Corrosion Protection and Bridge Concrete Repairs

20-Year History

We Save Structures™
The Concrete Preservation Alliance is a growing coalition of organizations committed to advancing best practices in the field of concrete preservation and infrastructure renewal.

The Alliance works together to promote education and awareness of concrete repair industry standards, new and innovative corrosion prevention technologies and sustainable construction practices.

WeSaveStructures.info
The construction industry is the largest user of resources and raw materials.

Approx. 40% of solid waste comes from construction and demolition.

Making new structures last longer and the rehabilitation and reuse of existing structures saves money compared to the cost of premature failure, demolition and rebuilding.

In addition to economic benefits, repairing and extending the service life of structures reduces the consumption of natural resources, pollution and construction waste.

https://www.wesavestructures.info/environmental-impact-calculator
Sep 9, 2020 | Corrosion Protection and Bridge Concrete Repairs
George Sergi, PhD
Vector Corrosion Technologies
Description: Electrochemical corrosion mitigation techniques were first applied to bridges in the early 1970s to mitigate or arrest corrosion of the reinforcing steel. The field has innovated and the technology has evolved since those early days. The first discrete galvanic anodes were installed in concrete repairs on the substructure of the Leicester Bridge in the UK in 1989. The performance of these anodes has been monitored for 20+ years. This webinar will discuss the development and long-term performance of discrete galvanic anodes on bridge structures in addition to the typical applications such as concrete repairs, joint repairs and bridge widenings.
Click Here to Register - 7:00 AM EDT / 1:00 PM CEST
Click Here to Register - 2:00 PM EDT

Oct 14, 2020 | Repair and Protection of Severely Corroded Bridge Substructures with Galvanic
Chris Ball
Vector Corrosion Technologies
Description: Accelerated bridge construction has gained prominence in recent years as a economical way to breathe new life into bridge structures long past their expected service life. The challenge is what to do with substructure elements that are often in as bad shape as the superstructure being replaced. An effective substructure preservation strategy is needed to ensure the expected service life of the new substructure matches the expected service life of the existing substructure elements such as the abutments, beams and piers. This webinar will discuss the use of galvanic encasements as an elegant solution to service life extension for substructures and their proven track record.
Click Here to Register - 7:00 AM EDT / 1:00 PM CEST
Click Here to Register - 2:00 PM EDT
Dr. George Sergi, CEng, BSc, MSc, PhD, FICorr, FIMMM, BS EN ISO 15257:2017 Level-4 CP Specialist

Dr. Sergi is Technical Director at Vector Corrosion Technologies leading the Research and Development Department which develops innovative solutions for corrosion in the Civil Engineering and Construction Industries.

Dr. Sergi has a PhD in Corrosion of Steel in Concrete from Aston University. While at the University, George led his team to develop the original Embedded Galvanic Anode for concrete. He later became Head of Corrosion at the Building Research Establishment (BRE) and Technical Manager at Fosroc International.

Dr. Sergi has published his work extensively and is the author or co-author of numerous special publications and several international patents. He has also taught corrosion by invitation at several international institutes and universities in France, Spain, Netherlands, Cyprus, USA and India.
Corrosion Protection and Extending the Life of Concrete Repairs for Bridges

- Development and 20-year performance of embedded galvanic anodes for concrete repair of bridges
- Applications for embedded galvanic anodes including concrete repair, joint repair and bridge widening
Incipient Anode Formation

Incipient anode (new corrosion site)

Concrete Repair

(Chasing the repairs!)
Incipient Anode Formation

Chloride Contaminated Concrete

- Fe → Fe$^{2+}$ + 2e$^-$
- $Fe^{2+}$ + 2Cl$^-$ → FeCl$_2$
- FeCl$_2$ + 2OH$^-$ → Fe(OH)$_2$ + 2Cl$^-$
- 2Fe(OH)$_2$ + $\frac{1}{2}$O$_2$ → Fe$_2$O$_3$ + 2H$_2$O

