How To: Design a Galvanic Corrosion Control System

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

Working together to promote education and awareness of:

- concrete repair industry standards,
- new and innovative corrosion prevention technologies
- sustainable construction practices.

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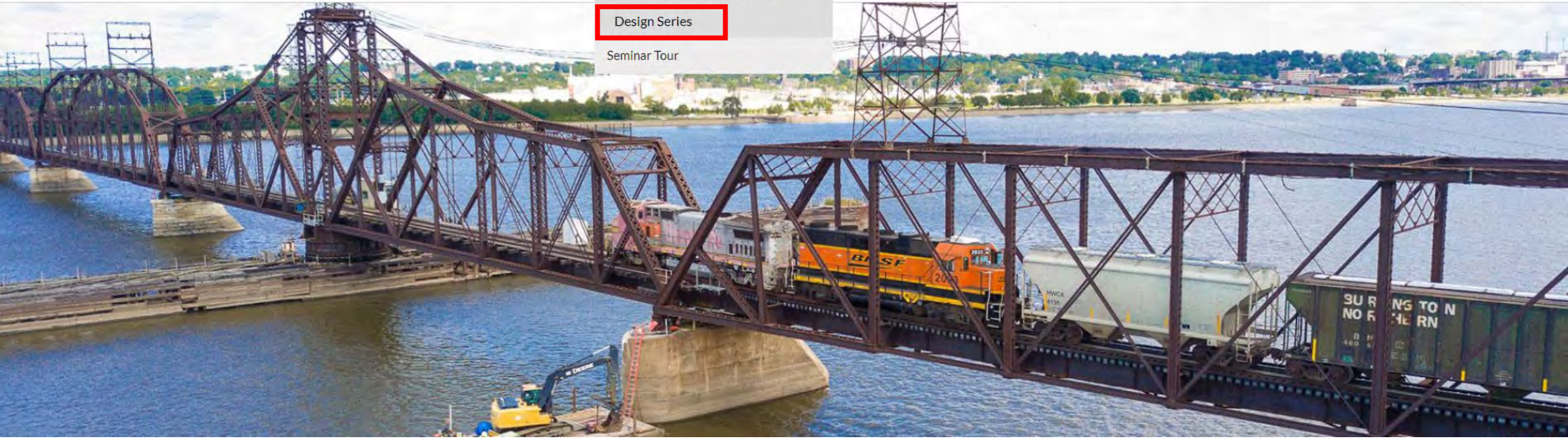

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SEMINARS ARE BACK, AND YOU'RE INVITED!

David Simpson, CP Level 4

David Simpson is the Director of Operations for Vector Corrosion Technologies Limited. David holds a first-class Honours Degree in Chemistry and Biology from Aston University, Birmingham, UK.

Prior to working for Vector, he held the positions of Corrosion Product Manager for Fosroc International and Technical Manager at Fosroc Ltd where he specialized in electrochemical repair methods and cement technology.

David is the forgoing Chairman of the Corrosion Protection Association and is an Icorr level 4 senior Cathodic Protection Engineer for reinforced concrete.

VECTOR CORROSION TECHNOLOGIES

A Clear Disclaimer to Start

The following presentation is a summary of common questions and discussion points that occur during a typical design.

This list is not exhaustive, and each project and structure will have its own individual needs and requirements that may not be fully discussed during this presentation.

It is always recommended to consult a qualified corrosion engineer. This presentation is here to inform and provide a brief insight into a number of items that are generally critical to the process.

A General Overview

Key Steps in the Process

- Do you have a corrosion issue?
- How do I define the problem?
- What are my constraints and restrictions?
- What am I trying to achieve?
- What information do I need to design a galvanic system?
- Two examples of a generic galvanic design
  - A Galvanic repair protection scheme – Cathodic Prevention
  - A Fusion corrosion system – Passivation & Cathodic Prevention
- Questions

In the Beginning….

Do I have a corrosion issue?

- It important not all concrete spalling/deterioration is due to reinforcement corrosion
  - Freeze thaw
  - Structural design issues
  - ASR
  - Chemical Attack
- Corrosion may be a secondary affect caused by concrete cover loss of degradation




How do We Define the Problem

Concrete Testing and Evaluation

The only way to identify the root cause of any deterioration and or corrosion risk is to carry out concrete testing.

Typical tests include the following

- Chloride Testing
- Carbonation Testing
- Concrete Cover Evaluation
- Petrographic analysis (Cement content XRD)
- Half-cell potential mapping
- Delamination survey

Others of note may include Resistivity testing, Corrosion Rate monitoring & Concrete Strength

Reference Webinar

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Aug 12, 2020 | Corrosion Assessments for Concrete Bridge Elements

Brian Pailes, P.E, Ph.D., NACE CP Specialist

VCS Inc.

Description: Corrosion of the reinforcing steel is the #1 cause of concrete failure on bridge structures. Before corrosion can be mitigated or brought to a halt, we must understand the underlying cause and quantify the magnitude and extent of corrosion risk. There are many destructive and non-destructive test methods that are effective in assessing corrosion risk. No one method will provide a complete assessment, but in combination can provide a holistic view of the structure's health. This webinar will compare and contrast the various methods available today.

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Wesavestructures.info/events/Corrosion-Assessments-for-Concrete-Bridge-Elements

How do We Define the Problem

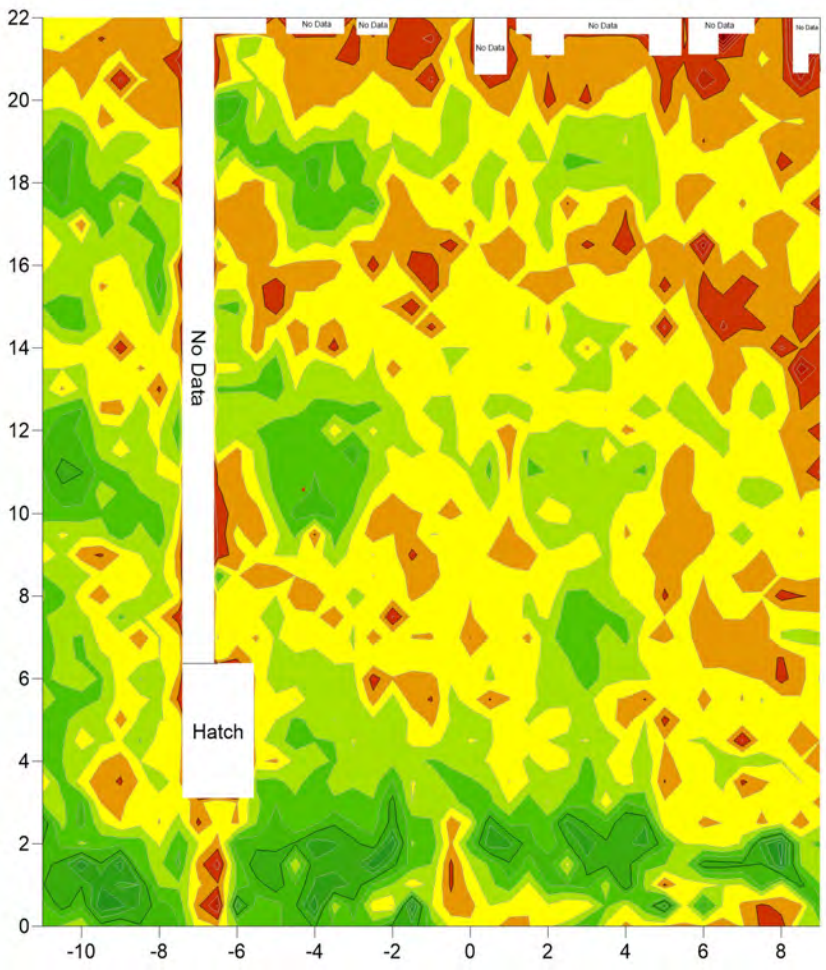
A Way of Quantifying Risk

- The whole purpose of any testing is to evaluate and assign risk. Only when we understand the risks involved should we consider a solution.
- The problem with ***Reinforcement Corrosion*** is it's not typically uniform over a structure,
  - Variability in Concrete Cover and therefore protection levels
  - Variability in water exposure and therefore chloride contamination
  - Structural variability which may exaggerate both of the above
  - Variability in concrete quality during construction, and or the inclusion of chloride in the mix
- As designers we need to address this variability and subdivide the structure into zones. The data from testing enables this to happen.

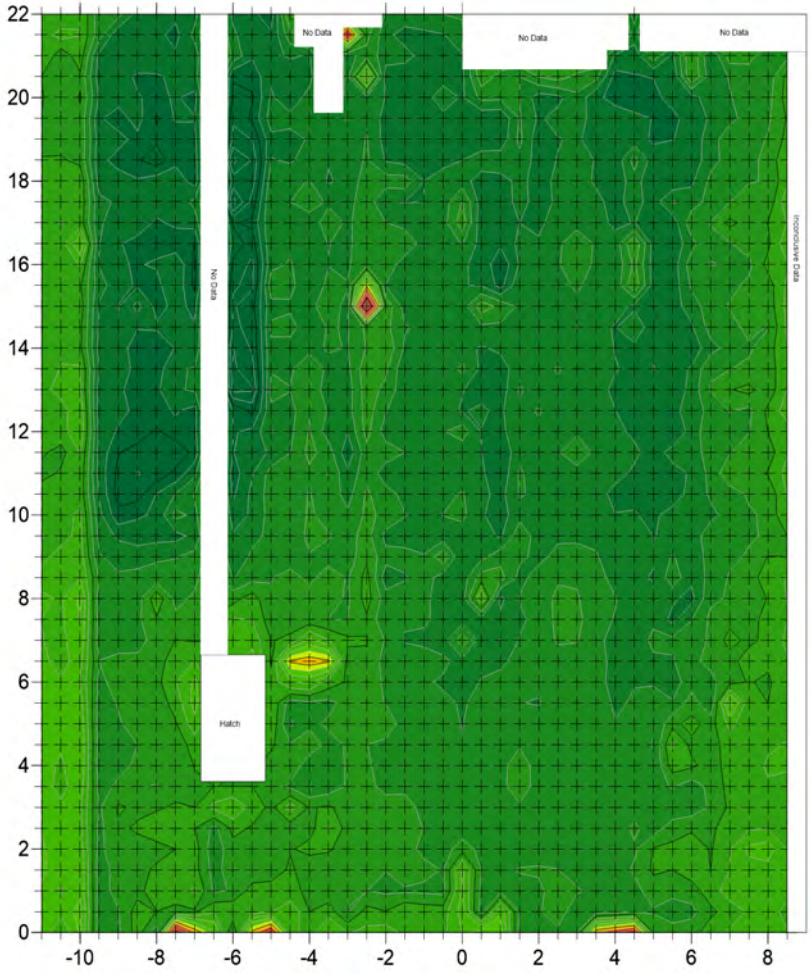
WITHOUT THIS DATA, ASSUMPTIONS HAVE TO BE MADE THAT MAYBE INCORRECT!

