MOTT MACDONALD

Selection of cathodic protection systems for reinforced concrete structures

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19 September 2024

INSTITUTE OF CORROSION

Agenda


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Mott MacDonald’s Materials and Corrosion Department
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Corrosion in Concrete
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Concluding Remarks

Who We Are and What We Do

1

Bristol, Manchester, Croydon

Corrosion specialists, Cement / concrete technologists, metallurgists, asphalt, heritage mortar and coatings experts

2

Anything Materials related

Cement, Concrete, Corrosion, Mortar, Asphalt etc

3

Condition Assessments

Residual Life Assessments

4

Forensic Engineering

5

Durability Assessments

6

Asset Management

7

Durability & Repair Design Cathodic Protection

8

Technical Advice / Trouble-shooting

9

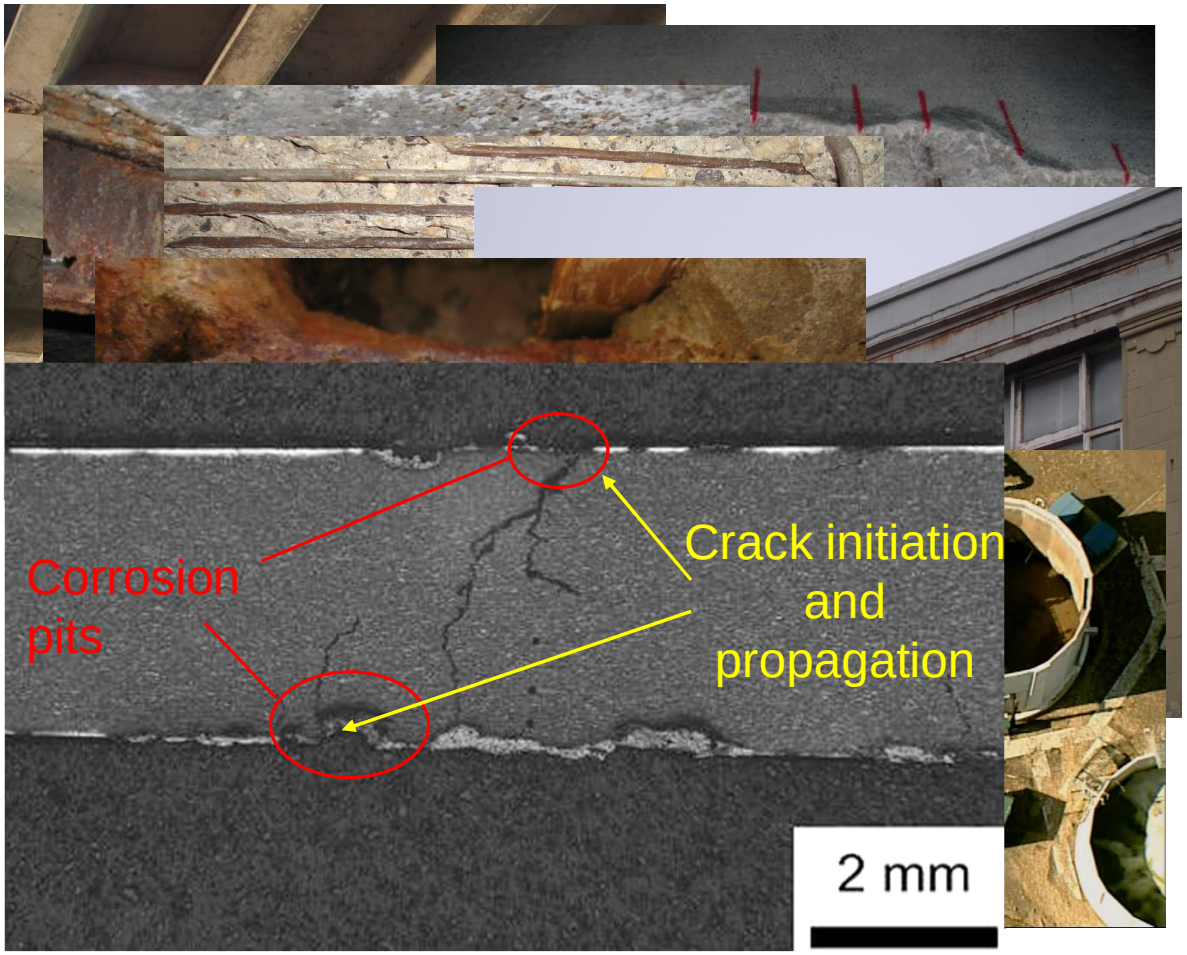
Expert Witness

Projects

- Bridges
- Multi-storey car parks
- Tunnels
- Steel framed buildings
- PT tanks / structural elements

