Corrosion Awareness Day 2023

Corrosion Mitigation by Cathodic Protection

Nigel Owen – Aberdeen Foundries

Corrosion Awareness

Corrosion Awareness

Scope

Corrosion Mitigation by Cathodic Protection

- Galvanic System- how anodes work
- Alloys for Sacrificial Anodes
- Design of a CP system to protect a structure
- Applications of Anodes
- The selection of the CP system: pros and cons of sacrificial and Impressed current
- Impressed current applications

Corrosion Awareness

To **Mitigate Corrosion by Cathodic Protection** we:

- Impose a current on the item of interest which will halt or reduce the corrosion level to one which is insignificant

- How?

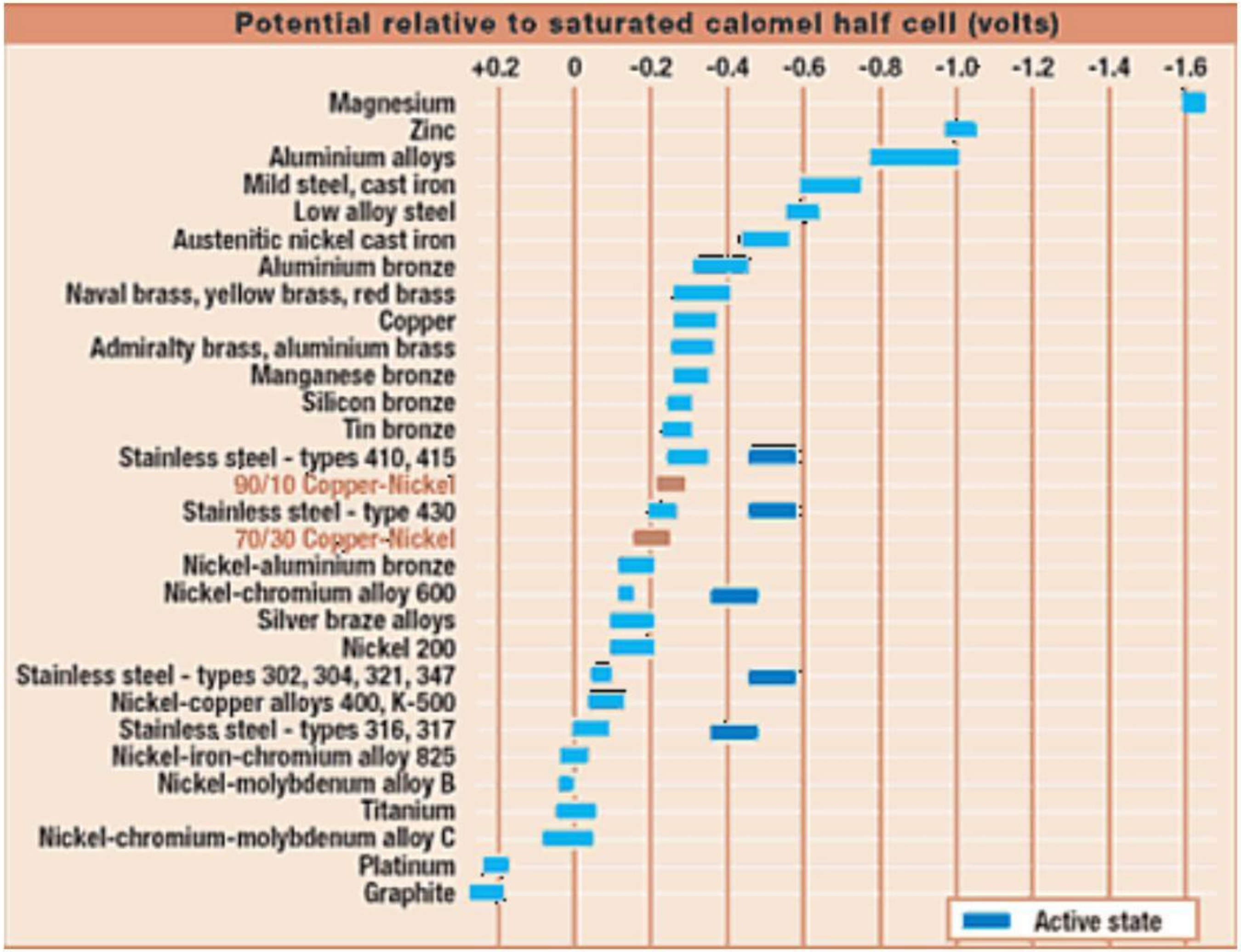
Either by:

- Utilising the galvanic properties of 2 dis-similar metals when joined together in a conductive medium (Anode/Cathode)

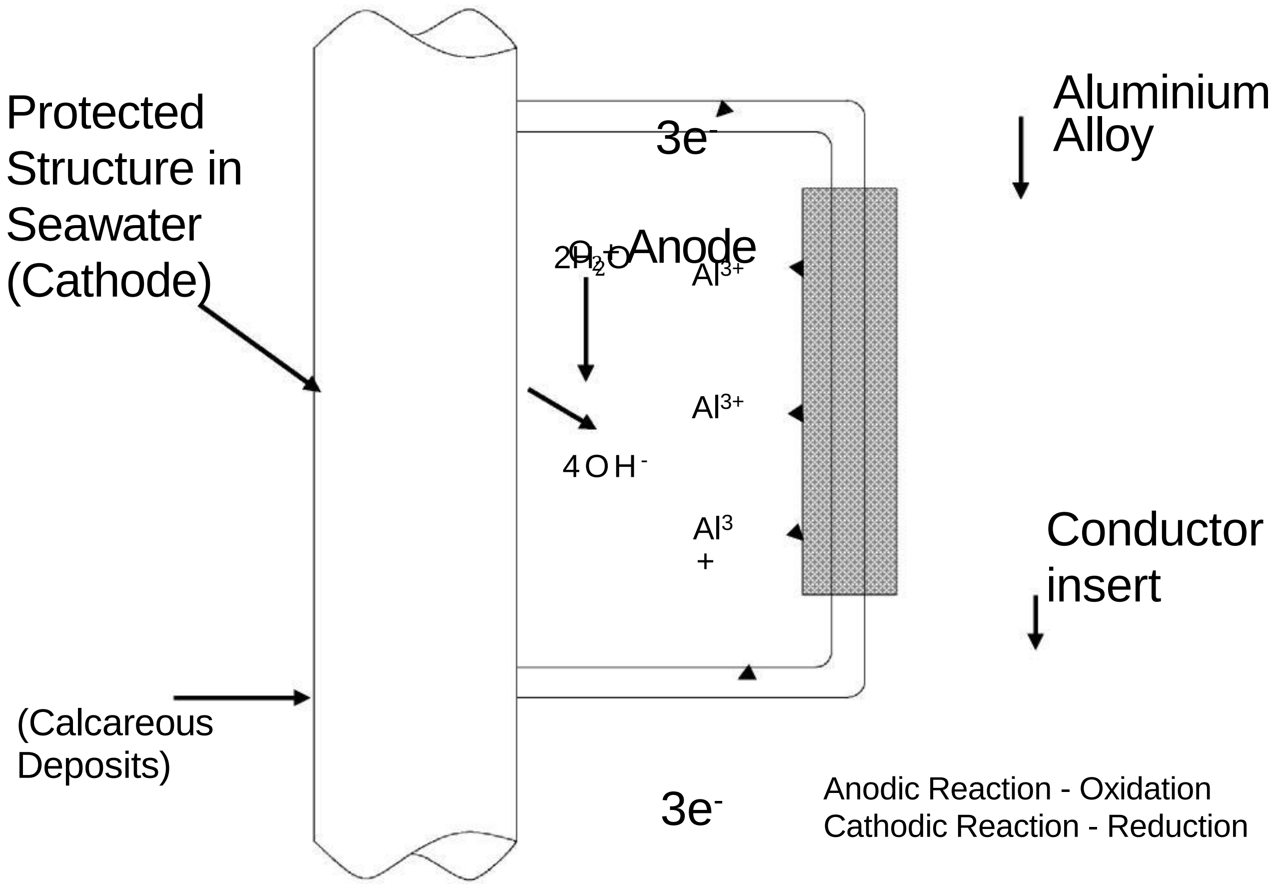
or

- Imposing a current using an electrical system (Impressed Current) to achieve similar