Concrete Cover Example

Concrete Cover Survey



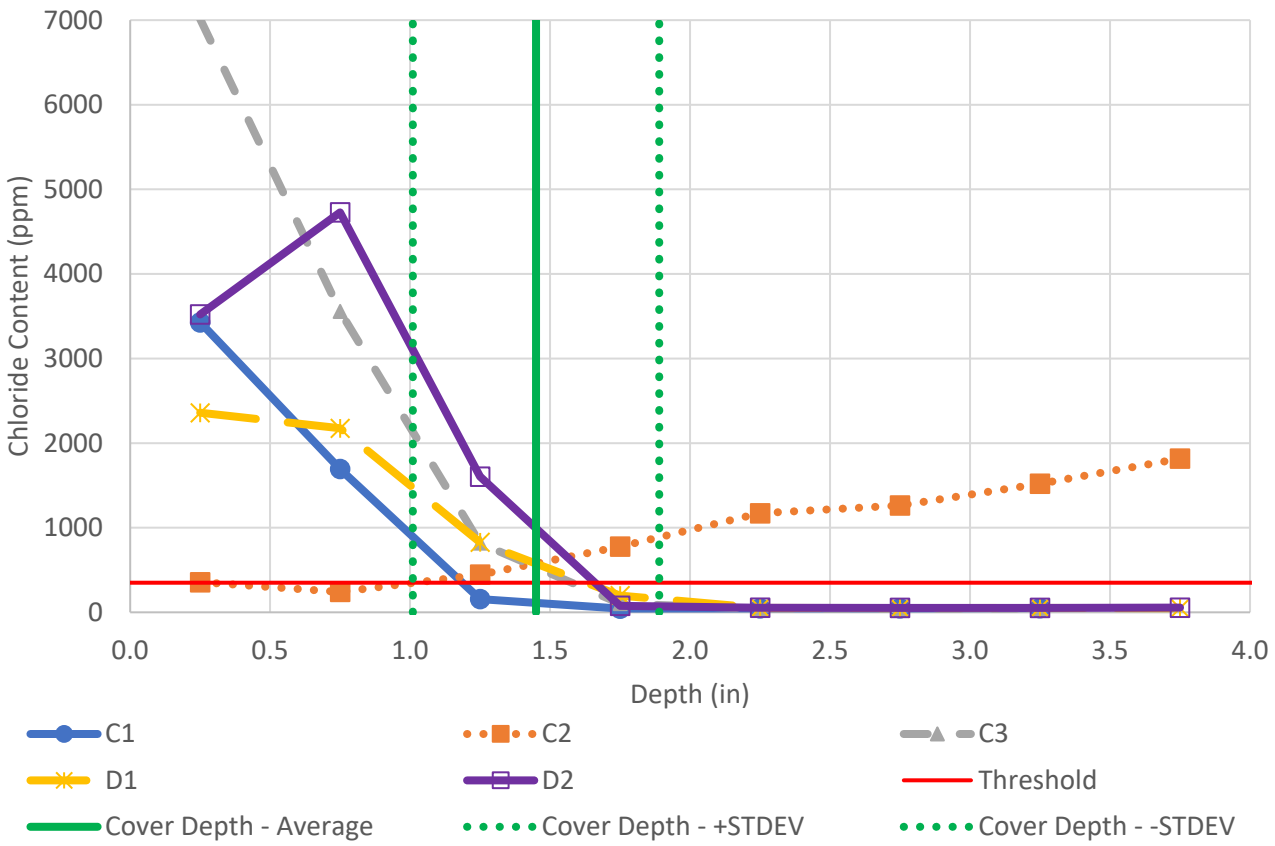
Half-cell Potential Survey



Chloride Testing/Profiling

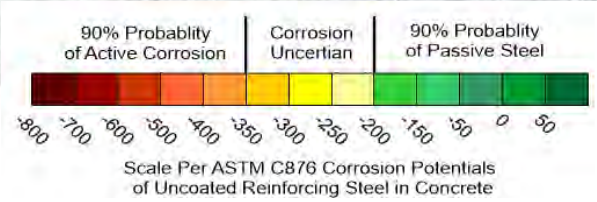
Statistical Analysis

Chloride Content by Weight of Cement (%)	Risk in Uncarbonated Concrete (pH>10)
<0.2	Negligible
0.2 – 0.4	Very Low
0.4 – 0.8	Low to Moderate
0.8 – 1.5	High
> 1.5	Extremely High



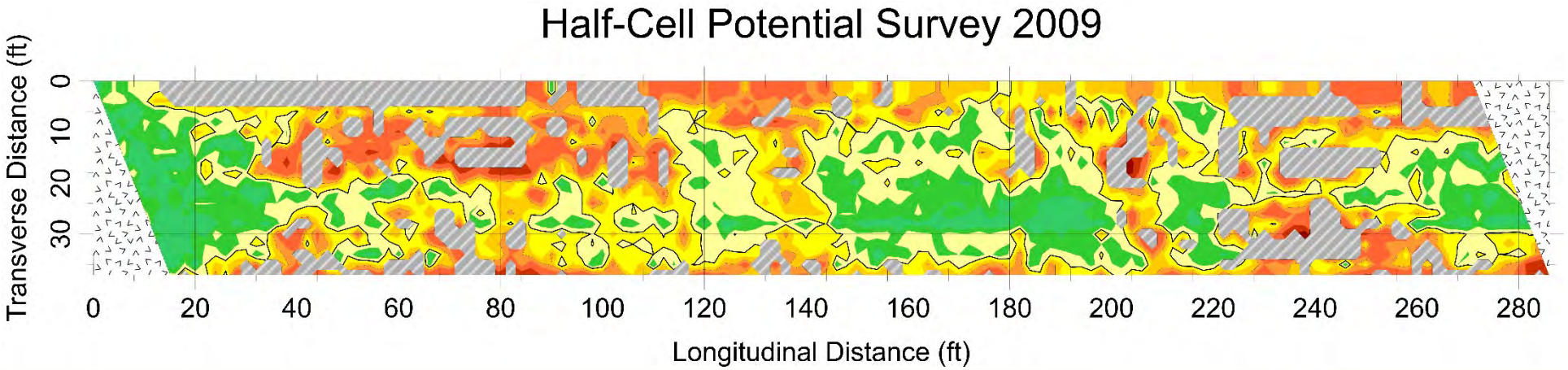
Water Exposure Example

Half-Cell Potential Mapping



Corrosion potential and delamination survey bridge deck

- Provides a picture of current damage and areas with a high probability of Active Corrosion



Concrete Testing

Risk Assessment

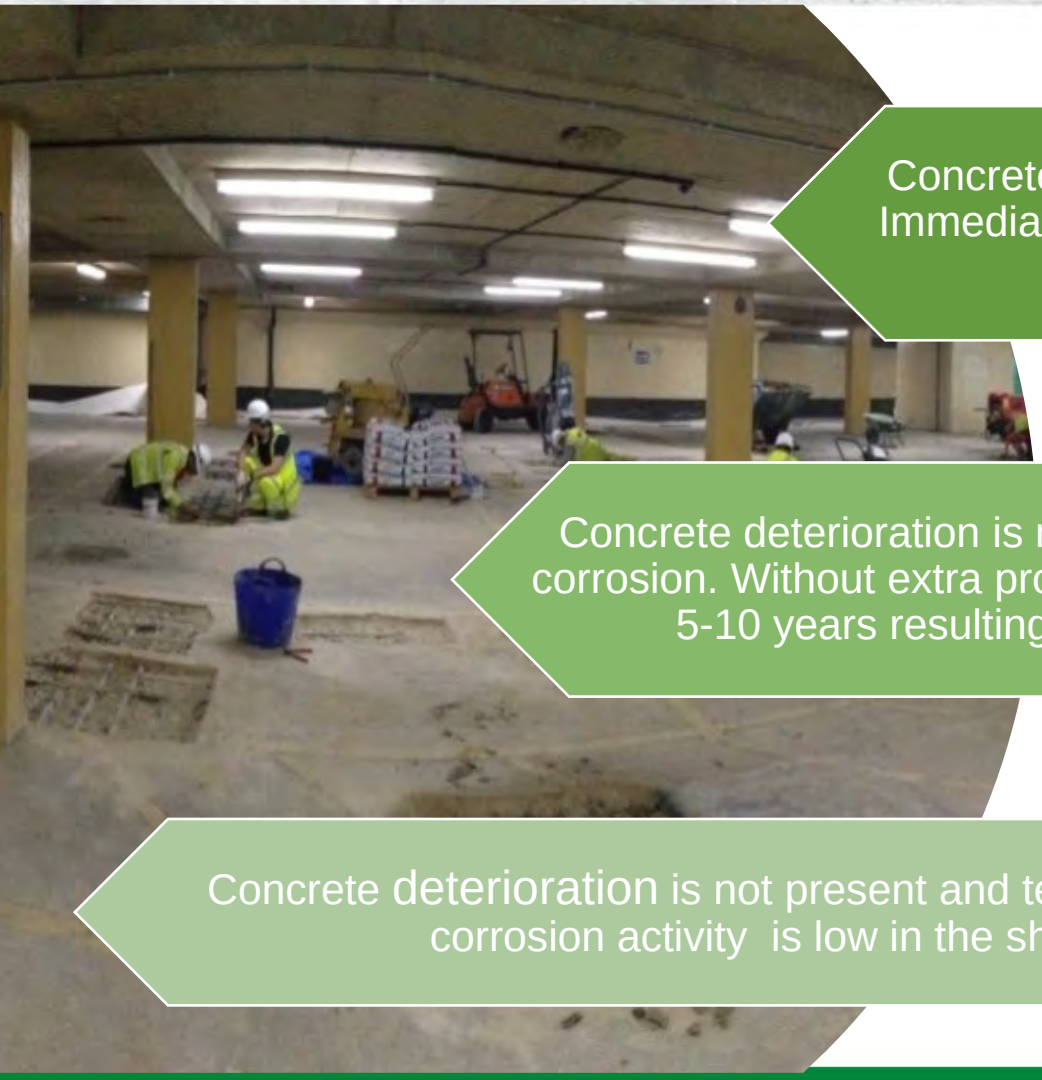
- While all the tests mentioned provide information, singly they are not able to provide the user or designer with a clear picture
- Only when all information is pulled together does a true risk profile appear and appropriate zoning of the structure can be made.
- At this stage, a variety of concrete repair and protective techniques can be applied and assessed against the life aspirations of the structure.
- As with testing, it is highly unlikely that a single method will be used. Often it is a holistic approach that is used bringing together multiple techniques.
- Corrosion Prevention/Protection maybe one of them.
- The rest of the presentation will assume chloride induced corrosion is present

Commercial and Use Considerations

Its' not all about the technical merit

- While corrosion protection and other techniques may technical be the best solution available for the structure, commercially not all of them may be suitable.
- This will vary for every project and will always be part of any remedial proposal. Other factors that can alter the type and size of system used. These can include,
  - Life expectancy of the structure
  - Location and access issues (water, highways, train tracks, vandalism, cost of repeat access etc)
  - Cost vs benefit
  - Monitoring and maintenance requirements
  - Health and safety considerations
  - Environmental impacts

3 types of Zone to Consider



Concrete has deteriorated due to corrosion activity on the steel reinforcement. Immediate action is required to make good. Incipient anode is a risk to the long term stability of the repair.

Concrete deterioration is not present but testing has shown an increased risk of corrosion. Without extra protection, corrosion will most likely initiate within the next 5-10 years resulting in further concrete and structural deterioration.

Concrete deterioration is not present and testing has shown that the risk of corrosion activity is low in the short to medium term.

Reference Webinar

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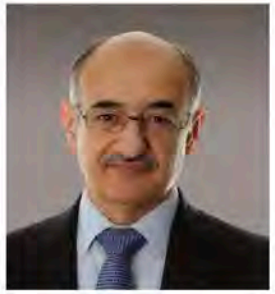
Sep 9, 2020 | Corrosion Protection and Bridge Concrete Repairs

Dr. George Sergi, CEng, BSc, MSc, PhD, FICorr, FIMMM, BS EN ISO 15257:2017 Level-4 CP Specialist

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.



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Target Repairs to Chloride Contaminated Concrete

Incipient Anode / Ring Anode Effect

Example 1 – Galvanic Repair Protection

Cathodic Prevention Risk Classification

- Identifying and analysing the cause of corrosion
- Structural zoning
- Risk classification & current density requirements
- Climate consideration
- Steel reinforcement evaluation & density calculation
- Current density prediction
- Zinc mass qualification

Reference Webinar

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PREVIOUS EVENTS

Jun 8, 2022 | Design Considerations for Galvanic Anodes

David Whitmore, P.Eng

Vector Corrosion Technologies

Over the past 20+ years, Vector Corrosion Technologies has learned a great deal about how galvanic anodes perform, age and protect steel in reinforced concrete over time. Variables like surface to mass ratio of the zinc core, the zinc core activation method and the environmental exposure conditions including the level of chloride contamination, moisture and temperature. In this presentation, Dave will be going beyond the datasheet to explain just how these factors govern the service life of zinc based cathodic protection systems.

Click here to download the slides to the presentation

Click here or below to view recording of webinar

David Whitmore, P.Eng., FACI, FCSCE, NACE CP Specialist

David Whitmore is President and Chief Innovation Officer for Vector Corrosion Technologies, a company which specializes in the repair and corrosion protection of reinforced concrete structures.

Dave is a registered Professional Engineer, a NACE Cathodic Protection Specialist and he serves on a number of repair, corrosion, sustainability and education committees of ACI, ICRI and NACE. He is a fellow of the American Concrete Institute and the Canadian Society of Civil Engineers.

He has been involved with US Federal Highway Administration on the Strategic Highway Research Program (SHRP) and SHRP 2 projects with regard to Electrochemical Chloride Extraction, Cathodic Protection of concrete bridge structures and Bridges for Service Life Beyond 100 Years.

VECTOR CORROSION TECHNOLOGIES

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Example 1 – Galvanic Repair Protection

Risk Classification & Current Density Requirements

DESIGN CRITERIA

Corrosion Risk Category	Chloride Level*	Minimum Current Density at 20 Years**
Low to Moderate	<0.8%	0.4mA/m² (0.04mA/ft²)
High	0.8%-1.5%	0.8mA/m² (0.07mA/ft²)
Extremely High	1.5%	1.6mA/m² (0.15mA/ft²)

* Chloride content is based on percent by weight of cement.