REINFORCED CONCRETE

- Cathodic protection works
- Site investigations and condition assessments
- Cathodic protection design
- Support to contractors during installation
- Commissioning
- Monitoring



Silver Jubilee Bridge (Runcorn – Widnes)

How does steel in concrete corrode

- Steel embedded in concrete normally does not corrode
- Protective passive oxide film on reinforcement
- Carbonation / chloride ingress
- Corrosion is initiated in presence of moisture
- Reaction products are bigger and concrete spalls and delaminates
- Section loss of reinforcement

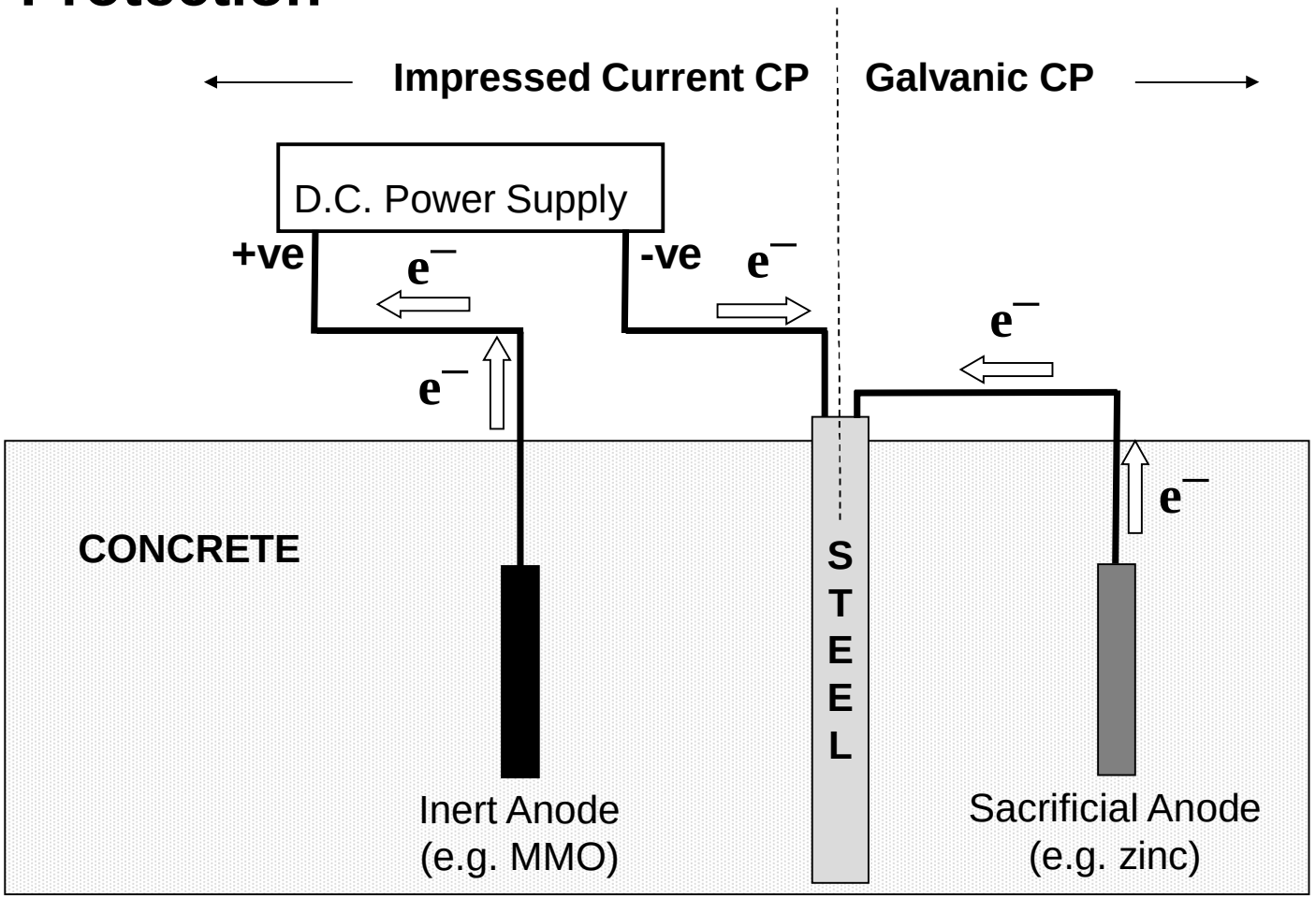
Corrosion Management Strategies

- Electro-chemical techniques
  - Cathodic protection / prevention
  - Electro-osmosis
  - Realkalisation
  - Chloride extraction
  - Corrosion inhibitors
- Physical solutions
  - Surface protection systems (barriers)