The Galvanic Table



Sacrificial Anode System



Anodic Reaction - Oxidation
Cathodic Reaction - Reduction

Primary Requirements for Sacrificial Anode - Reasons for selection

What makes the best anode material?

- Potential sufficiently electronegative – Galvanic Table vs your coupled material (driving potential)
- Base material can be alloyed with other elements to make it more electronegative and efficient
- Reactivity in Media - Conductivity (salinity)
- Broad Active Temperature Range
- High current output per Kg consumed
- Low Metal Cost (Amps per Kg)

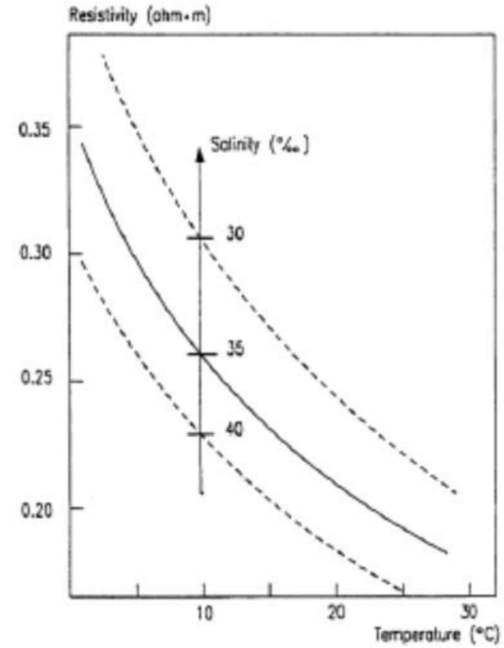


Figure 10-1
Seawater resistivity as a function of temperature for salinity 30 to 40 ‰.

* Chart From: DNV RPB401 Cathodic Protection Design 2010

Sacrificial Anode Material Types

- Magnesium
  - High Potential, -1.5 to -1.7V, (1200Amp.Hr/kg), Fresh water/Soil (5-100 ohm. m) , High cost/Kg., Low life.
  - Short term deployment in seawater
- Zinc
  - -1.05V, Low capacity/ Kg (800), Limited Temp (50 ° C), Seawater to 30 ohm. M, Sea bed, Brackish water
  - Boats and vessels.
- Aluminium
  - -1.10V, High Capacity/Kg (2500), High Temp (80-100 ° C), Seawater/Sea bed/ Mud to ~10 ohm. M
  - Large long life installations

Design of Sacrificial Anode cathodic protection system

System Parameters

- Design Life : Years or months
- Exposed surface Areas of the materials (cathode)
    - Bare, Painted, Plated & immersed in mud
    - Type of materials. (Carbon Steel, Stainless, Duplex, Aluminium etc)
    - All materials Conductive and have Continuity to the main unit

- Design Current Densities
    - Initial mean and final (for bare surfaces) affected by Geographic region and depth
    - Coating Breakdown factors (discounts applied for coating integrity)

    - Resistivity of Medium in which they are immersed: Seawater, Estuarine/River waters soils & muds/ sediment

C.P. Design: Capacity and Protection

Design Solution

- Select sacrificial anode material (Al, Zn or Mg base)

Material has properties of Amp Hr/ Kg and Potential

- Multiply areas of materials and Current density required with coating factors –
  - Calculate mean current Demand
    - Calculate the Mean mass requirement for system design life

7.7 Anode Mass Calculations

7.7.1 The total net anode mass, M_a (kg), required to maintain cathodic protection throughout the design life, t_f (yrs), is to be calculated from I_{cm} (A) for each unit of the protection object (including any current drain):

$$M_a = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \qquad (2)$$

In (2), 8760 refers to hours per year. u and ε (Ah /kg) are to be selected based on (6.8) and (6.5), respectively.