**Design current densities for the XPX are double the standard current densities at 20 years.

ISO Standard

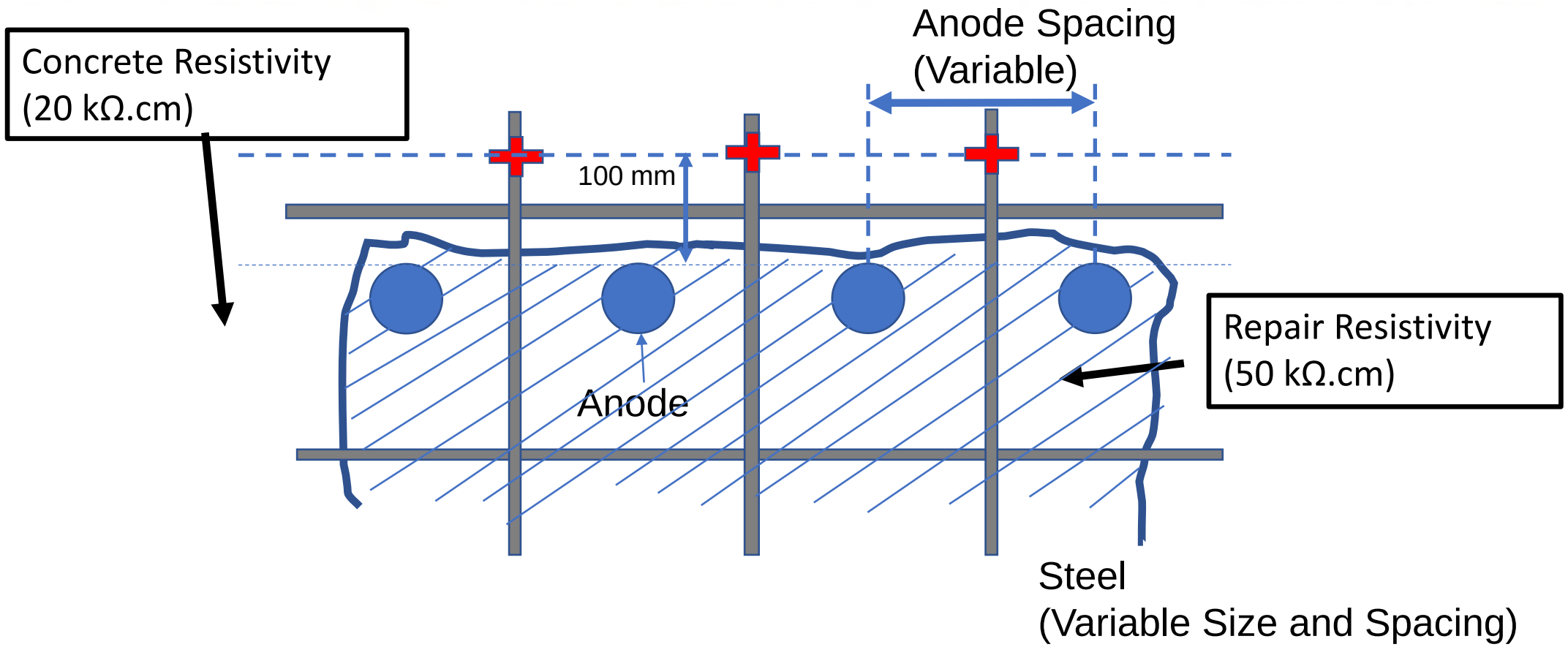
<u>0.2-2.0mA/m2</u>

0.2mA/m2 Only New Construction

Environment may override this e.g. Maine, Artificial environments etc

All based upon 10oC Average temperature

Current Density Assumption

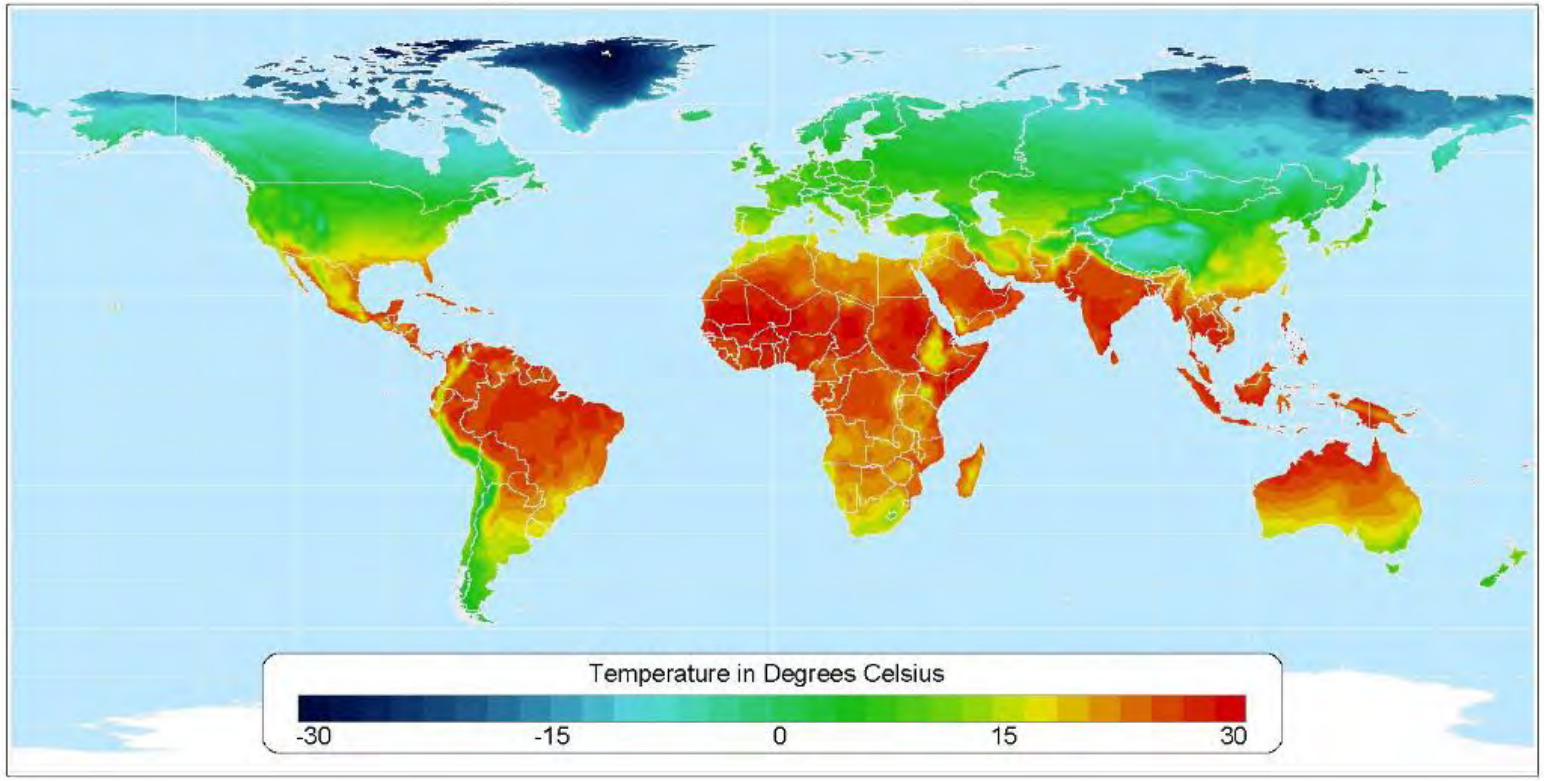


Desired design current density (0.4, 0.8 or 1.6 mA/m^2) is calculated to reinforcing steel between the anodes, 4 in. (100mm) outside of the repair.

Average Annual Temperature

- New York 11.9 ºC (53ºF)
- Chicago 10.2 ºC (50ºF)
- Los Angeles 17.6 ºC (64ºF)
- London 10.8 °C (51°F)
- Tokyo 15.2 °C (59°F)
- Sydney 18.0 °C (65°F)
- Miami 24.2 ºC (76ºF)
- Mumbai 26.4 °C (80°F)
- Singapore 26.7 °C (80°F)
- Dubai 28.2 °C (83°F)
- Jeddah 28.1 °C (83°F)

CLIMATE-DATA.ORG



Average annual temperature (ecoclimax.com)

Example 1 – Galvanic Repair Protection

Steel Density Calculation

- Protection to steel in concrete is provide by a DC current that is supplied to the steel in question
- The steel is not interested in the source
- As such we need to understand the surface area of steel per unit area. This is typically calculated in either m^2 or ft^2
- **<u>Is the steel continuous</u>**?
- This information is usually found on as build drawings
- Often these are missing and or very old and difficult to access
- Often what was designed in the engineering room is very different to what you find onsite.
- Therefore, validation of steel content and layout is vital to validate any design that has been done with as built drawings alone. GPR is a good option for this during the initial testing stage

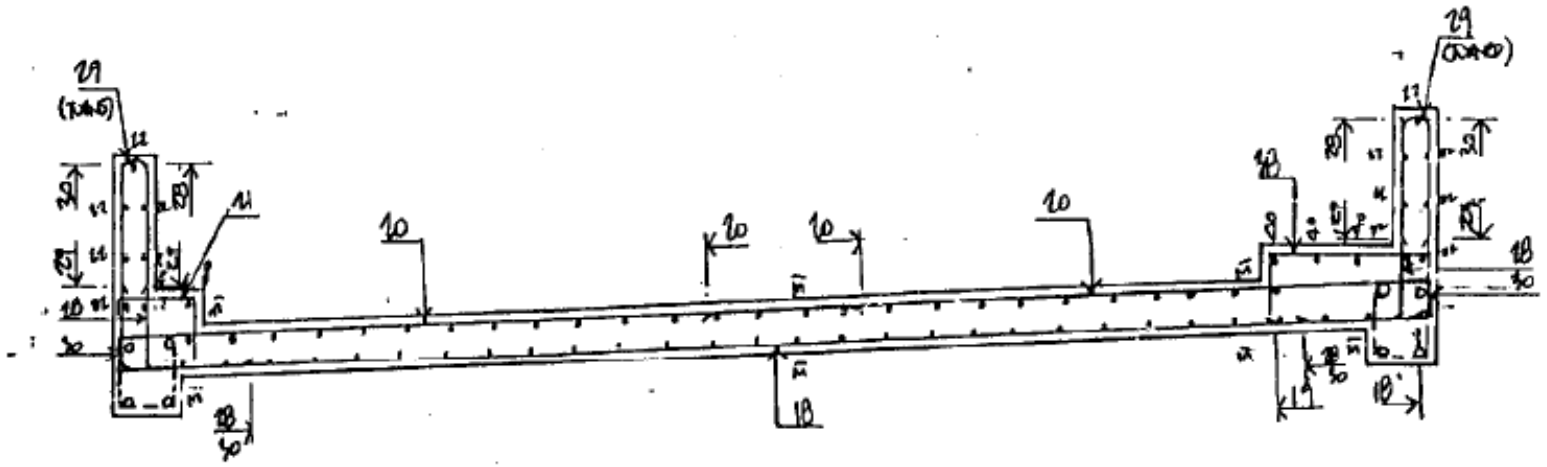
Example 1 – GPR scan Examples

Example 1 – Steel Density Calculation

Steel layout evaluations

Formula

SA = Bar Dia (m) x length (m) x number per m2 x Pi



Example 1 – Steel Density Calculation

Steel layout evaluations

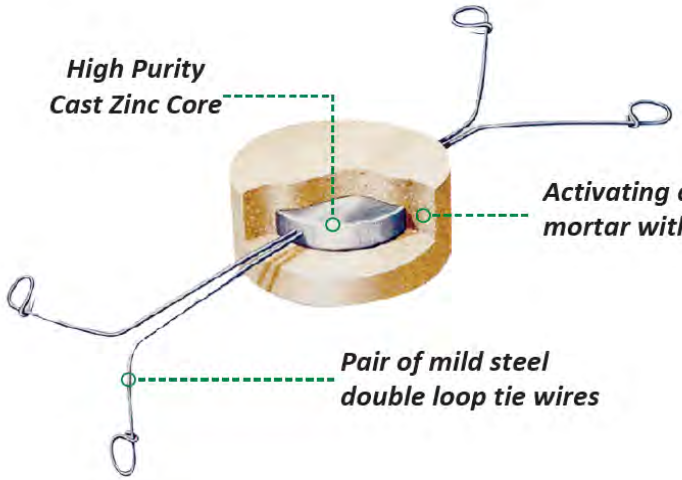
Bar Identification	Dia of Rebar (m)	Rebar Length (m)	Bar Spacing (m)	Number of Bars per m	Steel Surface Are (m^2)
Bar – 1. (layer 1 & 2)	0.016	1	0.15	13.2	0.67
Bar – 2. (layer 1 & 2)	0.010	1	0.15	13.2	0.42
				Error (10%)	0.11
				Total	**1.2**

Targeted Galvanic Repair

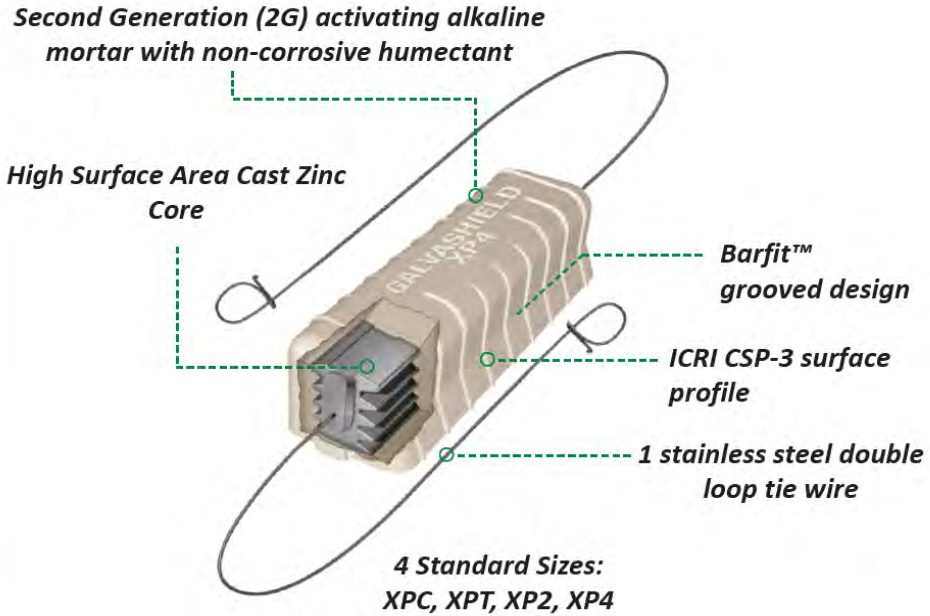
GALVASHIELD® XP

The Original Galvashield® XP Anode | **Today's Galvashield® XP Product Line**

1999 → 2023



1 standard size (XP), puck-shaped



4 Standard Sizes:
XPC, XPT, XP2, XP4

Example 1 – Patch Repair Protection

Risk Classification & Current Density Requirements

DESIGN CRITERIA

Corrosion Risk Category	Chloride Level*	Minimum Current Density at 20 Years**
Low to Moderate	<0.8%	0.4mA/m² (0.04mA/ft²)
High	0.8%-1.5%	0.8mA/m² (0.07mA/ft²)
Extremely High	1.5%	1.6mA/m² (0.15mA/ft²)

* Chloride content is based on percent by weight of cement.