Anode

-350 mV

Chloride-Free Patch

- $\frac{1}{2}$O$_2$ + H$_2$O + 2e$^-$ → 2OH$^-$

Cathode

-200 mV

2OH$^-$

-200 mV
Incipient Anode Formation

Chloride Contaminated Concrete

Anode Galvanically Protects Surrounding Rebar

Chloride-Free Patch

-350 mV

-200 mV

-1100 mV
Development of Galvanic Anodes

Cathodic Prevention (Corrosion Prevention)

• Purpose is to prevent corrosion from initiating in a chloride-contaminated environment
• Current density necessary to prevent corrosion from initiating is 0.2 to 2 mA/m², much lower than level necessary to stop on-going corrosion activity (ISO EN12696:2017)
• No existing criterion regarding potential shift
Development of Galvanic Anodes

Zinc Activation Technology

Alkali Activated

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

![Graph showing the effect of pH on the corrosion rate of zinc in aerated solutions. The graph indicates that high pH values (basic) are corrosive to zinc, whereas low pH values (acidic) are not corrosive to steel. The graph also highlights the stability of zinc in different pH conditions and the dissolution of the zinc films.]
Development of Galvanic Anodes

Galvanic anode developed in mid 1990’s

- First field trial was in 1999
- 10-year anode life
- Encasing mortar with increased porosity to accommodate corrosion products and saturated with lithium hydroxide
- pH of Sat. LiOH = 14.6
- Lithium ions inhibit ASR
Embedded Galvanic Anodes - Nomenclature

• Galvanic anodes for concrete contain chemicals in the covering material surrounding the zinc core that allow the anode to continue to produce protective current over time.

• Type A
  • Alkali-Activated
  • High pH environment around zinc core

• Type H
  • Halide-Activated
  • Chloride or bromide environment around zinc core

• Type 1 – Installed in standard repairs

• Type 2 – Installed in sound concrete

Source: Installation of Embedded Galvanic Anodes (ACI RAP Bulletin 8, 2010)
Development of Galvanic Anodes

1999 Field Trial, Leicester, UK
Potential Map Before Repair

Half-Cell Potentials
(mV v's sat. Cu/CuSO₄)

Sampling, Location A
Sampling, Location B

Grid (m)

0 0.5 1 1.5 2 2.5

0 0.5 1

Grid (m)

-100-0
-200--100
-300--200
-400--300

Sampling, Location A
Sampling, Location B
Chloride Concentrations Before Repair

- Mean in Pier
- Max in Pier
- A
- B

<table>
<thead>
<tr>
<th>Chloride Content by Weight of Cement %</th>
<th>Risk of Corrosion Uncarbonated concrete (pH &gt;10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.2</td>
<td>Negligible</td>
</tr>
<tr>
<td>0.2 to 0.4</td>
<td>Very Low</td>
</tr>
<tr>
<td>0.4 to 0.8</td>
<td>Low or Moderate</td>
</tr>
<tr>
<td>0.8 to 1.5</td>
<td>High</td>
</tr>
<tr>
<td>&gt;1.5</td>
<td>Extremely High</td>
</tr>
</tbody>
</table>
Current With Time of Individual Anodes

![Graph showing current (µA) over time (years) for individual anodes labeled 1 to 12.]
Condition of Anode After 10 Years

- Extent of pores containing white corrosion products
- Encasing Mortar
- Coherent interface
- Repair mortar
- Zinc corrosion product
- Bright Zinc substrate (top darker layer scraped off)
- Zinc substrate
- Tie wires
Cross Section of Anode After 10 Years

- **Zinc core**
- **Pseudomorphic replacement of the metal rich in zinc oxide**
- **Anode encasing mortar**
- **Repair Mortar**
- **Pores filled with zinc oxide/zinc hydroxide corrosion products**
Condition of Anode After 20 Years
Zinc Efficiency >70%

Zinc corrosion products
Tie wires
Corrosion products removed
Zinc Consumption of Individual Anodes After 20 Years

- Zinc consumption calculated from charged delivered using Faraday’s Law and an anode efficiency of 70%
Mean steel potentials shifted to less negative levels with time indicating reduced corrosion and increasing passivity.
• Accumulation of mean charge delivered by the anodes follows a predictive model based on a diminishing current according to the gradual loss of zinc surface area.

