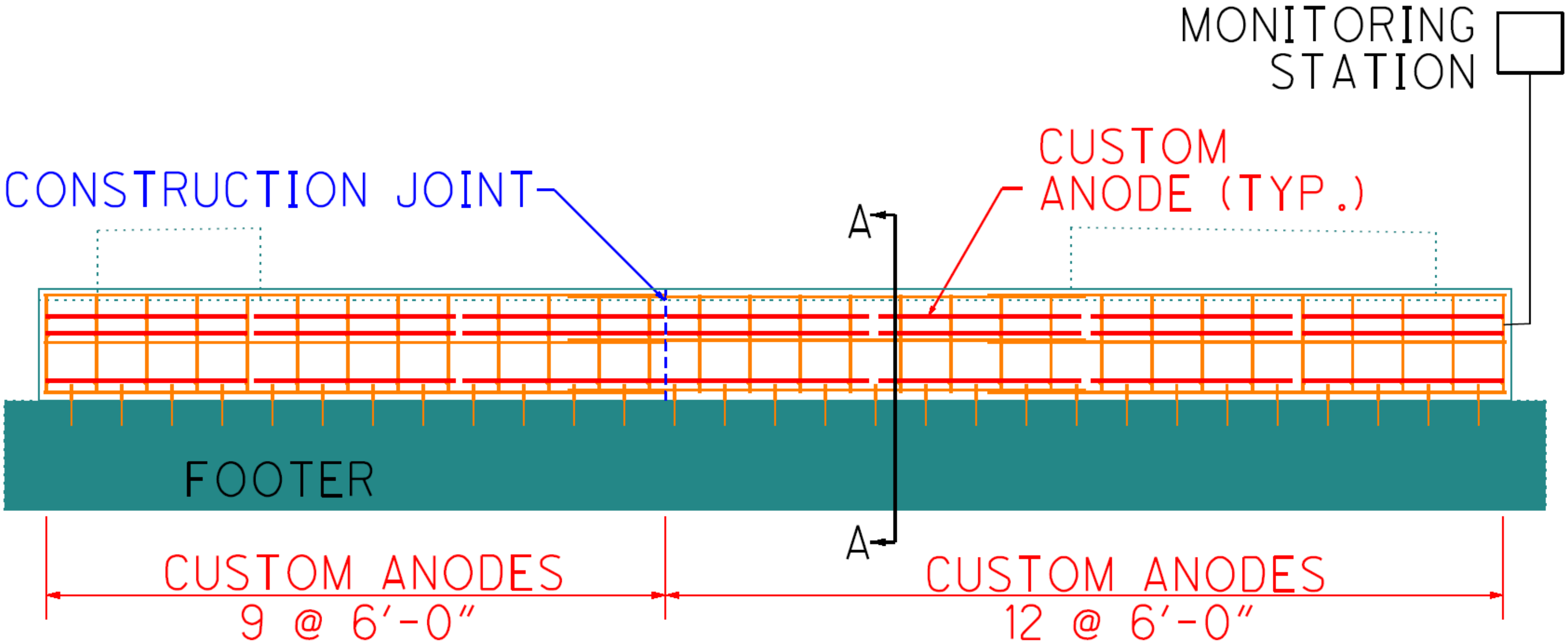

7 14:24

Part Width for Superloads

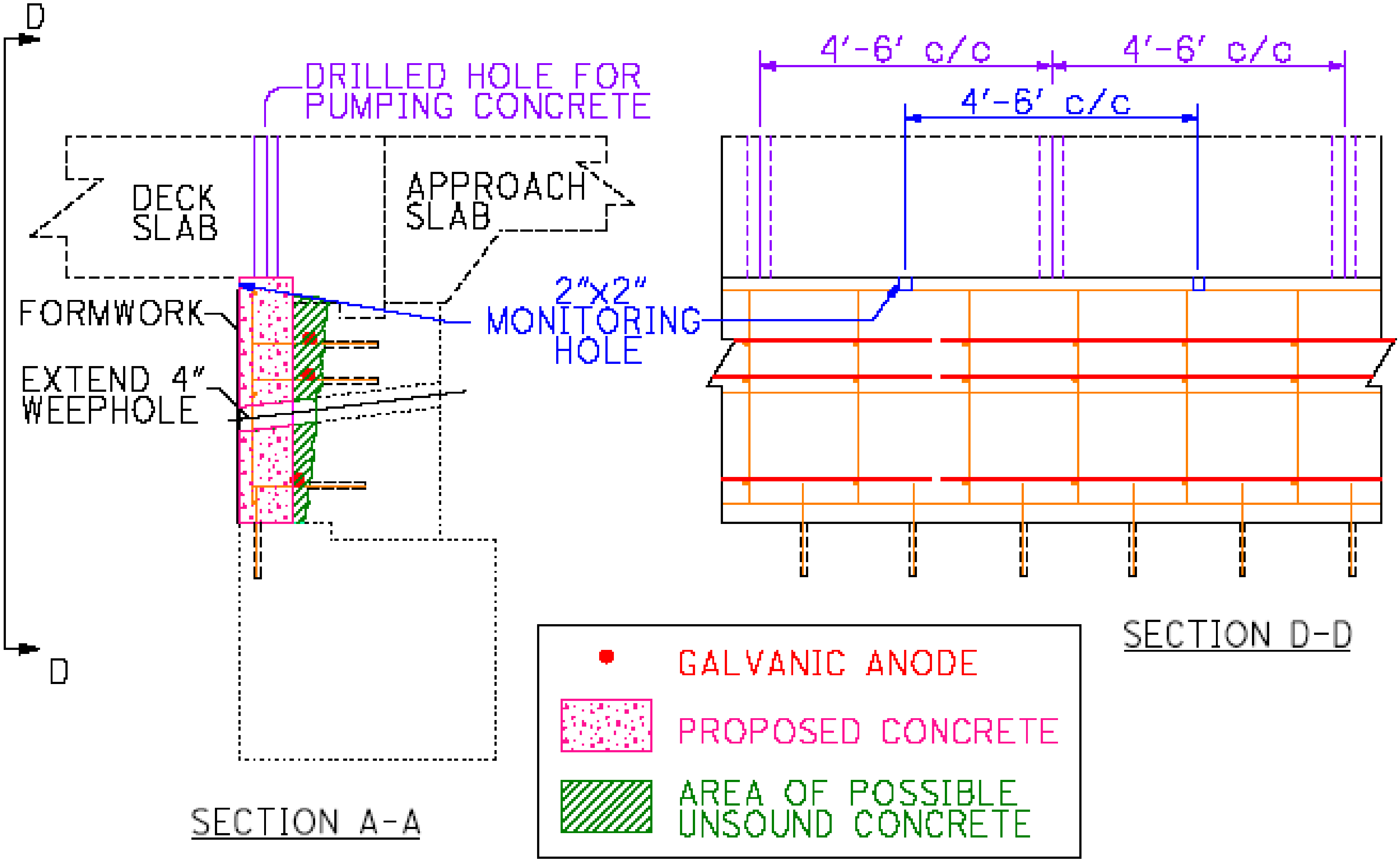
- Blanket permits issued up to 120,000 lbs.
- Loads must be accommodated throughout rehabilitation process