**Design current densities for the XPX are double the standard current densities at 20 years.

For patch repairs chloride level is the most common indicator used to identify risk.

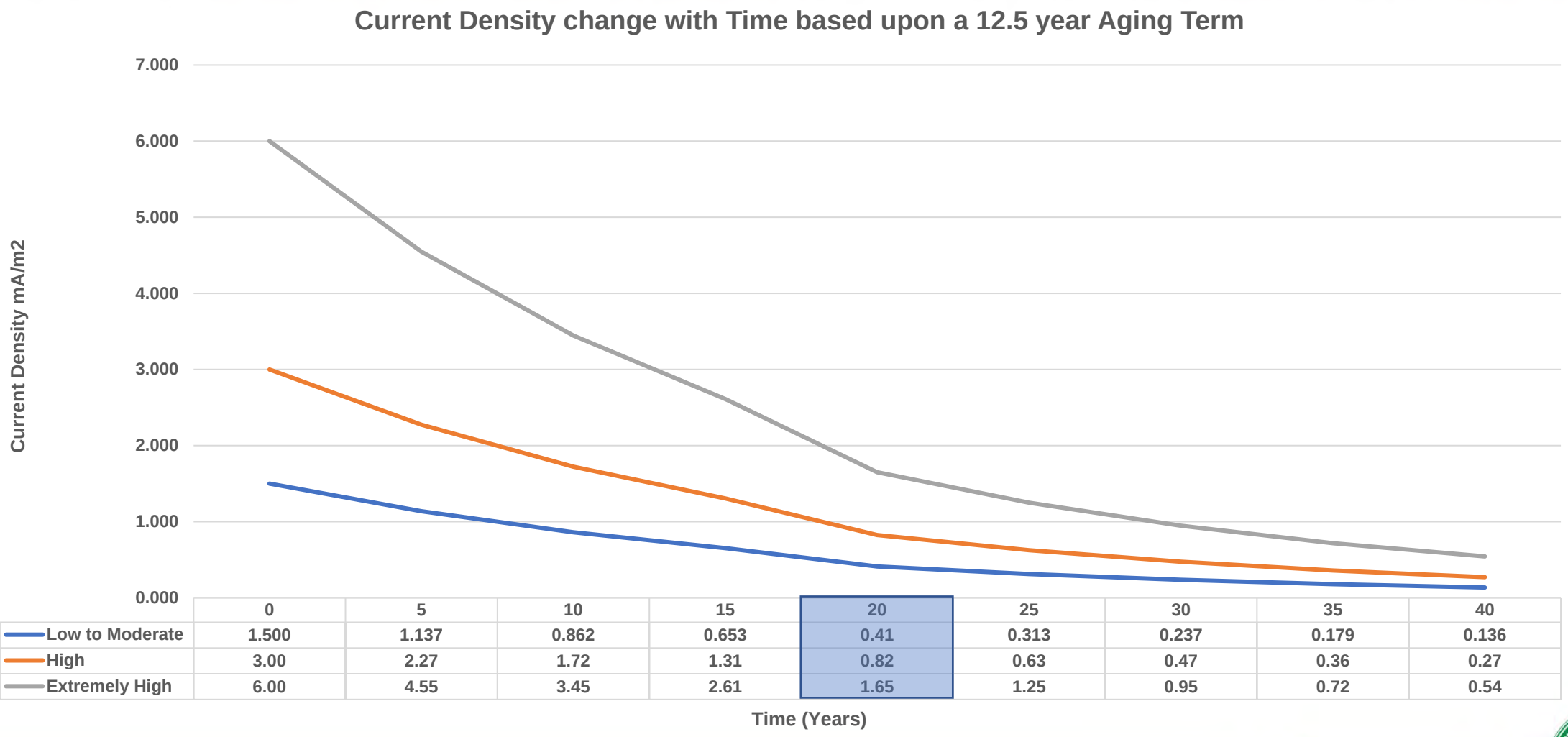
Environment may override this e.g. Maine, Artificial environments etc

All based upon 10oC Average temperature

Spacing Charts (High Risk)

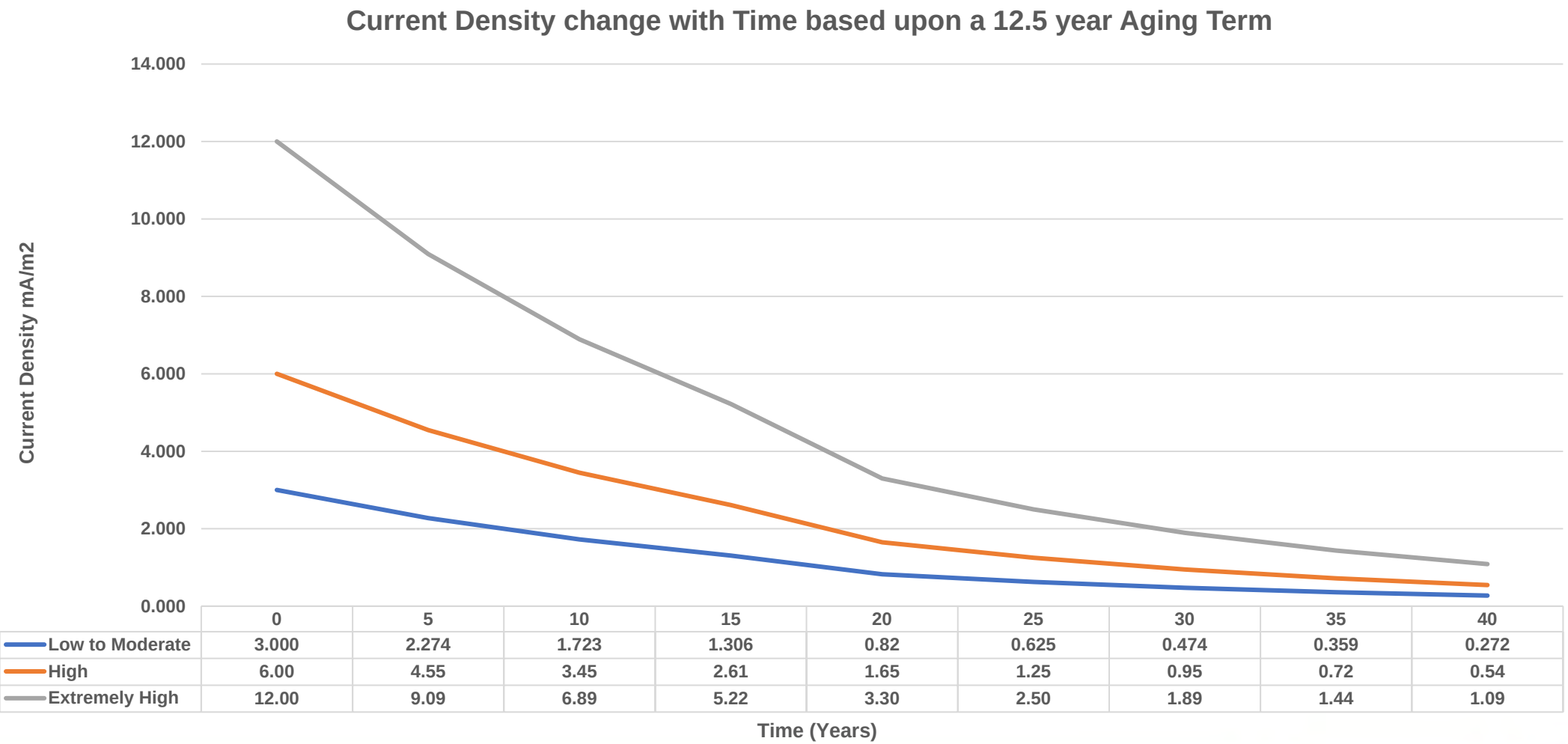
High Corrosion Risk (Chloride Content* 0.8% to 1.5%)						
Steel Density	XPT/XPC**		XP2		XP4/XPX	
	inch	mm	inch	mm	inch	mm
<0.3	18	450	28	700	28	700
0.31-0.6	12	300	19	475	25	625
0.61-0.9	10	250	15	375	20	500
0.91-1.2	8	200	13	325	17	425
1.21-1.5	7	175	11	275	15	375
1.51-1.8	6	150	10	250	14	350
1.81-2.1	5	125	9	225	13	325

Current Density Requirements



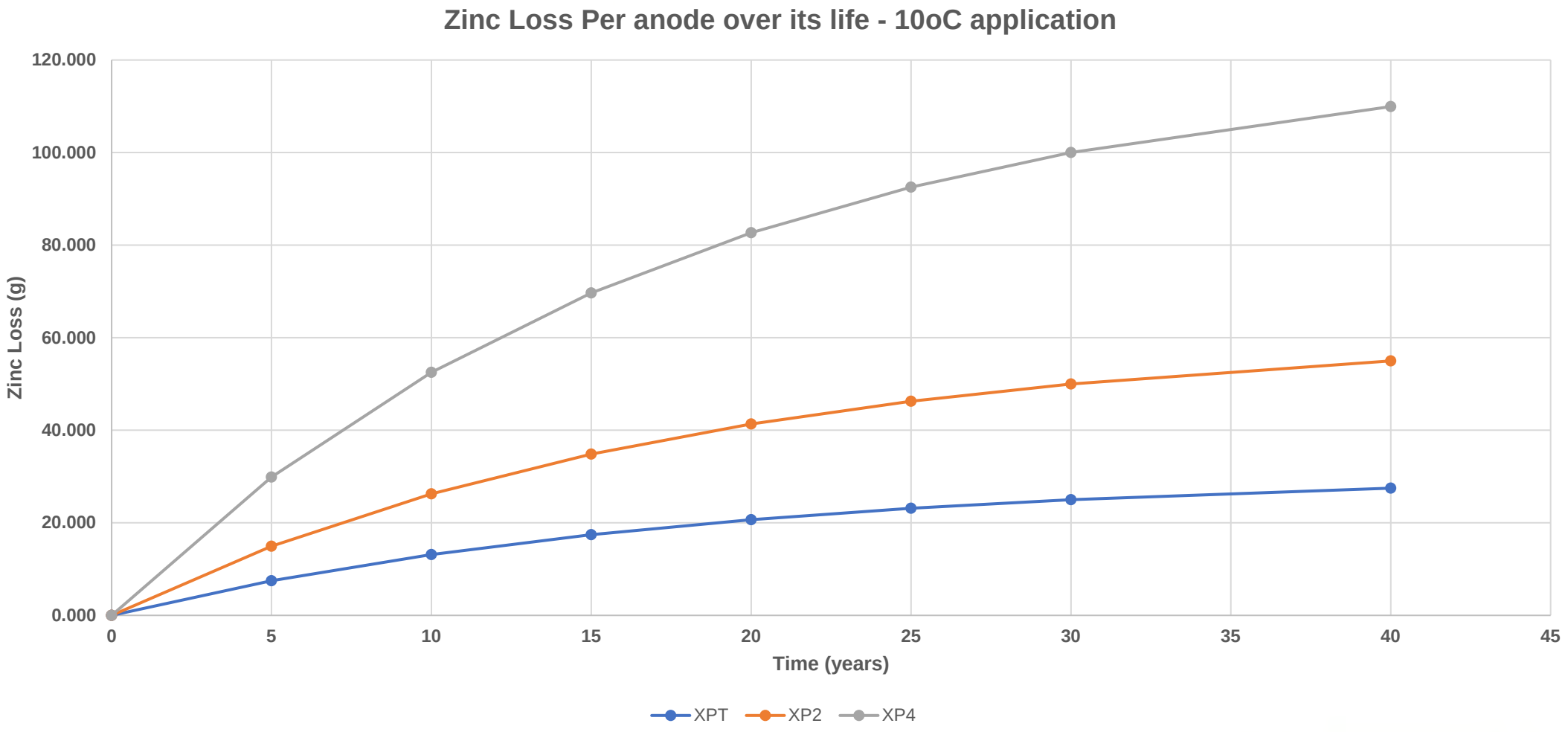
	0	5	10	15	20	25	30	35	40
Low to Moderate	1.500	1.137	0.862	0.653	0.41	0.313	0.237	0.179	0.136
High	3.00	2.27	1.72	1.31	0.82	0.63	0.47	0.36	0.27
Extremely High	6.00	4.55	3.45	2.61	1.65	1.25	0.95	0.72	0.54