• 250 μA up to Year-6

• 100 μA from Year-6 to Year-14 – from concentration of corrosion products

• 60 μA beyond Year-14 – from loss of LiOH saturation
Mean “Instant-On” Current per Anode

- Initial current output of each anode following depolarisation indicates “residual power” of the anode.
- Drop in “residual power” at 14 years is from reduction of LiOH to non-saturated state.
Potential Map After 20 Years

- Possible corrosion initiation between the two repair areas.
Fine Cracking After 15 Years
Enlarged Cracking After 20 Years
Mean Current Density of Anodes up to 20 Years

- Anode aging factor, current halves every 7 years
- Anode current density remained above 0.4 mA/m² throughout original 10-year anode design life
- No evidence of corrosion after 10 years
Summary of Lessons Learned

New Improved Features of Anodes

• Empirical determination of current output per anode type
• Determination of Aging-Factor (Half-Life) and factors affecting it
• Reassessment of lithium hydroxide content in encasing mortar
• Redesign of connecting wires
• Confirmation of efficiency of zinc metal
• Reassessment of current density requirement
• Improved specification and more intelligent design parameters
Galvashield® XP

The Original Galvashield® XP Anode

Twenty years of anode development

1999 → 2019

Today's Galvashield® XP Product Line

- Second Generation (2G) activating alkaline mortar with non-corrosive humectant
- High Surface Area Cast Zinc Core
- Barfit™ grooved design
- ICRI CSP-3 surface profile
- 1 stainless steel double loop tie wire
- 4 Standard Sizes: XPC, XPT, XP2, XP4

- High Purity Cast Zinc Core
- Activating alkaline mortar with pH 14+
- Pair of mild steel double loop tie wires
- 1 standard size (XP), puck-shaped
Galvashield® XP Range of Anodes

Galvashield® XPT

Galvashield® XP2

Galvashield® XP4

- XPT Essentially replacing XP
- XP2 = 2 Times the Surface Area
- XP4 = 4 Times the Surface Area
Galvashield® XP Range of Anodes

Relative performance of anodes

Relative surface area
XPT = 1
XP2 = 2
XP4 = 4
Incipient Anode Mitigation – Galvashield® XP Installation
Incipient Anode Mitigation – Bridge Widening
Incipient Anode Mitigation – Structure Expansion
Incipient Anode Mitigation – Expansion-Joints and Adjoining Repairs

• 2-mile section of the Viaduct in need of repair owing to long-term chloride contamination.
• Carries 12,000 vehicles per day.
• Consists of 165 sections separated by expansion joints.
• Over 12,000 substantial repairs were required on the deck.
Incipient Anode Mitigation – Oldbury Viaduct Expansion-Joints and Adjoining Repairs

- ICCP Below the Deck
- Galvanic Anodes on Deck at Expansion Joints and repairs
Incipient Anode Mitigation – Oldbury Viaduct

• Overall, more than 12,000 repairs were carried out with anodes positioned at 450 mm (18 in) spacings along the expansion joints or repair perimeter.
Corrosion Control Anodes

Galvashield® CC-Type Anodes

- Connection wire
- Encasing mortar
- Zinc core
Corrosion Control Anodes

Galvashield® CC-Type Anodes

• Prestressed Concrete Box Girder
Distributed Anode System

Galvashield®
DAS Anodes

- Abutment extension
- Steel addition
- Protection of existing steel
Distributed Anode System
## Aging Factor of Alkali-Activated Anodes

