Corrosion Protection and Bridge Concrete Repairs

20-Year History

We Save Structures™

CONCRETE PRESERVATION ALLIANCE

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

OUR MEMBERS

VECTOR CORROSION TECHNOLOGIES

vector-corrosion.com

VCS VECTOR CORROSION SERVICES

vcservices.com

NDT CORPORATION

Concrete & Geophysical Testing

ndtcorporation.com

VECTOR CONSTRUCTION

vector-construction.com

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

Inputs

Volume of concrete to be preserved	10000	yd3	7645	m3
	Calculate		Calculate	

Outputs

Emissions

Concrete CO2	2633	US tons CO2	2385	metric tons CO2
Steel CO2	2835	US tons CO2	2569	metric tons CO2
Total Carbon Dioxide	5468	US tons CO2	4954	metric tons CO2
Equivalent to annual CO2 emission of:	1243	people	1239	people
NOx (as NO2)	9747	lbs	4347	kg
SO2	2722	lbs	1214	kg
Total Pollutants	10947469	lbs	4959689	kg

Waste Generation

Solid Waste (Rubble)	20250	US tons	18348	metric tons
Energy (heat generation from cement production, cement hydration, and steel production)	23846	GJ	22633	GJ
Equivalent energy to boiling	30	Olympic Pools	28	Olympic Pools

Natural Resources Required

Fine aggregate	5265	US Tons	4770	metric tons
Coarse aggregate	8302	US Tons	7523	metric tons
Cement	4500	US Tons	4014	metric tons
Steel	1620	US Tons	1468	metric tons
Total tons	19687	US Tons	17775	metric tons
Potable Water	253012	gal	936512	liters
Equivalent to daily water usage for:	2530	people	2341	people

Environmental Impact Calculator on WeSaveStructures.Info

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CONCRETE PRESERVATION ALLIANCE

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 1999. 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 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

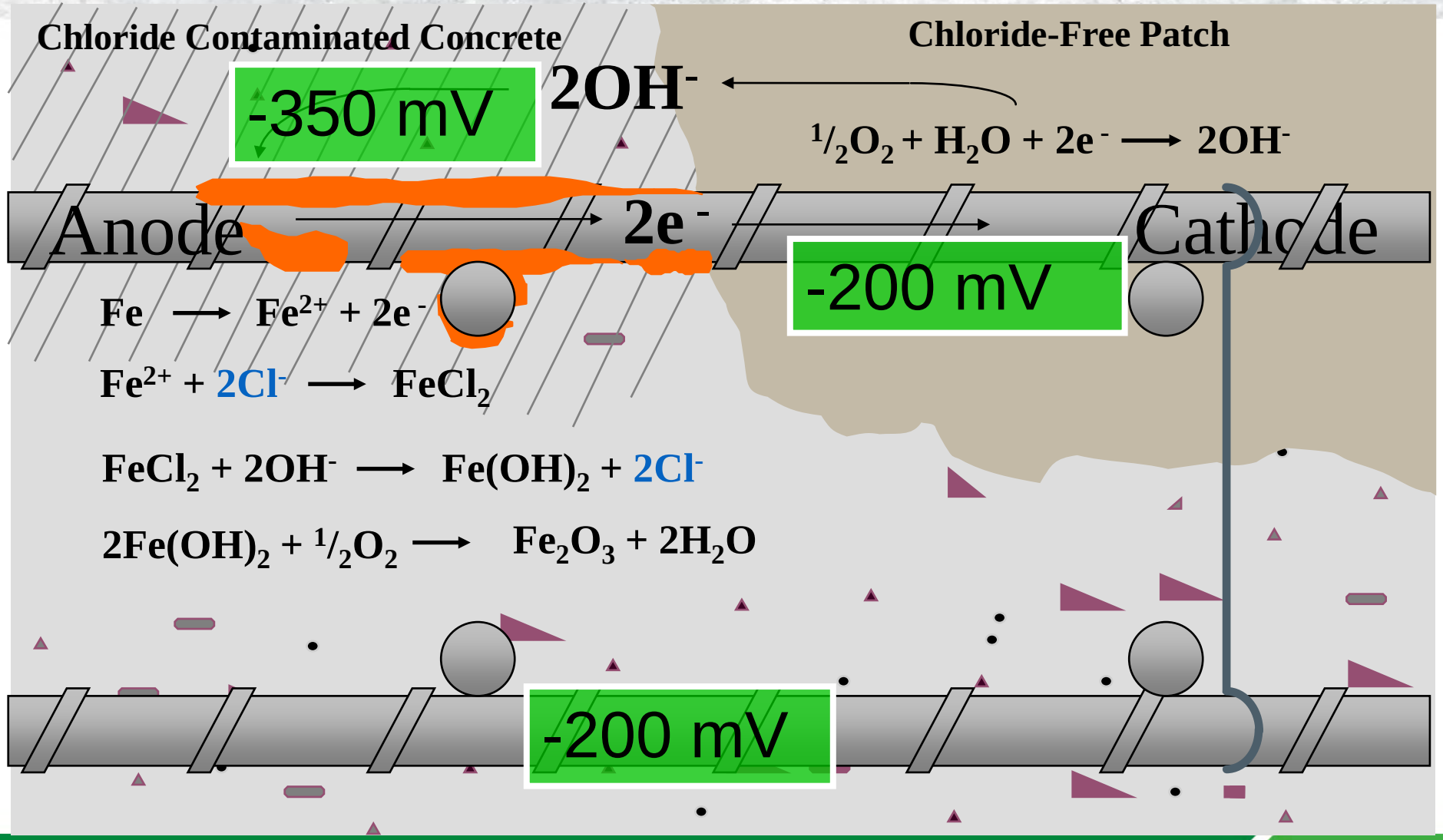
Incipient Anode Formation

Incipient anode
(new corrosion site)

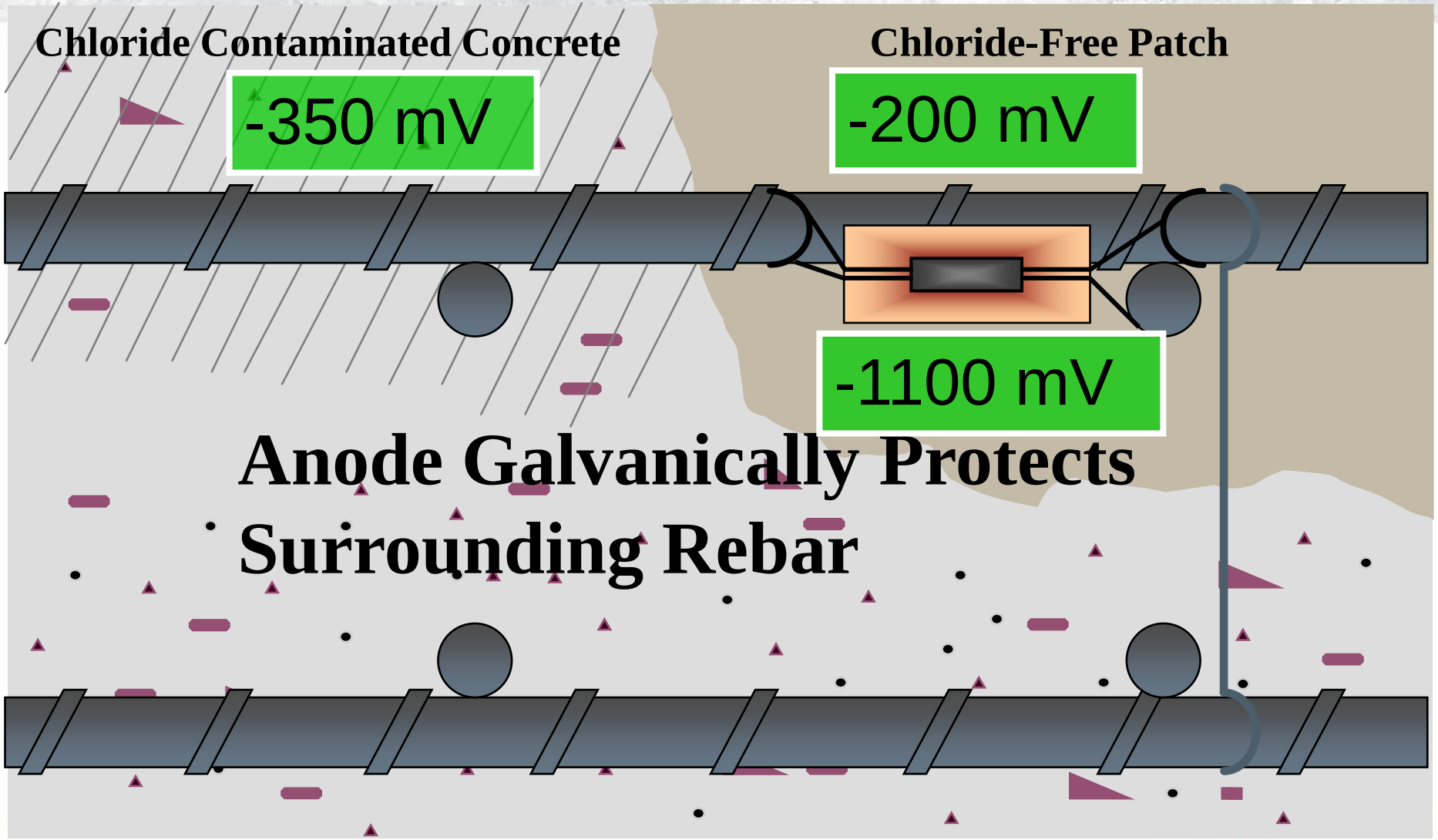
Concrete Repair

(Chasing the repairs!)

Incipient Anode Formation



Incipient Anode Formation



Development of Galvanic Anodes

Cathodic Prevention (Corrosion Prevention)

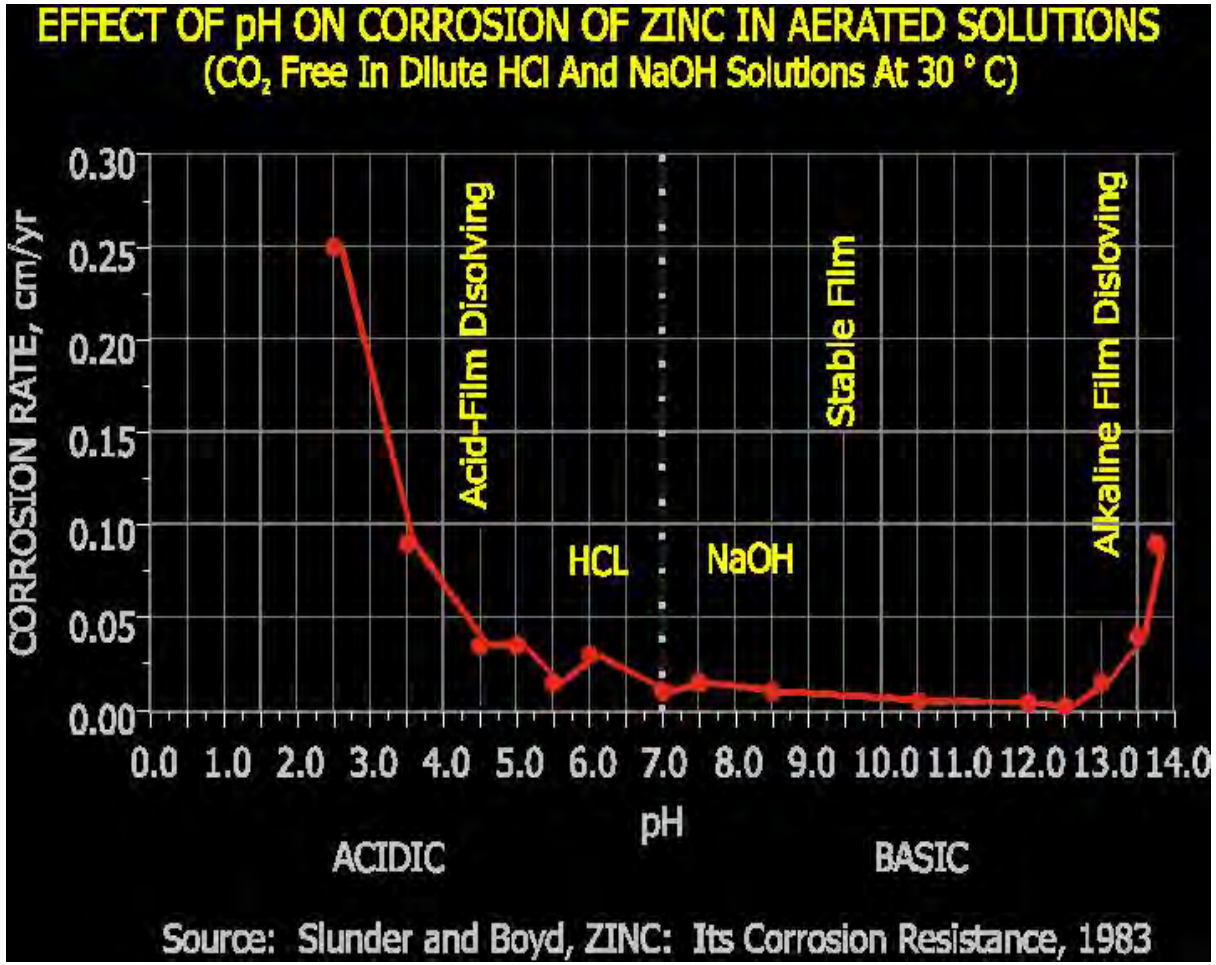
- Purpose is to prevent corrosion from initiating in a chloride-contaminated environment
- Current density necessary to prevent corrosion from initiating is 0.2 to 2 mA/m^2, much lower than level necessary to stop on-going corrosion activity (ISO EN12696:2017)
- No existing criterion regarding potential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