XPX Current Density >15oC



	0	5	10	15	20	25	30	35	40
Low to Moderate	3.000	2.274	1.723	1.306	0.82	0.625	0.474	0.359	0.272
High	6.00	4.55	3.45	2.61	1.65	1.25	0.95	0.72	0.54
Extremely High	12.00	9.09	6.89	5.22	3.30	2.50	1.89	1.44	1.09

Zinc Loss Over Time



Targeted Repair Examples

Bill Of Quantities

Estimate

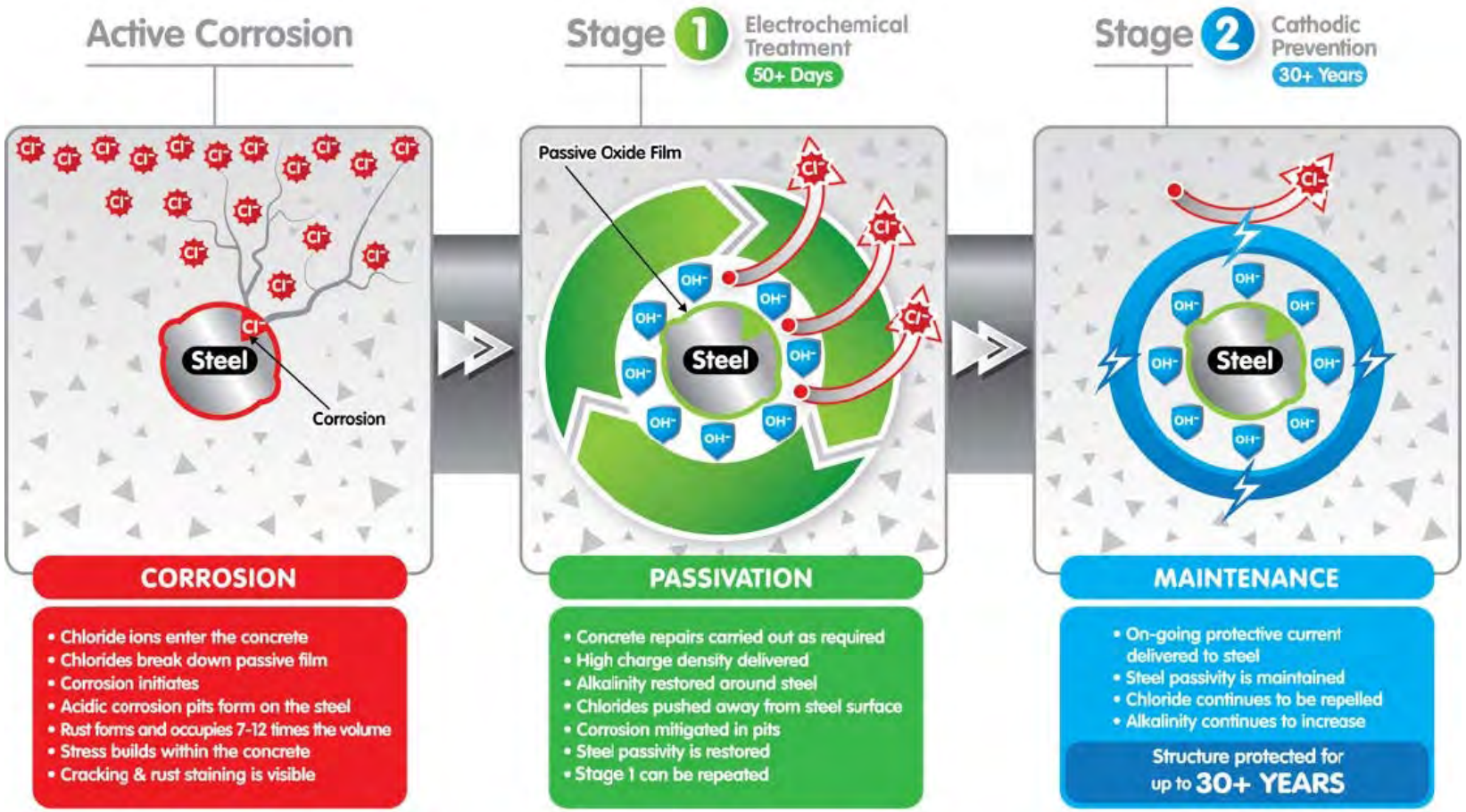
- One of the hardest elements with Galvanic repair is estimating the anode number
- Varies massively with repair size
- Repair size can increase between 20-50% from an initial markup or delamination survey
  - Clean back to un-corroded steel
  - Delamination is not fully identified until breakout occurs
- We typically estimate 3-4 anodes per m2 of repair, but this can vary from project to project

Summary

Take Home Lessons

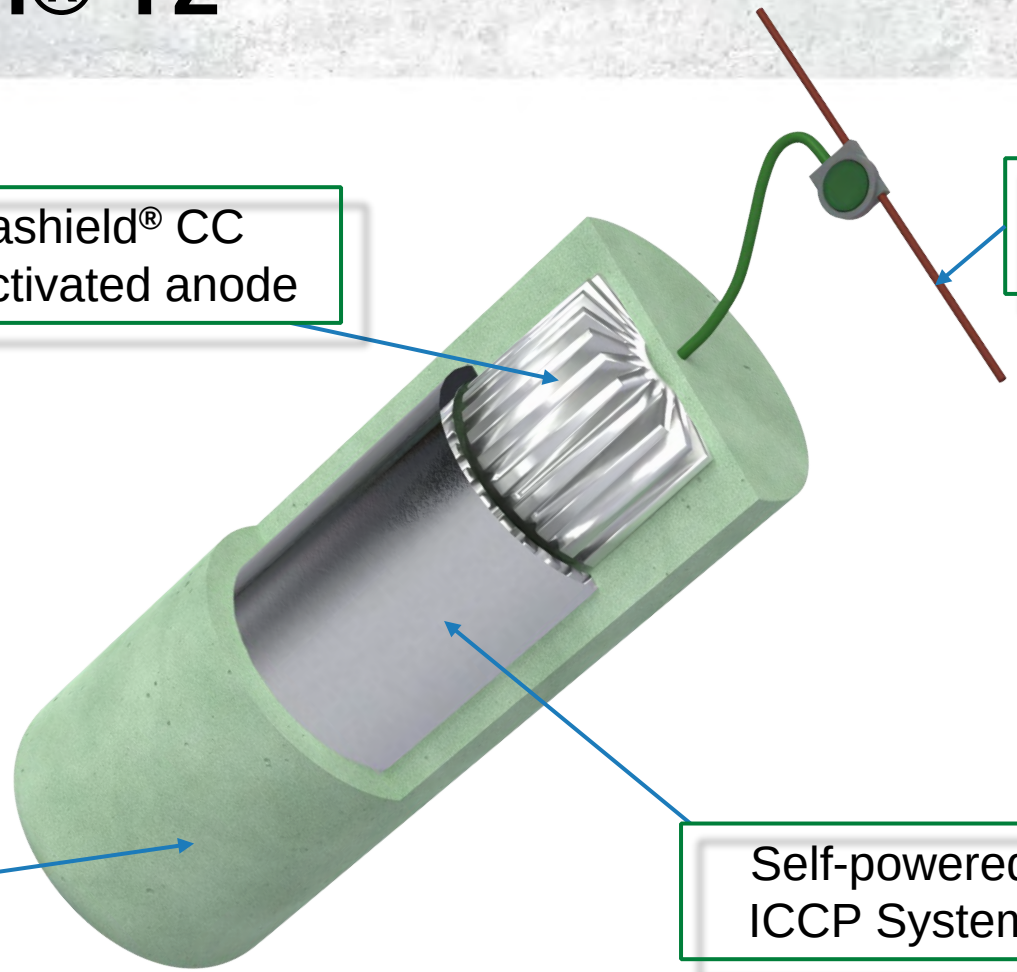
- Zinc mass does not determine anode output and therefore the level of protection
- It is the combination of activator, surface area and zinc mass
- All our anodes contain excess zinc. Not because we like waste but because you have to account for anode surface area changes with time and impacts on current output
- Performance is related to current density not zinc mass
- We need to design for minimum current densities for the life of the product
- Average temperature plays a huge role in performance and longevity – You cannot just use the same products unless you want a much shorter life expectancy

Example 2 – Fusion Design



Galvashield® Fusion® T2

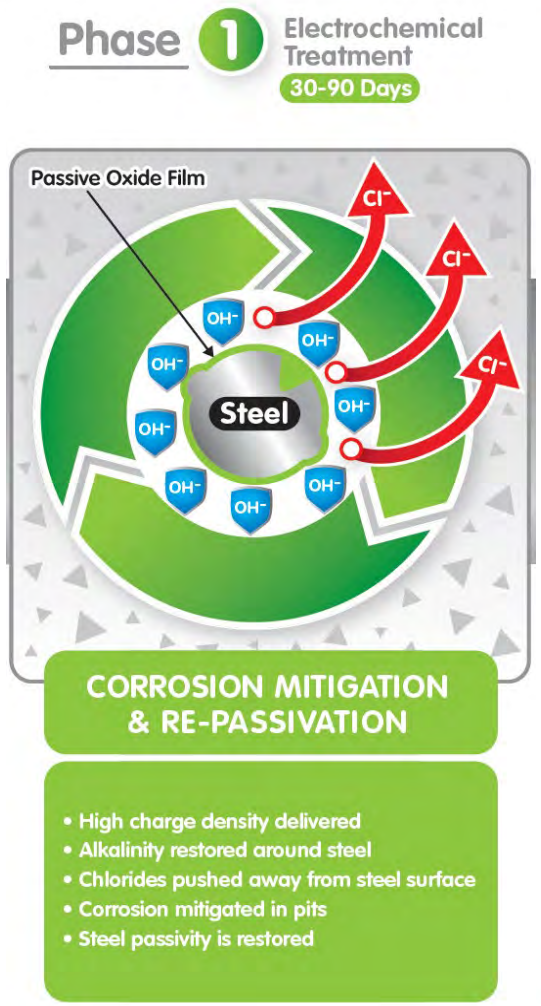
Galvashield® Fusion® T2



Example 2 – Fusion Design

2 Stage Design Process – Stage 1 Design (Passivation)

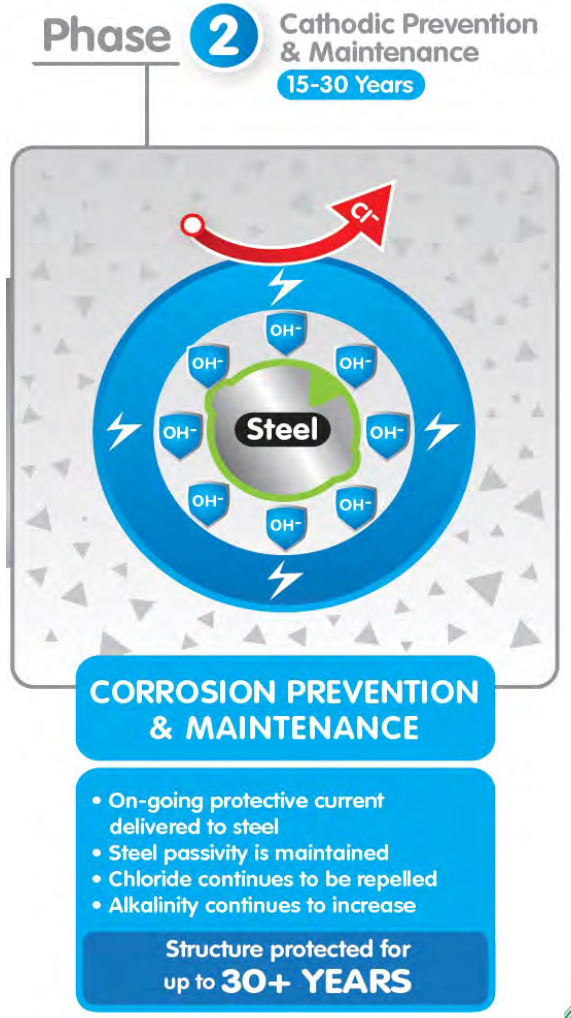
- Stage 1 design is related to corrosion risk again. We relate this to chloride level by weight of cement
- We design to achieve a fixed charge density per area during stage 1.
- This period is there to passivate steel and stop corrosion
- This enables us to calculate the number of anodes required per m2