Strip Anodes

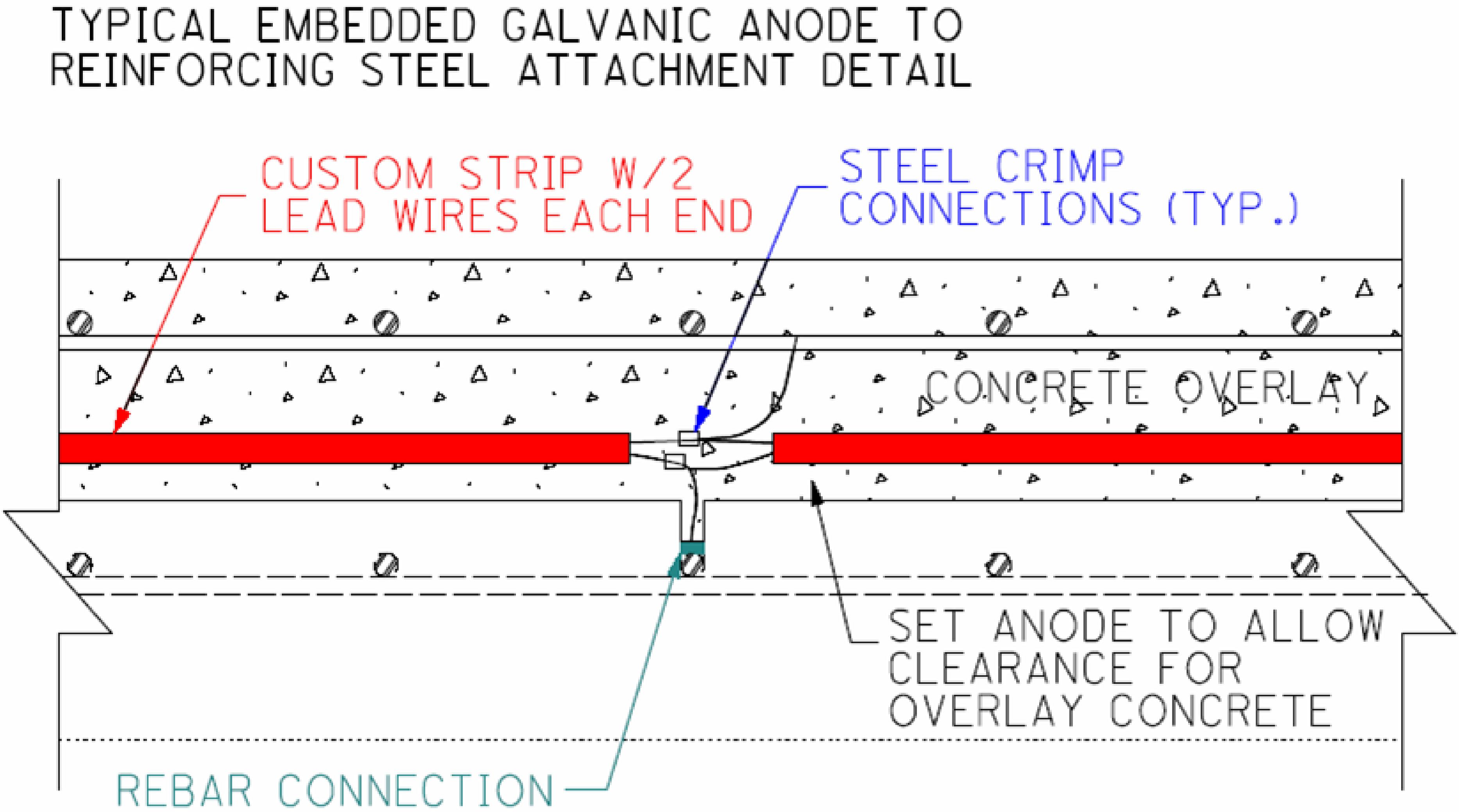
Elevation View with Anodes



Cross Sections with Anodes

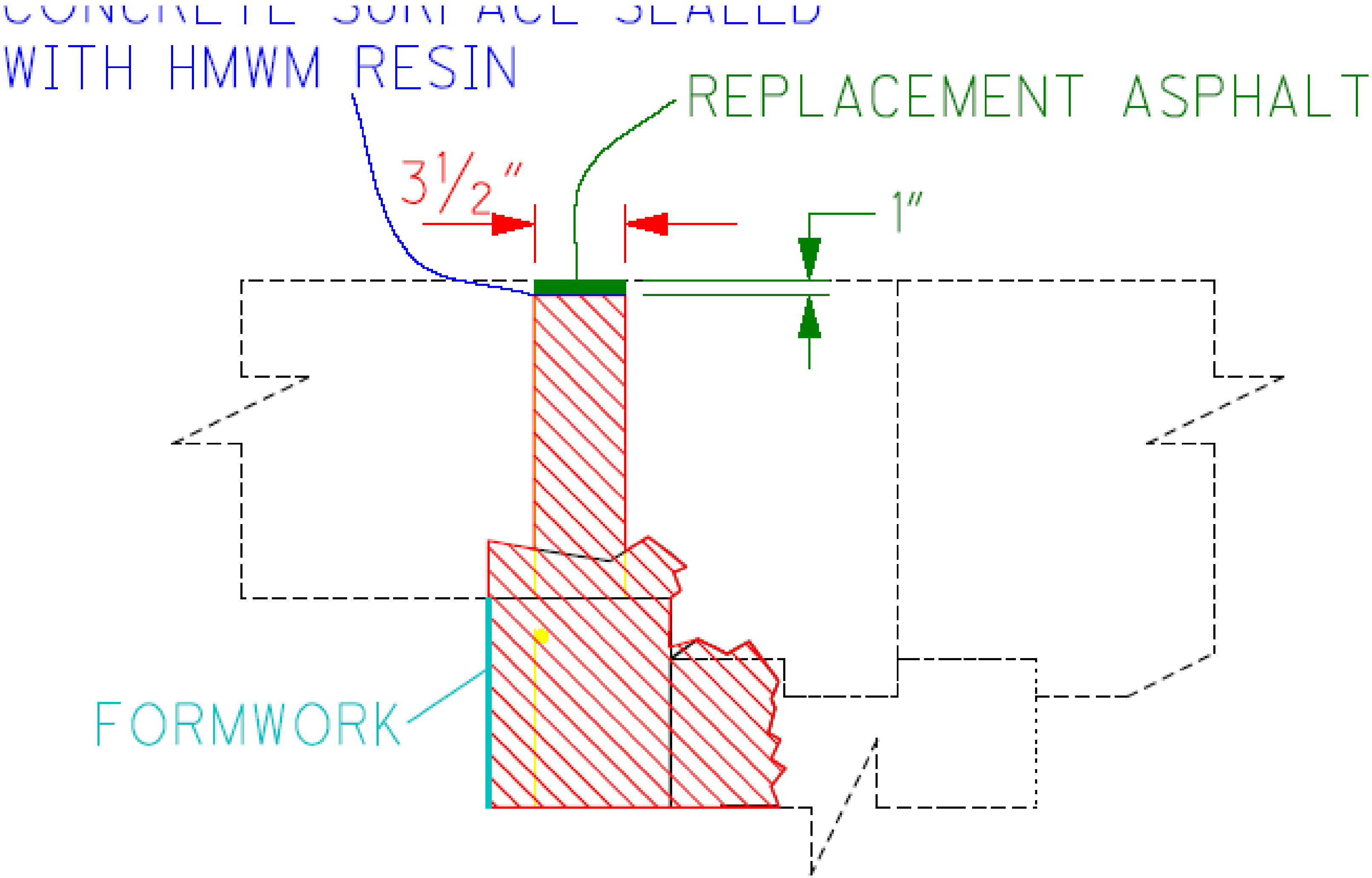


Plan View


TYPICAL EMBEDDED GALVANIC ANODE TO
REINFORCING STEEL ATTACHMENT DETAIL
CUSTOM STRIP W/2
LEAD WIRES EACH END
STEEL CRIMP
CONNECTIONS (TYP.)
CONCRETE OVERLAY
SET ANODE TO ALLOW
CLEARANCE FOR
OVERLAY CONCRETE
REBAR CONNECTION

Connection of Anodes to Rebar

Proposed Filled Core Hole



ITEM 519 SPECIAL-PATCHING CONCRETE STRUCTURE, MISC


7 19:51


7 14:33

Project Evaluation

- Project had minimal impact on interstate traffic
- One step repair with galvanic protection
- Cost Comparison
  - Rehabilitation with anodes - $319K
  - Abutment Replacement / Temporary Shoring - $427K
  - Replacement of structures - $4.5M
- Success continues to be tracked through monitoring