Development of Galvanic Anodes

Zinc Activation Technology

Alkali Activated

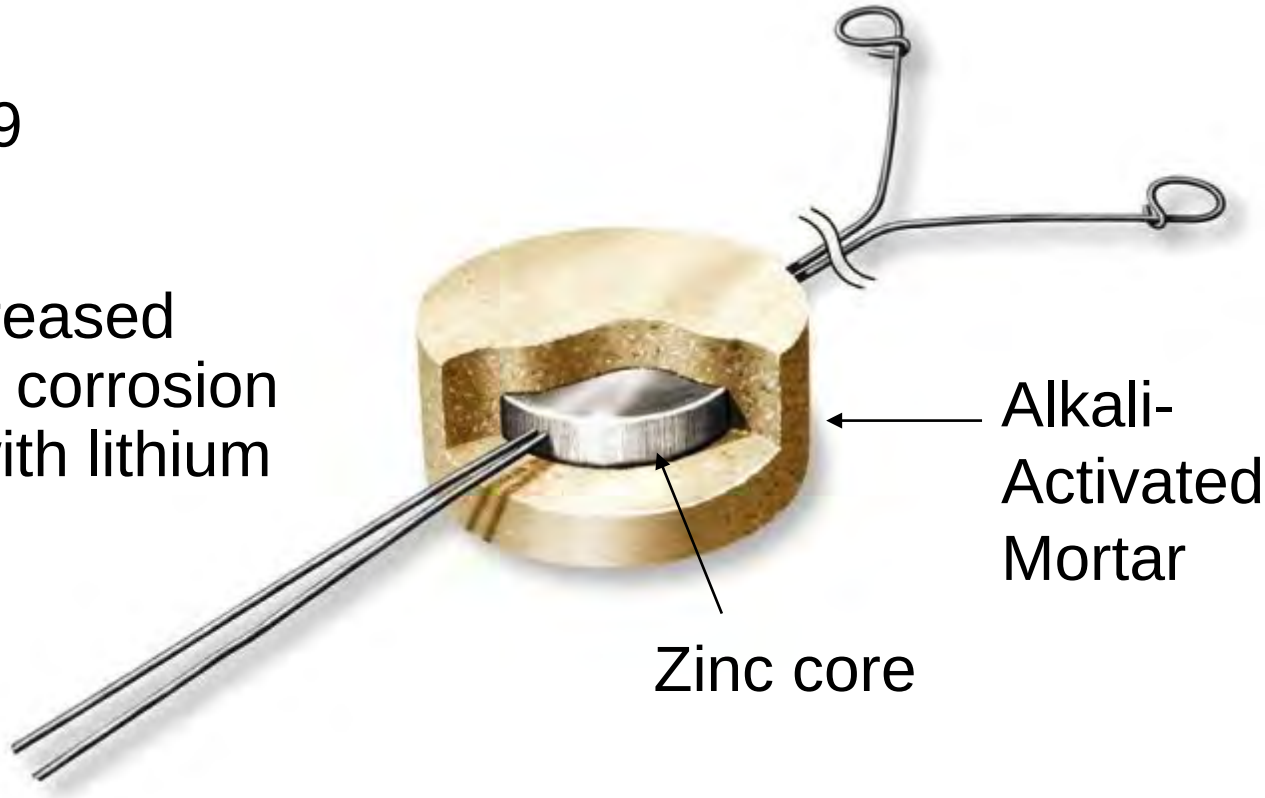
- High pH is corrosive to zinc but not to steel
- Allows zinc anodes to remain active and provide protection to reinforced concrete over time



Development of Galvanic Anodes

Galvanic anode developed in mid 1990's

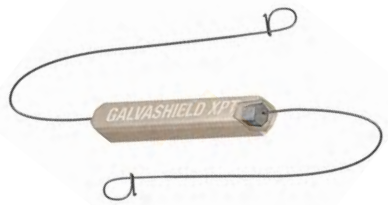
- First field trial was in 1999
- 10-year anode life
- Encasing mortar with increased porosity to accommodate corrosion products and saturated with lithium hydroxide
- pH of Sat. LiOH = 14.6
- Lithium ions inhibit ASR



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

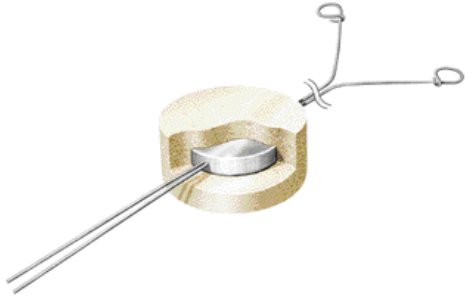


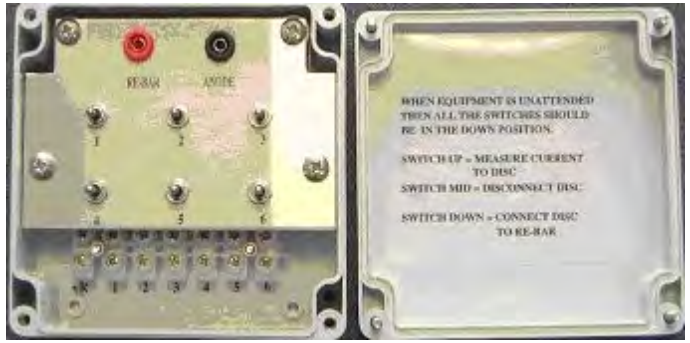
- Type 2 – Installed in sound concrete

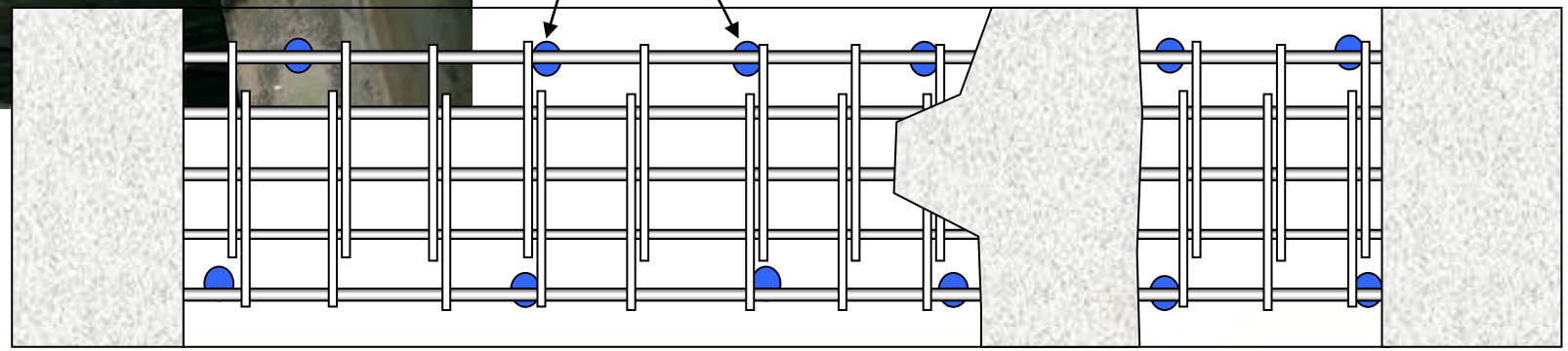
Source: Installation of Embedded Galvanic Anodes (ACI RAP Bulletin 8, 2010)

