
Stop Corrosion
Extend Life
With Advanced Anode
Technology
cpt

Agenda

Introduction

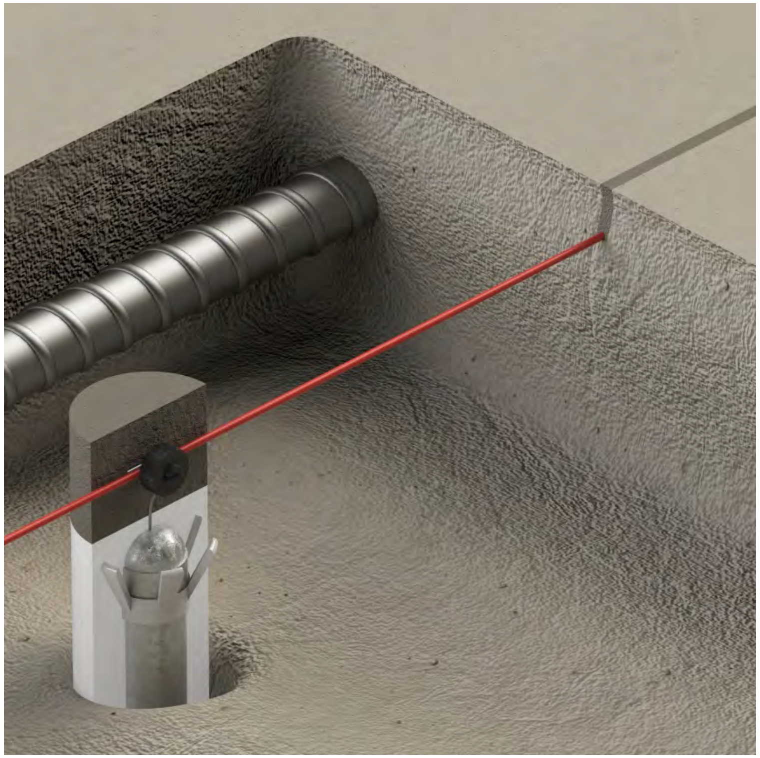
Background to corrosion

Stopping corrosion with smart technology

Case histories

Who we are and what we do

- Design and manufacture of innovative products for corrosion mitigation
- Testing & evaluation
- Specification & design
- On site support



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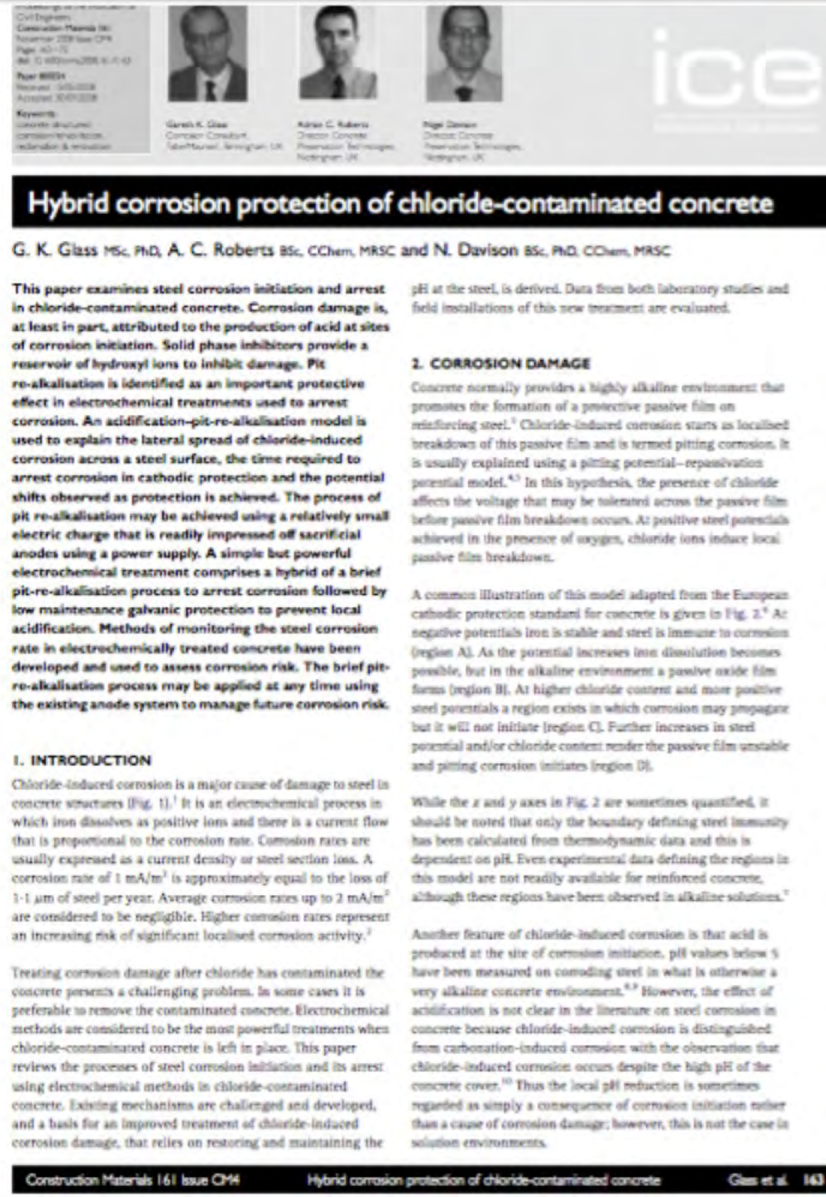

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Hybrid corrosion protection of chloride-contaminated concrete

G. K. Glass MSc, PhD, A. C. Roberts BSc, CChem, MRSC and N. Davison BSc, PhD, CChem, MRSC

This paper examines steel corrosion initiation and arrest in chloride-contaminated concrete. Corrosion damage is, at least in part, attributed to the production of acid at sites of corrosion initiation. Solid phase inhibitors provide a reservoir of hydroxyl ions to inhibit damage. Pit re-alkalisation is identified as an important protective effect in electrochemical treatments used to arrest corrosion. An acidification–pit-re-alkalisation model is used to explain the lateral spread of chloride-induced corrosion across a steel surface, the time required to arrest corrosion in cathodic protection and the potential shifts observed as protection is achieved. The process of pit re-alkalisation may be achieved using a relatively small electric charge that is readily impressed off sacrificial anodes using a power supply. A simple but powerful electrochemical treatment comprises a hybrid of a brief pit-re-alkalisation process to arrest corrosion followed by low maintenance galvanic protection to prevent local acidification. Methods of monitoring the steel corrosion rate in electrochemically treated concrete have been developed and used to assess corrosion risk. The brief pit-re-alkalisation process may be applied at any time using the existing anode system to manage future corrosion risk.

1. INTRODUCTION

Chloride-induced corrosion is a major cause of damage to steel in concrete structures (Fig. 1).[1] It is an electrochemical process in which iron dissolves as positive ions and there is a current flow that is proportional to the corrosion rate. Corrosion rates are usually expressed as a current density or steel section loss. A corrosion rate of 1 mA/m^2 is approximately equal to the loss of 1·1 μm of steel per year. Average corrosion rates up to 2 mA/m^2 are considered to be negligible. Higher corrosion rates represent an increasing risk of significant localised corrosion activity.[2]

Treating corrosion damage after chloride has contaminated the concrete presents a challenging problem. In some cases it is preferable to remove the contaminated concrete. Electrochemical methods are considered to be the most powerful treatments when chloride-contaminated concrete is left in place. This paper reviews the processes of steel corrosion initiation and its arrest using electrochemical methods in chloride-contaminated concrete. Existing mechanisms are challenged and developed, and a basis for an improved treatment of chloride-induced corrosion damage, that relies on restoring and maintaining the pH at the steel, is derived. Data from both laboratory studies and field installations of this new treatment are evaluated.

2. CORROSION DAMAGE

Concrete normally provides a highly alkaline environment that promotes the formation of a protective passive film on reinforcing steel.[3] Chloride-induced corrosion starts as localised breakdown of this passive film and is termed pitting corrosion. It is usually explained using a pitting potential–repassivation potential model.[4,5] In this hypothesis, the presence of chloride affects the voltage that may be tolerated across the passive film before passive film breakdown occurs. At positive steel potentials achieved in the presence of oxygen, chloride ions induce local passive film breakdown.

A common illustration of this model adapted from the European cathodic protection standard for concrete is given in Fig. 2.[6] At negative potentials iron is stable and steel is immune to corrosion (region A). As the potential increases iron dissolution becomes possible, but in the alkaline environment a passive oxide film forms (region B). At higher chloride content and more positive steel potentials a region exists in which corrosion may propagate but it will not initiate (region C). Further increases in steel potential and/or chloride content render the passive film unstable and pitting corrosion initiates (region D).

While the x and y axes in Fig. 2 are sometimes quantified, it should be noted that only the boundary defining steel immunity has been calculated from thermodynamic data and this is dependent on pH. Even experimental data defining the regions in this model are not readily available for reinforced concrete, although these regions have been observed in alkaline solutions.[7]

Another feature of chloride-induced corrosion is that acid is produced at the site of corrosion initiation. pH values below 5 have been measured on corroding steel in what is otherwise a very alkaline concrete environment.[8,9] However, the effect of acidification is not clear in the literature on steel corrosion in concrete because chloride-induced corrosion is distinguished from carbonation-induced corrosion with the observation that chloride-induced corrosion occurs despite the high pH of the concrete cover.[10] Thus the local pH reduction is sometimes regarded as simply a consequence of corrosion initiation rather than a cause of corrosion damage; however, this is not the case in solution environments.

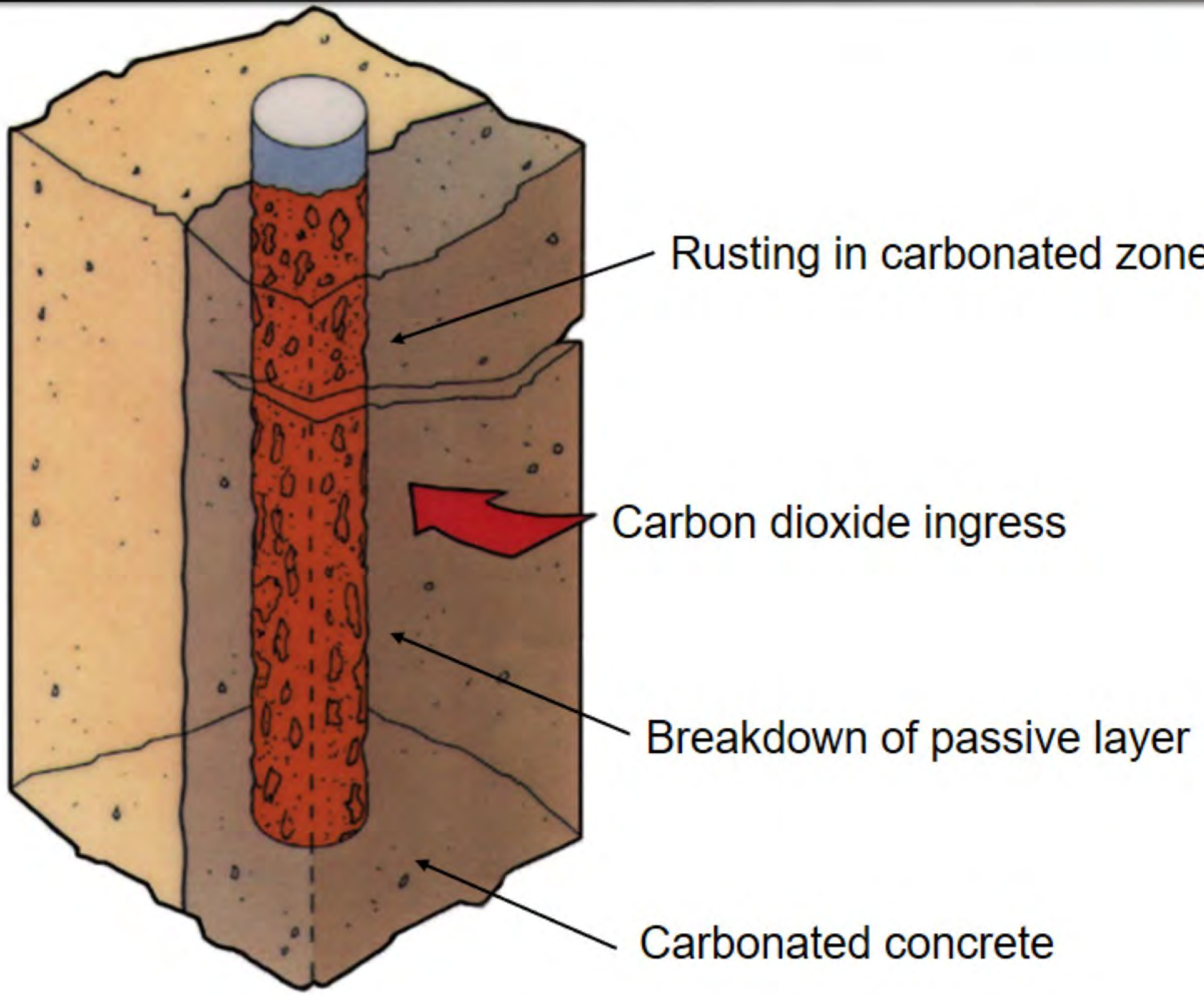
Background

“Almost 50% of repairs and interventions exhibit signs of failure within 5 years”
ConRepNet 2007

“Wrong diagnosis and inappropriate repair strategy account for 70% of failures”
ConRepNet 2007

Background

Carbonation induced corrosion



Concrete Carbonation

cpt
Concrete Preservation Technologies

- Carbonation
  - Carbon dioxide dissolves in the pore solution (water) in concrete to form carbonic acid which neutralises the local high pH environment.