Acknowledgements

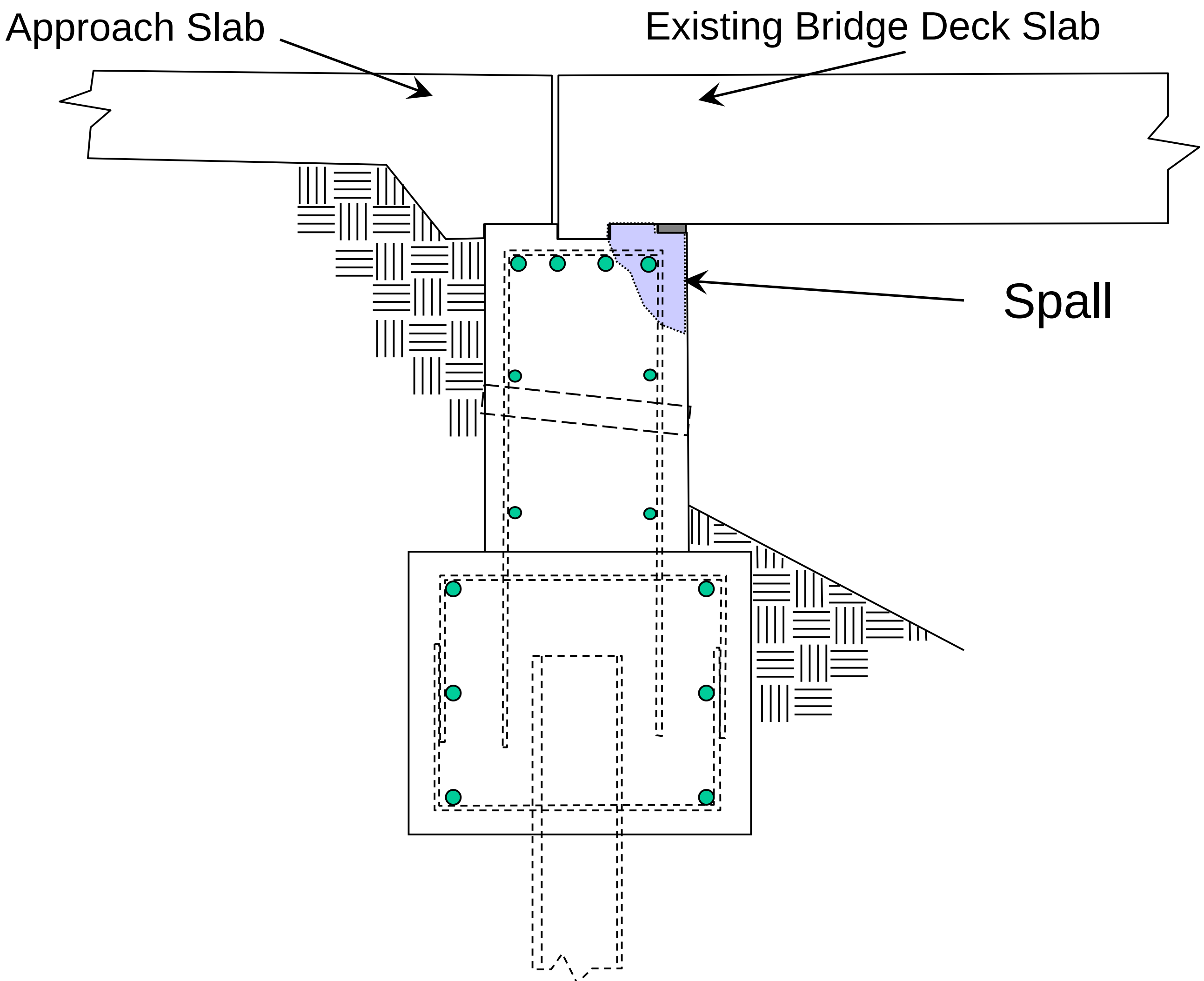
- Mary Hoy, E.I. – PowerPoint presentation
- Matt Miltenberger, P.E. Tourney Consulting
- Rachel Stiffler
  Vector Corrosion Technologies
- ODOT Office of Structural Engineering

Distributed Galvanic Anode Systems to Improve the Service Life of Slab Bridge Abutment Repairs