*Text From: DNV RPB401 Cathodic Protection Design 2017

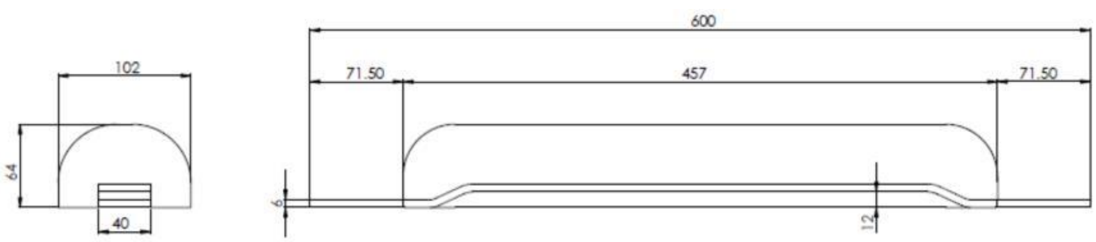
Sacrificial Anodes: Design

Anode Type Solution

- Decide Type of anodes that can be fitted or will be most practical to fit (Flush fit, Standoff Type , Long or Short, Bracelet?)
- Estimate number, distribution of anodes (spacing/coverage) and anode mount type (position/utilisation factor) Consider fit: 1 large vs several smaller

Proceed with Design:

- Calculate anode resistance from shape & mount type
- Check the initial and final current output of the anode types meets the given required current for polarisation and final life



NOTES:-
1. GROSS WEIGHT - 6.2 KG
2. NET WEIGHT - 5.4 KG
2. INSERT - BS EN 10025 S275, SHOTBLASTED TO S.A 2.5.
3. EPOXY PAINT ON FLUSH ANODE BACK TO 200µm D.F.T

$$C_{a\,tot} = N \cdot C_a \geq I_{cm} \cdot t_f \cdot 8760$$
$$I_{a\,tot\,i} = N \cdot I_{ai} \geq I_{ci}$$
$$I_{a\,tot\,f} = N \cdot I_{af} \geq I_{cf}$$

Anode Design:
Anode Resistance for Shape/Mount Type & Utilisation Factor

Recommended Practice DNV-RP-B401, October 2010
Page 24

Table 10-7 Recommended Anode Resistance Formulae for CP Design Calculations.

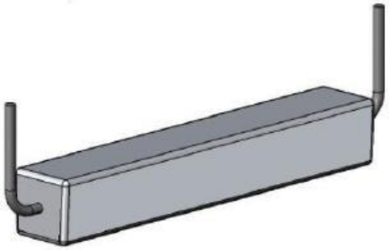
Anode Type	*Resistance Formula*
Long slender stand-off 1) 2) $L \geq 4r$	$R_a = \frac{\rho}{2 \cdot \pi \cdot L}\left(\ln\frac{4 \cdot L}{r} - 1\right)$
Short slender stand-off 1) 2) $L < 4r$	$R_a = \frac{\rho}{2 \cdot \pi \cdot L}\left[\ln\left\{\frac{2L}{r}\left(1+\sqrt{1+\left(\frac{r}{2L}\right)^2}\right)\right\}+\frac{r}{2L}-\sqrt{1+\left(\frac{r}{2L}\right)^2}\right]$
Long flush mounted 2) $L \geq 4 \cdot$ width and $L \geq 4 \cdot$ thickness	$R_a = \frac{\rho}{2 \cdot S}$
Short flush-mounted, bracelet and other types	$R_a = \frac{0.315 \cdot \rho}{\sqrt{A}}$

1) The equation is valid for anodes with minimum distance 0.30 m from protection object. For anode-to-object distance less than 0.30 m but minimum 0.15 m the same equation may be applied with a correction factor of 1.3

2) For non-cylindrical anodes: $r = c/ 2\pi$ where c (m) is the anode cross sectional periphery

Table 10-8 Recommended Anode Utilisation Factors for CP Design Calculations.