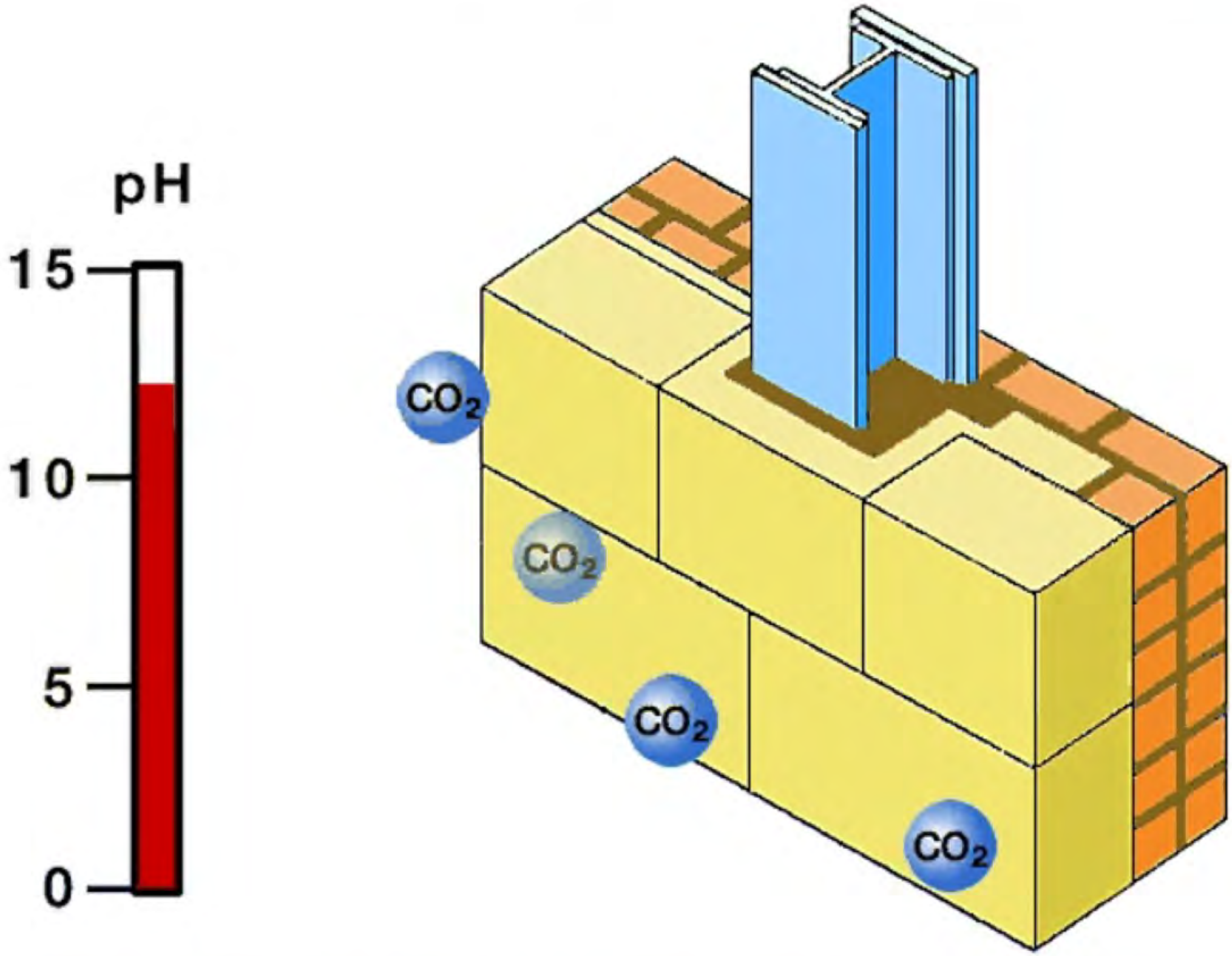
Concrete Carbonation

Concrete Preservation Technologies

Low cover and poor quality concrete exacerbates corrosion issues

Background

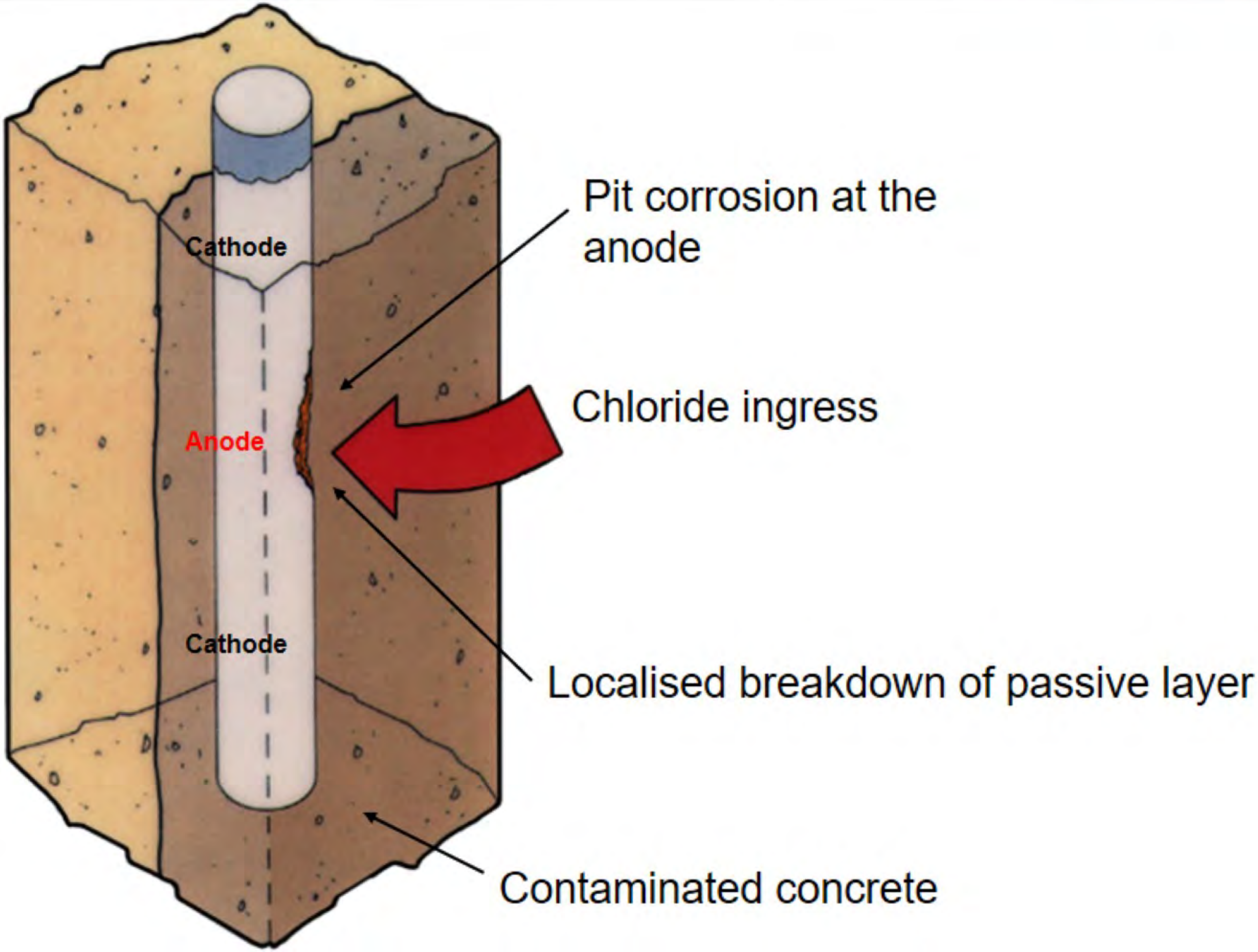
Background



Carbonation Induced Corrosion

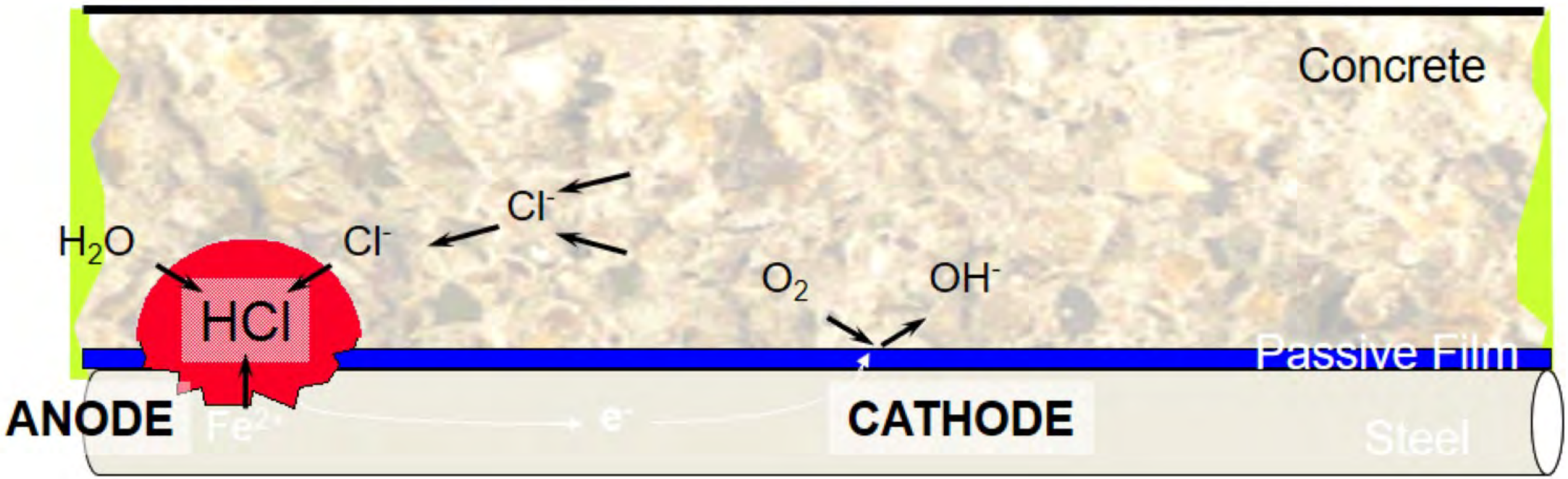
Steel frame corrosion issues

Chloride induced corrosion



Pipers Row MSCP 1997 UK

Background

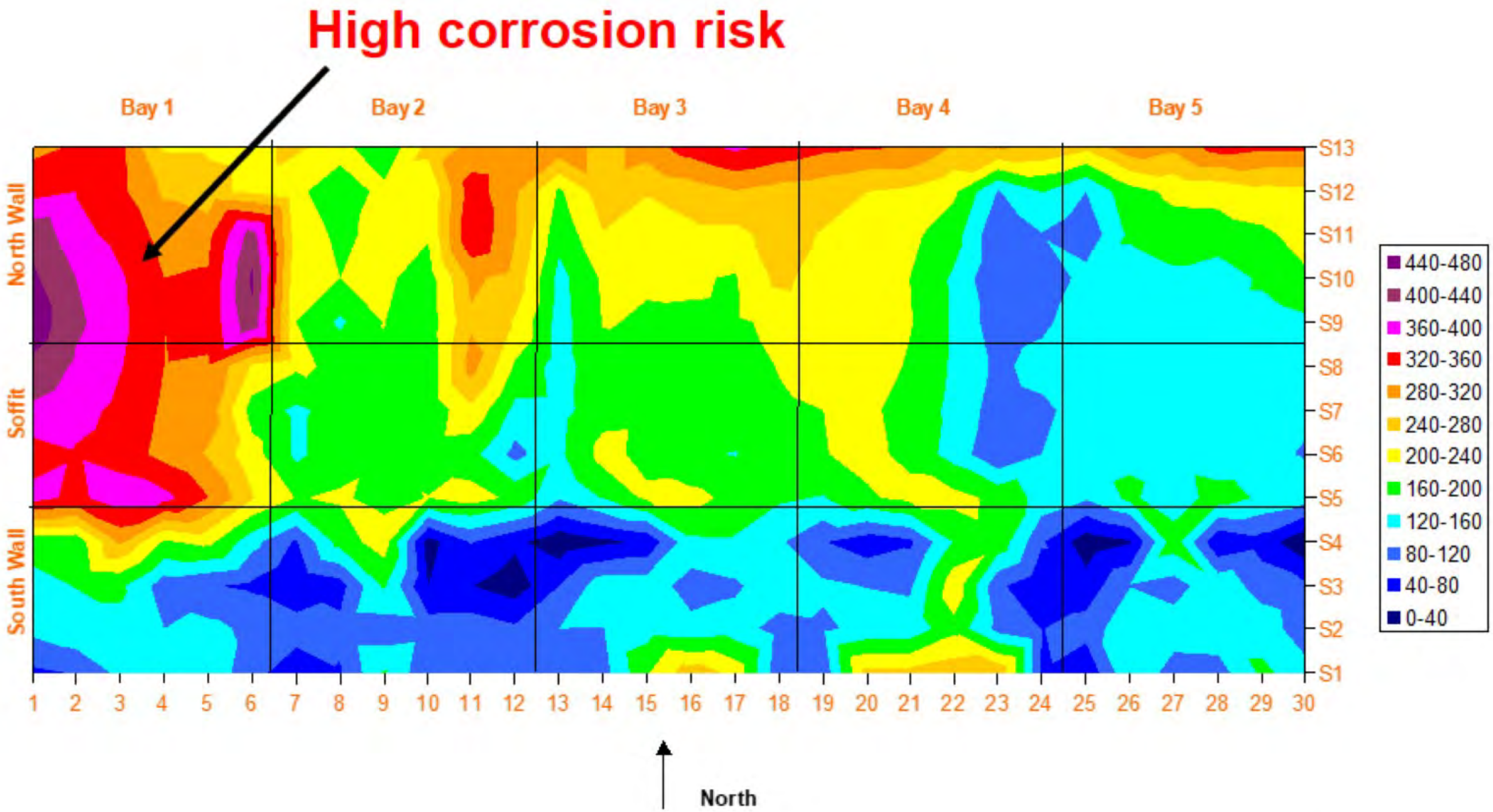


Corrosion is an electrochemical process

Carbonation or chloride attack?