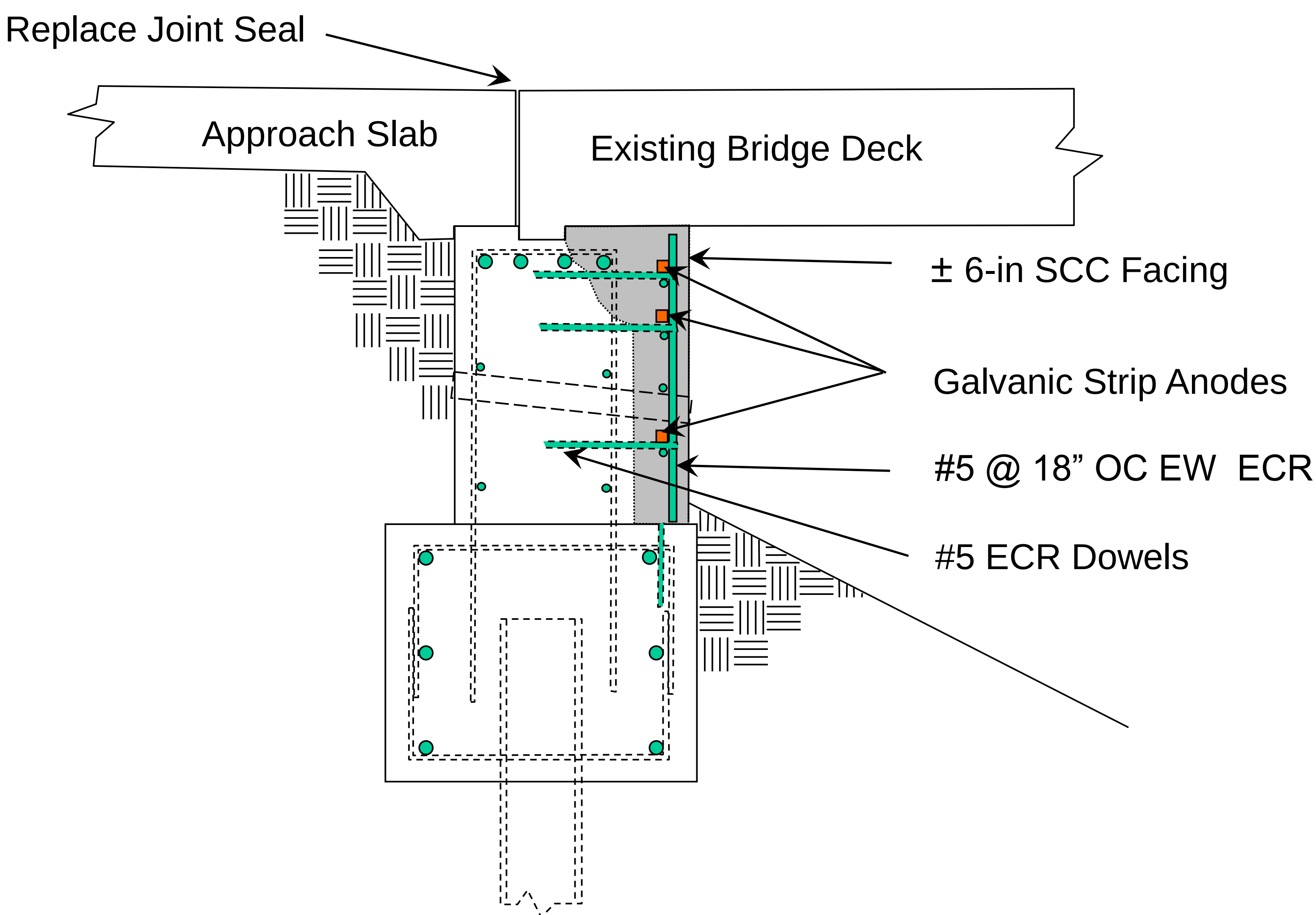
Brad Lightle, PE - Ohio DOT

Chris Ball - Vector Corrosion Technologies

Typical Slab Bridge Abutment



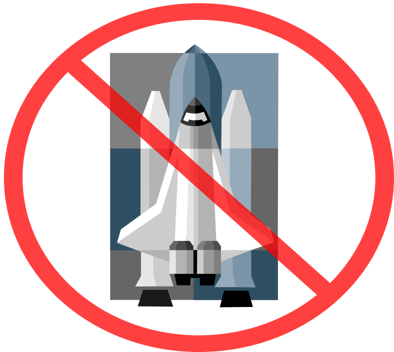
Abutment Repair Detail With Galvanic Protection



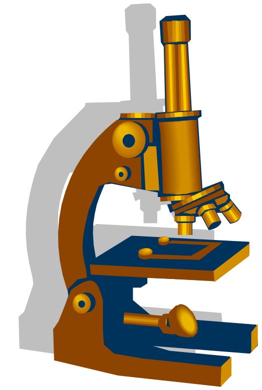
Galvanic Protection Systems

- Two different metals are connected in same electrolyte (concrete)

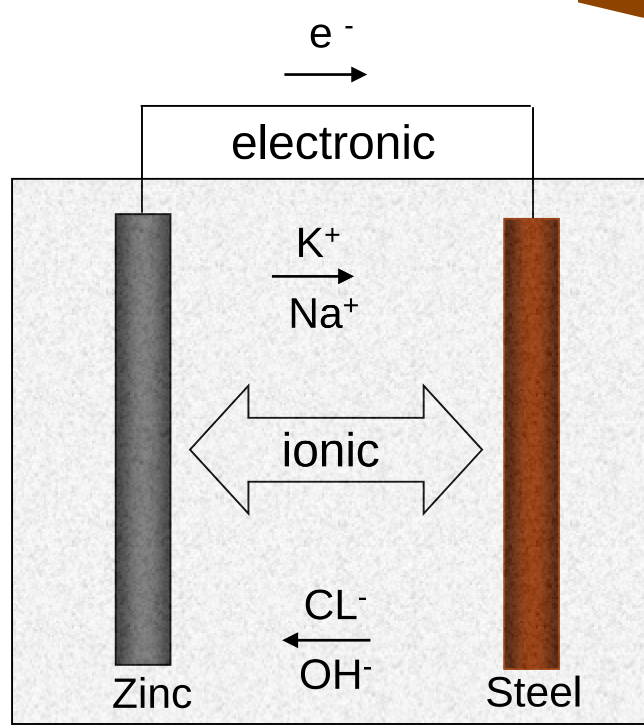
- More “active” metal = anode
- More “noble” metal = cathode
- Anode corrodes to protect cathode
- Natural reaction
  - no external power required
- Safe for prestressed concrete



Potentials and Current Flow



Partial Galvanic Series	
<u>Metal</u>	<u>Voltage</u>
Zinc	-1100 mV
Steel in concrete	-200 mV to -500 mV
*Typical potentials measured with respect to copper-copper sulfate electrode	