Development of Galvanic Anodes

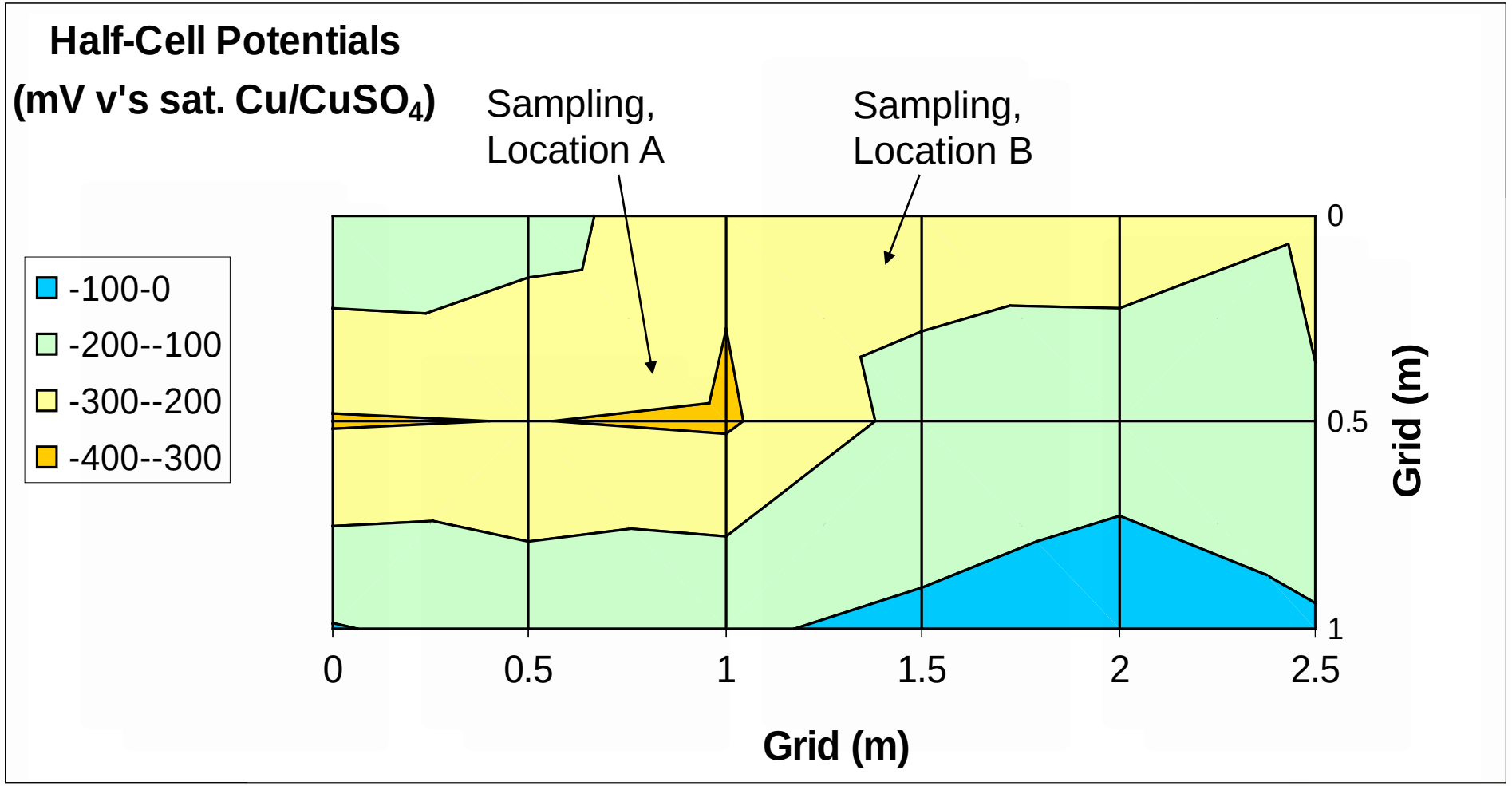
1999 Field Trial, Leicester, UK



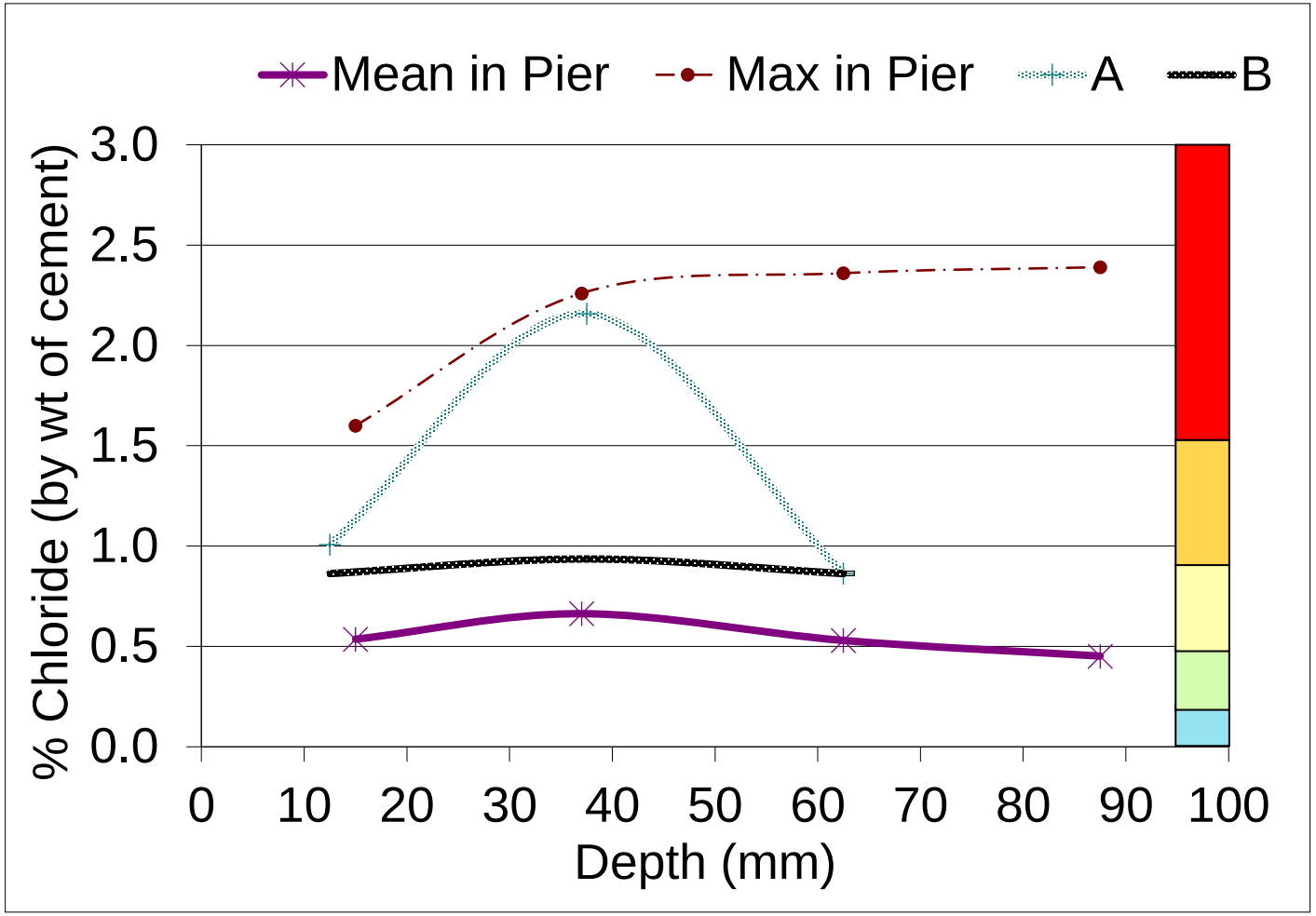




Potential Map Before Repair

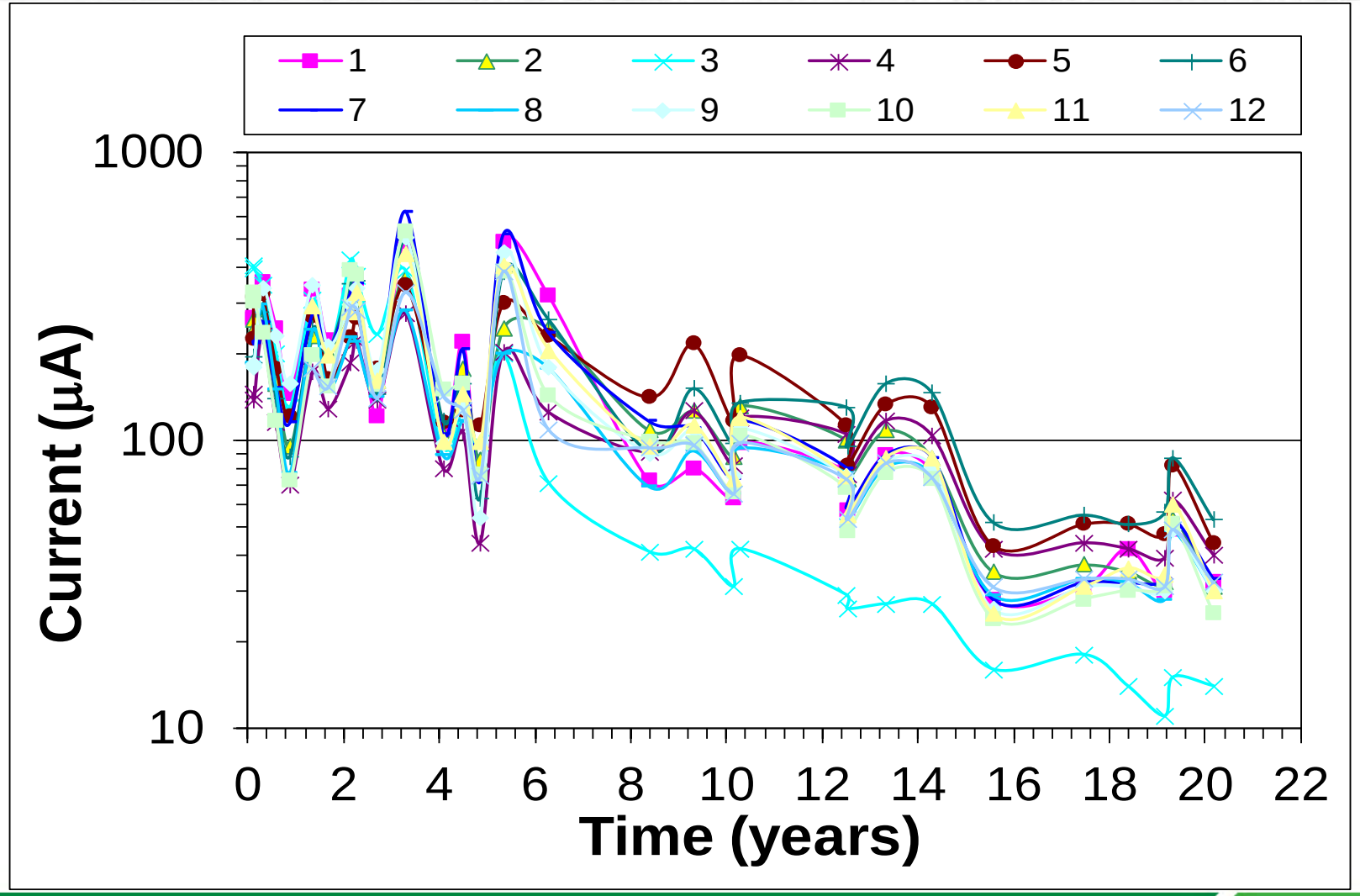


Chloride Concentrations Before Repair

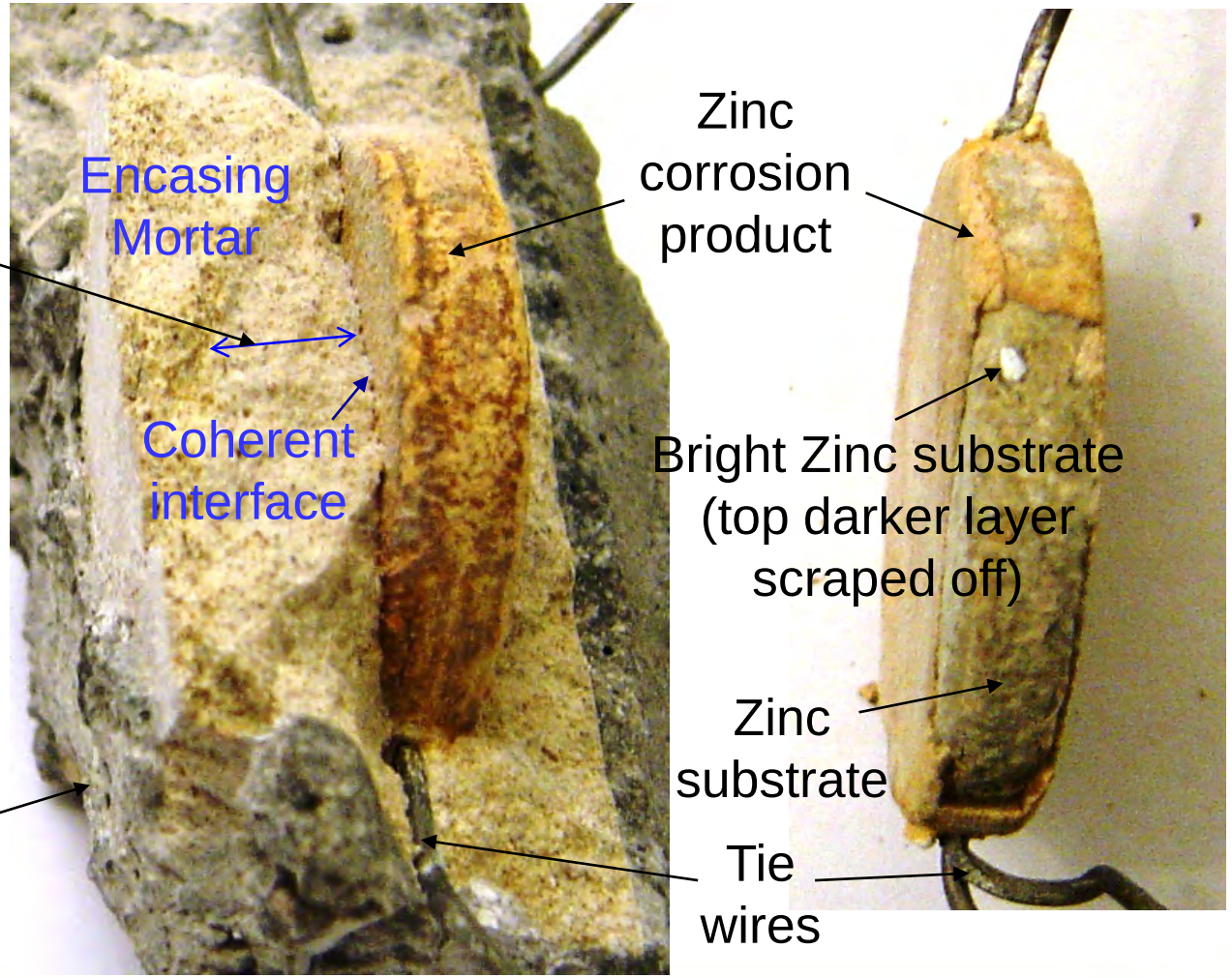


Chloride Content by Weight of Cement %	Risk of Corrosion Uncarbonated concrete (pH >10)
<0.2	Negligible[i]
0.2 to 0.4	Very Low[i]
0.4 to 0.8	Low or Moderate[i]
0.8 to 1.5	High[i]
>1.5	Extremely High[i]