Cathodic Protection

- CP polarises the reinforcement in an electrical circuit making all the steel to be protected cathodic with respect to a system of installed anodes
- CP can stop corrosion in any environment
- Continuous penetration of chlorides can be tolerated / contaminated concrete remains
- Impressed, galvanic and hybrid systems

Cathodic Protection



Concrete Repair Basis

- Ageing of UK infrastructure as structures are generally 40-70 years old
- Highways England specifies a service life of 120 years
- Regular exposure to de-icing salts
- Expected residual service life / life extension is currently 50-80 years

Option Selection

- Typically, a CP system is pre-selected based on an engineer's experience and preference.
- Design needs to consider:
  - Aggressiveness of environment,
  - Area to be protected,
  - Area of steel,
  - Type of anode,
  - Sensitivity of the concrete to other deterioration mechanisms (ASR, SCC).

Option Selection

- Structures Option Management Report (SMOR) in accordance with CS 462 if there is more than one BS EN 1504-9 option for repairing or managing a structure.
- The SMOR should consider:
  - Various repair / CP systems
  - Associated health & safety risks
  - Estimated whole life costs
  - Impact of repair on the road/rail/etc network
  - Future management strategy
  - Environmental aspects
  - Sustainability

Option Selection

- A scoring system to assess the different options was developed for TfW and includes the following:
- Technical applicability: 20%
- Environmental impact (exposure / working time on site) 10%
- Sustainability (embodied carbon, traffic delays/restrictions) 30%
- Health & Safety and Welfare (traffic management, activities) 20%
- Whole life cost (CAPEX, whole-life cost, user-delay): 20%

100%

There is a desire to significantly increase the weighting of sustainability, HSW and environment – 60% vs 40% for technical and whole-life cost.

Basic Parameters

CP System	GCP	HCP	ICCP
Design Life:			
Anode system	**15-20 years**	**25-30 years**	**75+ years**
Electrical equipment	-	-	25 years
Estimated Cost / Unit:			
Design and installation	£300/m^2	£400-£555/m^2	£480-540/m^2
Anode removal	£150/m^2	£150/m^2	-
Electrical equipment and replacement/installation	-	-	£3,500-£6,000 EA plus TM (System stabilise – simpler supply)
Monitoring	Required annually but often undertaken as part of General (every 2 years) and Principal Inspections (every 6 years)	Required annually but often undertaken as part of General (every 2 years) and Principal Inspections (every 6 years); Initial first year monitoring: £3,000-£6,000; Annual monitoring: £1,000-£5,000/year	Required annually; Initial first year monitoring: £3,000-£6,000; Annual monitoring: £1,500-£5,000/year
Operation and Maintenance	**Replacement of whole system, i.e. anodes / monitoring equipment** at 15-20 year intervals	**Replacement of whole system, i.e. anodes / monitoring equipment** at 25+ year intervals	**Replacement of electrical power supply and monitoring systems** at 25+ year intervals; Potentially remote monitoring equipment: £500 to £1000 [CPA (2019)]; Electricity costs: approx. £30/year

Practical Considerations

CP System	GCP	HCP	ICCP
Network disruptions / installation time	Initial: Lowest disruptions; Maintenance: Reoccurrence; Overall: **Highest network disruption** during whole-life cycle of a structure.	Initial: Medium; Maintenance: Reoccurrence; Overall: Medium network disruption.	Initial: Highest; Maintenance: Minimal. Replacement of power supply and monitoring systems; Overall: **Least network disruption**.
Practical Considerations	Larger diameter drill holes; The **reinstatement with new anodes at the end of the design life may not be a practical option**;	Additional drill holes are often required due to shorts; Drill holes larger diameter than for ICCP; **The reinstatement of existing with new anodes may not be a practical option**; Full encasement of anodes is required but difficult to verify in practice. A systematic decrease in performance may occur where voids are present.	Short-circuits between anode and reinforcement causes faults; The system **requires power and needs to be switched on** to work; Protection of control unit against the risk of vandalism, damage from flooding and accessibility for monitoring; **SIM cards** used for remote monitoring require regular replacement, i.e. every 2 years; More complex wiring may create faults.