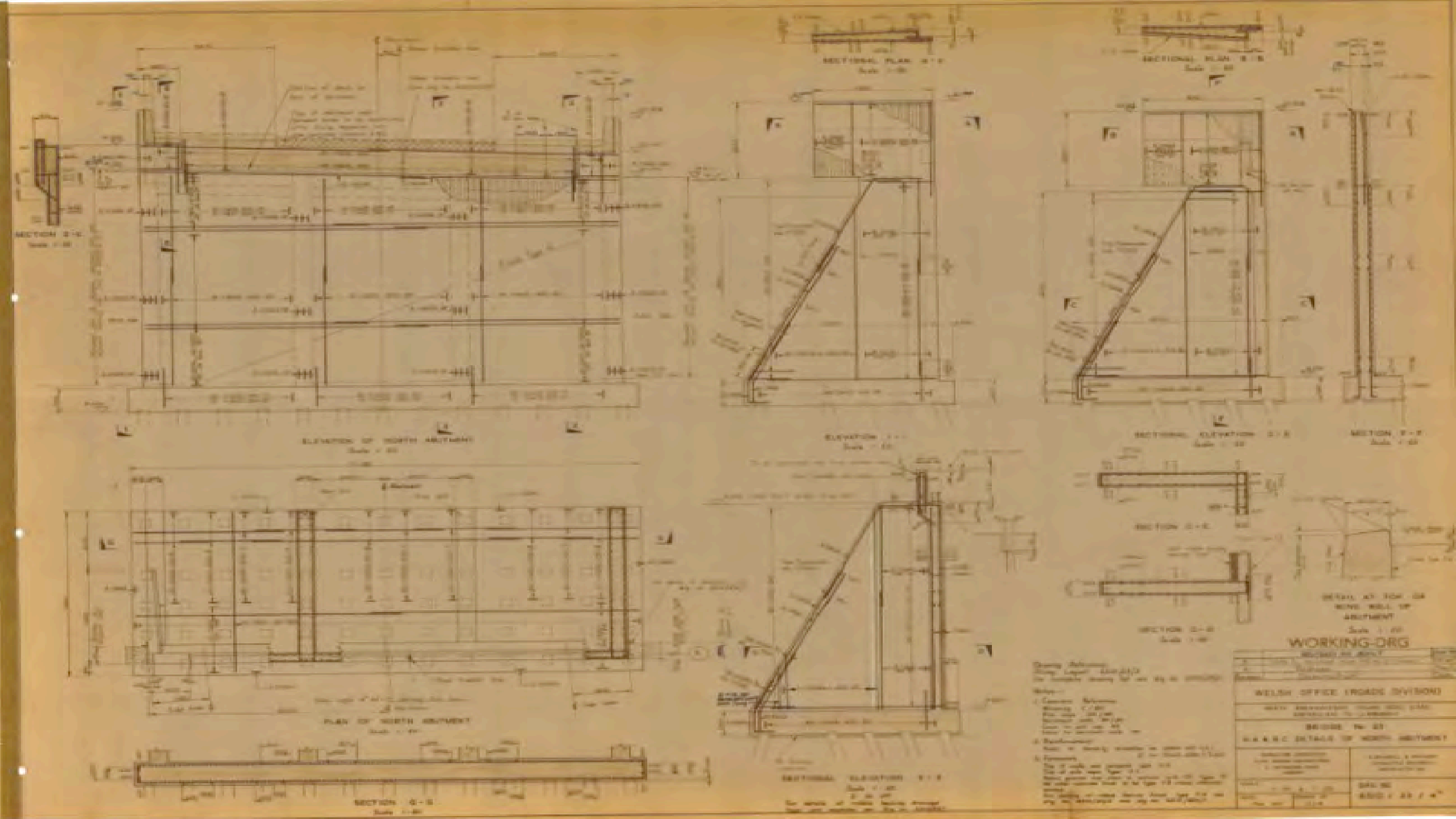
Example 2 – Fusion Design

2 Stage Design Process – Stage 2 Maintenance

- Stage 2 aims to provide a maintenance level of current to prevent corrosion from re initiating
- The ISO Standard calls this Cathodic Prevention
- Minimum current density of 0.4mA/m^2 at 30 years



Example 2 – Fusion Design

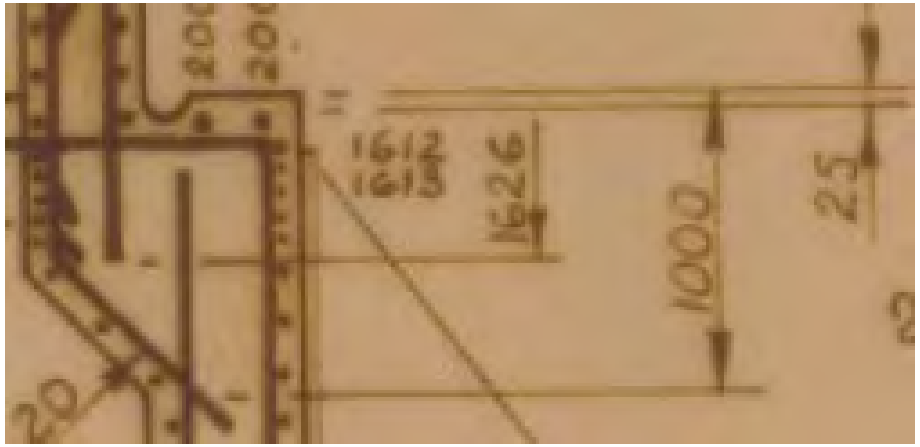

ELEVATION OF NORTH ABUTMENT
PLAN OF NORTH ABUTMENT
SECTION G-G
SECTIONAL PLAN
ELEVATION
SECTIONAL ELEVATION
SECTIONAL PLAN
SECTIONAL ELEVATION
SECTION F-F
SECTION C-C
SECTION D-D
DETAIL AT TOP OF WING WALL OF ABUTMENT
WORKING-DRG
WELSH OFFICE (ROADS DIVISION)
BRIDGE No. 23
D.R.A.B.C. DETAILS OF NORTH ABUTMENT

Example 2 – Steel Density Calculation

Steel layout evaluations

Formula

SA = Bar Dia (m) x length (m) x number per m2 x Pi



Example 2 – Steel Density Calculation

Steel layout evaluations

Bar Identification	Dia of Rebar (m)	Rebar Length (m)	Bar Spacing (m)	Number of Bars per m	Steel Surface Are (m^2)
Bar – 1. (layer 1)	0.016	1	0.15	6.7	0.34
Bar – 2. (layer 1)	0.016	1	0.30	3.3	0.17
Bar – 3. (layer 1)	0.020	1	0.50	2.0	0.13
				Error (10%)	0.06
				Total	**0.7**

Example 2 – Stage 1 Design

Passivation Design – 2% Chloride by Weight of cement

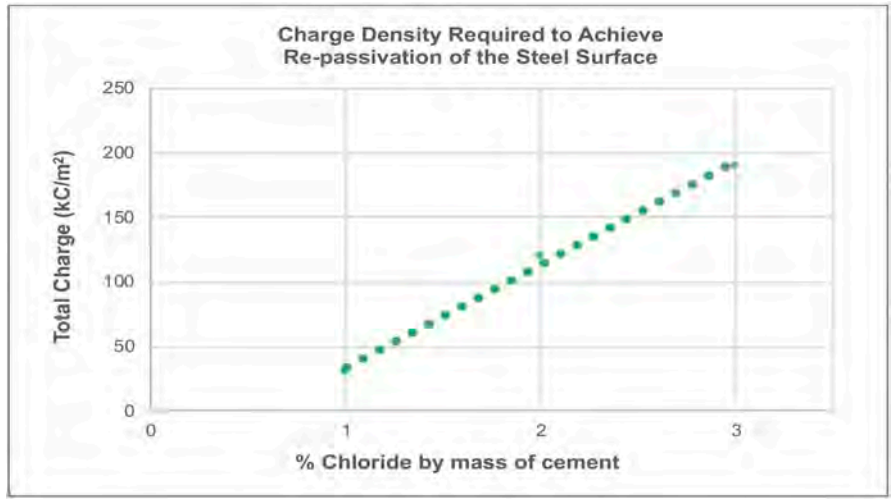
Charge required = % Chloride x 100

Minimum Charge density 75kC/m^2

Maximum Charge density 300kC/m^2

- Charge required per m^2 200kC/m^2 (2% x 100)
- Fusion Standard anode has a capacity of 50kC per anode
- Multiply charge requirement (200) by the steel density (0.7)
- Number of anodes required per m^2 = (200 x 0.7) / 50

  = **3 Anodes per m^2**
- Anode spacing of 550mm or 22inches



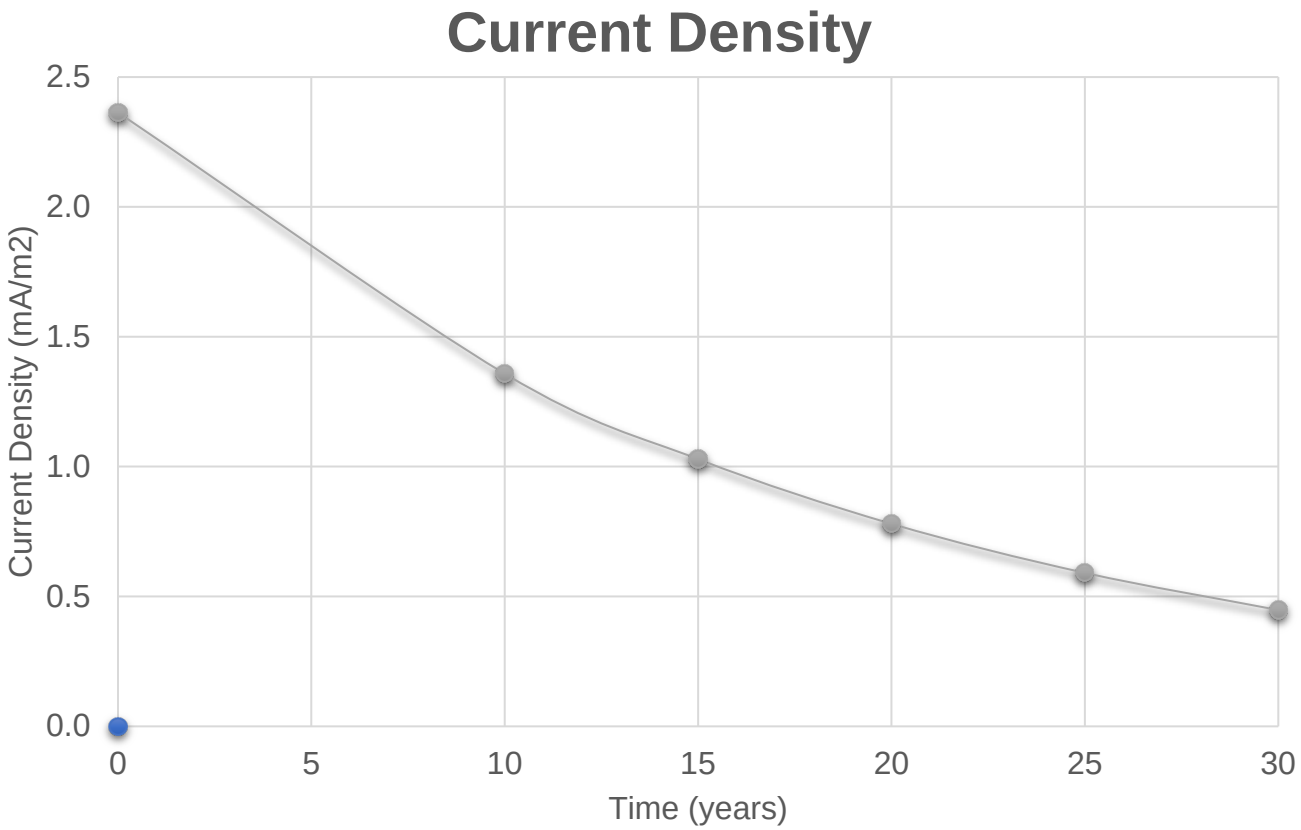
Example 2 – Stage 2 Design

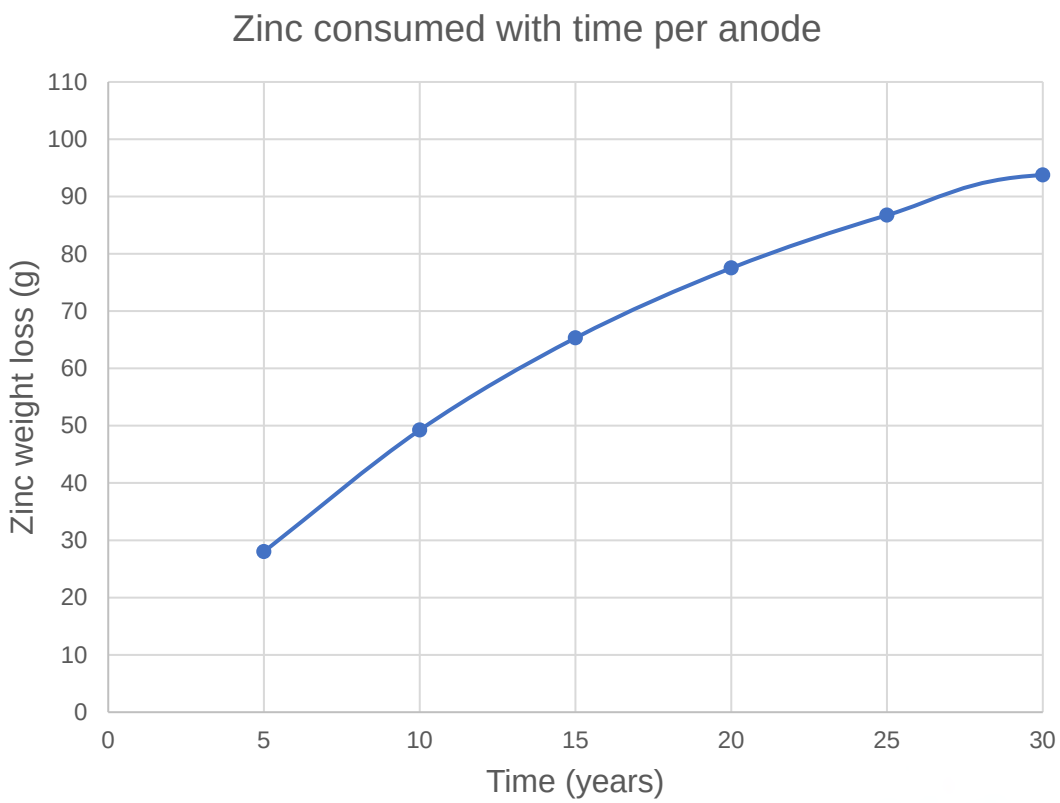
Cathodic Prevention (0.4mA/m^2 – 2mA/m^2)