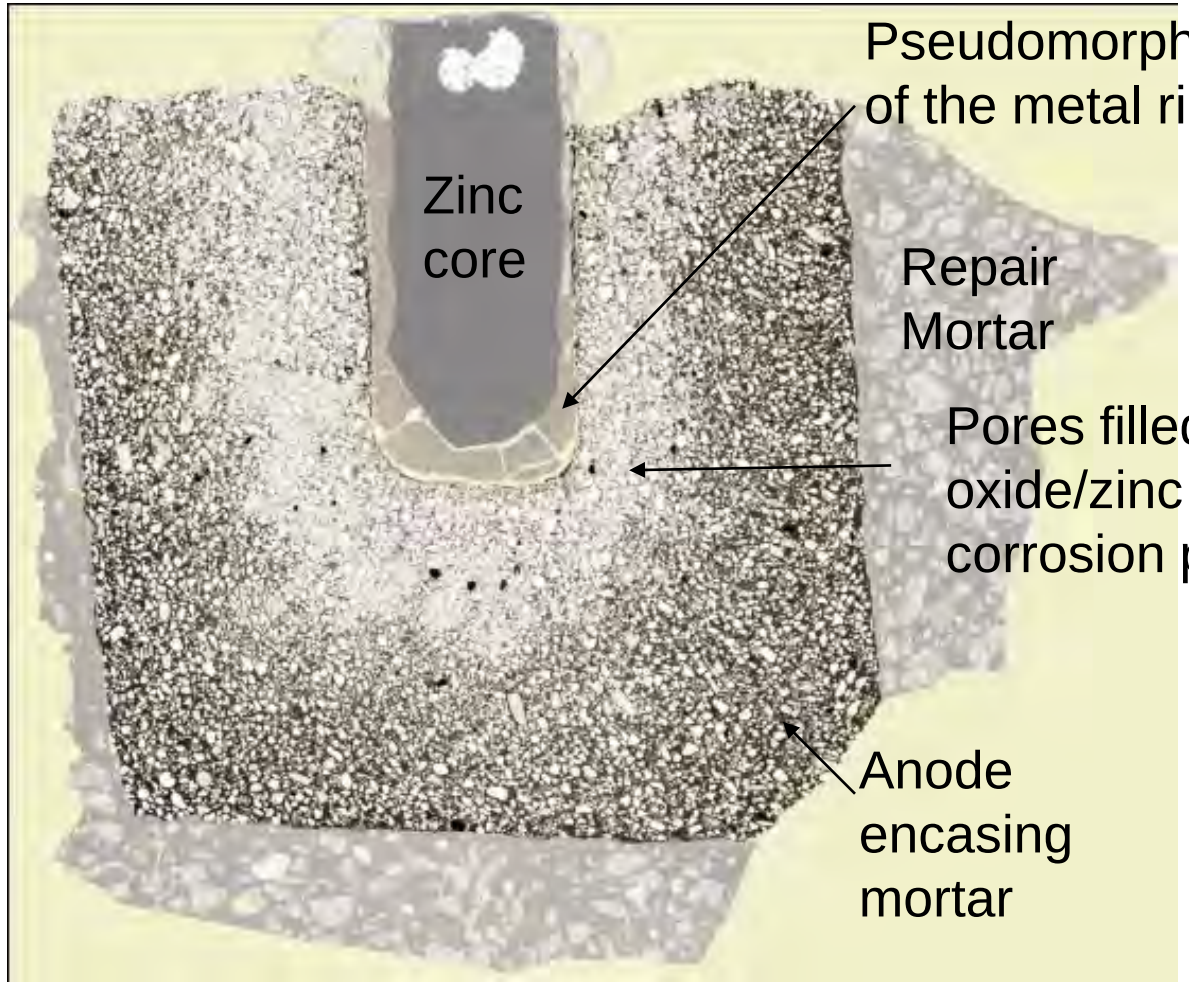
Current With Time of Individual Anodes



Condition of Anode After 10 Years



Cross Section of Anode After 10 Years



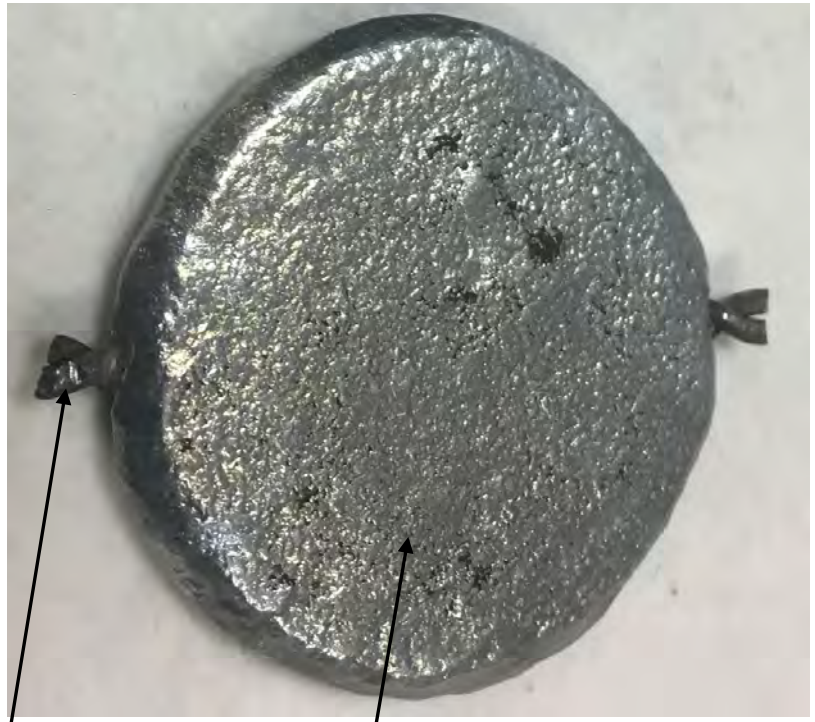
Pseudomorphic replacement of the metal rich in zinc oxide

Repair Mortar

Pores filled with zinc oxide/zinc hydroxide corrosion products

Anode encasing mortar

Condition of Anode After 20 Years
Zinc Efficiency >70%



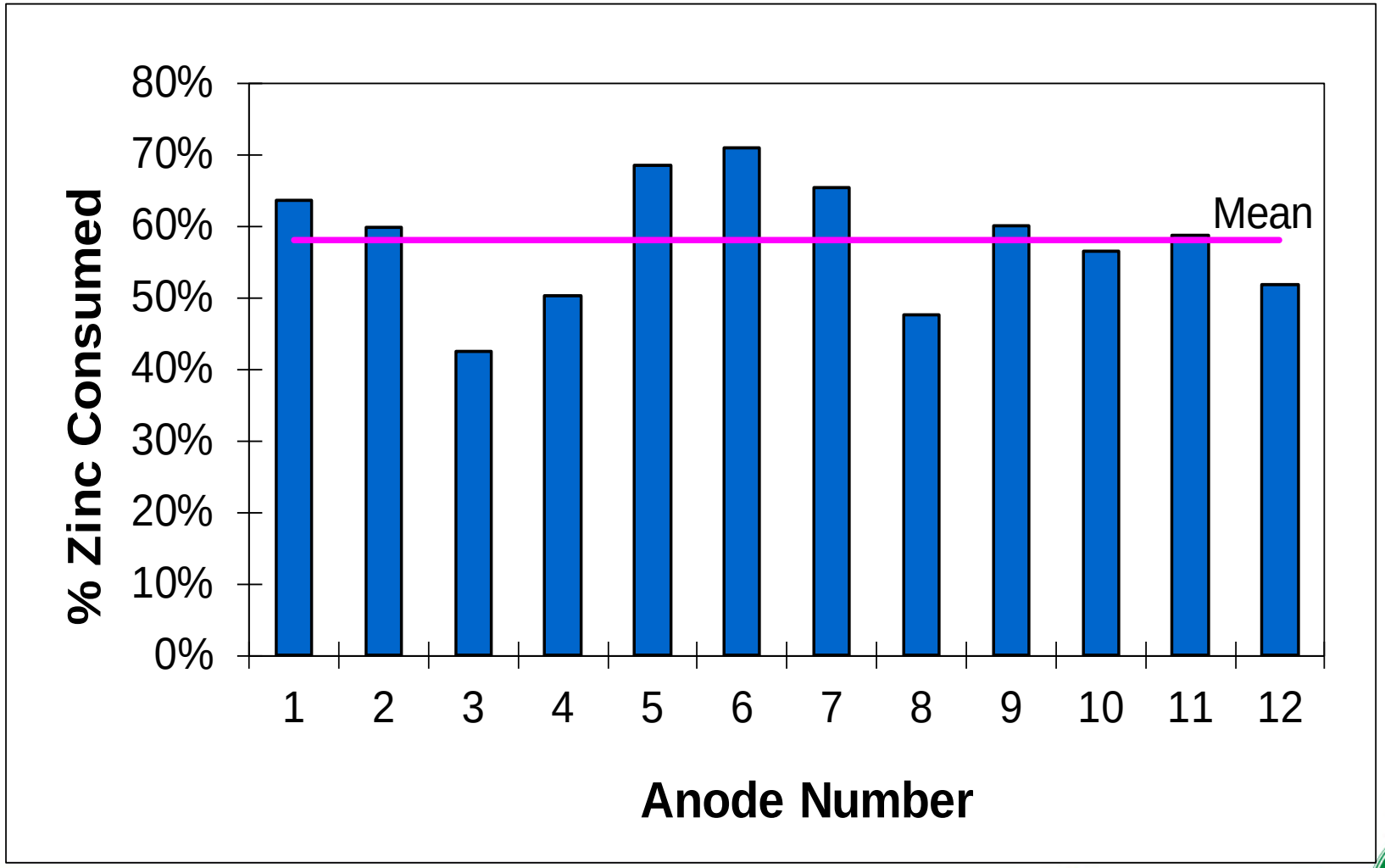
Zinc corrosion products

Tie wires

Corrosion products removed

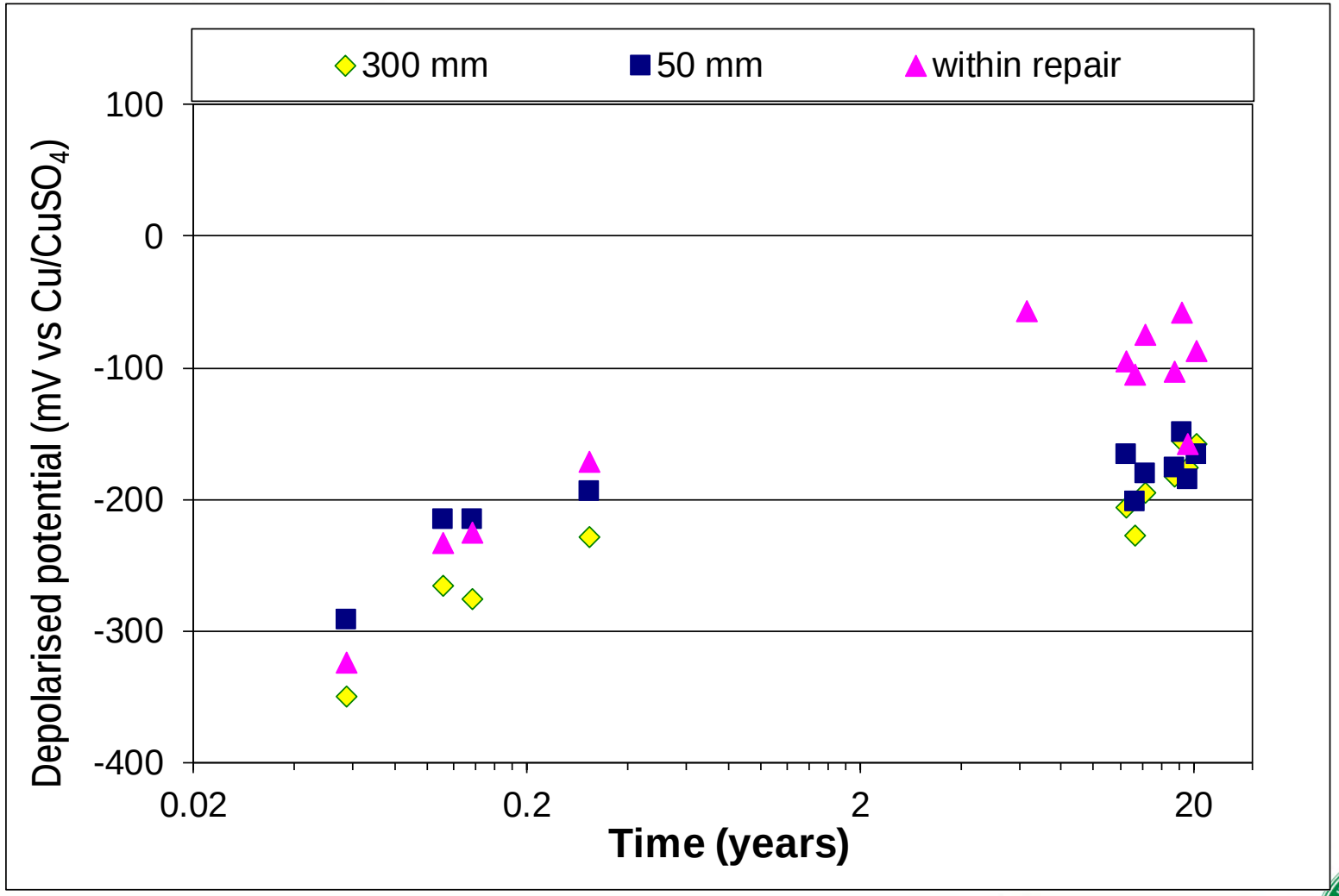
Zinc Consumption of Individual Anodes After 20 Years

- Zinc consumption calculated from charged delivered using Faraday's Law and an anode efficiency of 70%



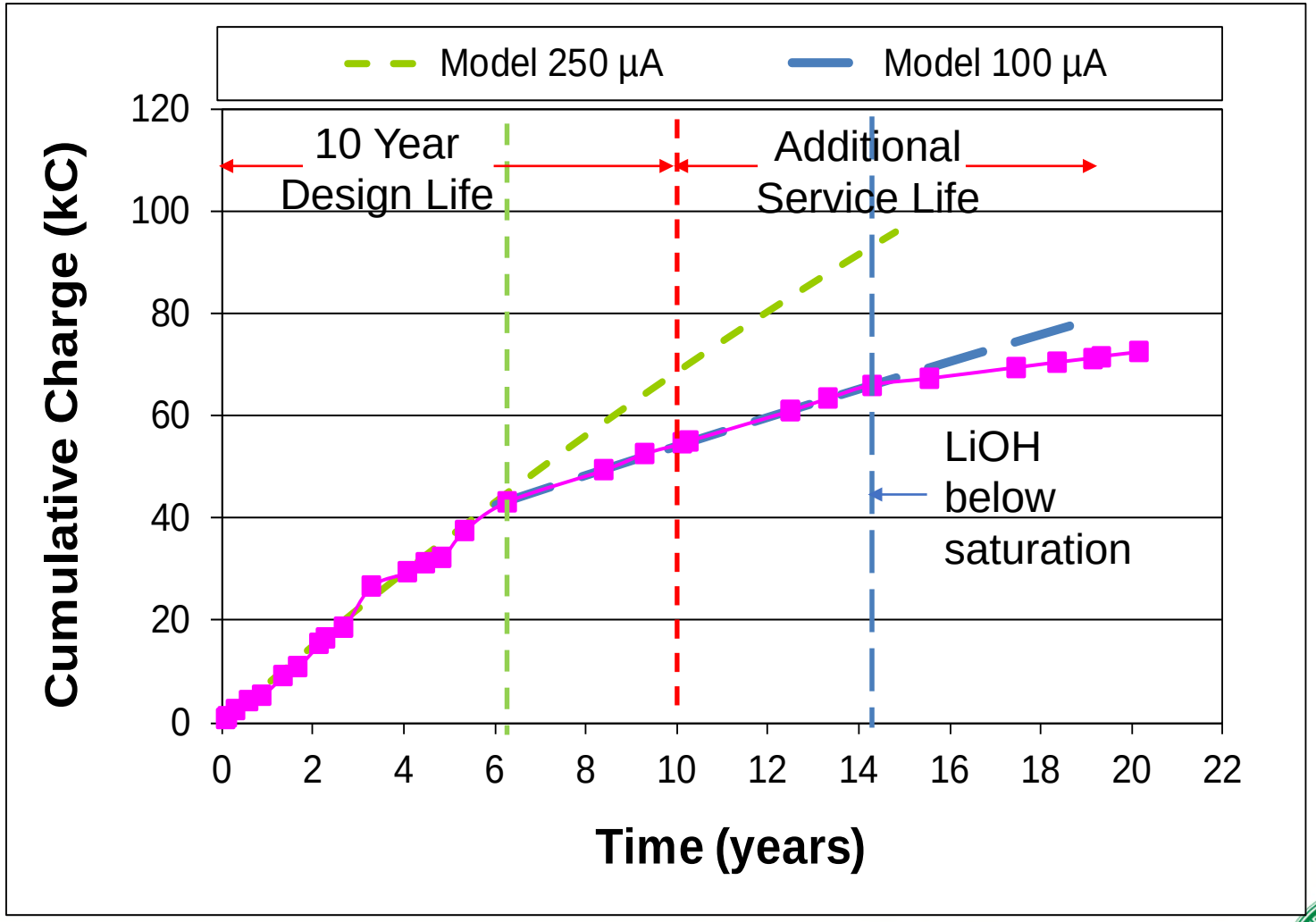
Mean Depolarised Potential with Time

- Mean steel potentials shifted to less negative levels with time indicating reduced corrosion and increasing passivity