Testing and investigation

Half cell potential evaluation



ASTM C876 -200 to –350 mV = intermediate risk < -350 mV = high risk

Control of corrosion

1. Patch repair protection (Reactive)

- PatchGuard sacrificial anodes

2. Targeted corrosion protection (Reactive and Proactive)

- Traditional impressed current cathodic protection (ICCP)
- **CPT innovation:** removing the complexity with DUOGUARD HYBRID ANODE CP

Patch repair protection

The problem … "the newly established cathodic area within the repair will drive the new anode site in the contaminated region"


CI/SfB q4
February 2000

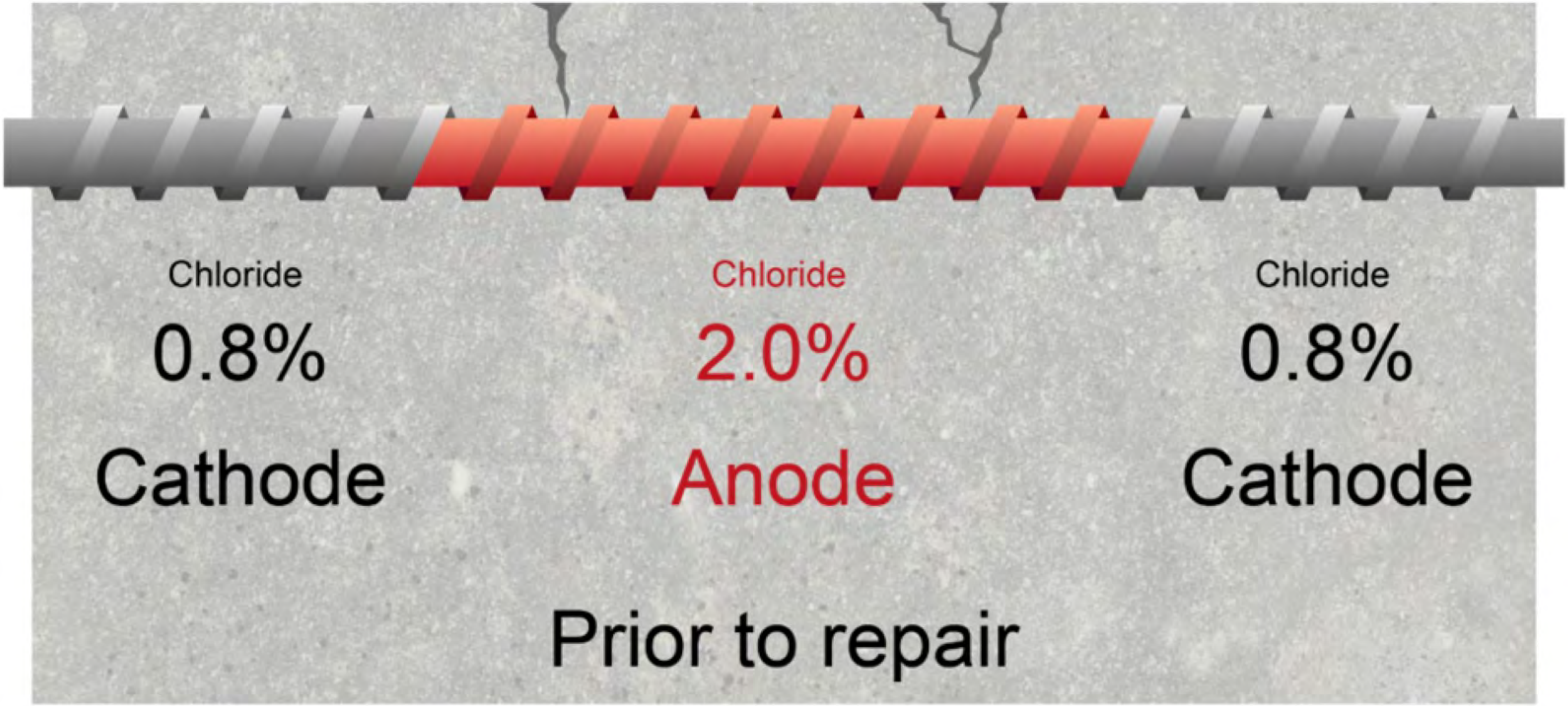
Corrosion of steel in concrete
Durability of reinforced concrete structures

Digest 444
Part 1

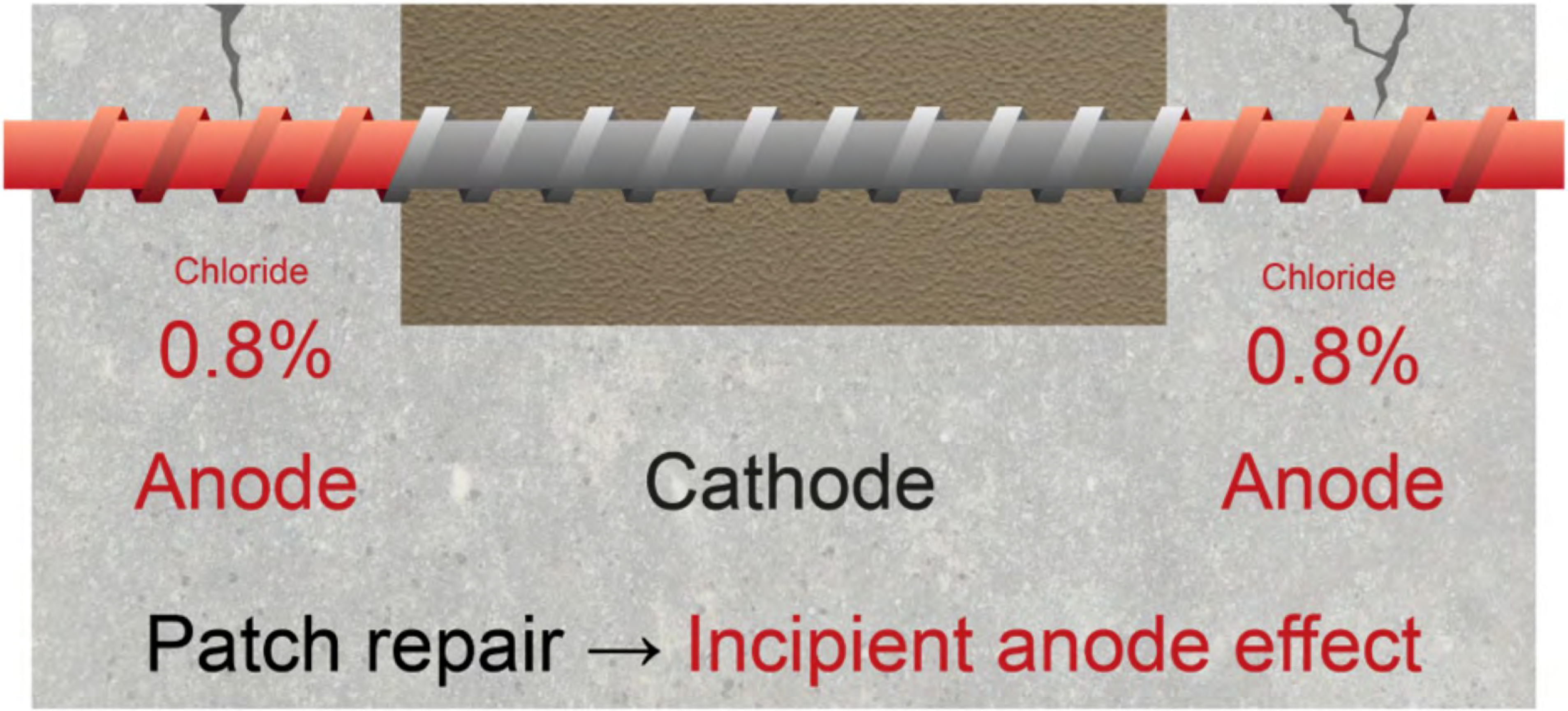
'Incipient' corrosion

Patch repair protection

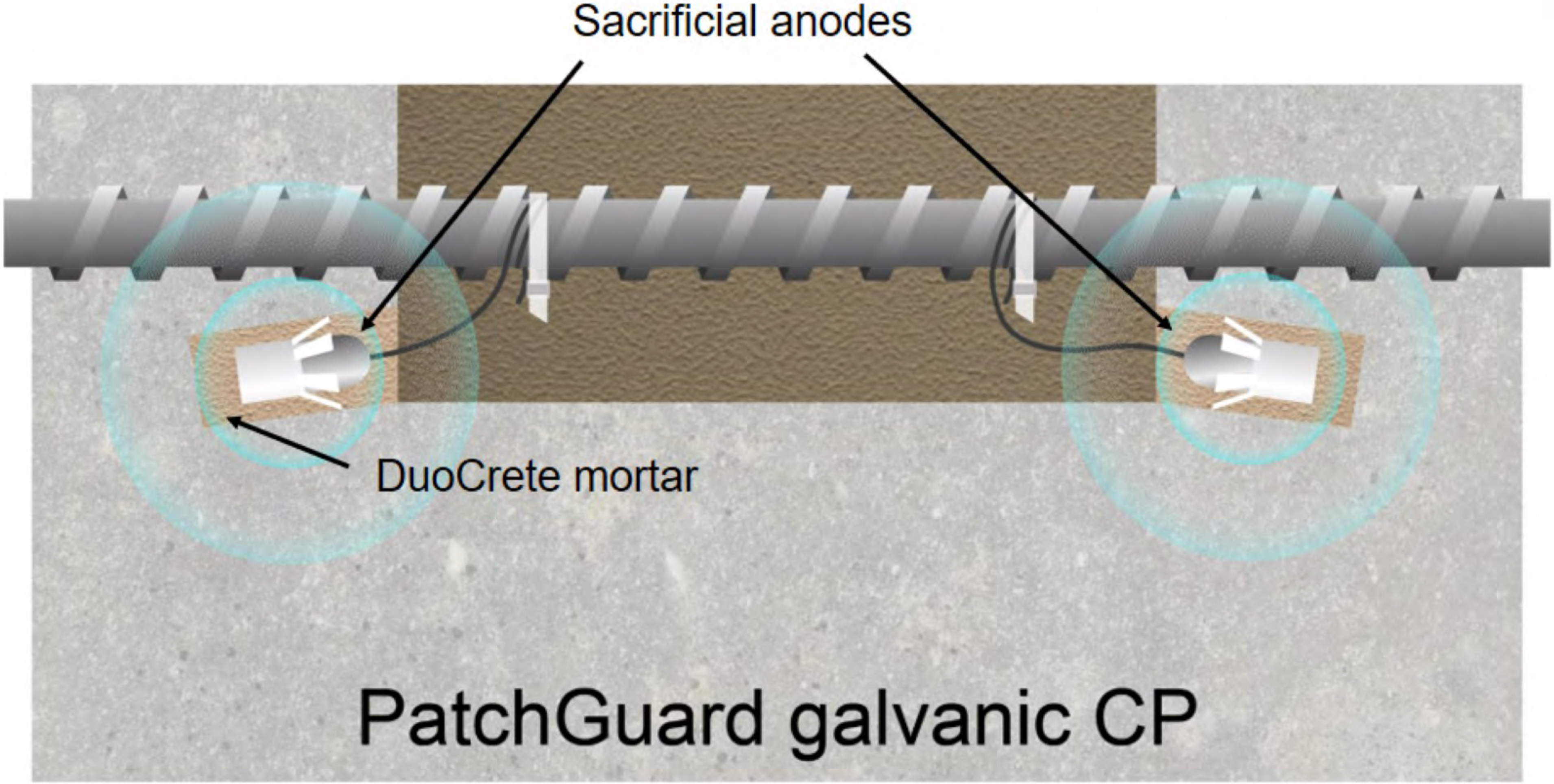
Patch repair protection



Patch repair protection



Patch repair protection



Patch repair protection

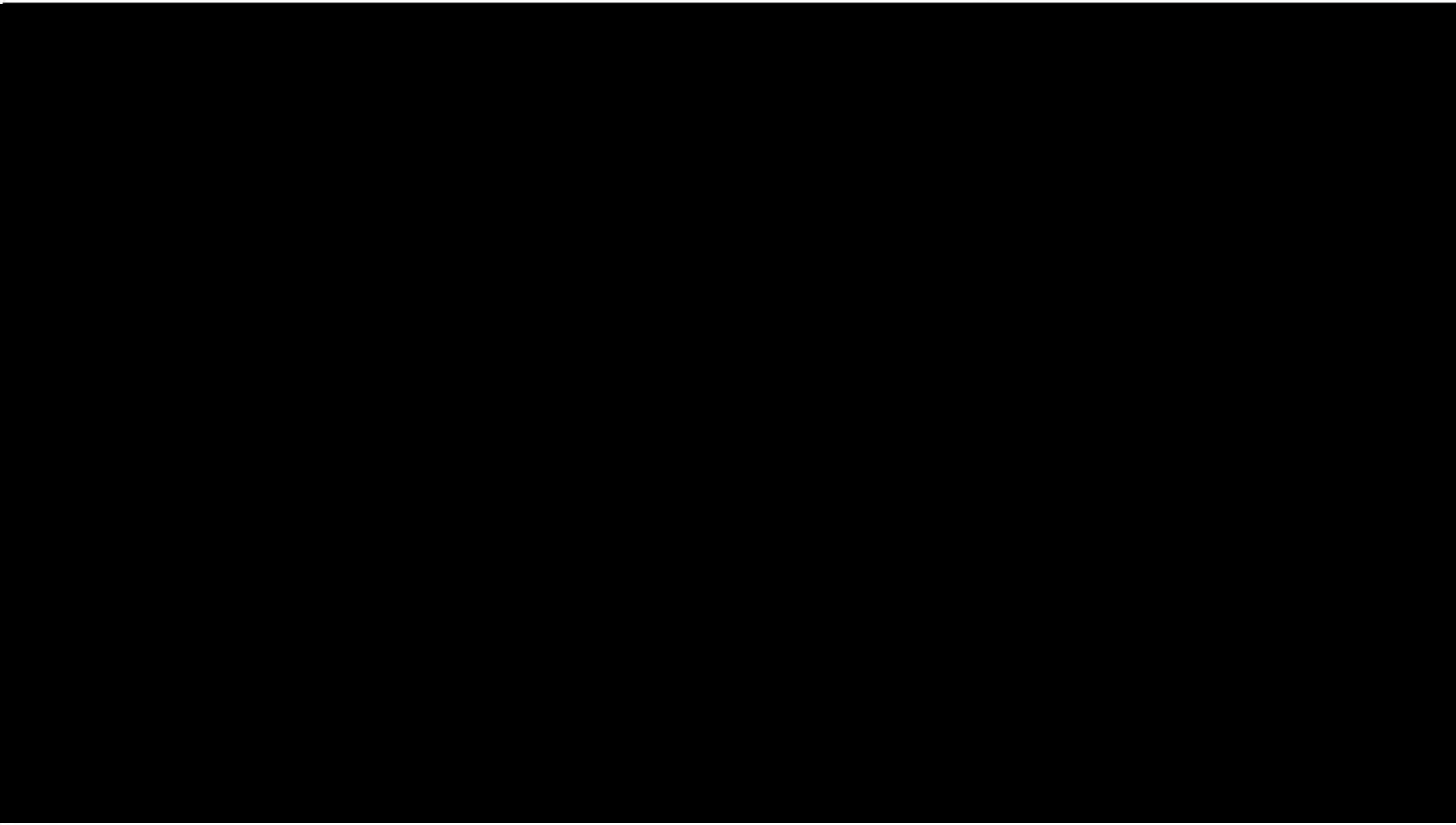
PatchGuard Installation on a car park in Letchworth, UK