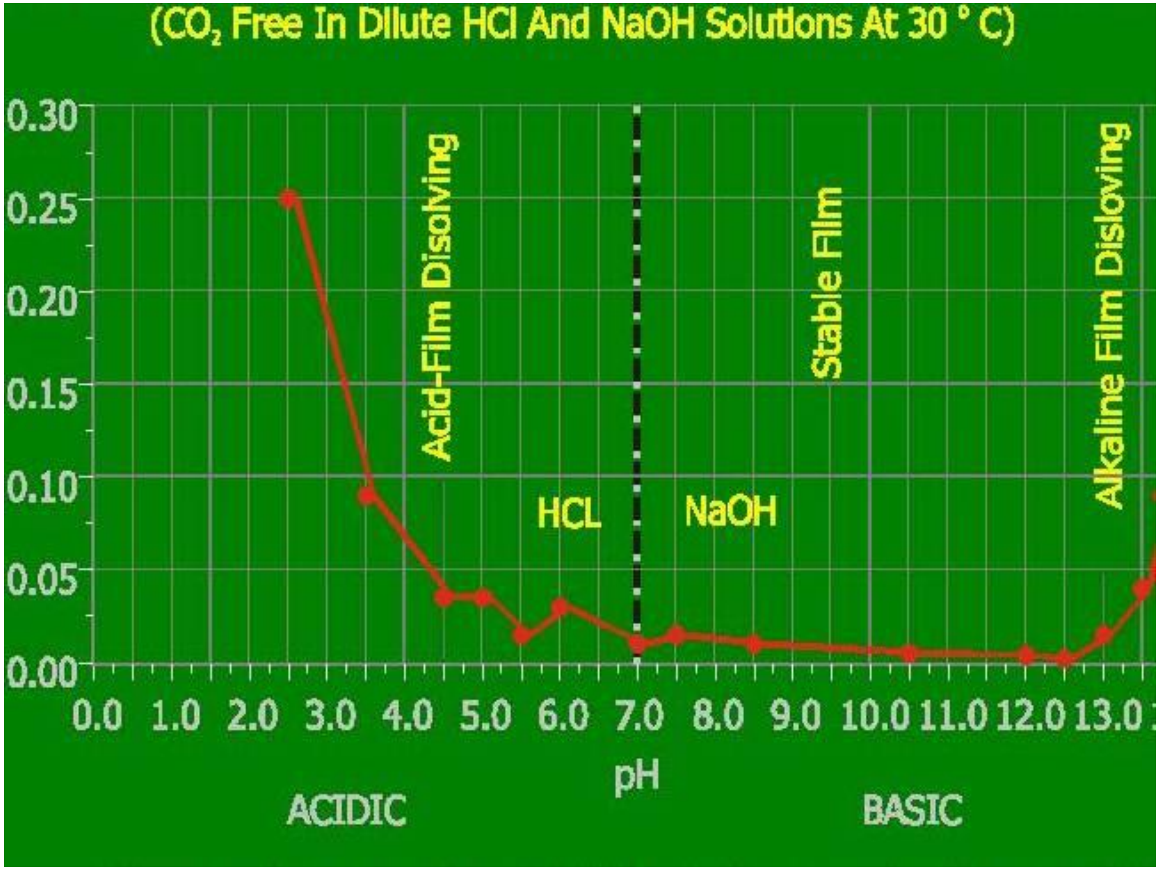
Distributed Galvanic Anodes

- Distributed anode units are pre-manufactured
  - Zinc around a steel core
  - Integral connections
- Typical sizes
  - 0.2 to 2.0 lb. of zinc per lineal foot of anode
  - Up to 7.5 ft in length
- Anode size and spacing: based on steel-to-concrete surface area ratio and service life