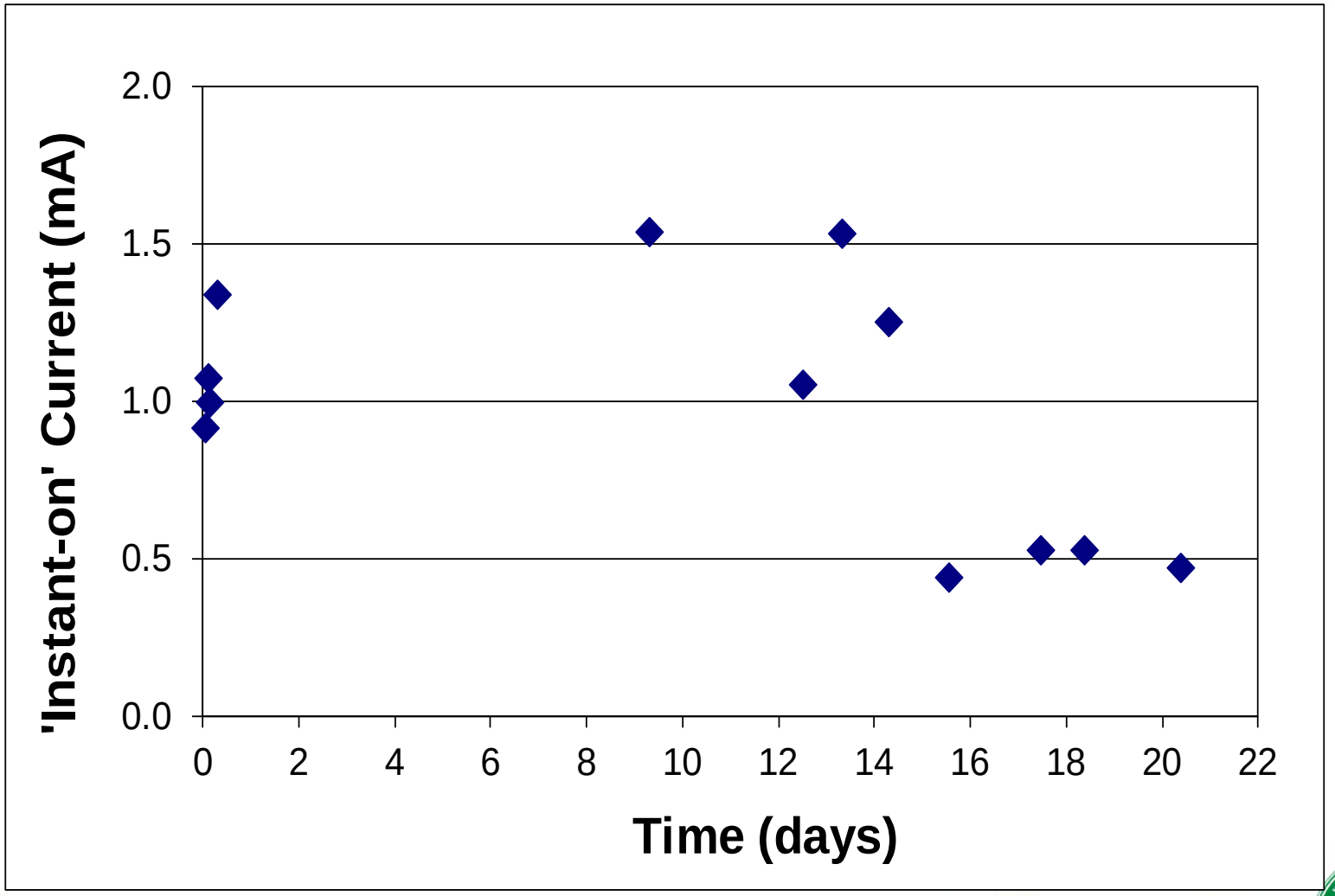
Cumulative Charge from Anodes with Time

- 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



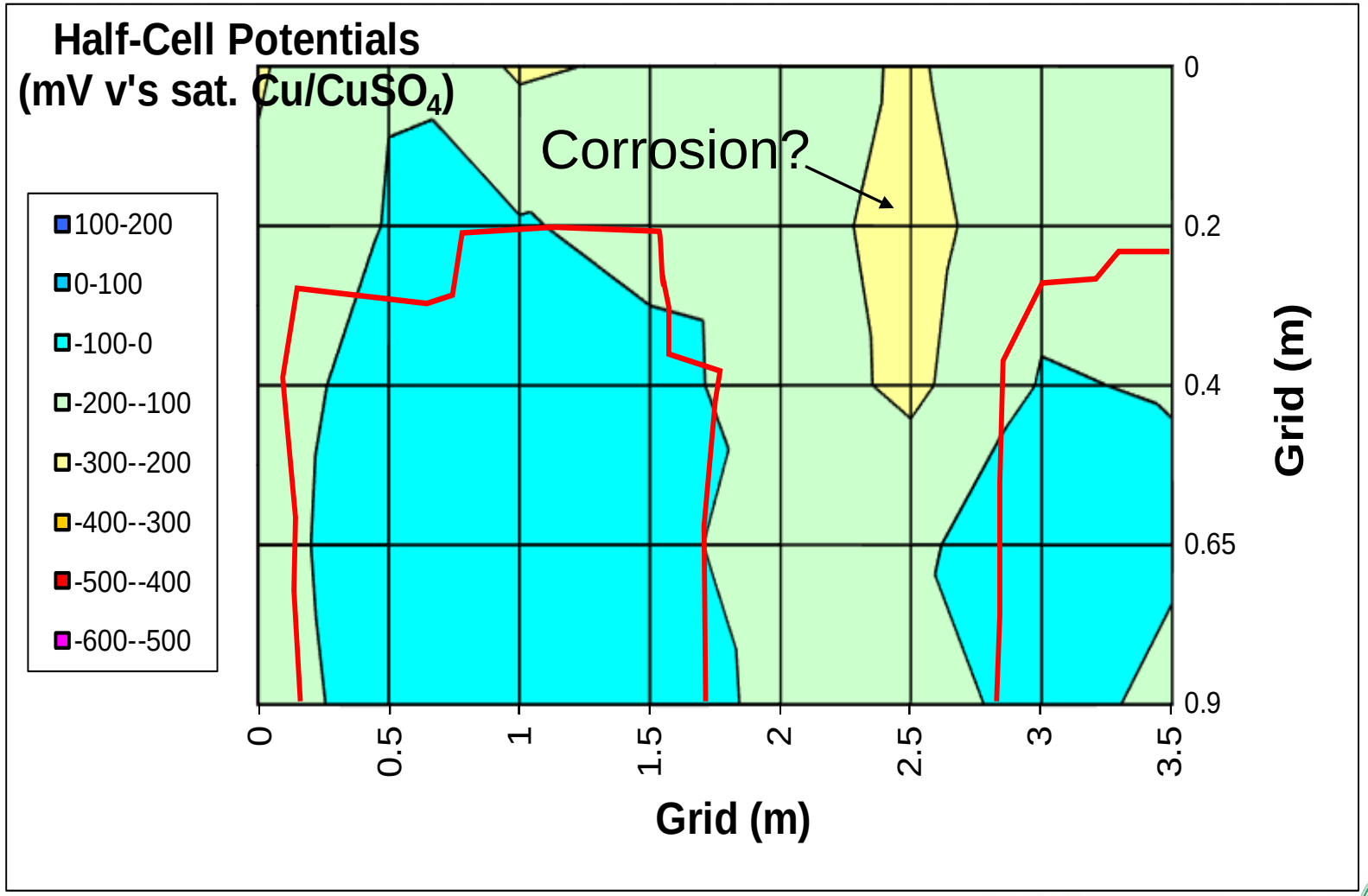
Mean “Instant-On” Current per Anode

- 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.

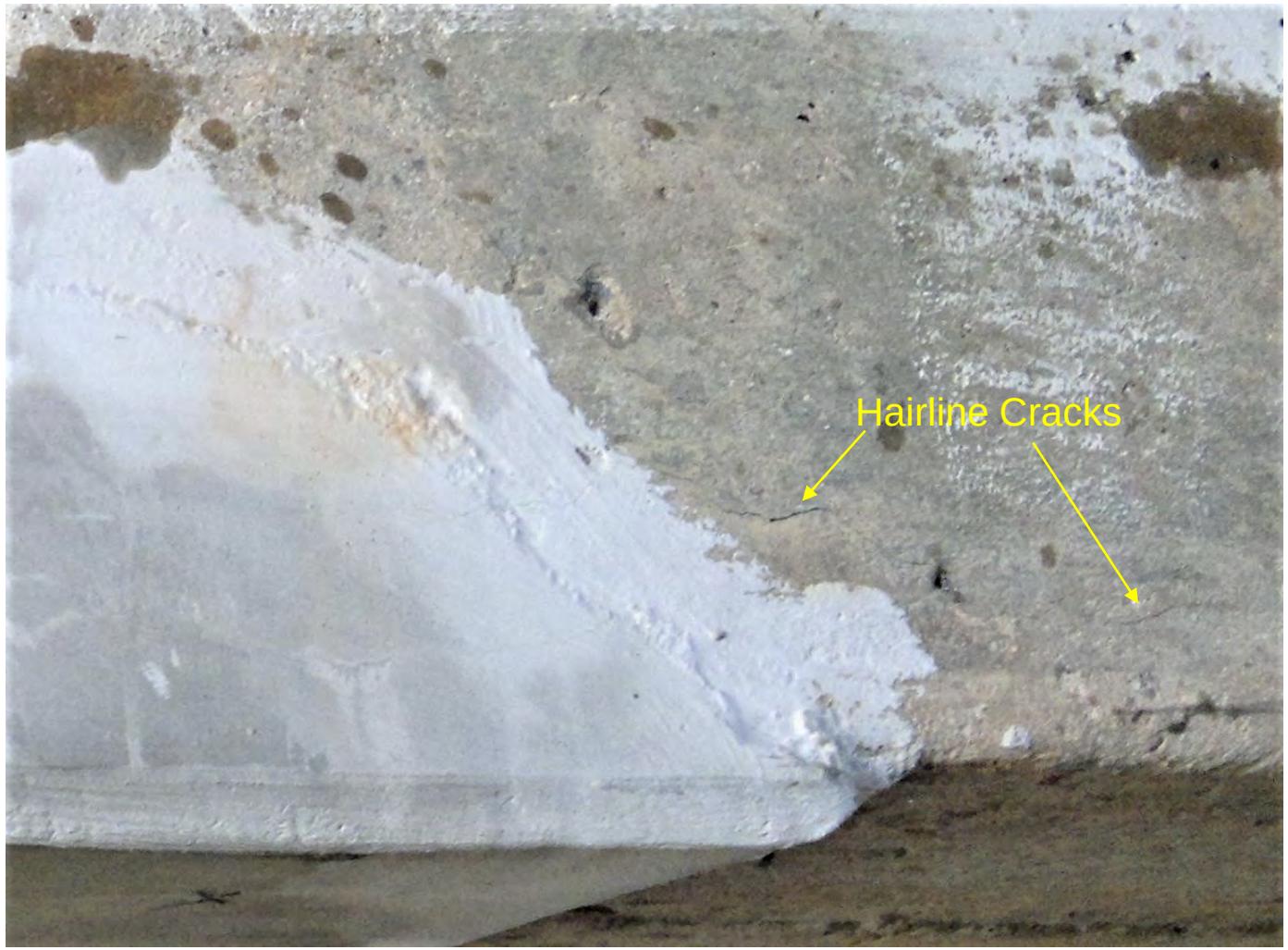


Potential Map After 20 Years

- Possible corrosion initiation between the two repair areas.