<table>
<thead>
<tr>
<th>Anode type and size</th>
<th>Site Location/ Concrete Element</th>
<th>Initial current per anode (mA)</th>
<th>Anode spacing (mm)</th>
<th>$\lambda$</th>
<th>$t_{1/2}$</th>
<th>Mean $t_{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>X1- Repair</td>
<td>Leicester Crossbeam</td>
<td>0.25</td>
<td>600</td>
<td>0.101</td>
<td>6.9</td>
<td></td>
</tr>
<tr>
<td>X1- Repair</td>
<td>Leicester Column</td>
<td>0.50</td>
<td>750</td>
<td>0.165</td>
<td>4.2</td>
<td></td>
</tr>
<tr>
<td>X1- Grid</td>
<td>India Slab</td>
<td>0.62</td>
<td>300</td>
<td>0.118</td>
<td>5.9</td>
<td></td>
</tr>
<tr>
<td>X2- Repair</td>
<td>Leicester Column</td>
<td>0.26</td>
<td>300</td>
<td>0.055</td>
<td>12.6</td>
<td>13.0</td>
</tr>
<tr>
<td>X2- Grid</td>
<td>India Slab</td>
<td>0.99</td>
<td>300</td>
<td>0.055</td>
<td>12.6</td>
<td></td>
</tr>
<tr>
<td>X2- Grid</td>
<td>M53 Abutment</td>
<td>0.29</td>
<td>300</td>
<td>0.050</td>
<td>13.9</td>
<td></td>
</tr>
<tr>
<td>X4- Repair</td>
<td>Leicester Column</td>
<td>0.36</td>
<td>300</td>
<td>0.075</td>
<td>9.2</td>
<td>10.3</td>
</tr>
<tr>
<td>X4- Grid</td>
<td>India Slab</td>
<td>2.22</td>
<td>300</td>
<td>0.066</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>X4- Grid</td>
<td>M53 Abutment</td>
<td>0.55</td>
<td>300</td>
<td>0.066</td>
<td>10.5</td>
<td></td>
</tr>
<tr>
<td>X4- Grid</td>
<td>Ivy St. Abutment</td>
<td>0.64</td>
<td>300</td>
<td>0.064</td>
<td>10.8</td>
<td></td>
</tr>
<tr>
<td>Long Rod</td>
<td>Ohio Abutment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11.3</td>
</tr>
<tr>
<td>Long Rod</td>
<td>North Otter Bridge Deck</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean all</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10.0</td>
</tr>
</tbody>
</table>
## Design Parameters

### Anode Spacing for Low to Moderate Corrosion Risk (Chloride Content < 0.8% or Carbonated Concrete)

<table>
<thead>
<tr>
<th>Protection Level</th>
<th>Corrosion Prevention</th>
<th>Corrosion Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Galvashield® Anode</td>
<td>GPT/GPC**</td>
<td>XP2</td>
</tr>
<tr>
<td>Steel Density Ratio</td>
<td>mm</td>
<td>in.</td>
</tr>
<tr>
<td>&lt;0.3</td>
<td>750</td>
<td>30</td>
</tr>
<tr>
<td>0.31 - 0.6</td>
<td>600</td>
<td>24</td>
</tr>
<tr>
<td>0.61 - 0.9</td>
<td>500</td>
<td>20</td>
</tr>
<tr>
<td>0.91 - 1.2</td>
<td>450</td>
<td>18</td>
</tr>
<tr>
<td>1.21 - 1.5</td>
<td>400</td>
<td>16</td>
</tr>
<tr>
<td>1.51 - 1.8</td>
<td>350</td>
<td>14</td>
</tr>
<tr>
<td>1.81 - 2.1</td>
<td>300</td>
<td>12</td>
</tr>
</tbody>
</table>
### Galvashield® XP2 Anode