Activation Technology

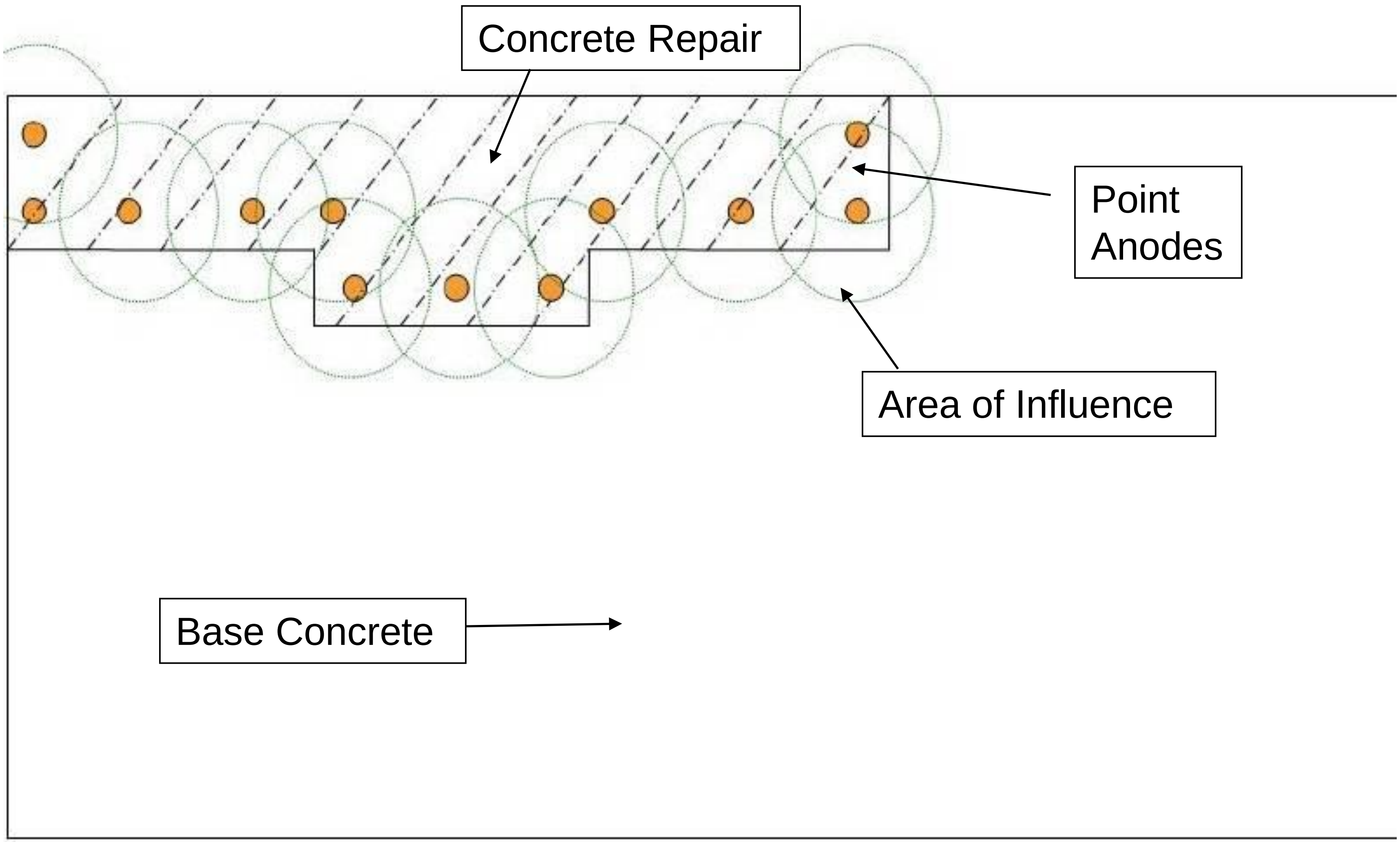
Alkali Activated

- High pH is corrosive to zinc but not to steel
- Allows zinc anodes to provide protection to reinforced concrete over time