1. Drill a hole and apply PG Mortar

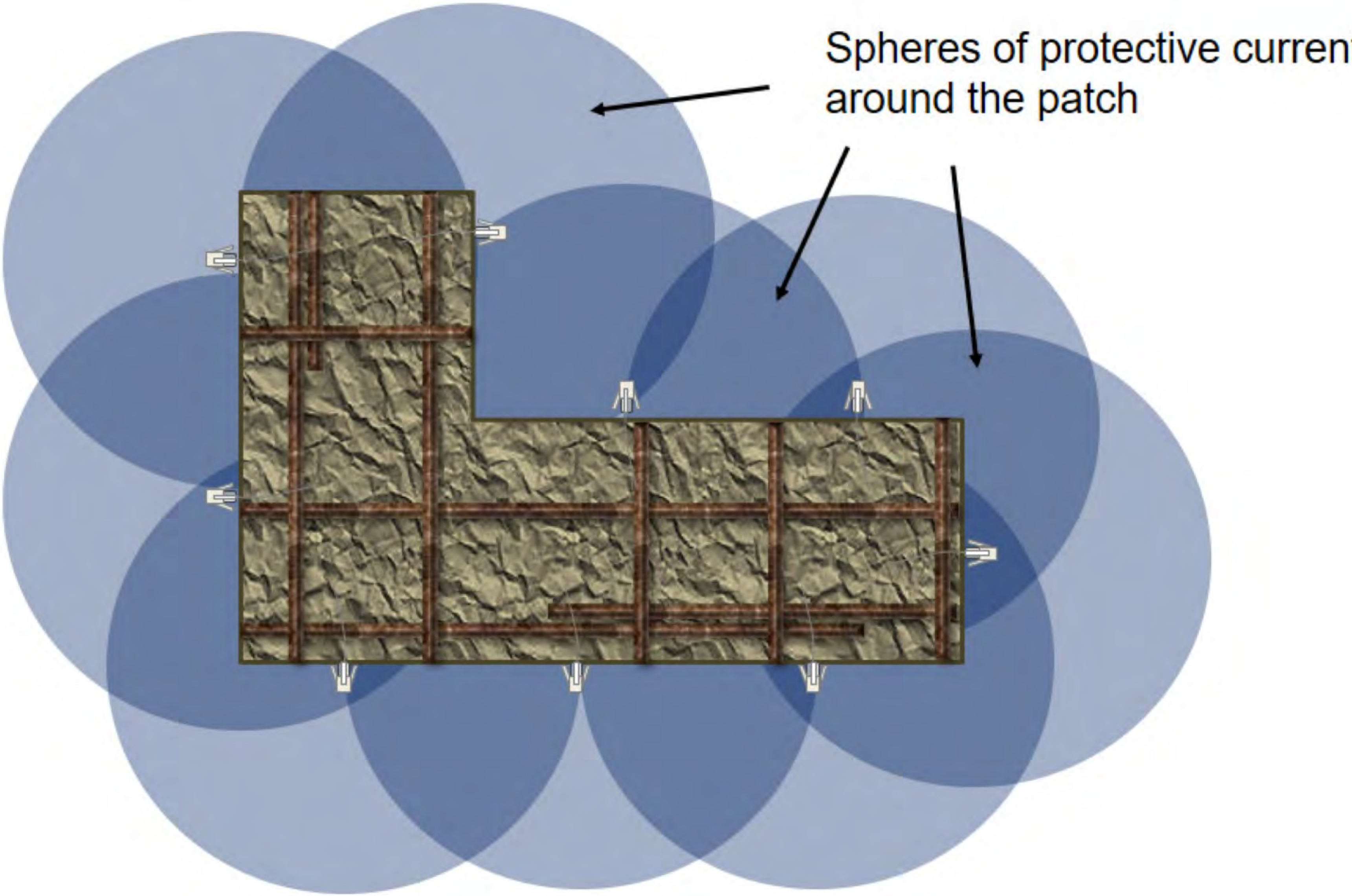
2. Insert the anode

3. Fix anode wire to steel and apply repair mortar

Patch repair protection



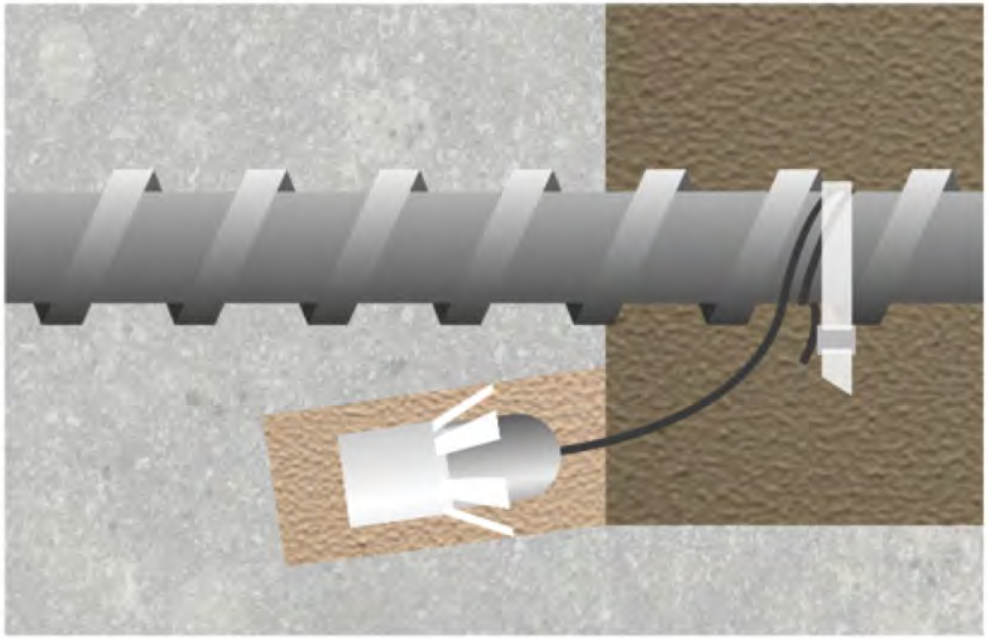
Patch repair protection



Patch repair protection - PatchGuard

Eliminates incipient anode effect

Located in surrounding concrete for maximum influence



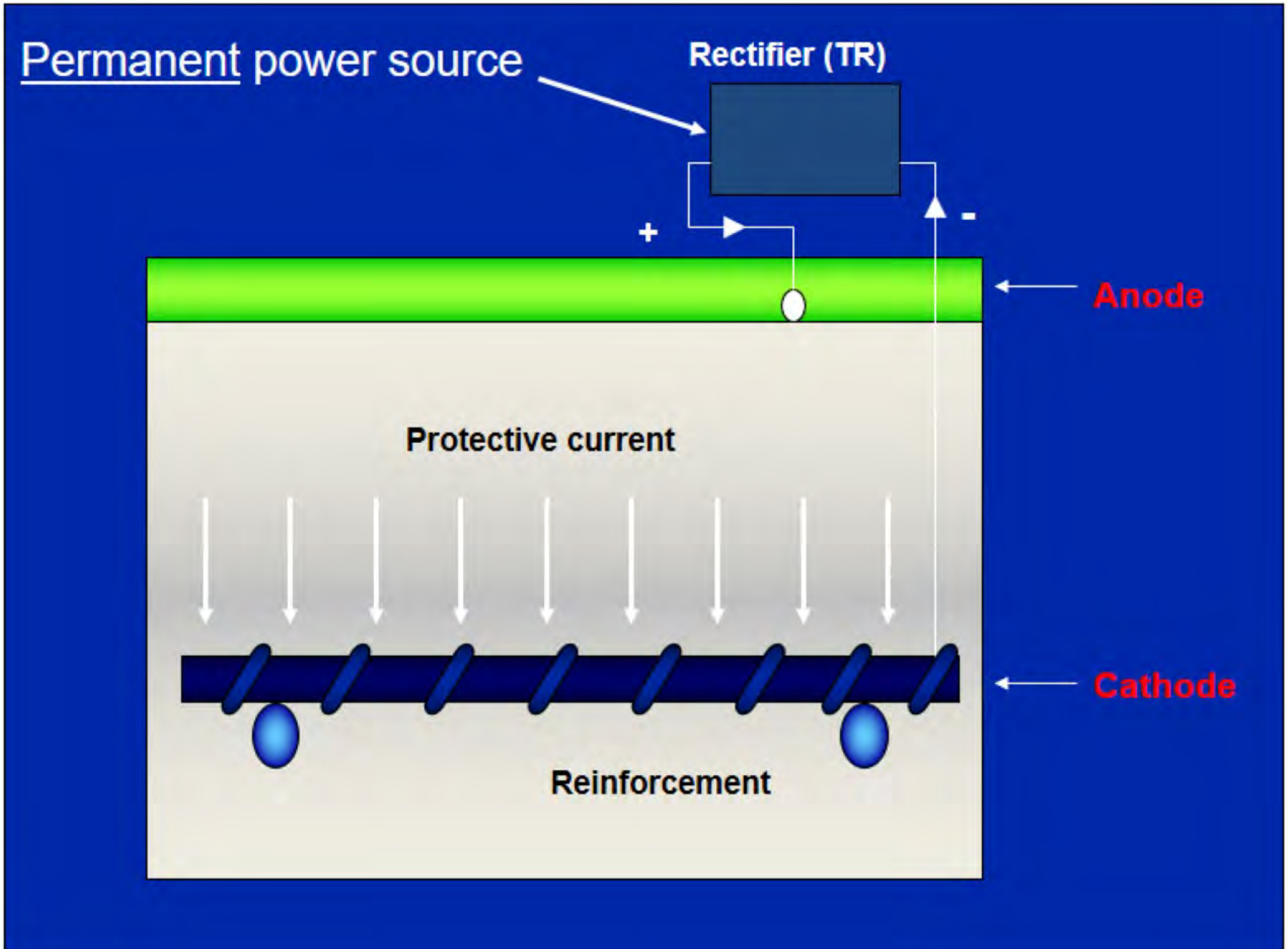
15 – 20 year life

Simple installation

Maintenance free

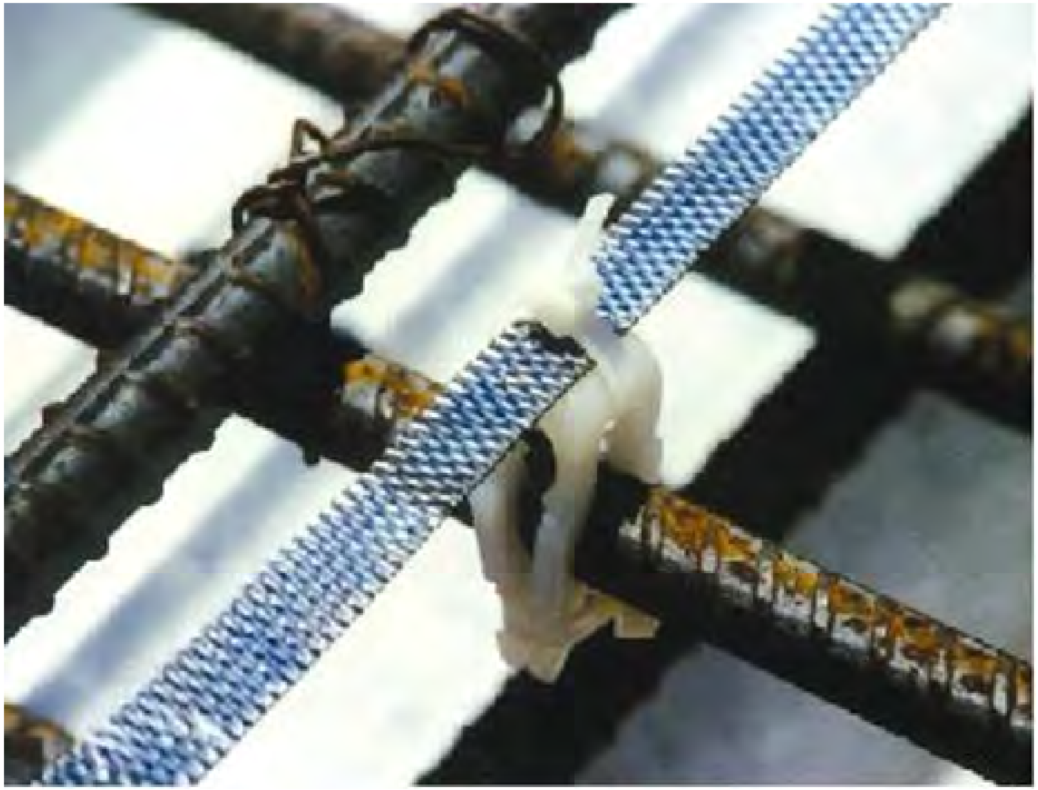
Targeted corrosion protection

Traditional impressed current cathodic protection



Impressed current – anode example

Impressed current - anodes



Traditional ICCP - issues