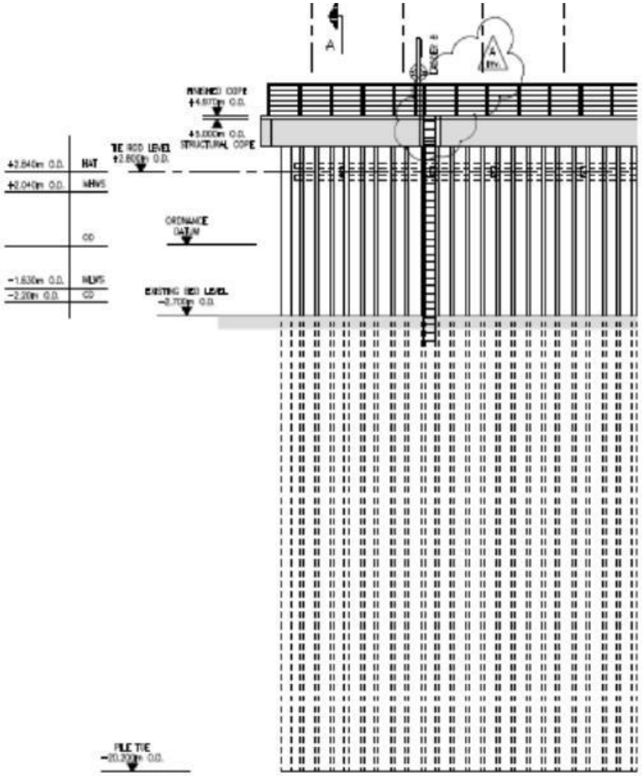
Anode Type	*Anode Utilisation Factor*
Long slender stand-off $L \geq 4r$	0.90
Short slender stand-off $L < 4r$	0.85
Long flush mounted $L \geq 4$ width and $L \geq 4$ thickness	0.85
Short flush-mounted, bracelet and other types	0.80



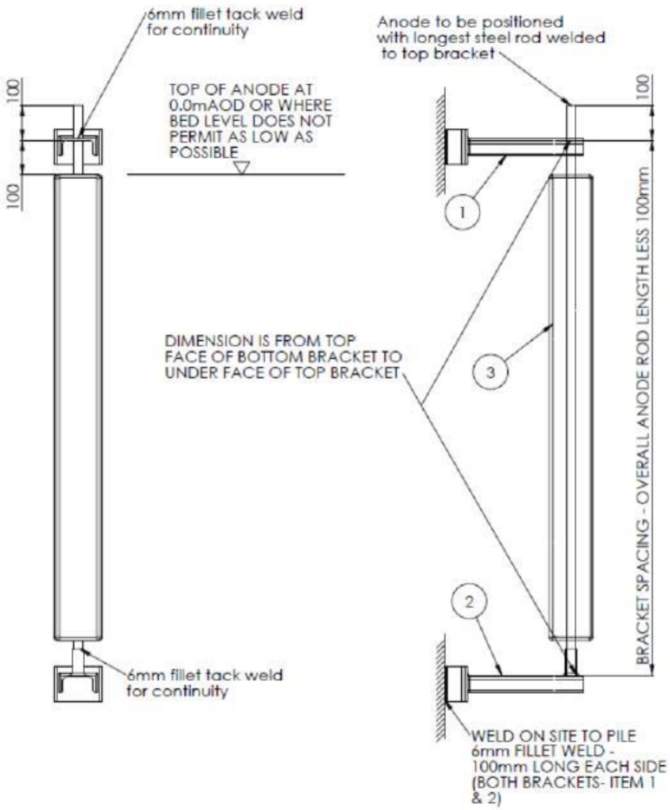
*Text From: DNV RPB401 Cathodic Protection Design 2017