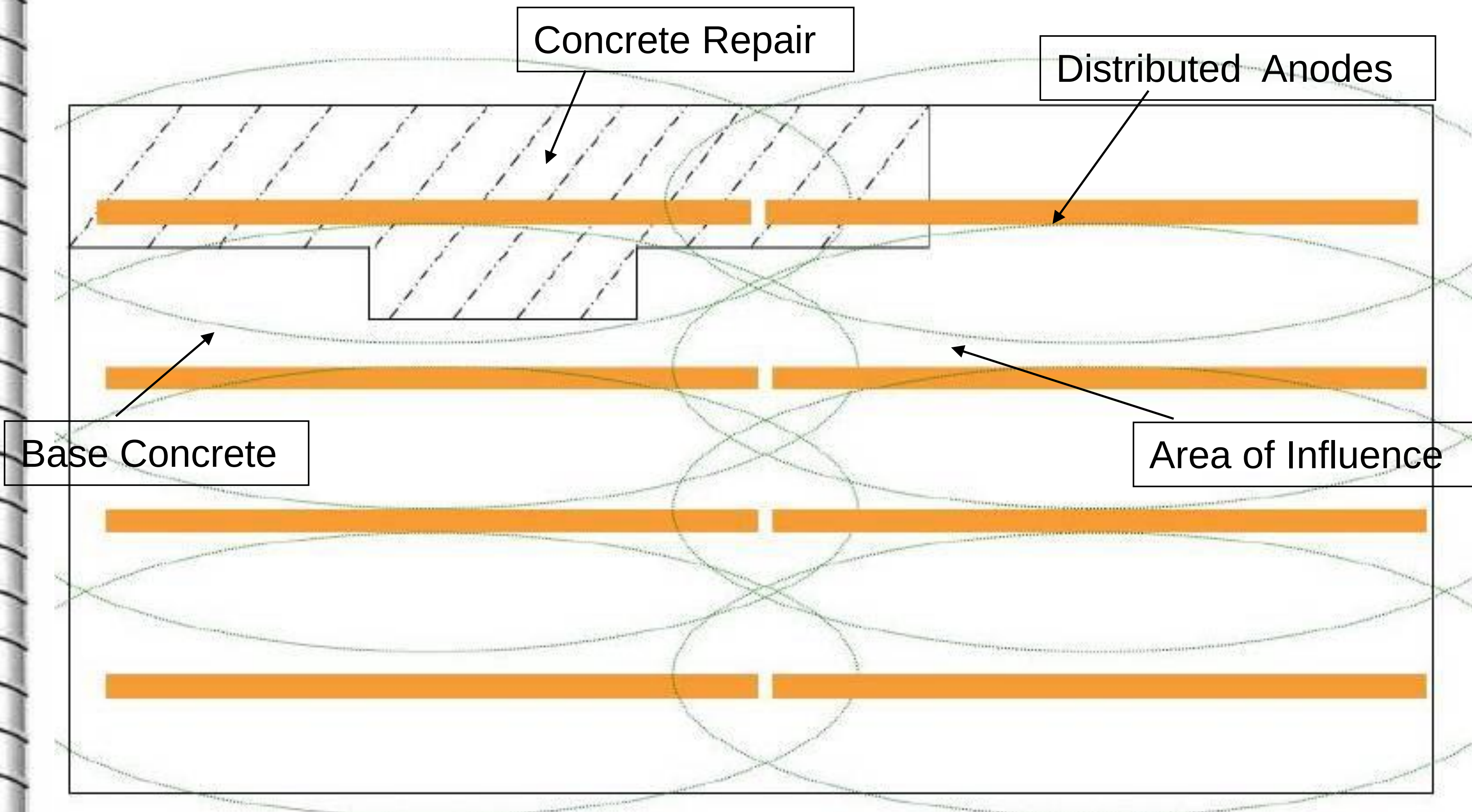


Point vs. Distributed Anodes

Point Anodes Protection



Distributed Anodes Protection



Kirkwood Road Bridge Before Repair
May, 2005


Abutment Condition Before Repair

Spall removal

Dowels and anodes installed

Anodes wired together and to reinforcing


Anodes wired for monitoring

Monitoring station

Ready for Forms

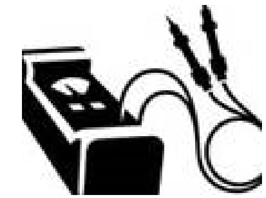
Forms installed


SCC Pumping Port

Forms removed

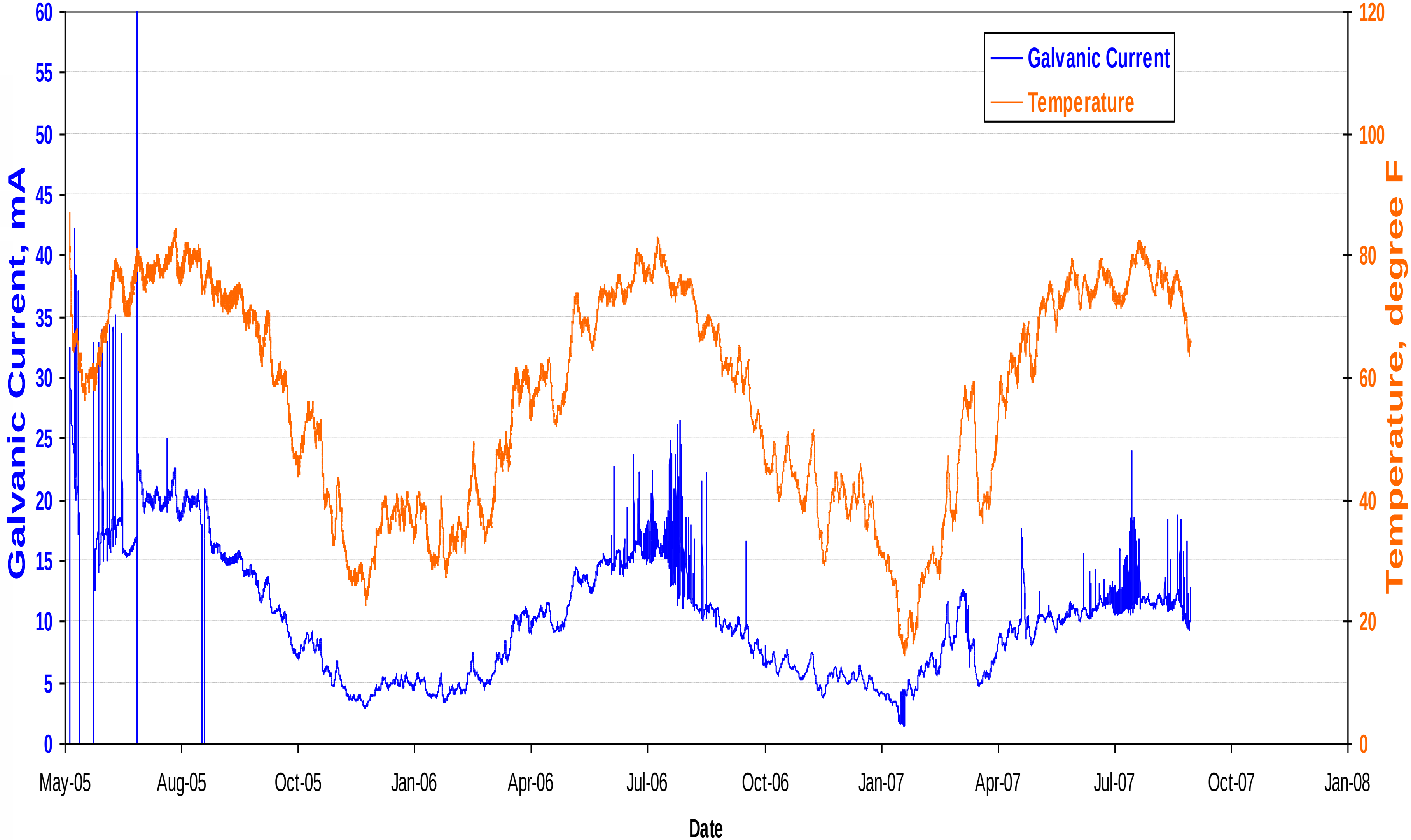
Completed repair

Galvanic Anode Monitoring



- Data logger installed in junction box
- Measurements taken every 4 hours
  - Anode Current Output
  - Internal and Ambient Temperatures
- Corrosion potentials and depolarization data collected on periodic site visits
  - Surface readings with copper-copper sulfate reference electrode
- Information used to determine level of protection and estimate anode service life

Kirkwood Road – Protective Current



Corrosion Mitigation for Reinforced Concrete Structures

Level of Protection	Objective	Typical Current Density Required