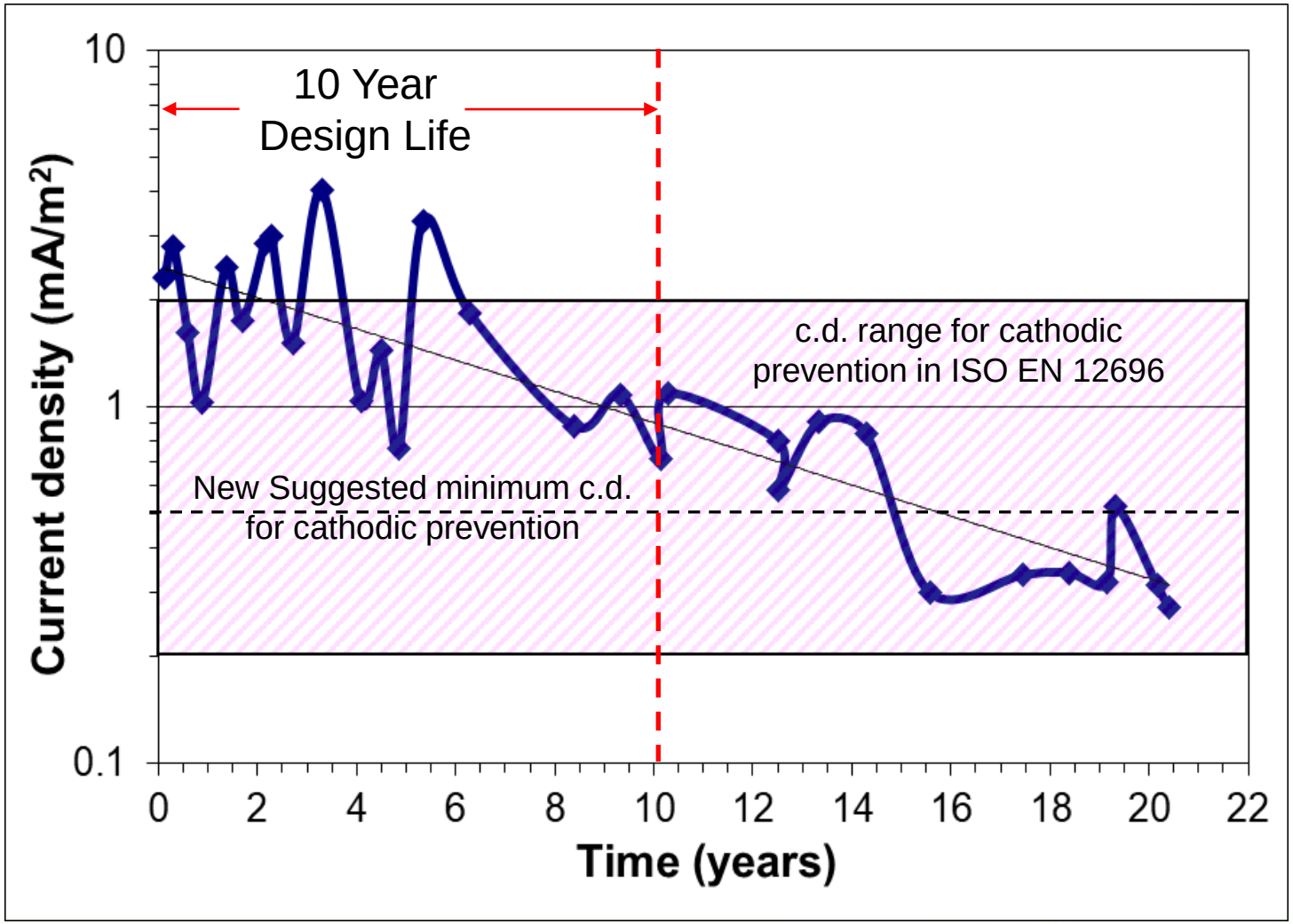
Fine Cracking After 15 Years



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/m^2 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