- Cost
- Complexity
- Vandalism
- **Maintenance**

Traditional ICCP - issues

Traditional ICCP - issues

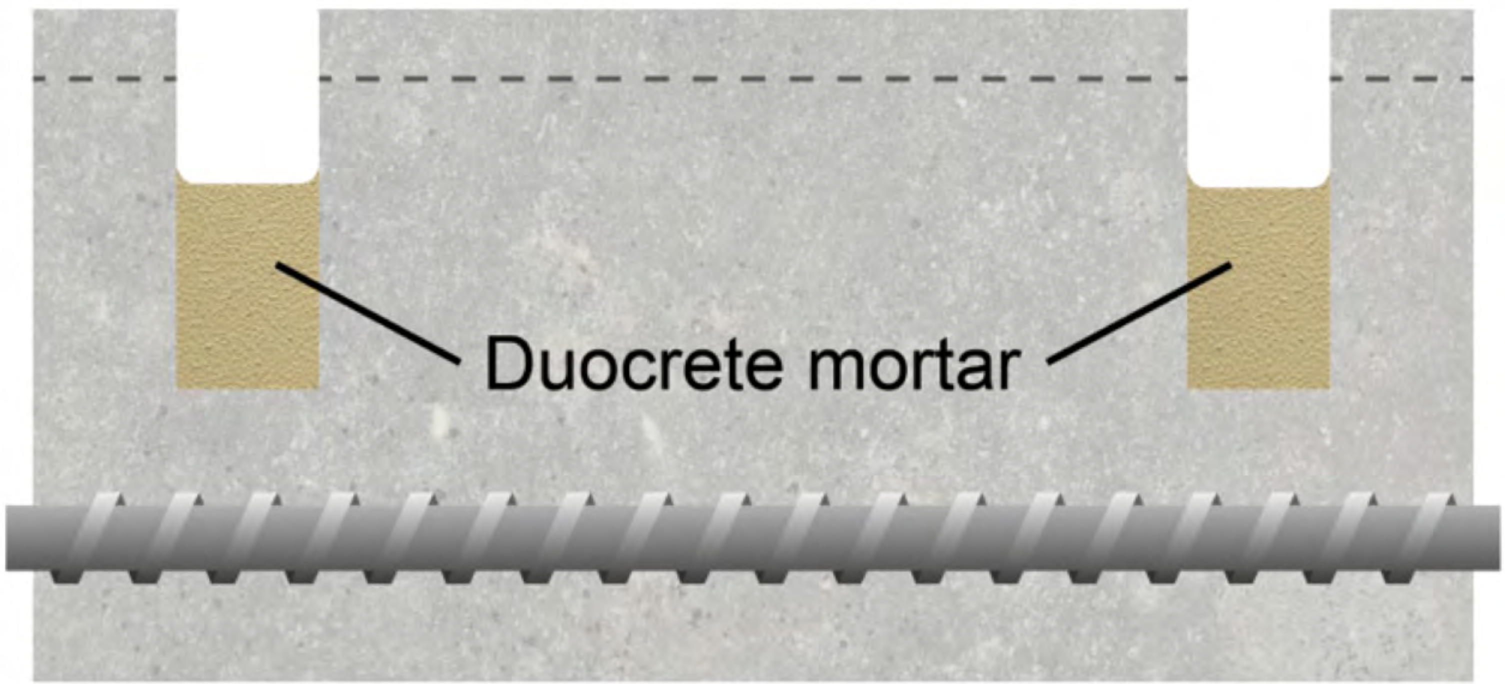
Traditional ICCP - issues

DuoGuard – hybrid CP

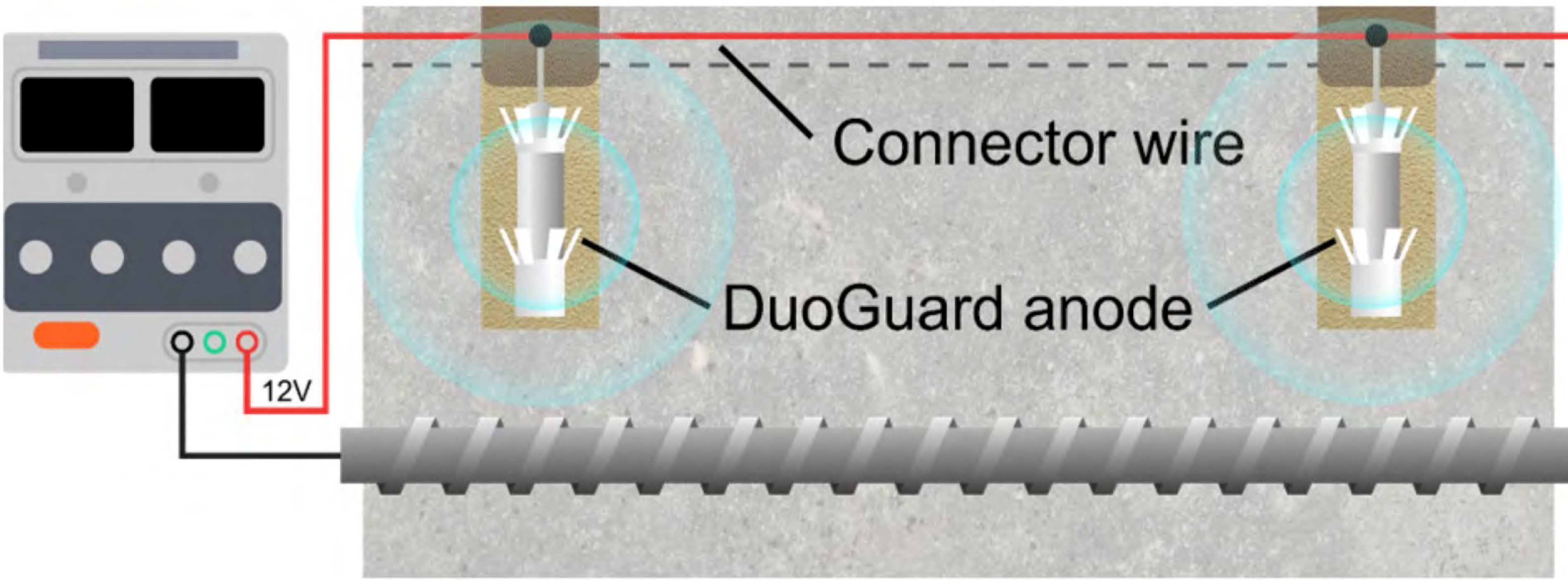
The World's first hybrid anode

Removing the complexity from CP

DuoGuard – how it works

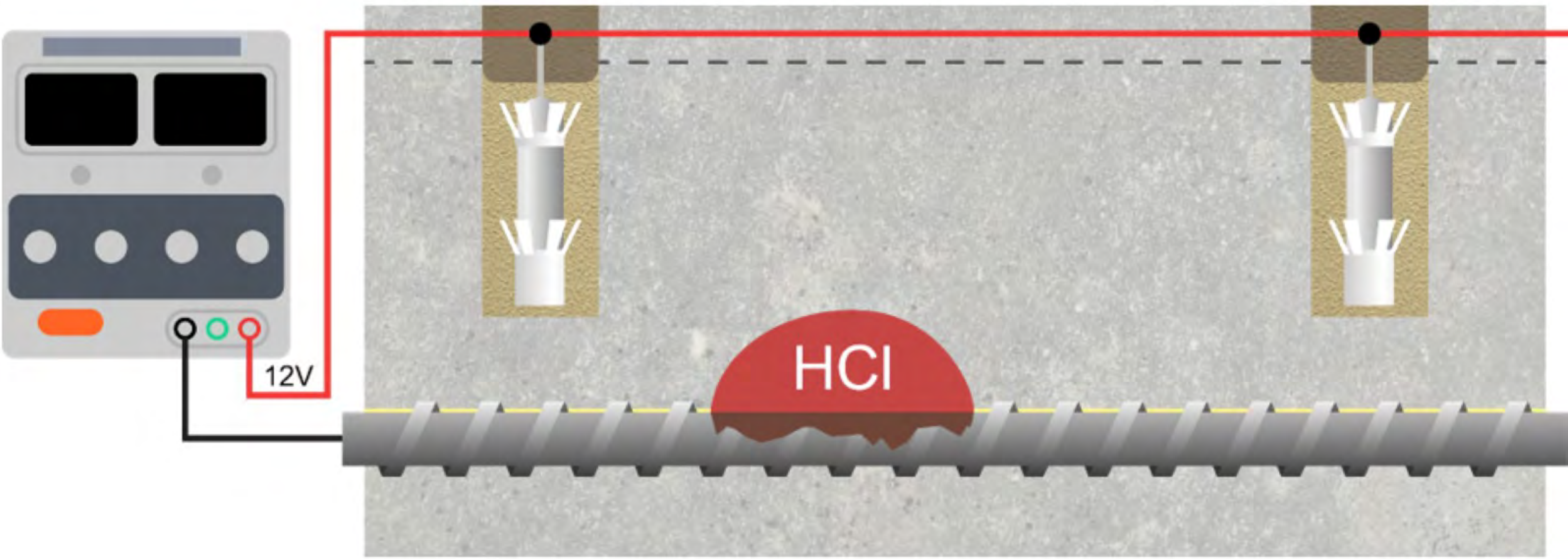


DuoGuard – how it works

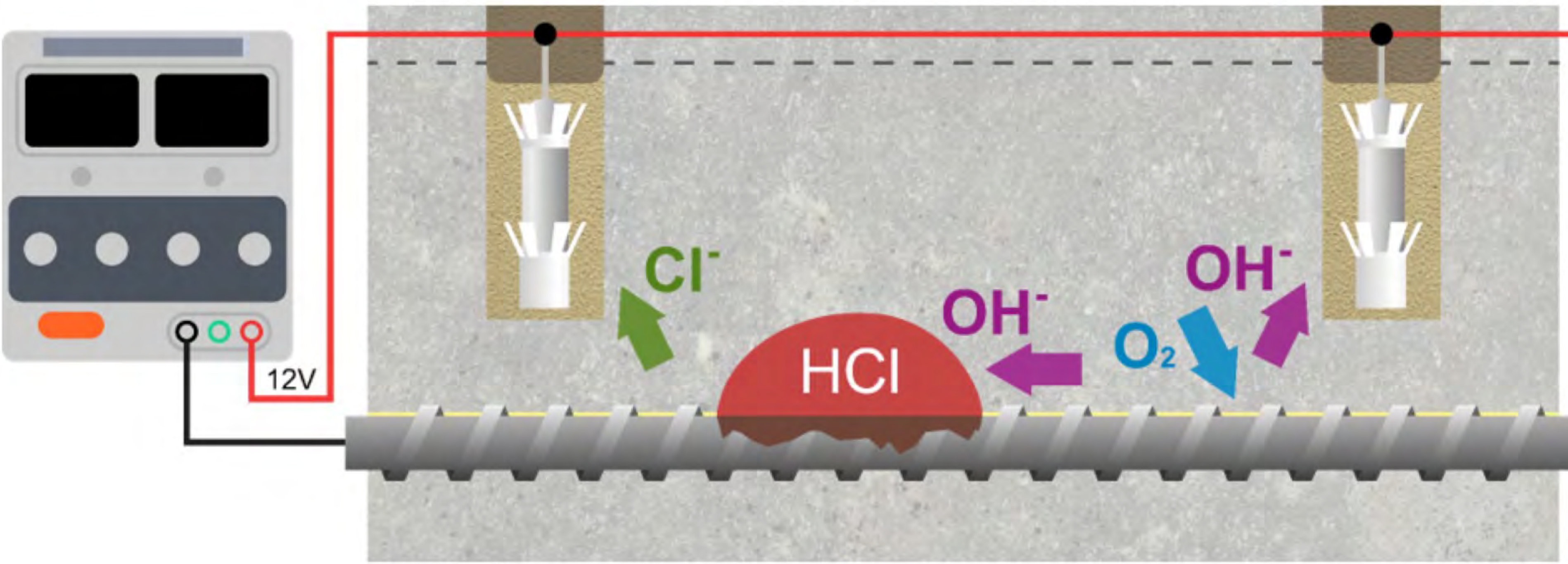


Temporary impressed current mode to stop corrosion

DuoGuard – how it works

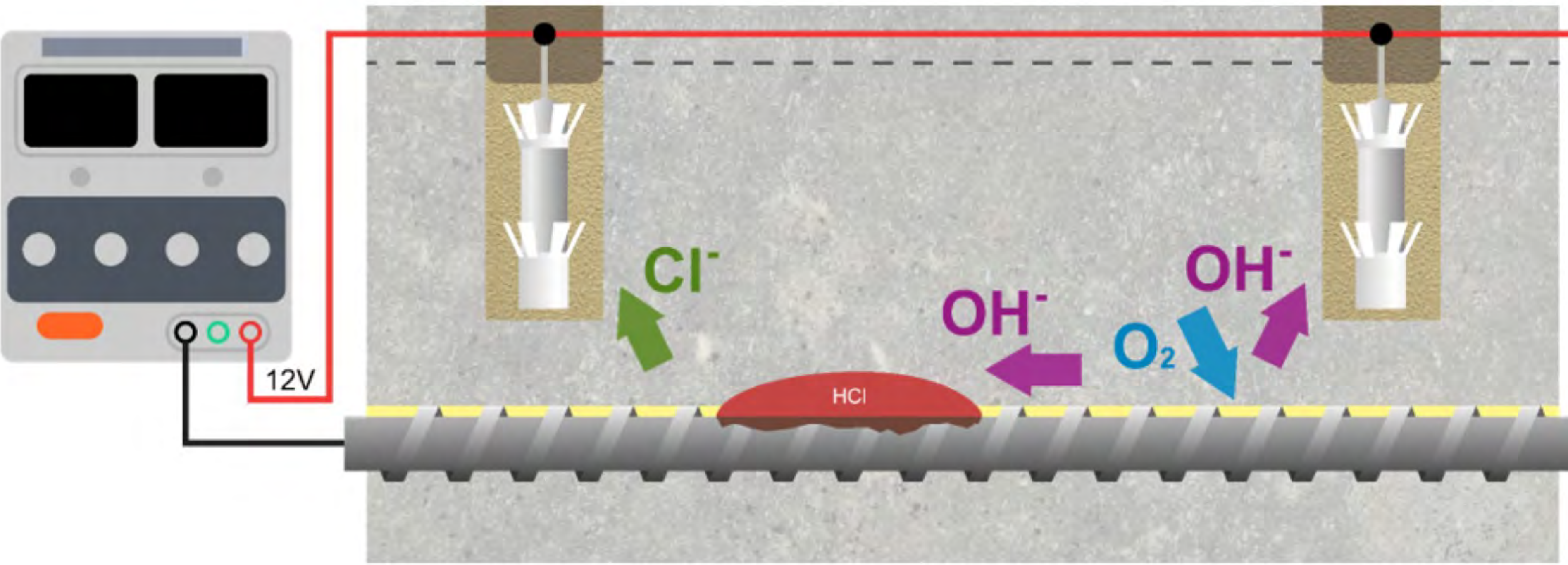


DuoGuard – how it works



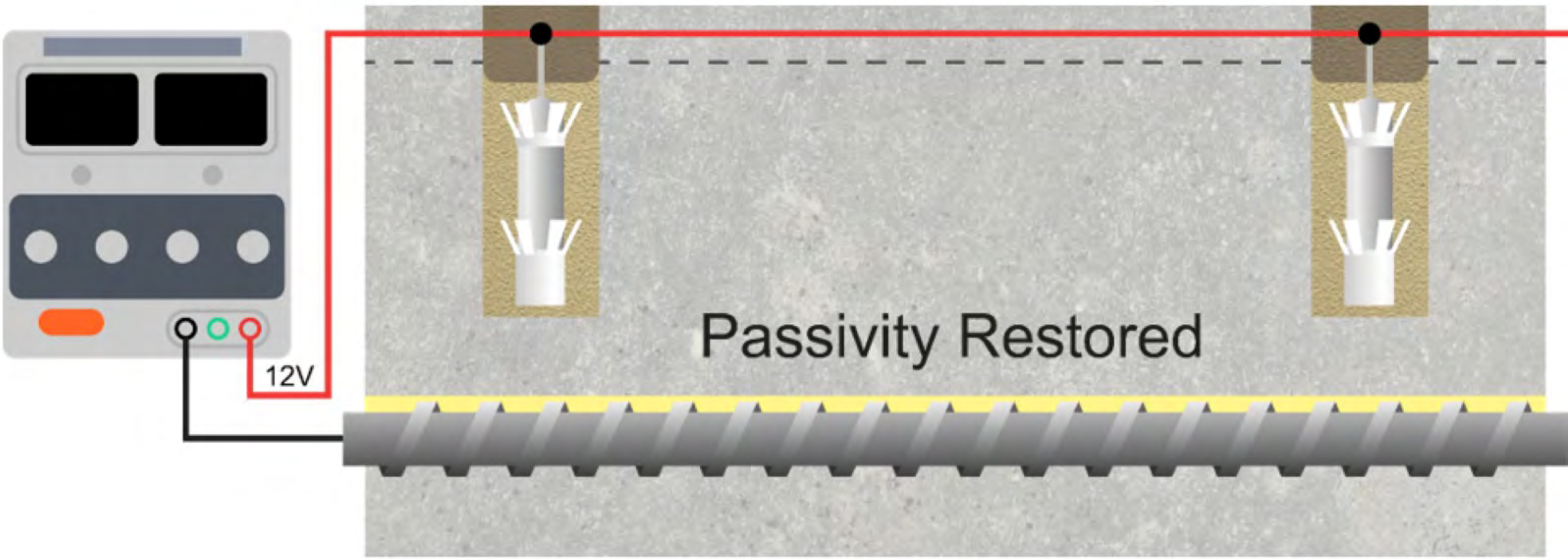
Some chloride begins to migrate to the installed anode