Corrosion Prevention	Prevent Initiation of Corrosion	0.25 to 2 mA/m2
Corrosion Control	Reduce Active Corrosion	1 to 7 mA/m2
Cathodic Protection	Stop Active Corrosion	2 to 20 mA/m2

Kirkwood Road Performance

Date	Temp	mA/m2	Polarization	Instant Off
5/6/05		37.7		654*
7/20/05		13.9	346	1000
8/16/05	87	12.9	333	987
10/26/05	54	5.4	394	1048
12/7/05	51	3.2	339	993
5/1/06	57	7.5	335	989
12/20/06	40	4.3	500	1154
5/30/07	79	7.5	446	1100
9/20/07	75	9.7	484	1138

* Native Potential

Cathodic Protection Criteria: Polarization > 100 mV or Inst. Off > 850 mV

Lessons Learned - Anodes

- Easy installation
  - approx. 5 min. each
- Minimal training required
- Temperature affects current output
- Anode system is meeting NACE cathodic protection criteria
- Theoretical anode life = 21.8 years
  - Based on current output data from monitoring

Other Distributed Anode System Applications

I-75 in Auglaize County, 2006

Galvanic Strips In 8 Bridge Deck Overlays Lake County, OH

Bridge Column Repair with Reinforced Concrete Jacket

Bridge Pier Cap Repair with Galvanic Anode Strips

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