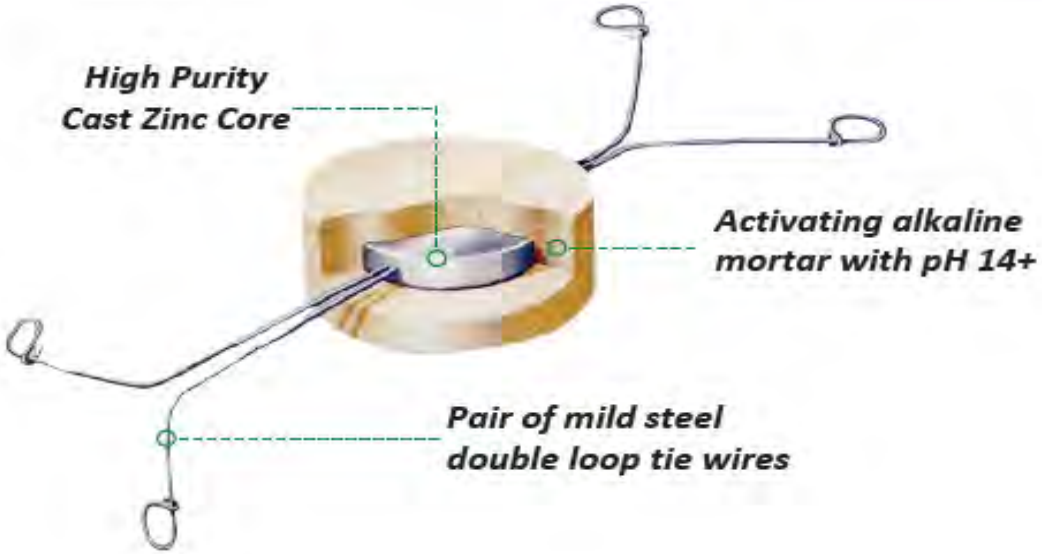
GALVASHIELD® XP

The Original Galvashield® XP Anode

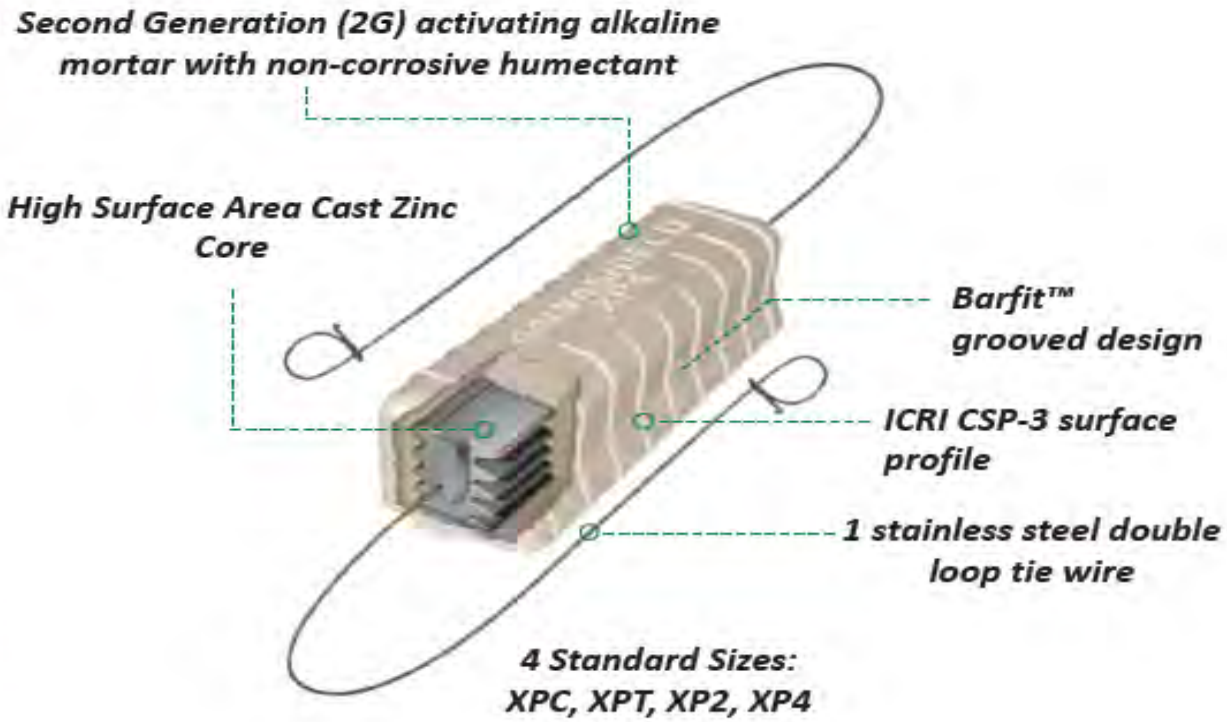
Today's Galvashield® XP Product Line

Twenty years of anode development

1999 → 2019



1 standard size (XP), puck-shaped



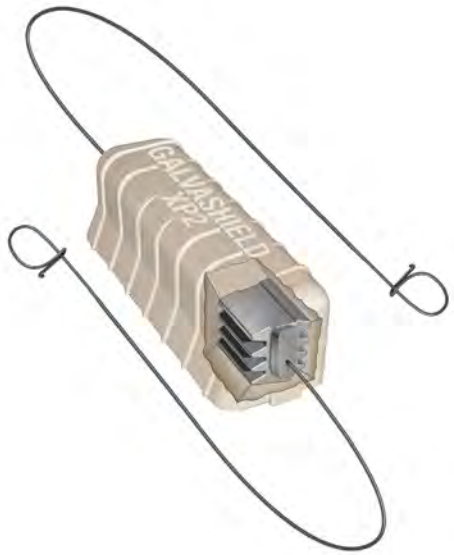
4 Standard Sizes: XPC, XPT, XP2, XP4

Galvashield® XP Range of Anodes

Galvashield® XPT

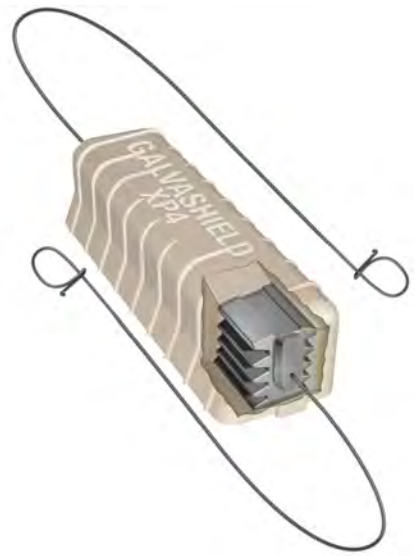
- XPT Essentially replacing XP

Galvashield ® XP2



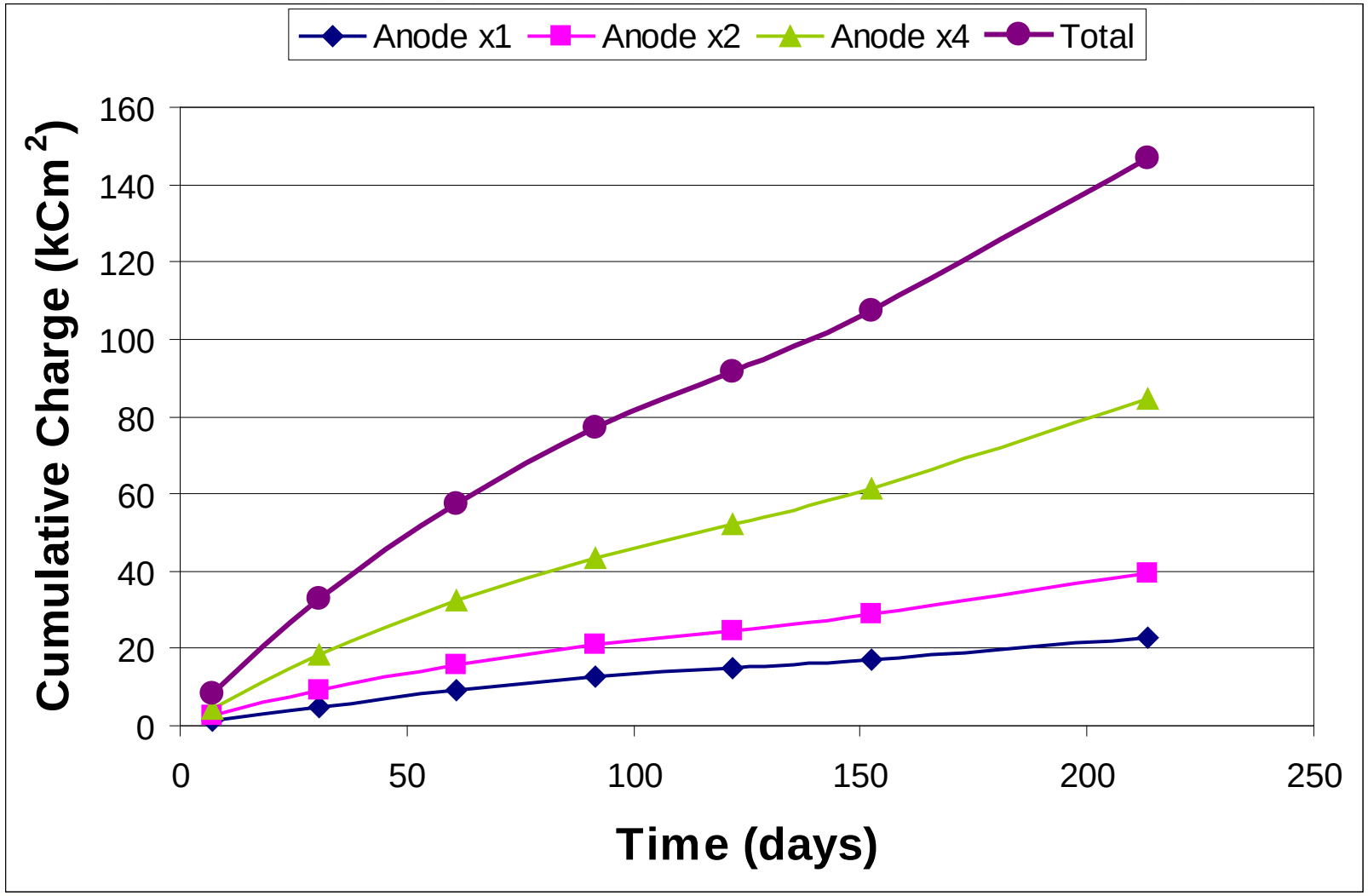
- XP2 = 2 Times the Surface Area

Galvashield ® XP4



- XP4 = 4 Times the Surface Area

Galvashield® XP Range of Anodes



Relative performance of anodes

Relative surface area

XPT = 1

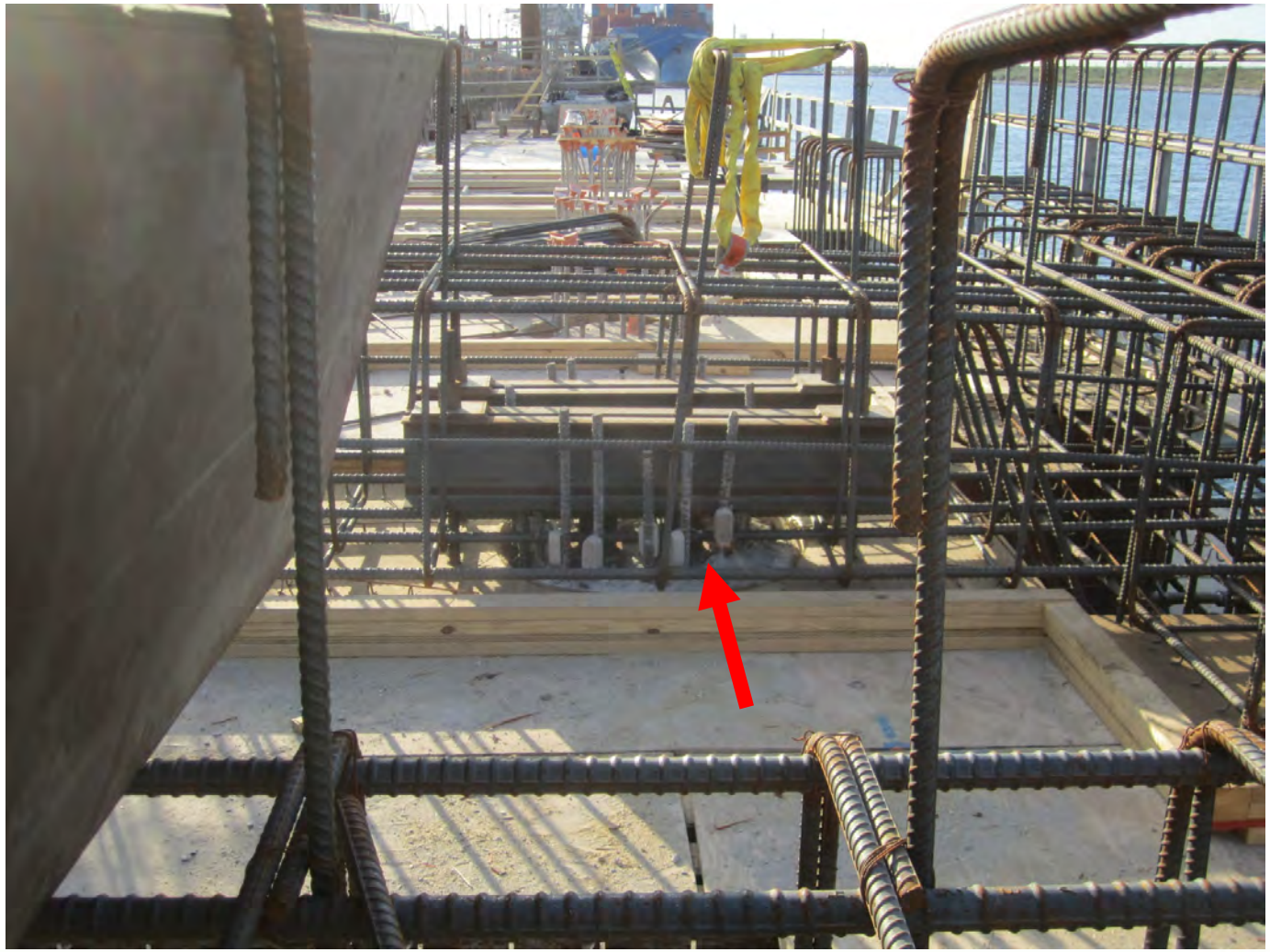
XP2 = 2

XP4 = 4

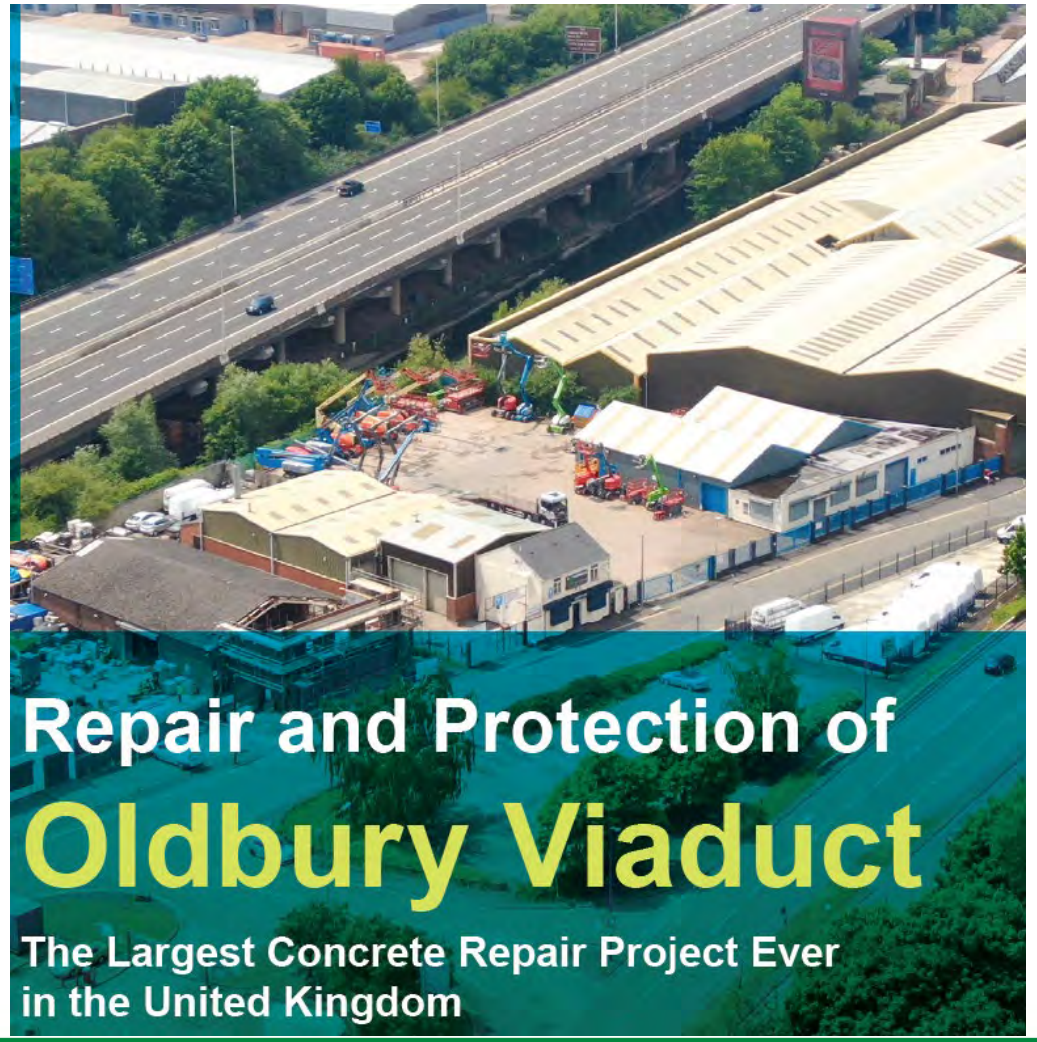
Incipient Anode Mitigation – Galvashield® XP Installation

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

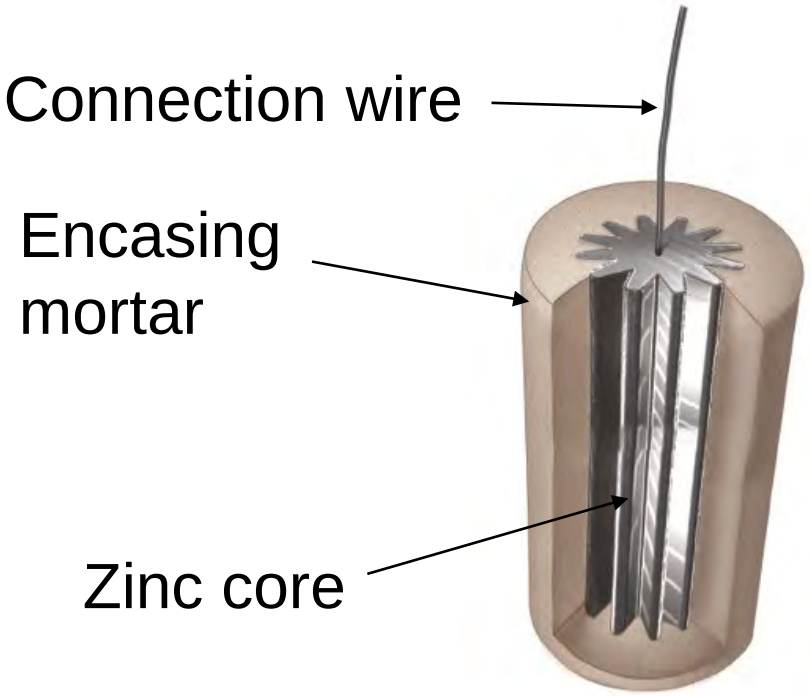
- Galvanic Anodes on Deck at Expansion Joints and repairs

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



Corrosion Control Anodes

Galvashield® CC-Type Anodes

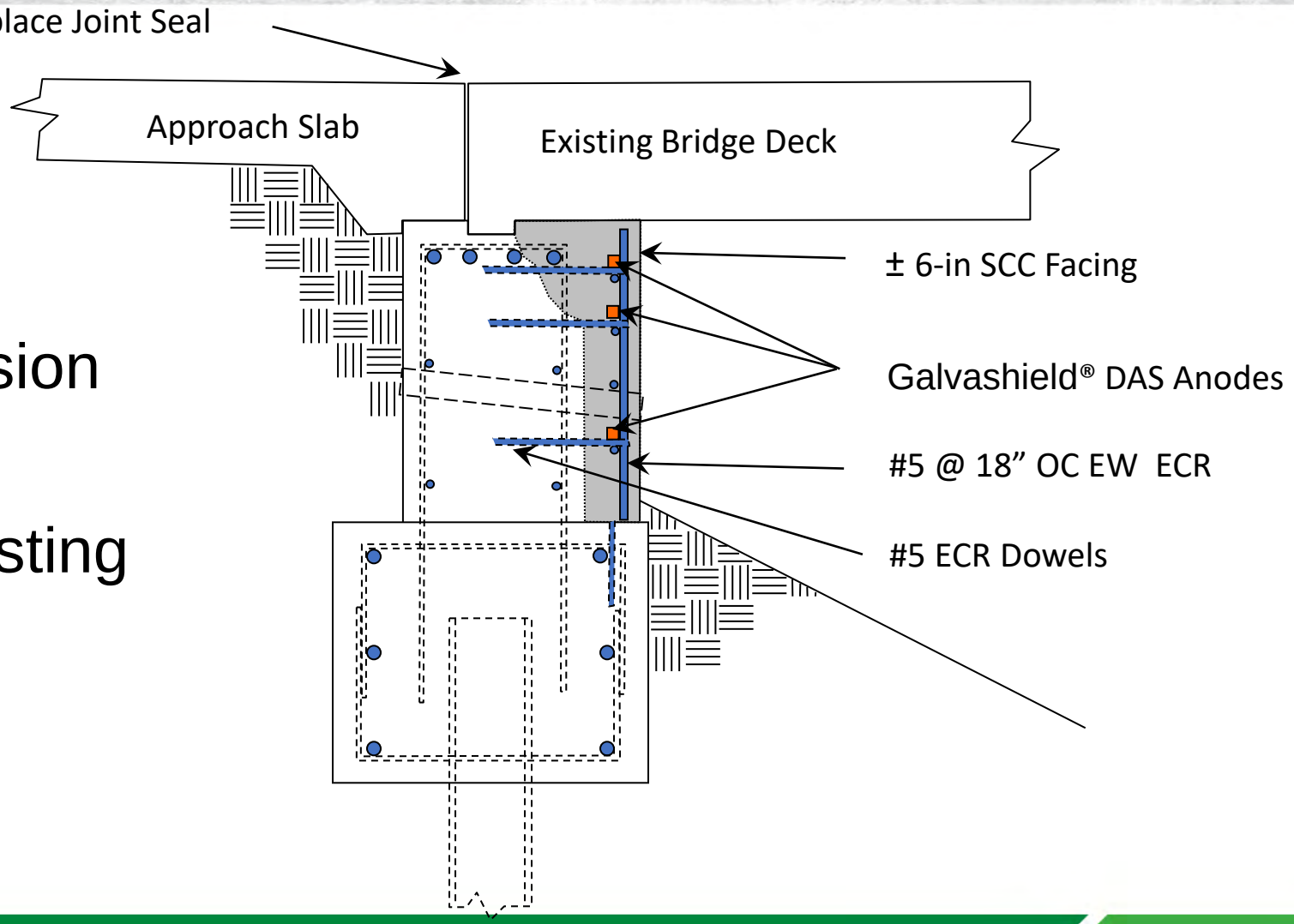
- Prestressed Concrete Box Girder

Distributed Anode System

Galvashield®

DAS Anodes

- Abutment extension
- Steel addition
- Protection of existing steel



Distributed Anode System

Aging Factor of Alkali-Activated Anodes

Anode type and size	Site Location/ Concrete Element	Initial current per anode (mA)	Anode spacing (mm)	λ	$t_{1/2}$	Mean $t_{1/2}$
X1- Repair	Leicester Crossbeam	0.25	600	0.101	6.9	5.6
X1- Repair	Leicester Column	0.50	750	0.165	4.2	
X1- Grid	India Slab	0.62	300	0.118	5.9	
X2- Repair	Leicester Column	0.26	300	0.055	12.6	13.0
X2- Grid	India Slab	0.99	300	0.055	12.6	
X2- Grid	M53 Abutment	0.29	300	0.050	13.9	
X4- Repair	Leicester Column	0.36	300	0.075	9.2	10.3
X4- Grid	India Slab	2.22	300	0.066	10.5	
X4- Grid	M53 Abutment	0.55	300	0.066	10.5	
X4- Grid	Ivy St. Abutment	0.64	300	0.064	10.8	
Long Rod	Ohio Abutment			0.089	7.8	11.3
Long Rod	North Otter Bridge Deck			0.047	14.7	
Mean all					10.0	

