MARINE STRUCTURES
CORROSION AND METHODS OF PREVENTION

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INTRODUCTION

- Corrosion & Accelerated Low Water Corrosion (ALWC)
- Introduction to Marine Cathodic Protection (CP)
- Galvanic Anodes versus Impressed Current
- Project Examples
- CP of Steel in Concrete
- Case Study: Steel in Concrete & Seawater
- Conclusions
CORROSION

- All metals, except Gold, will corrode with time, to try and form a stable oxide compound.

- Corrosion rate depends on the metal and its environment.

ACCELERATED LOW WATER CORROSION
ALWC: Background

• Many established forms of localised corrosion, including microbial corrosion
• Since early 1980s increasing reports in UK of corrosion just above LAT
• Quoted range of corrosion rates of 0.3-4.0 mm/side/year
• Is it new?
• Influencing Factors?
• 2005 CIRIA report
Identification
Location

- Sheet Piles
- In-pans & out-pans
- Increasingly identified in the band LAT-Mid tide
- U Piles: More prevalent on out-pans?
- Geographic Location?
Introduction to Cathodic Protection

• Humphrey Davy used galvanic anodes in 1824
• Thomas Edison used impressed current in 1890
• Established standards
  - BS EN ISO 13174: 2012 (previously 2001)
  - DNV RP 401 : 2010
• CP well established & proven for steel in sea water
• Mandated for Offshore Installations and Pipelines
• CP of Reinforced Concrete Marine Structures Common
Introduction: Galvanic Anodes

\[ 2e^- \rightarrow Al^{++} \]

\[ O_2 + 2H_2O \rightarrow 4OH^- + 2e^- \]
Introduction: Impressed Current

\[
\begin{align*}
\text{O}_2 + 2\text{H}_2\text{O} & \rightarrow 4\text{OH}^- \\
4\text{Cl}^- & \rightarrow 2\text{Cl}_2 \\
2\text{H}_2\text{O} & \rightarrow \text{O}_2 + 4\text{H}^+ \\
\end{align*}
\]
GALVANIC OR IMPRESSED CURRENT? –
THE CASE FOR GALVANIC ANODES

• No power supplies
• No electricity bill
• No cabling
• Less to go wrong
• Less frequent inspection & monitoring
Galvanic Anodes For Installation to Sheet Piles: 
Al/Zn/In Alloy Most Common
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GALVANIC OR IMPRESSED CURRENT? –
THE CASE FOR IMPRESSED CURRENT

• Longer anode life
• For new build 50% less capital cost
• Accurate “Instant Off” potentials
• Less anodes to install
• OK if high seawater resistivity
• OK if high bed level (close to mid tide)
GALVANIC OR IMPRESSED CURRENT? –
THE CASE FOR IMPRESSED CURRENT

Anodes Durable but Lightweight
MMO Coated Ti Anode on GRP shield with steel insert
MMO Coated Ti Anode for Tubular Piles
Cabling must run from anodes to T-R
Typical Transformer-Rectifier
DOES IT WORK?
DOES IT WORK?

Visual condition of pile after 3 months
LIMITATIONS

- Top of Pile
- High Tide
- Mid Tide
- Low Tide
- Bed Level
- Full Protection
- Some Protection
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GALVANIC OR IMPRESSED CURRENT? – SUMMARY

- Most UK ports retro-fitting CP use galvanic anodes
- Impressed current used for new ports or extensive upgrading
- Impressed current used in estuarine ports with high water resistivity or shallow water depths
CP OF STEEL IN CONCRETE

• Exposure to seawater, spray will result in chloride ingress, frequently structures are exposed to chloride levels way beyond safe limits.
• Mid-tide to top of splash zone is the best environment for corrosion (Cl\textsuperscript{-} & O\textsubscript{2} both present).
• Cathodic Protection systems to stop corrosion of steel in concrete: to prevent this:
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Example of ‘Incipient Anode’ Effect: can be expected in <5 years in marine conditions
Impressed Current Systems

Anode types can be:

- Conductive coatings (not suitable for marine conditions)
- Conductive Cementitious Coatings
- Ti Mesh / Sprayed Concrete Overlay
- Discrete Anodes
- Ribbon Anodes
Impressed Current Systems

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CP OF STEEL IN CONCRETE
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CASE STUDY: PROTECTION OF REINFORCED CONCRETE & STEEL

Existing 1960s jetty

- Combination of existing reinforced concrete pile and pre-stressed concrete piles
- Existing steel piles
- New steel piles
- 30-year life extension required
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JETTY CASE STUDY

ZONE 1

ZONE 2

ZONE 3

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Power supply & Monitoring equipment

JETTY CASE STUDY

All PCs running Internet Browser

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JETTY CASE STUDY

South Hook LNG Terminal CP SYSTEM

Performance Verification WINDOW

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CONCLUSIONS

• CP is a useful tool in providing corrosion prevention in marine environments

• There is an extensive track record of using CP to prevent corrosion by ALWC, primarily using galvanic anodes

• Impressed current is used for new build steel piling or for ports in brackish waters

• CP is widely used to prevent reinforcement corrosion, often using impressed current systems, but galvanic system are increasingly being used