<table>
<thead>
<tr>
<th>Half Life</th>
<th>Initial Current (μA)</th>
<th>Current (μA)</th>
<th>Final Current (μA)</th>
<th>Zinc Used (g)</th>
<th>c.d. at above spacing and steel density (mA/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>250</td>
<td>86</td>
<td>50</td>
<td>47</td>
<td>2.60, 1.53, 1.17, 0.90, 0.69, 0.53</td>
</tr>
<tr>
<td>13</td>
<td>250</td>
<td>86</td>
<td>50</td>
<td>47</td>
<td>1.97, 1.16, 0.88, 0.68, 0.52, 0.40</td>
</tr>
</tbody>
</table>

**Steel Dens.**
- Spacing-1: 400
- Spacing-2: 460

**Years**
- 0, 10, 15, 20, 25, 30

**Graphs**
- **c.d. with time**
- **Zinc consumed with time**
Improved Design Parameters

Design from Initial Current Density

As previous example:

• From datasheet tables for Corrosion Control:
  • Steel Density = 0.61
  • Chloride Level <0.8 %
  • XP2 Spacing = 400 mm (16 in)
  • Set initial current/anode at 0.25 mA/m² (e.g. UK or similar environment) which comes to 2.6 mA/m²
  • Assuming Aging term of 13 years sets 30-year c.d. at 0.56 mA/m²
Improved Design Parameters

Design for Long-Term Current Density

As previous example:

- In Spreadsheet, Set 30-year c.d. at 0.4 mA/m²
- Set steel density at 0.6
- Set initial current/anode at 0.25 mA/m² (e.g. UK environment)
- Spacing comes out at 460 mm and Initial c.d. at 1.97 mA/m²
In Summary

• Galvanic anodes are ideal for mitigating incipient anode formation, i.e. early corrosion at the periphery of concrete repairs. The application can be extended to any cases where new concrete is placed adjacent to old concrete.

• Other types of alkali-activated embedded anodes have evolved to cover a wide range of applications of corrosion control and repair.

• Analysis of field results of up to 20 years has allowed determination of the aging behaviour of alkali-activated anode types which appear to diminish in current delivery capability according to the half-life principle.

• Understanding of long-term behaviour of galvanic anodes has enabled better control of design parameters and improved design of galvanic systems.
QUESTIONS?
Contact Dr. Sergi

Dr. George Sergi
Technical Director
Vector Corrosion Technologies Limited
Cradley Heath, UK

Office: (+44) 1384 671 400
drsergi@vector-corrosion.com
Oct 14, 2020 | Repair and Protection of Severely Corroded Bridge Substructures with Galvanic Encasements
Chris Ball
Vector Corrosion Technologies

Description: Accelerated bridge construction has gained prominence in recent years as an economical way to breathe new life into bridge structures long past their expected service life. The challenge is what to do with substructure elements that are often in as bad shape as the superstructure being replaced. An effective substructure preservation strategy is needed to ensure the expected service of the new substructure matches the expected service life of the existing substructure elements such as the abutments, beams and piers. This webinar will discuss the use of galvanic encasements as an elegant solution to service life extension for substructures and their proven track record.

Click Here to Register - 7:00 AM EDT / 1:00 PM CEST
Click Here to Register - 2:00 PM EDT / 11:00 AM PDT

Nov 11, 2020 | Pile Protection for Coastal Bridges
Jason Chodachek
Vector Corrosion Technologies

Description: Marine environments are among the most corrosive exposure conditions for reinforced concrete or steel structures. Tidal action and salt water splashing on piles creates ideal conditions for corrosion and the effects can wreak havoc on marine structures of all kinds. While the marine environment presents significant challenges for service life, there are proven methods of extending the life of both concrete and steel piles in fresh, brackish and even salt water. This webinar will compare the various marine pile protection options available today and explore methods of evaluating and protecting steel sheet piles.

Click Here to Register - 7:00 AM EST / 1:00 PM CEST
Click Here to Register - 2:00 PM EST / 11:00 AM PDT