DuoGuard – how it works

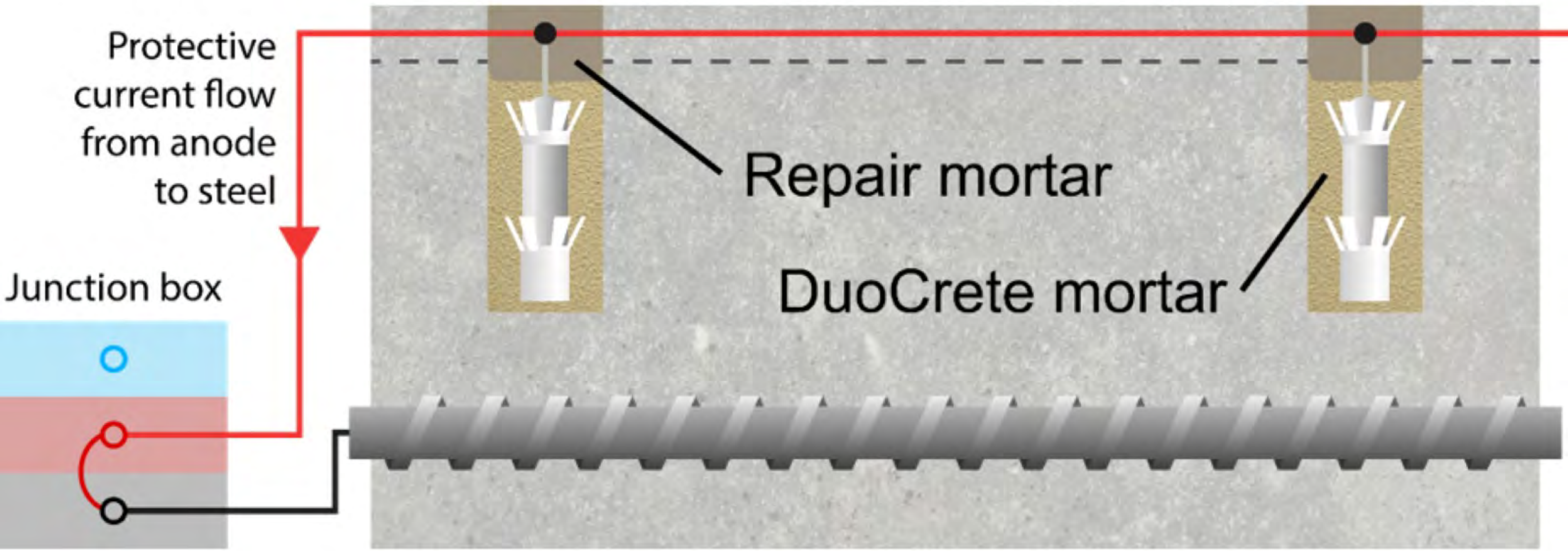


The pH gradient assists hydroxyl ion migration to the pit

DuoGuard – how it works

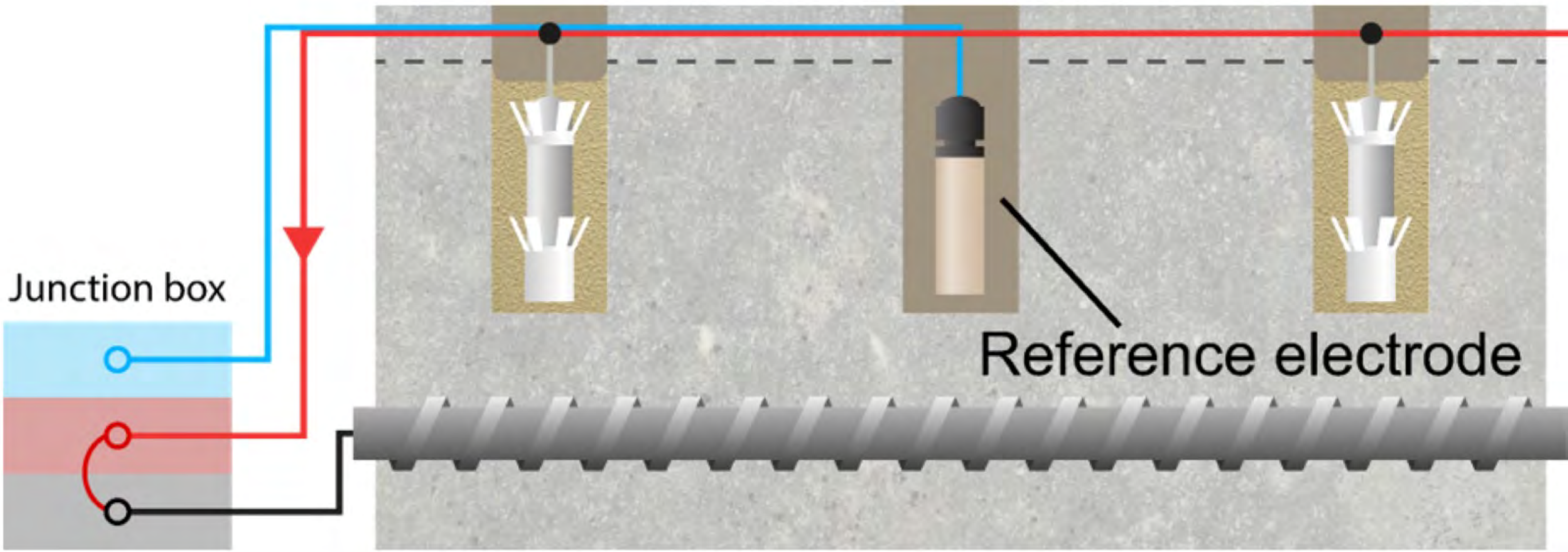


DuoGuard – how it works



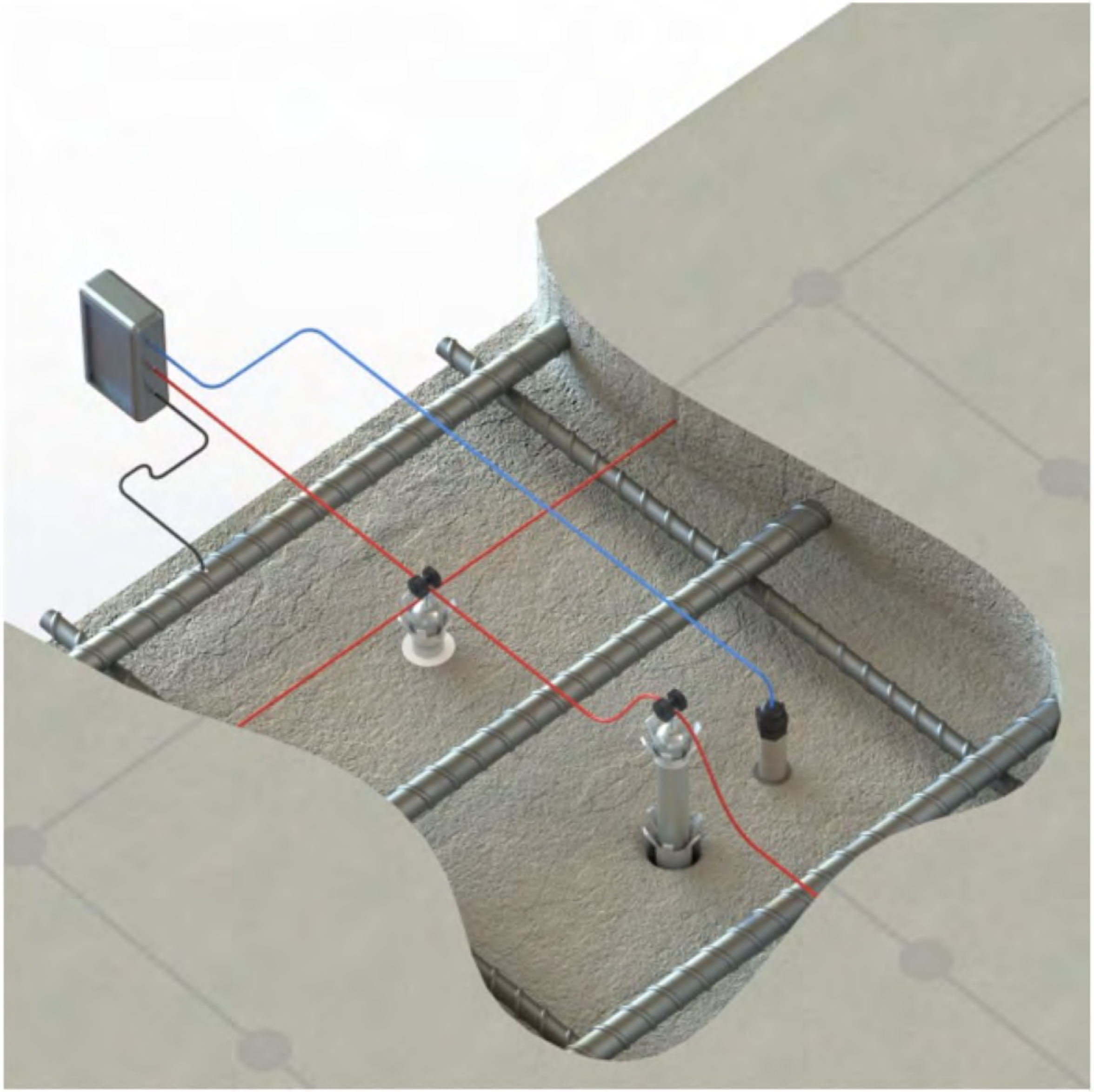
Galvanic mode to prevent corrosion returning

DuoGuard – how it works



DuoGuard – how it works

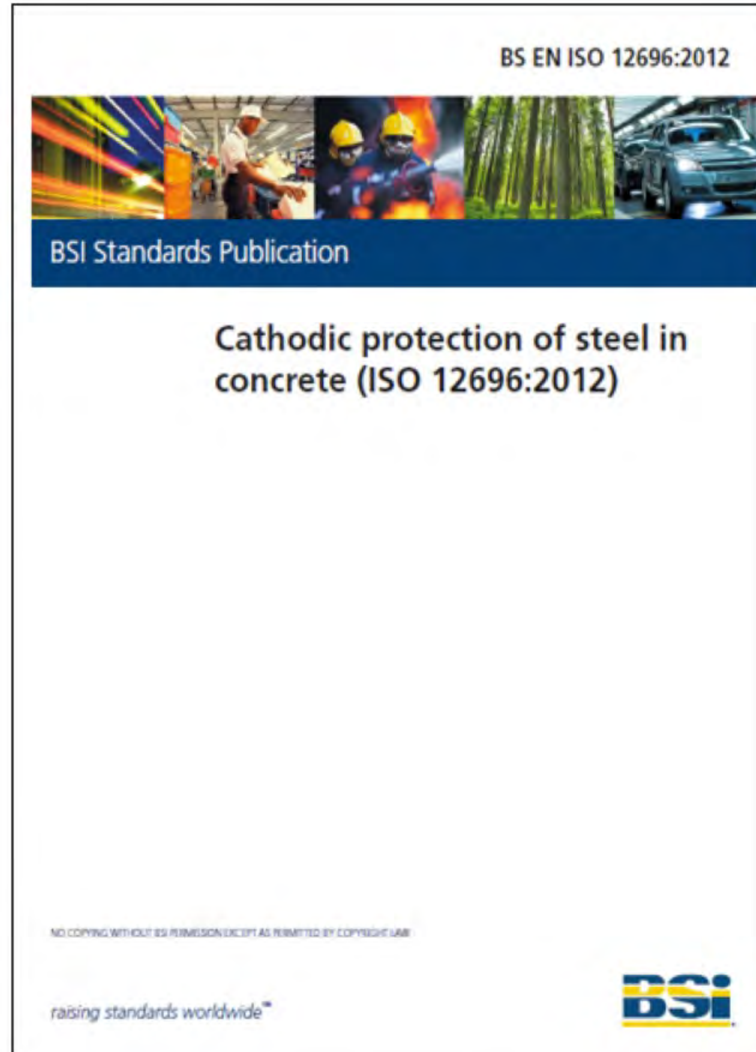
DuoGuard – how it works



International CP standard

ISO 12696

- 2 – 20mA/m^2: stops active corrosion
- 0.2 – 2mA/m^2: maintains passivity
- Min 100mV potential shift
- Corrosion rate <2mA/m^2 = passive


BS EN ISO 12696:2012

BSI Standards Publication

Cathodic protection of steel in concrete (ISO 12696:2012)

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raising standards worldwide™