- Aim to achieve a minimum of 0.4mA/m^2 at 30 years

	Time (Years)					
	0	**10**	**15**	**20**	**25**	**30**
Current Density (mA/m^2)	2.13	1.22	0.93	0.70	0.53	0.40
Zinc Loss (75% Efficiency/Utilisation)	0	147	196	232	260	281

Example 2 – Stage 2 Design





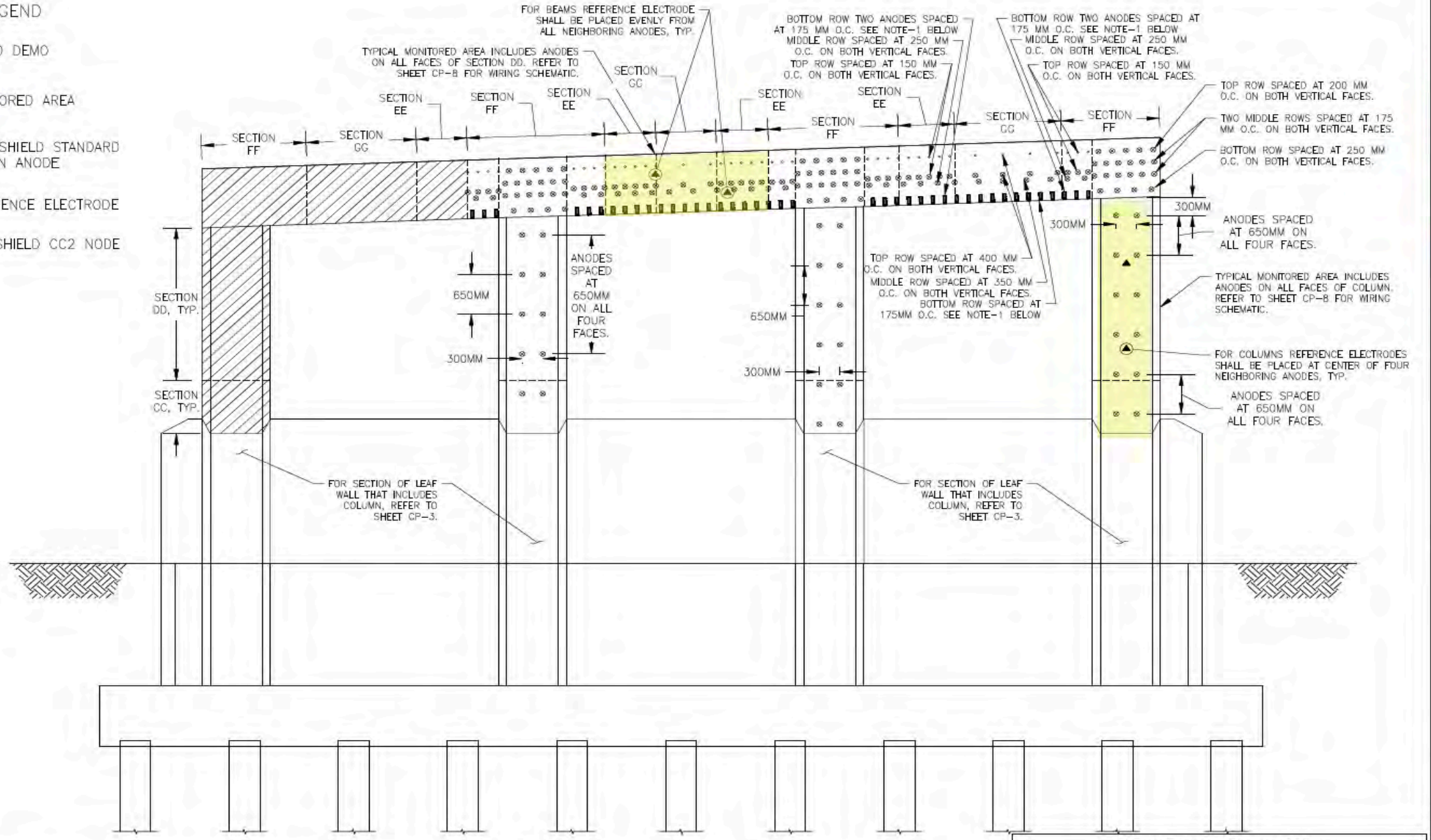
Performance Specification & Drawings

Pre-Qualification & Product Specifications

- Clearly defined parameters for the design for equivalency
  - Current Density Prediction
  - Activation method
  - Galvanic Aging term used
  - Anode efficiency & Utilisation
  - Temperature evaluation and performance
  - Zinc mass prediction
- The material manufacture should provide all of this information for prequalification against the performance specification

LEGEND

- HYDRO DEMO
- MONITORED AREA
- GALVASHIELD STANDARD FUSION ANODE
- REFERENCE ELECTRODE
- GALVASHIELD CC2 NODE



NOTE:
1. BOTTOM ROW OF ANODES TO BE XP4 ANODES IN PATCH REPAIR AREAS AND CC2 OTHERWISE. SEE CP-9.0 TO CP-9.2 FOR XP4 INSTALLATION DETAILS
2. TOP ROW OF CC2 ANODES TO FOLLOW FUSION ANODE SPACING LOCATED AT 200MM FROM THE TOP OF THE PIER

1 REAR ELEVATION ANODE PLACEMENT MAP
SCALE: N.T.S

ESTIMATED ANODE QUANTITIES	
OPTION1: LEAF REINFORCEMENT CONTINUOUS WITH COLUMN REINFORCEMENT FUSION ANODES	690
ESTIMATED CC2 ANODE QUANTITIES	78

DRAWING REVISIONS

#	DATE	BY	DESCRIPTION
0	2-11-21	S.Y.	INITIAL DRAWINGS
1	3-15-21	S.Y.	CP DESIGN REV
2	5-06-21	S.T.	ANODE PLACEMENT
3	5-19-21	S.T.	CP DESIGN REV
4	6-01-21	S.T.	CP DESIGN REV

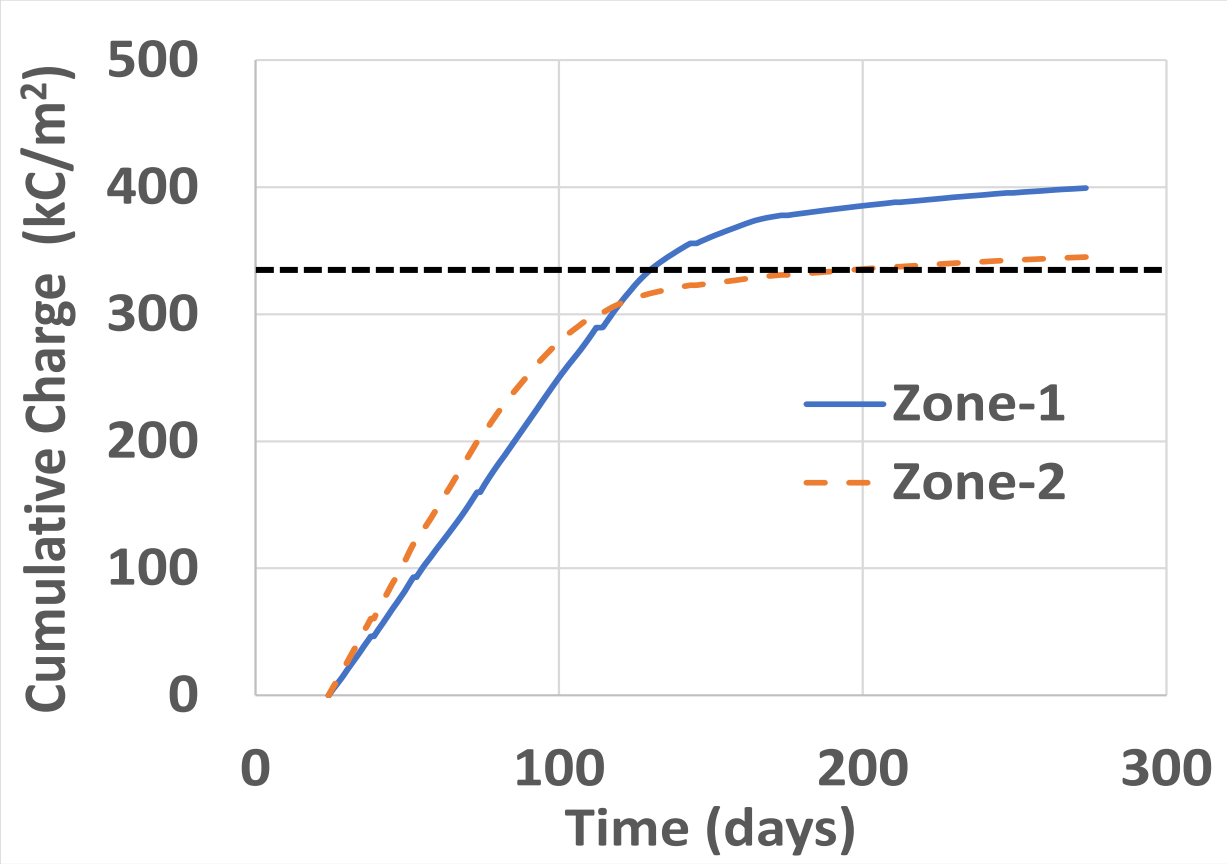
ABERDULAIS PIER
ABERDULAIS, UNITED KINGDOM