Example of a project to Design install a Sacrificial CP system

- Harbour wall CP protection system



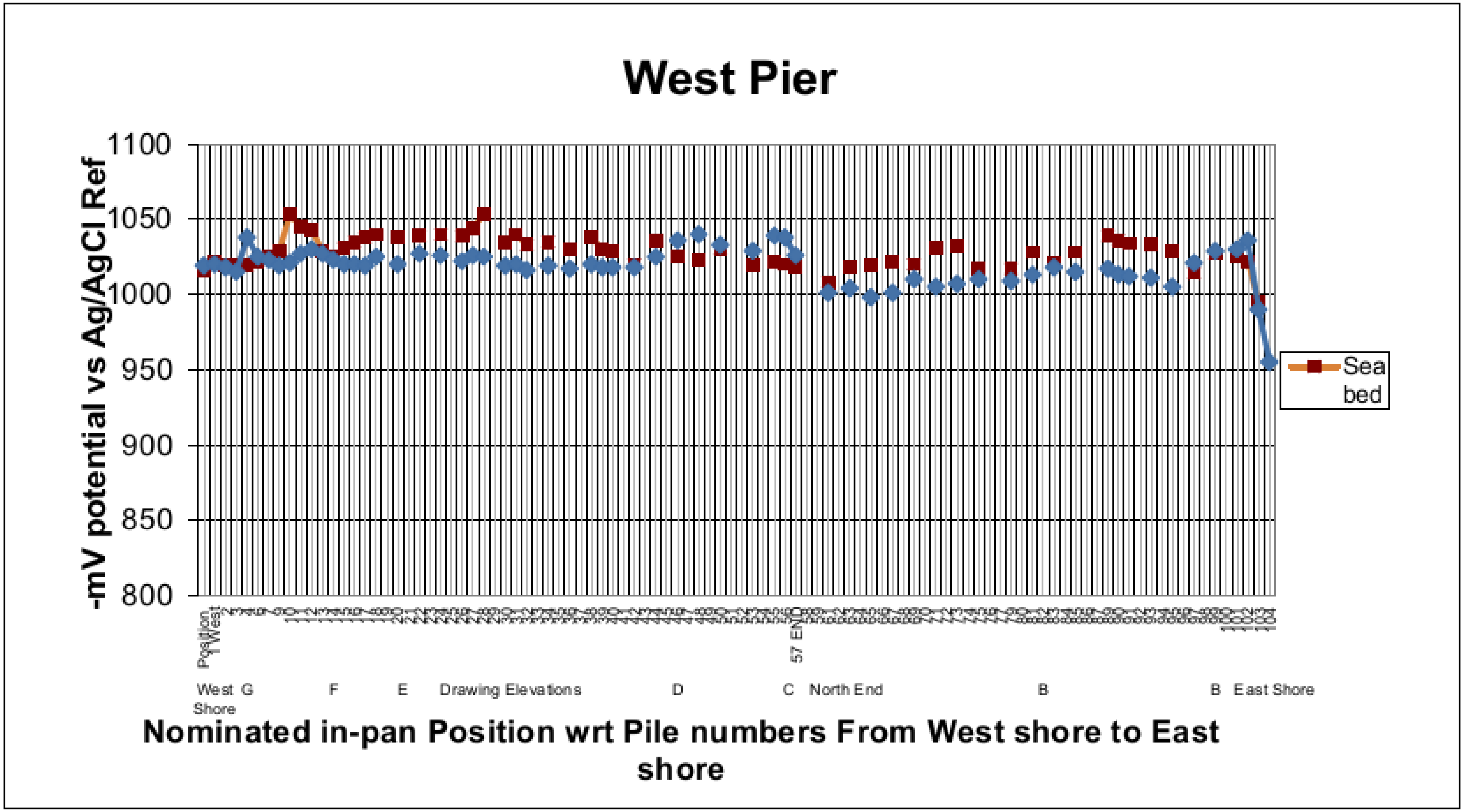
Design & Install Anodes