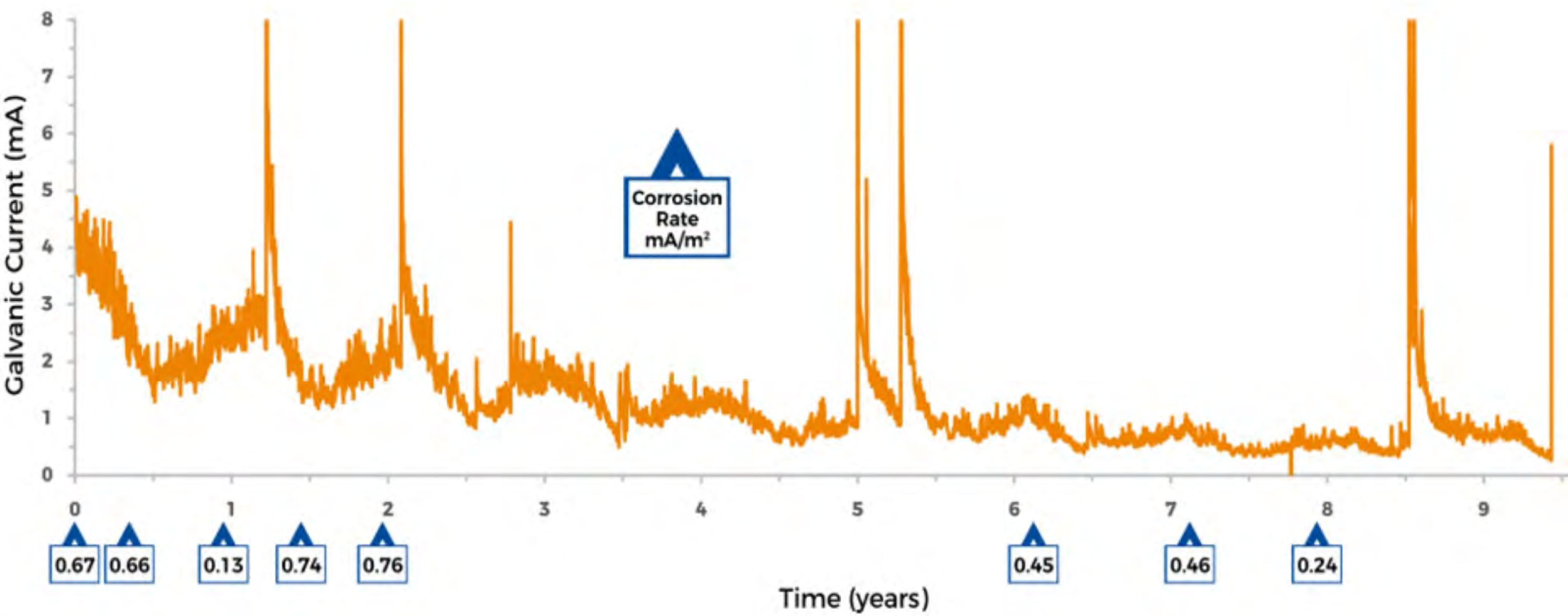
BSI

DuoGuard – performance data

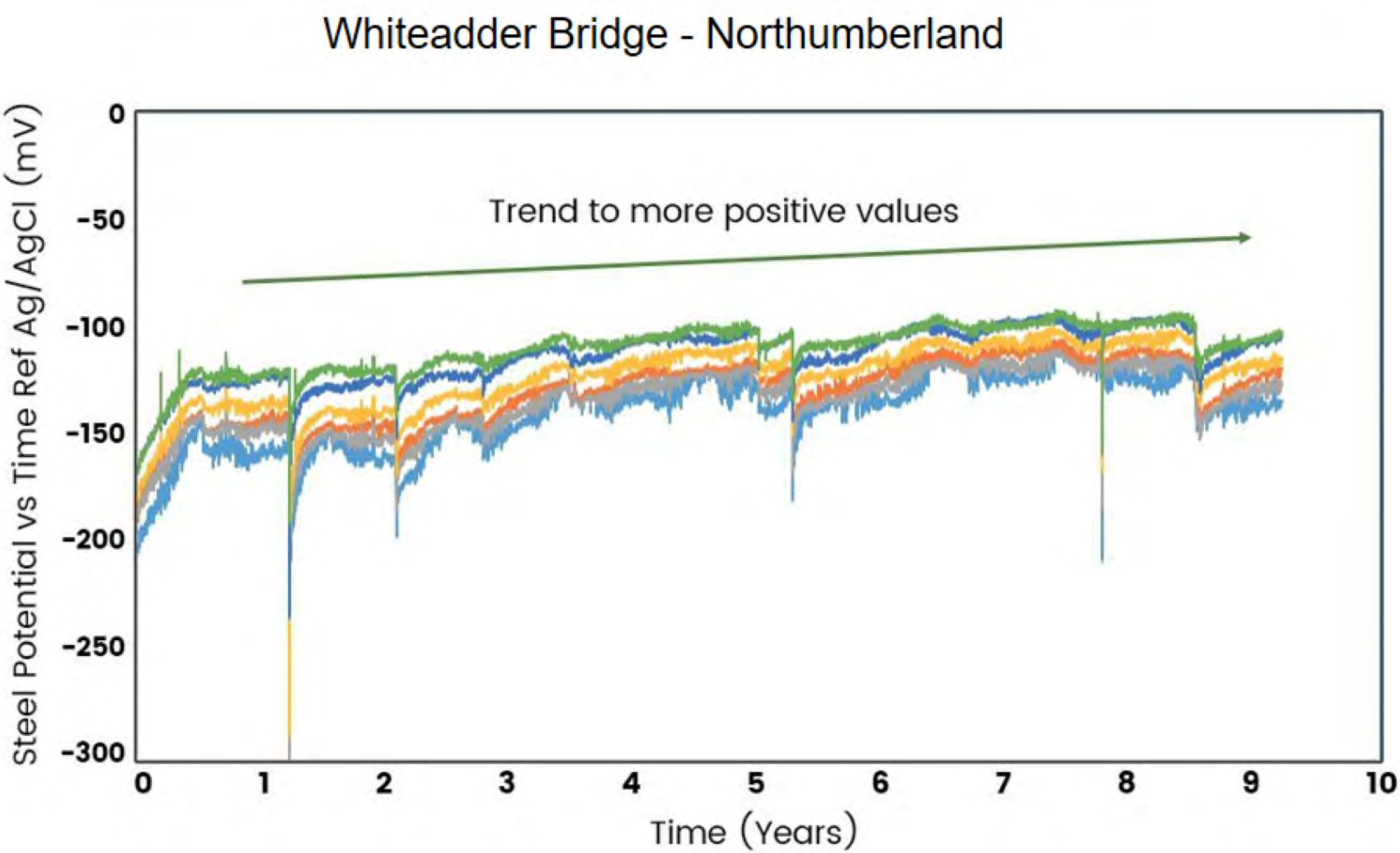
Whiteadder Bridge, Northumberland

DuoGuard – performance data

Whiteadder Bridge - Northumberland



DuoGuard – performance data



DuoGuard – hybrid CP

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Construction Materials

Hybrid anode concrete corrosion protection – independent study
Dodds, Christodoulou and Goodier

ice | proceedings

Proceedings of the Institution of Civil Engineers

http://dx.doi.org/10.1680/jcoma.16.00024
Paper 1600024
Received 16/05/2016 Accepted 11/10/2016
Keywords: concrete structures/corrosion

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Institution of Civil Engineers
publishing

Hybrid anode concrete corrosion protection – independent study

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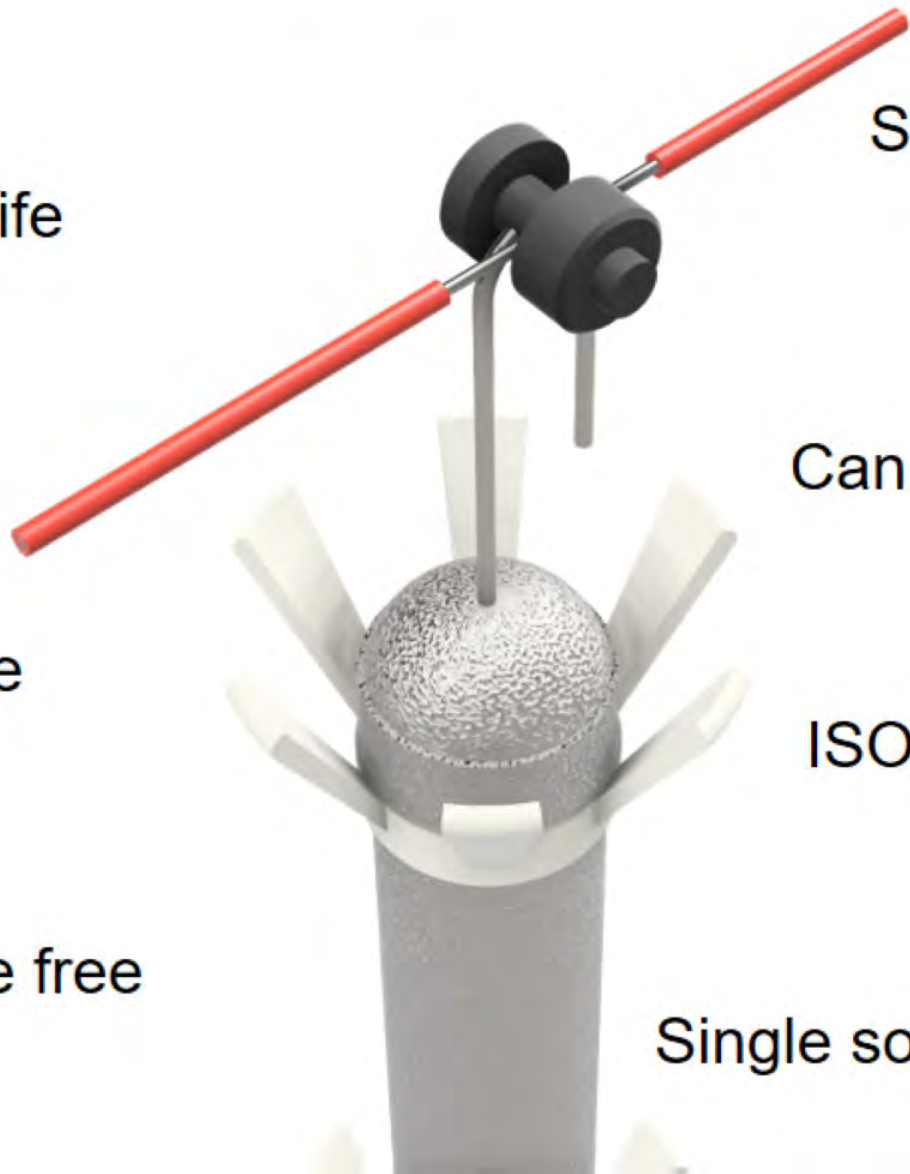
This study was the first of its kind to investigate the long-term performance of hybrid anode systems in reinforced concrete as part of a holistic approach to corrosion risk assessment. An independent appraisal of the site performance of hybrid anode corrosion protection systems (UK invention disclosed in Patent GB2426008B) was conducted on six bridge structures in 2014. The aim of the study was to investigate the effectiveness of current design approaches in meeting the residual service life when the anodes are operating in the galvanic phase. This was achieved by analysing data on the general condition of the structures, studying the ongoing performance of the installed hybrid anodes and assessing the overall corrosion risk. It was found that the six structures were generally in good condition, with low associated corrosion risk in areas protected by the hybrid anode systems. This is a positive finding for the wider implementation of hybrid anode systems as an alternative corrosion management technique. The reinforcement in the protected areas remained predominately in a passive condition, with calculated corrosion rates below the ISO 12696:2012 recommended threshold of 2 mA/m^2. Recommendations regarding design are provided in order to improve the redundancy, functionality and robustness of hybrid anode systems.

DuoGuard



Simple installation

25 + years life

Can be monitored

Design service

ISO 12696 compliant

Maintenance free

Single source responsibility

DuoGuard - installation

Sherbourne Footbridge, Salford - Urban Vision

DuoGuard - installation

Sherbourne Footbridge, Salford - Urban Vision

DuoGuard – performance data

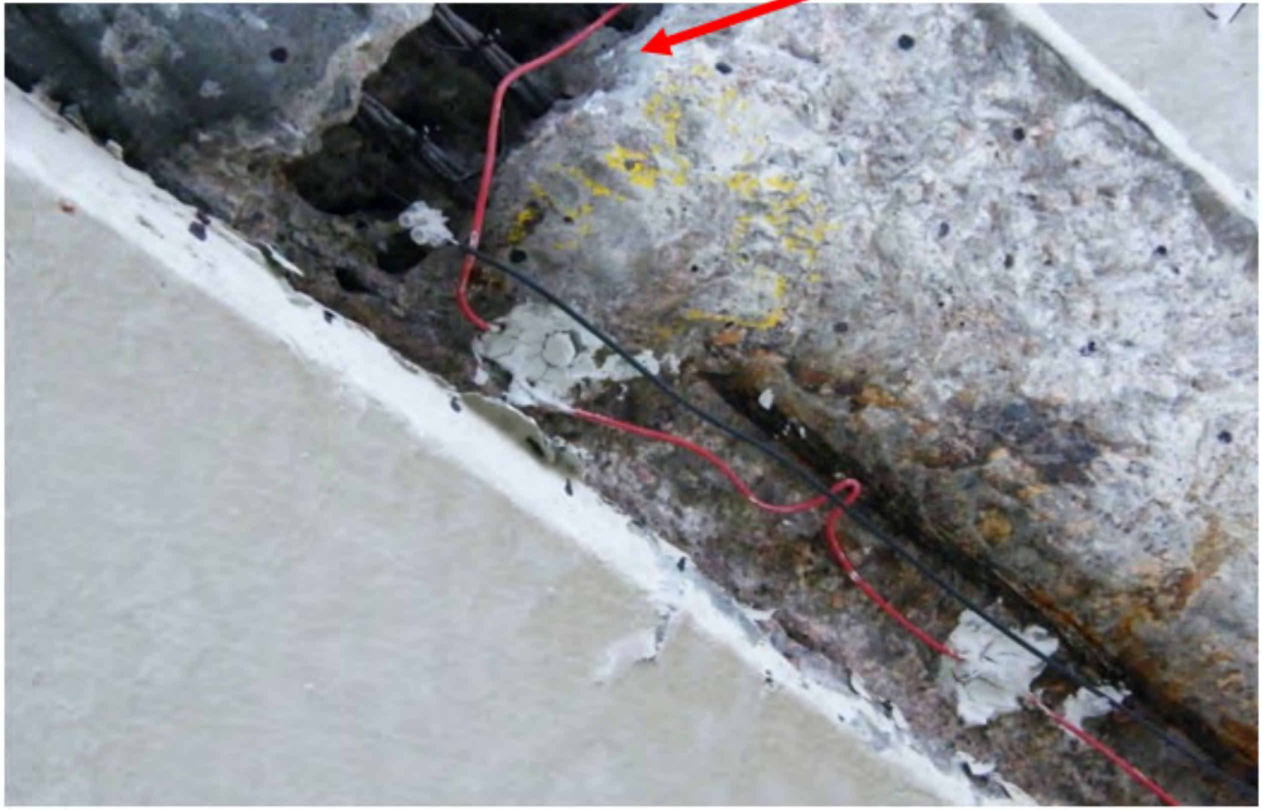
DuoGuard – performance data

Kyle of Tongue Bridge, Sutherland – a world first for CPT

DuoGuard – performance data

Kyle of Tongue Bridge

Prestressed tendons



DuoGuard – performance data

Kyle of Tongue Bridge, Sutherland

Span	Date	Corrosion Rate (mA/m²)	Date	Corrosion Rate (mA/m²)
Span 8-9	01/9/2011	**39.9**	12/1/2012	**0.74**
Span 9-10	02/9/2011	**6.03**	12/1/2012	**1.19**
Span 12-13	1/10/2011	**2.47**	12/1/2012	**0.54**
Span 16-17	21/7/2011	**6.8**	12/1/2012	**0.86**

Case histories

Aust Jetty, National Grid

PROBLEM

- Severn tidal location
- Chloride contamination
- Corrosion to trestle legs, beams and deck

SOLUTION

- Long term low maintenance solution
- Targeted DuoGuard Galvanic CP System; won competitive tender against ICCP
- Previous ICCP system stolen within 1 month

Case histories

Case histories

Case histories

Dagenham Jetty

PROBLEM

- Thames estuary location
- 1930's construction
- Chloride contamination
- Corrosion to beams and deck