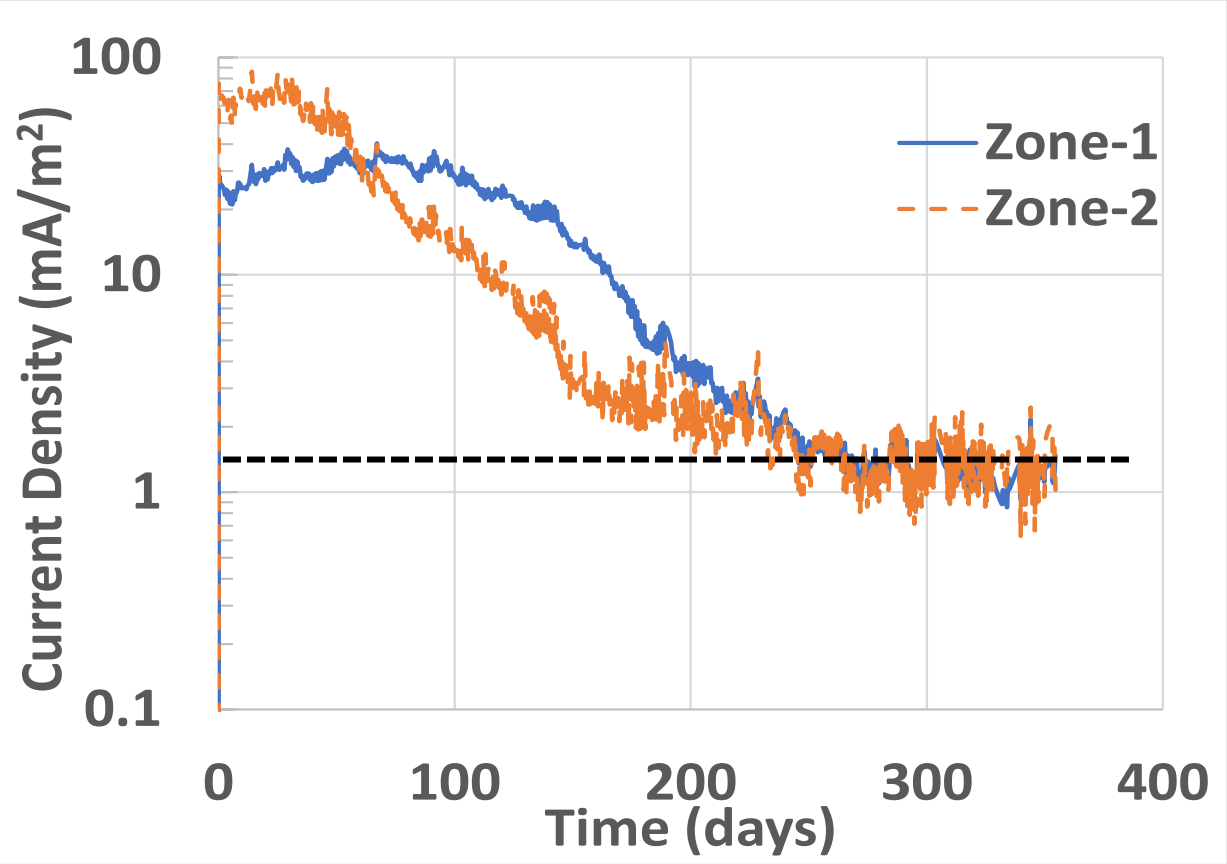
REAR PLAN VIEW OF ANODE PLACEMENT

VECTOR CORROSION SERVICES, INC.
27A UPPER HIGH STREET,
CRADLEY HEATH,
UK B64 5HX
44-0-1384-671414
WWW.VCSERVICES.COM

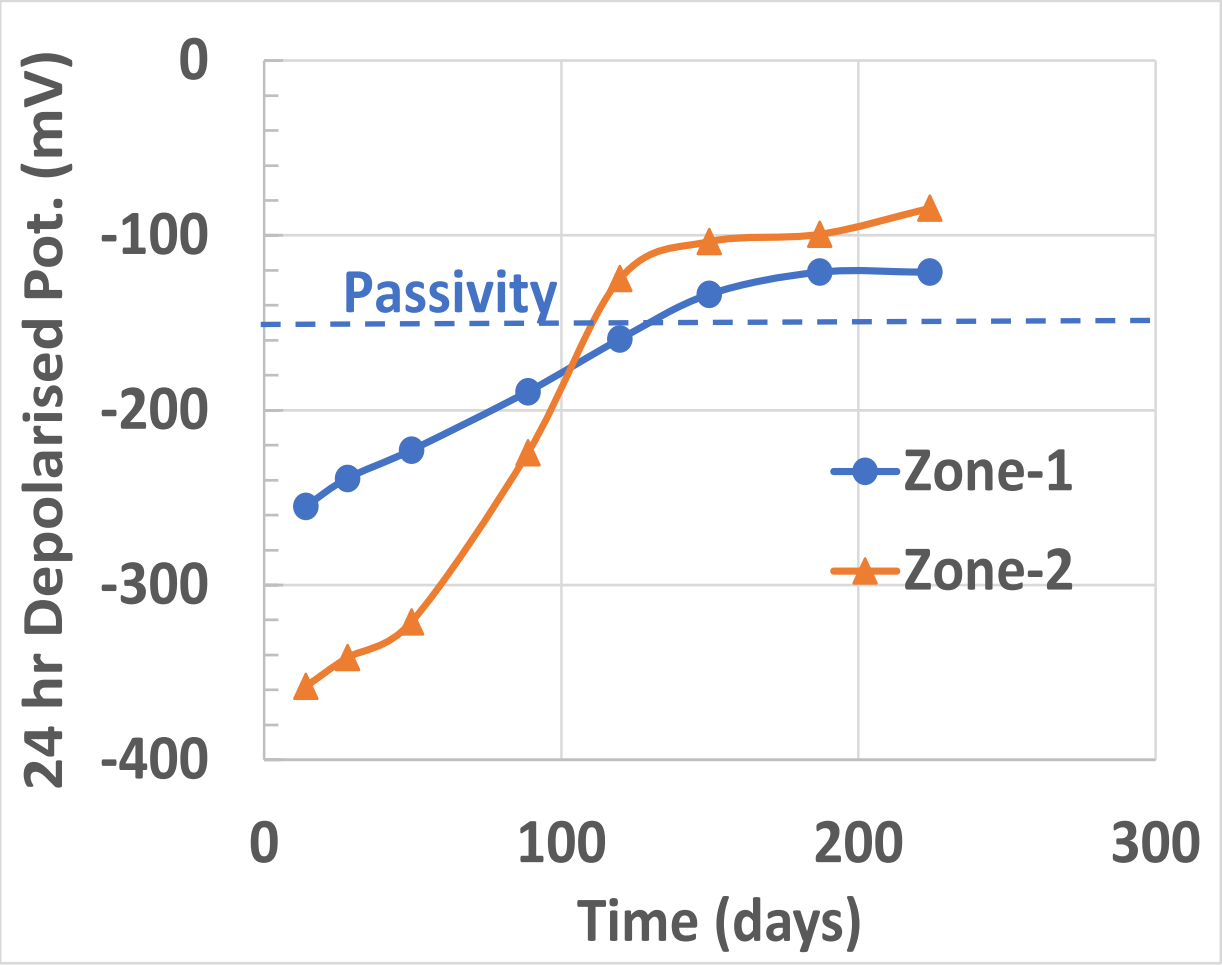
PROJECT NO. F21004UK
DRAWING NO. CP-2.1

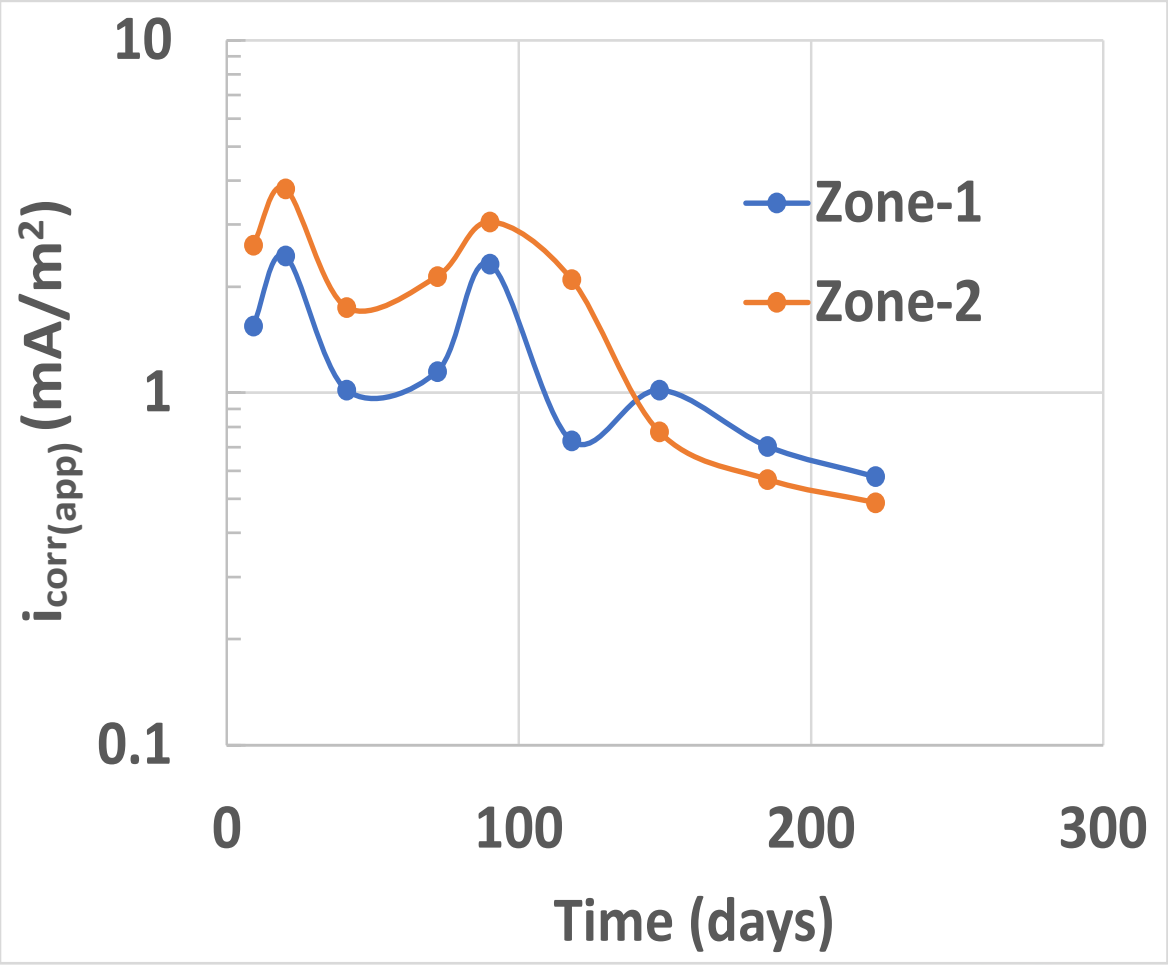
Monitored Data from Site





Monitored Data from Site

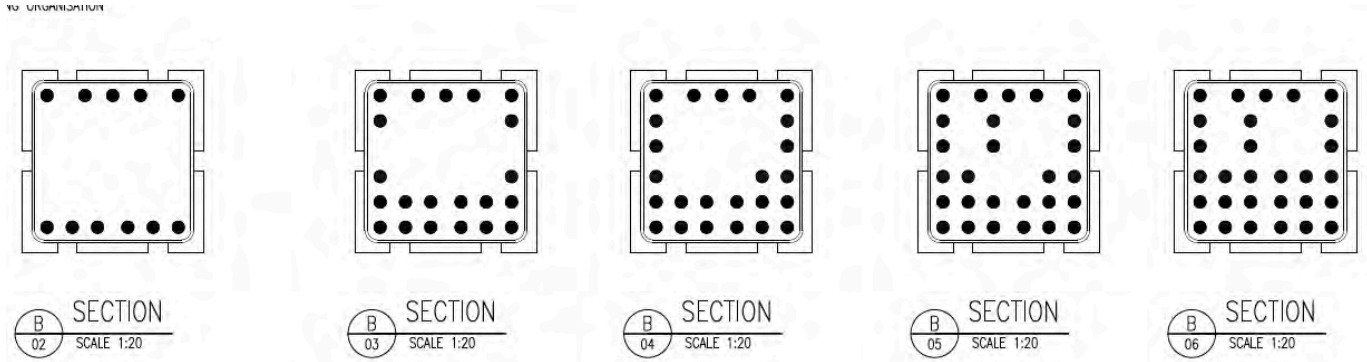




Additional Point

Things to consider

- As I stated I can't cover all elements in 45 minutes of design
- This presentation has concentrated on a m2 or ft2 area of concrete
- Not all concrete structures are large flat areas
- Columns and Beams tend to be design differently.
- Break the surfaces down into zones because the steel distribution does not tend to be equal. Especially for Beams. Therefore, zoning of the elements is important.



Design Process Overview

Concrete Testing

- Corrosion Evaluation
- Corrosion Variability & Risk
- Reinforcement Validation
- Reinforcement continuity

Design Process Overview

Concrete Testing

Commercial Impacts

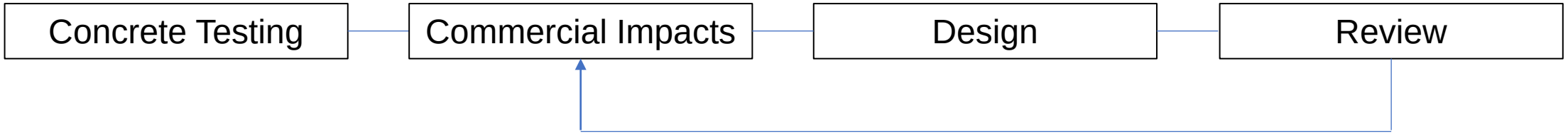
- Life Expectancy
- Budget
- HSE & Environment
- Product Selection & Type

Design Process Overview

Concrete Testing — Commercial Impacts — Design

- Corrosion Risk
- Steel Evaluation & Zoning
- Steel Density Calculations
- Anode Design

Design Process Overview



Not all Anodes are Created Equal!

Galvanic Anode Designs

- All galvanic anodes are different.
  - Different activators
  - Different zinc surface areas
  - Different zinc masses
  - Different efficiencies and utilisation
- It's imperative that material manufactures demonstrate how their anodes work and age with time
- We need to design for end of life not beginning
- Performance is related to current density NOT mass of zinc

Contact David

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DESIGN SERIES

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Jan 25, 2023 | How to Design a Galvanic Anode System for Concrete Structures

David Simpson

Vector Corrosion Technologies

As the popularity of galvanic anodes for reinforced concrete increases, the design process continues to evolve and provide much more flexibility to design professionals than simply using the anode spacing tables in a product data sheet. This how-to webinar will summarise the latest advancements in predicting embedded anode's long-term performance and demonstrate how this information is utilized in providing reliable designs. This presentation is most beneficial for those currently specifying systems, those new to the industry or with a general interest in galvanic technology for concrete.

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Feb 8, 2023 | How to Use Galvanic Anodes to Extend the Life of New Concrete Structures

Dr. George Sergi, PhD

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