Advantages and Disadvantages

CP System	GCP	HCP	ICCP
Design Life: Anode system	**15-20 years**	**25-30 years**	**75+ years**
Electrical equipment	-	-	25 years
Robustness and Performance	Fairly robust within the limits of the system's service life; **Performance will be affected** if chloride content and moisture in concrete increases.	**Long-term field data are limited** to maximum 20 years; The system is fairly robust; There is limited comprehensive field data to **validate the passivation ability** of hybrid anodes.	Highly robust but system needs to be on and monitored regularly. The **performance can be monitored and adjusted**;
Main advantages	**No AC** connection required; No maintenance required for life extensions within the system's design life;	**No AC** connection required; No maintenance required for life extensions within the system's design life;	**High robustness** of system. Electrical equipment that fails can be easily replaced; **High levels of control**; Ongoing **Cl contamination can be better tolerated** than HCP.
Main disadvantages	**Replacement of whole system** may be required; **Consumption of zinc in anodes may vary** during expected design life; Not controllable;	**Replacement of whole system** may be required; Consumption of zinc in anodes may vary during expected design life; Limited comprehensive **track record** of field applications; **Not controllable**;	**AC** connection required; **Replacement** of power supply and monitoring equipment; Mesh and overlay: additional **dead load**; Mesh and overlay: Change in aesthetic appearance.

Health & Safety

CP System	GCP	HCP	ICCP
Health and Safety	Hand-arm vibration syndrome **(HAVS)** – significant number of drill holes can be required; Anodes are generally **larger than discrete ICCP anodes** resulting in longer drilling times, i.e. increased risk of HAVS; Working with cementitious materials (COSHH).	Hand-arm vibration syndrome **(HAVS)** – significant number of drill holes can be required; Anodes are generally **larger than discrete ICCP anodes** resulting in longer drilling times, i.e. increased risk of HAVS; Working with cementitious materials (COSHH).	Depending on ICCP system: - Mesh and overlay / surface applied systems: **HAVS** from mesh fixings and reference electrodes; - Discrete anode system: HAVS similar to hybrid but smaller diameter holes, so typically less drilling; **Electrical shock** – working AC power; Sharp edges from mesh; Manual handling; Working with cementitious materials (COSHH).

What specific system should be used?

- Galvanic CP – around 200 years track record
  - Discrete vs Surface applied (ZLA): HSW and installation time
- Hybrid CP – 10-20 years
  - Discrete: HSW
- ICCP – around 40 years track record
  - Mesh & overlay: dead load, vibration risk, reduced head room
  - Discrete: limited element thickness, cover, short circuits
  - Cassette system: vulnerable to theft or damage
  - Conductive coating: localised conditions govern current discharge, debonding

Example – Abutment Life Extension of 75 years

	GCP	HCP	ICCP	
System Replacement	3x	2x		1x
Cost	3x £300/m^2	2x £400-£555/m^2		1x £480-540/m^2
Duration (anode installation)	3x 14 weeks	2x 20 weeks	Mesh & Overlay (Discrete)	1x 12 weeks (1x 22 weeks)
Duration (set up, clearance, scaffolding, demobilisation)	3x 13 weeks	2x 13 weeks		1x 13 weeks
Electrical equipment				2 days EA
CO_2e (Materials)	2.4-5.4 $kgCO_2e/m^2$	1.6-3.6 $kgCO_2e/m^2$		8 $kgCO_2e/m^2$ (3 $kgCO_2e/m^2$) +0.1 $kgCO_2e$/annum
Total disruptions **CO_2e** **TM** **H&S** **Environmental**	81 weeks	66 weeks		26 (36) weeks

Conclusions

- Selection of most suitable CP system depends on various factors
- The system with the lowest whole-life cost may not be the most sustainable and environmentally friendly solution
- Authorities are willing to invest more to achieve sustainability goals, reduce impact on the local economy and society
- ICCP systems are the most robust with the longest design life and potentially shortest disruptions
- GCP are more applicable for one-time short-term repairs
- HCP systems for medium-term repairs

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Thank you