SOLUTION

- Long term low maintenance solution
- 12,000 DuoGuard anodes installed

Case histories

P Birmingham New Street, Network Rail, UK

PROBLEM

- Visible cracking & spalling to main beams
- Fast track programme
- Client requirement: no maintenance cost

SOLUTION

- CPT Visual assessment & evaluation
- Hybrid Treatment; no complex wiring, no on-going maintenance cost
- 4000 sqm completed in 3 months

Case histories

P Preston Bus Station Car Park

PROBLEM

- Chloride contamination, low cover
- Spalling decks and soffits
- Damage related to traffic flow
- Client requirement: ease of maintenance

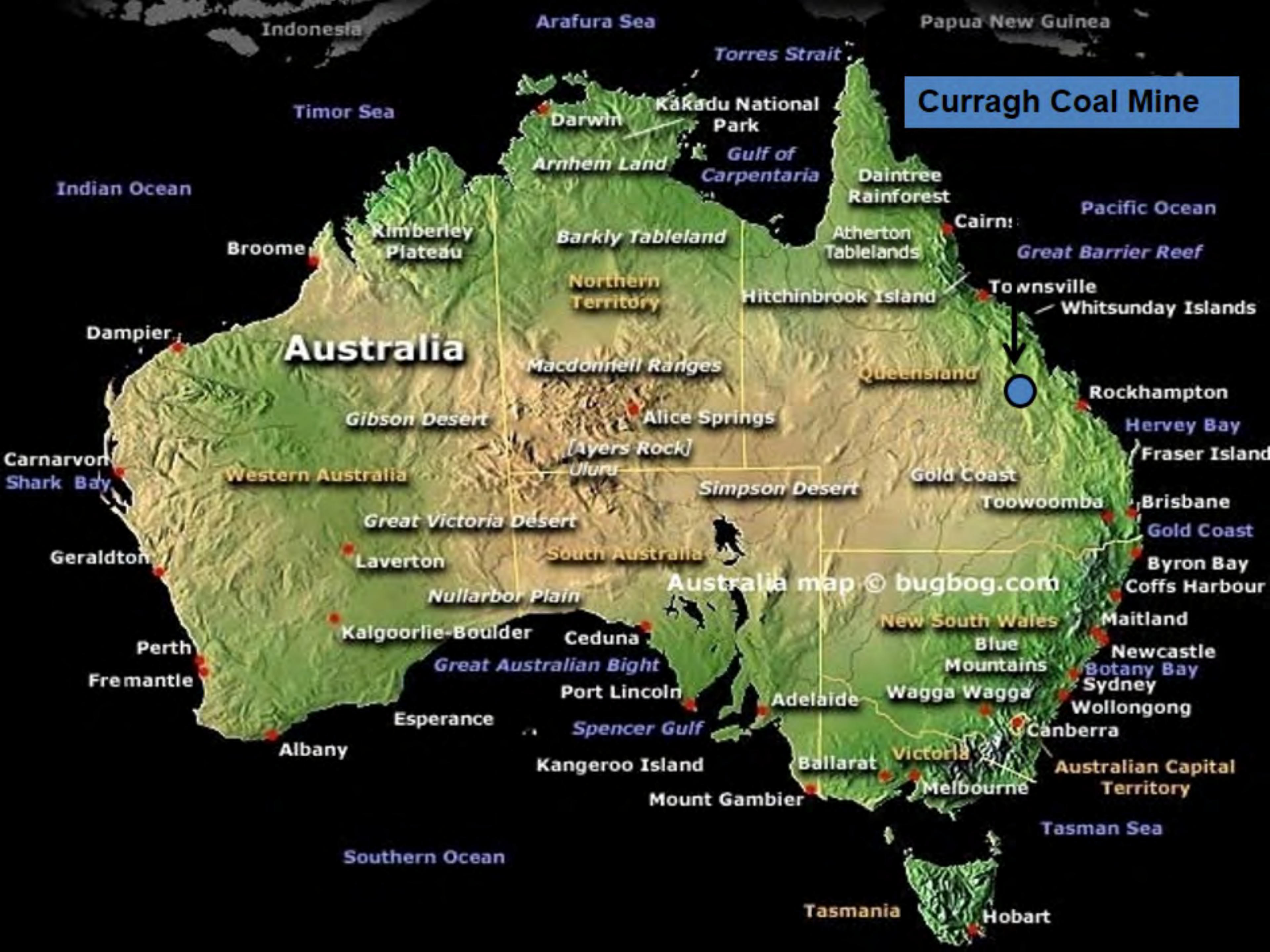
SOLUTION

- CPT testing and assessment
- Targeted DuoGuard to decks
- PatchGuard to soffit patch repairs

Case Histories

Case Histories

Arousa, Spain - DuoGuard


Curragh Coal Mine
Indonesia
Arafura Sea
Papua New Guinea
Torres Strait
Timor Sea
Darwin
Kakadu National Park
Gulf of Carpentaria
Arnhem Land
Indian Ocean
Daintree Rainforest
Pacific Ocean
Cairn
Broome
Kimberley Plateau
Barkly Tableland
Atherton Tablelands
Great Barrier Reef
Northern Territory
Hitchinbrook Island
Townsville
Whitsunday Islands
Dampier
Australia
Macdonnell Ranges
Queensland
Rockhampton
Gibson Desert
Alice Springs
Hervey Bay
[Ayers Rock]
Uluru
Fraser Island
Carnarvon
Shark Bay
Western Australia
Simpson Desert
Gold Coast
Toowoomba
Brisbane
Great Victoria Desert
Gold Coast
Geraldton
Laverton
South Australia
Byron Bay
Australia map © bugbog.com
Coffs Harbour
Nullarbor Plain
New South Wales
Maitland
Kalgoorlie-Boulder
Ceduna
Blue Mountains
Newcastle
Perth
Great Australian Bight
Botany Bay
Fremantle
Sydney
Port Lincoln
Adelaide
Wagga Wagga
Wollongong
Esperance
Spencer Gulf
Canberra
Albany
Ballarat
Victoria
Australian Capital Territory
Kangeroo Island
Melbourne
Mount Gambier
Tasman Sea
Southern Ocean
Tasmania
Hobart

Case histories

Lighthouse & Saline Water Containment Tank, Australia

Protecting Half Joints

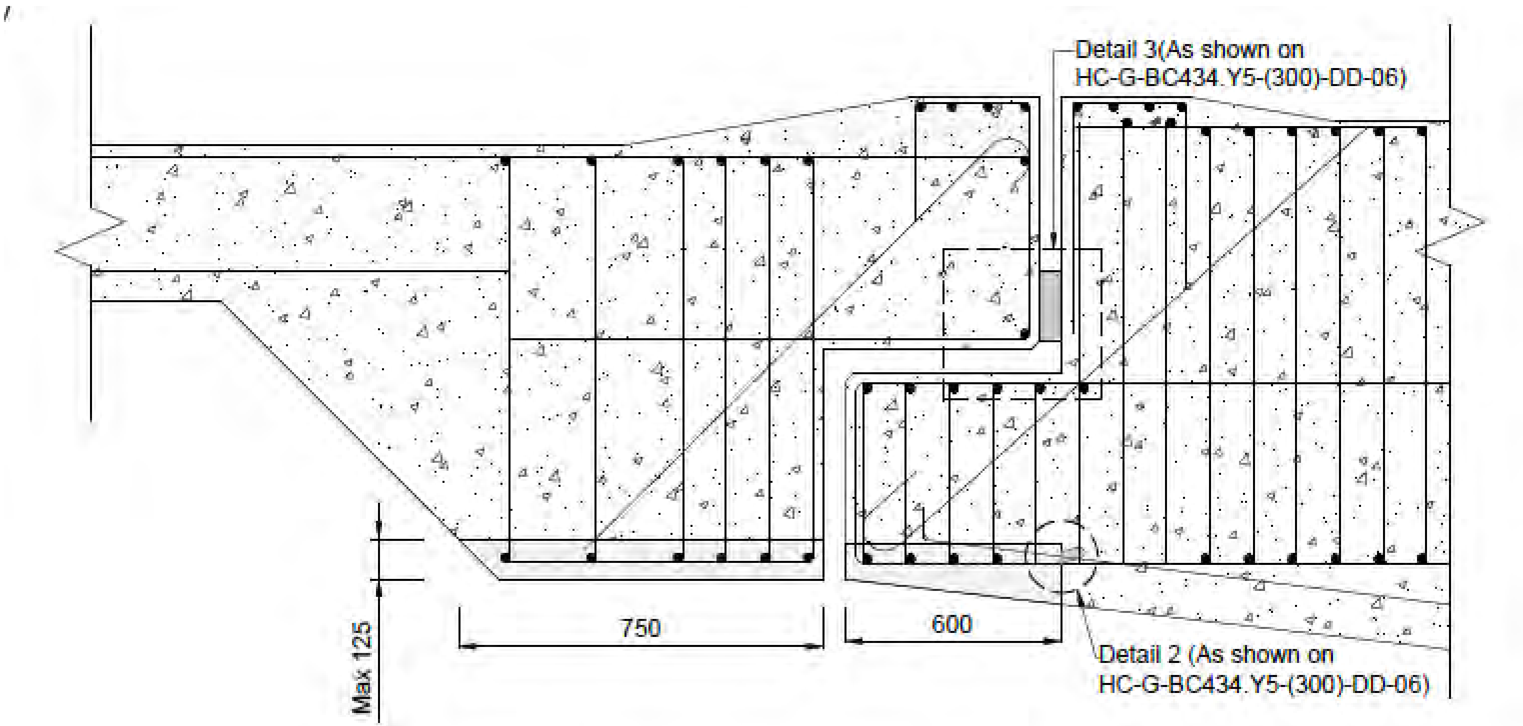
Half Joint Failure, Lake Shore Drive, Chicago

Protecting Half Joints

Lilley Bottom Bridge, Hertfordshire.
Typical half joint design

Protecting Half Joints

Lilley Bottom Half Joint.
ProtectorJoint in situ.



Section A-A - Typical Half Joint Repair Cross Section
Scale (N.T.S.)

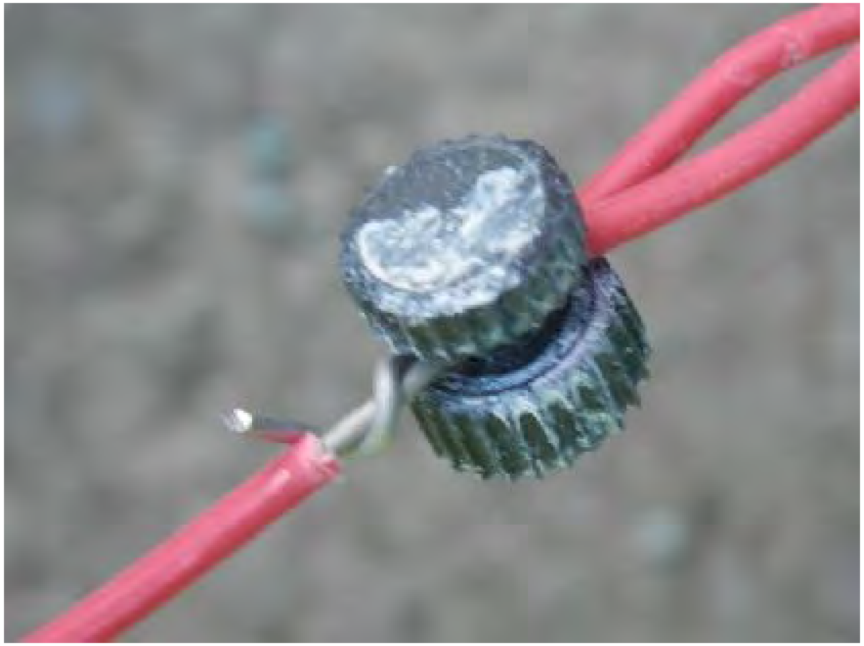
Protecting Half Joints

ProtectorJoint anodes connected ready for installation

Protecting Half Joints

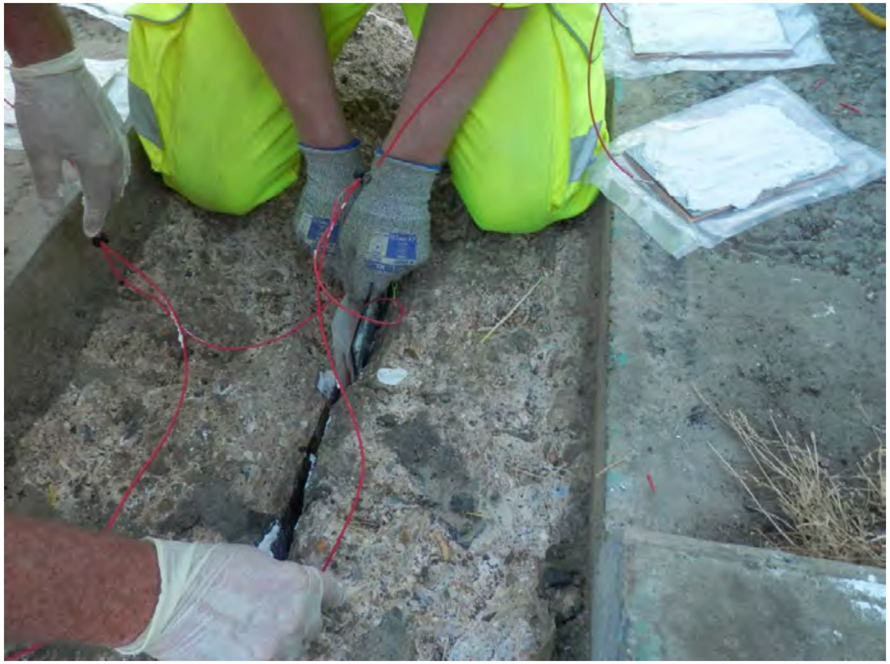
Connection to the steel

Connection to the Feeder Wire



Protecting Half Joints

- Joint exposed ready for installation
- ProtectorJoint installed into the half joint



Protecting Half Joints

Fire retardant strip over anodes

Protecting Half Joints

New bridge joint seal installed

Protecting Half Joints

Monitoring Enclosure containing anode/steel/reference probe connections

Protecting Half Joints

ProtectorJoint Monitoring Results

Data was obtained from the monitoring enclosure on initial installation, at 2 months and 6 months.

Zone	Current output after 1 day/mA	Current output 2 months after installation/mA	Current output 6 months after installation/mA
West Joint	33	15	23
East Joint	36	16.2	22

Zone	Estimated Corrosion rate (mA/m2)	Current Density (mA/m2)
West Ref 1	0.42	1.96
West Ref 2	0.52	2.28
East Ref 1	0.78	2.28
East Ref 2	0.93	1.44

To conclude …

Why use CPT?

- Proven technology
- Track record
- Technical expertise
- Bespoke testing services
- Specification and design
- Guidance and support

On site contractor training