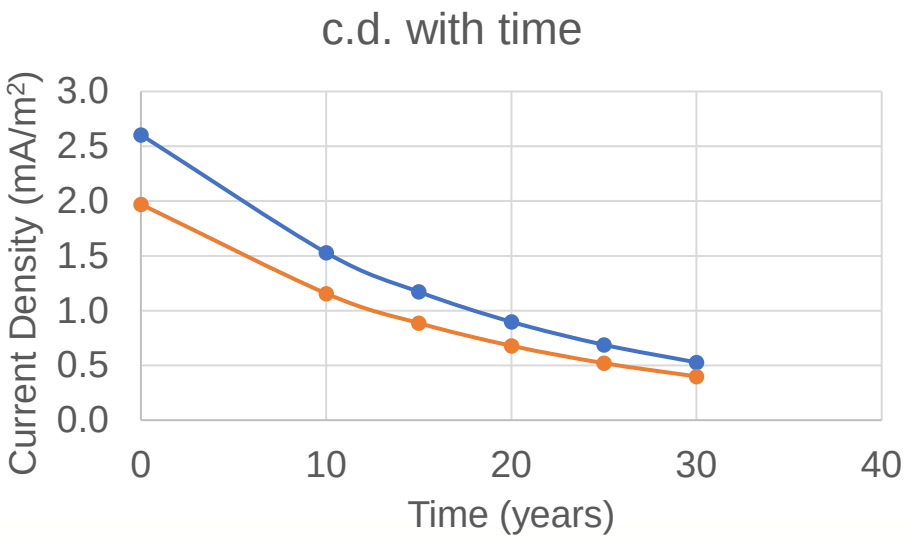
Design Parameters

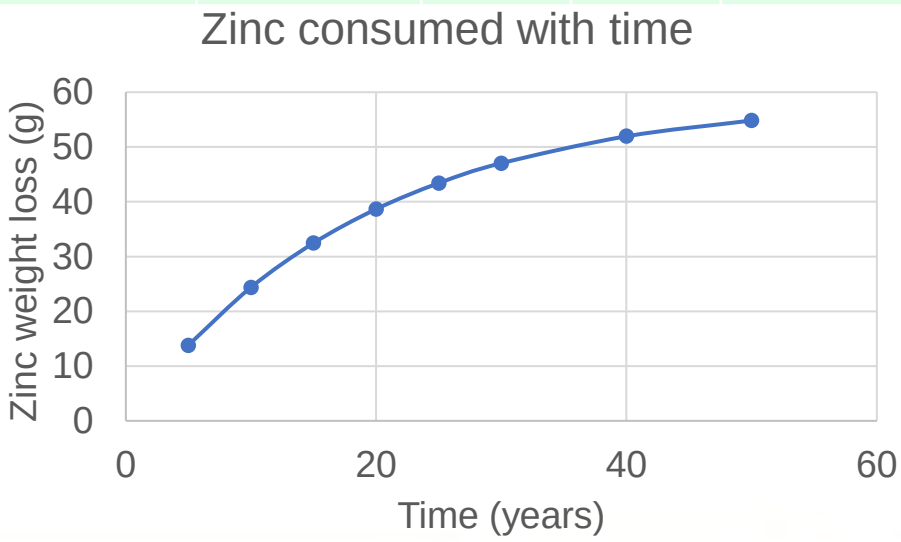
Anode Spacing* for Low to Moderate Corrosion Risk (Chloride Content < 0.8% or Carbonated Concrete)										
Protection Level	Corrosion Prevention						Corrosion Control			
Galvashield® Anode	XPT/XPC**		XP2		XP4		XP2		XP4	
Steel Density Ratio	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
<0.3	750	30	750	30	750	30	600	24	750	30
0.31 - 0.6	600	24	700	28	750	30	500	20	700	28
0.61 - 0.9	500	20	650	26	750	30	400	16	550	22
0.91 - 1.2	450	18	550	22	750	30	350	14	450	18
1.21 - 1.5	400	16	500	20	675	27	250	10	425	17
1.51 - 1.8	350	14	450	18	600	24	200	8	375	15
1.81 - 2.1	300	12	425	17	550	22	175	7	350	14

Improved Design Parameters

Galvashield® XP2 Anode

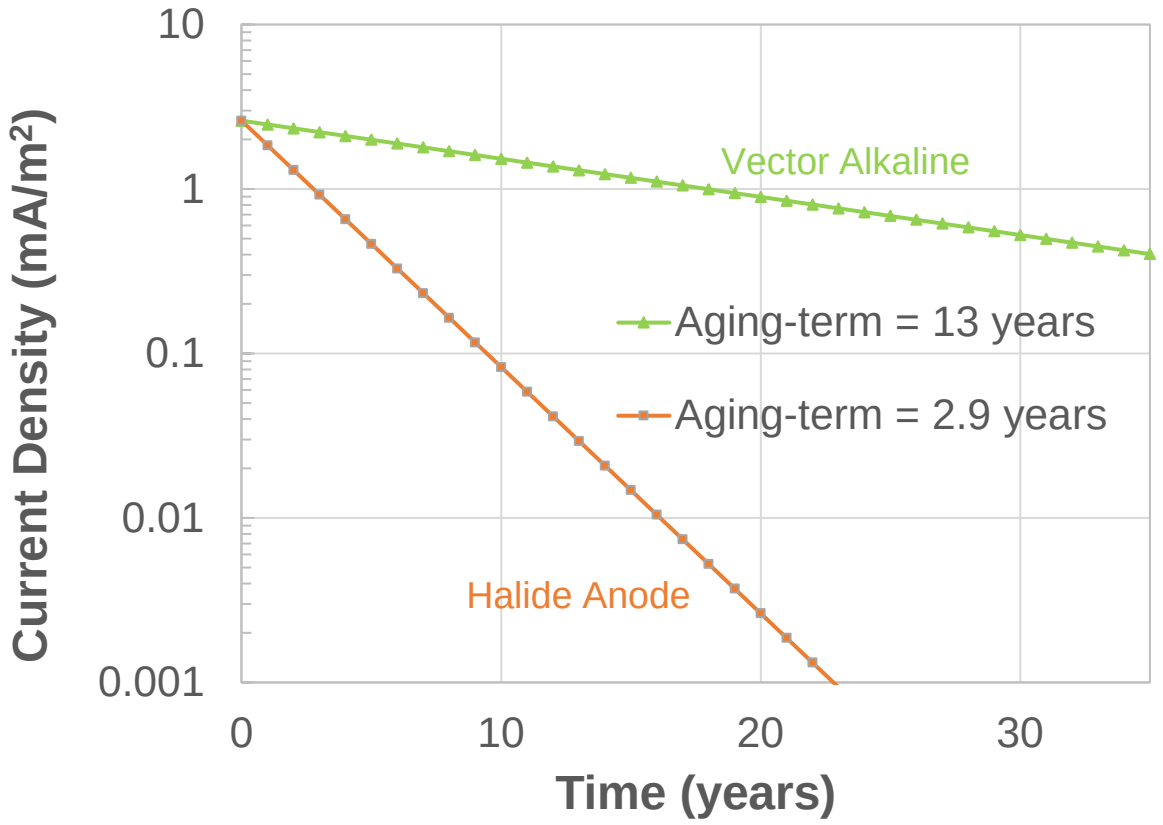
						Tables	Calculation			
					Steel Dens.	Spacing-1	Spacing-2			
					0.61	400	460			
					Years					
		20 years	30 years		0	10	15	20	25	30
Half Life	Initial Current (μA)	Current (μA)	Final Current (μA)	Zinc Used (g)	c.d. at above spacing and steel density (mA/m²)					
13	250	86	50	47	2.60	1.53	1.17	0.90	0.69	0.53
13	250	86	50	47	1.97	1.16	0.88	0.68	0.52	0.40





Improved Design Parameters

Design from Initial Current Density

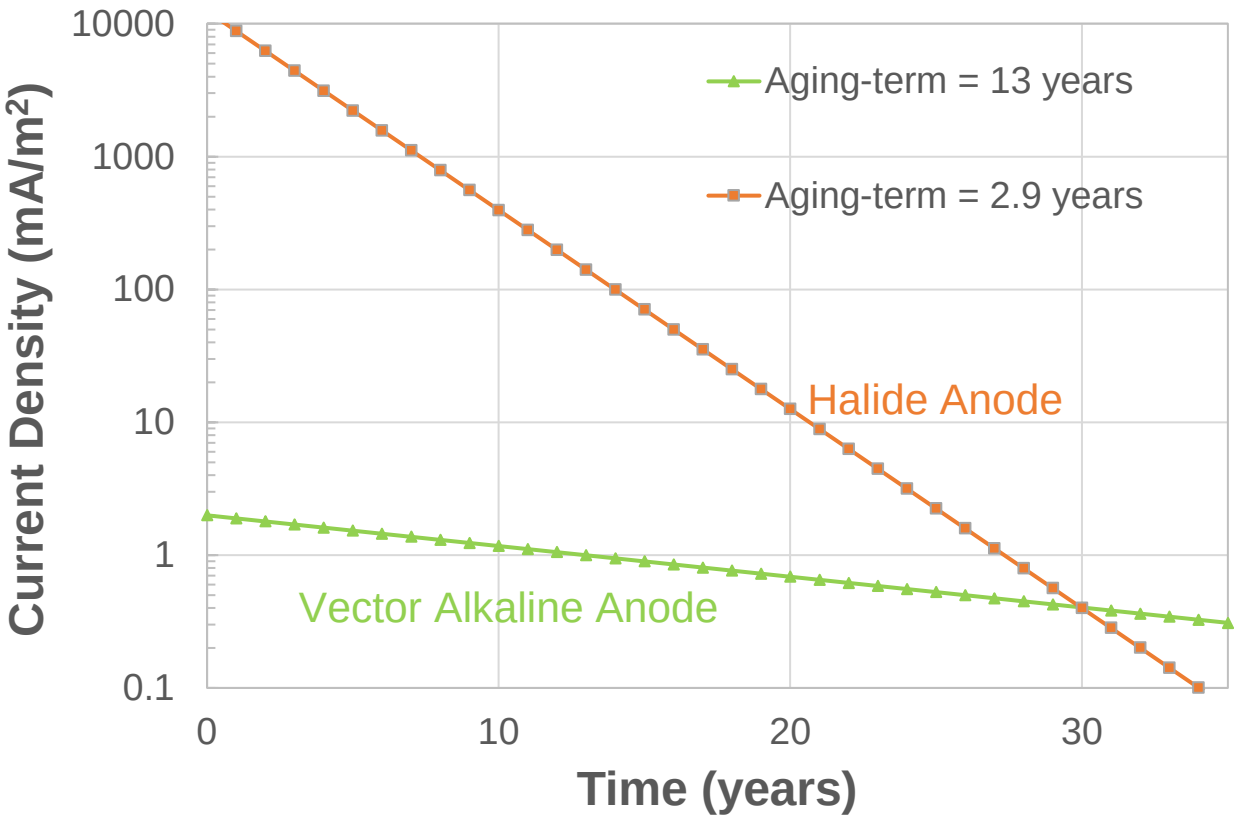


As previous example:

- 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/m^2 (e.g. UK or similar environment) which comes to 2.6 mA/m^2
- Assuming Aging term of 13 years sets 30-year c.d. at 0.56 mA/m^2

Improved Design Parameters

Design for Long-Term Current Density



As previous example:

- In Spreadsheet, Set 30-year c.d. at 0.4 mA/m^2
- Set steel density at 0.6
- Set initial current/anode at 0.25 mA/m^2 (e.g. UK environment)
- Spacing comes out at 460 mm and Initial c.d. at 1.97 mA/m^2

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?

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CONCRETE PRESERVATION ALLIANCE

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 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 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

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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.

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