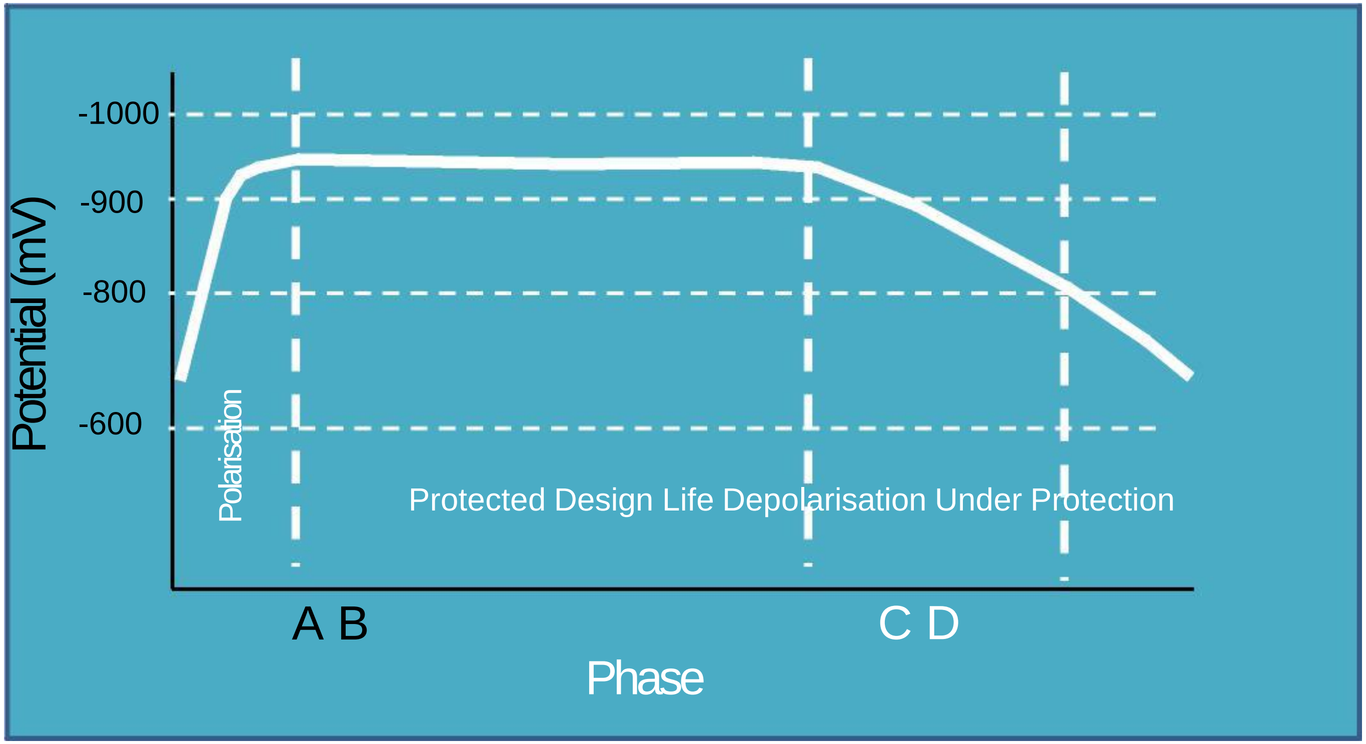
Long standoff anodes for Harbour wall installation

Install Anodes

CP Site Survey

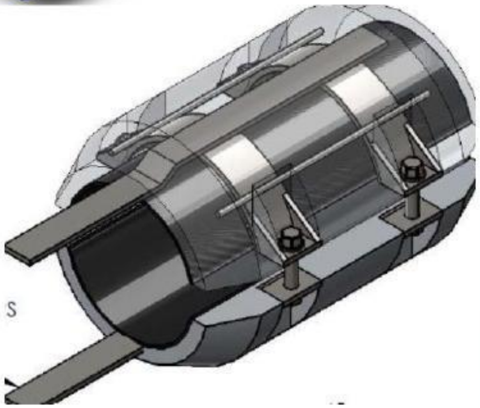


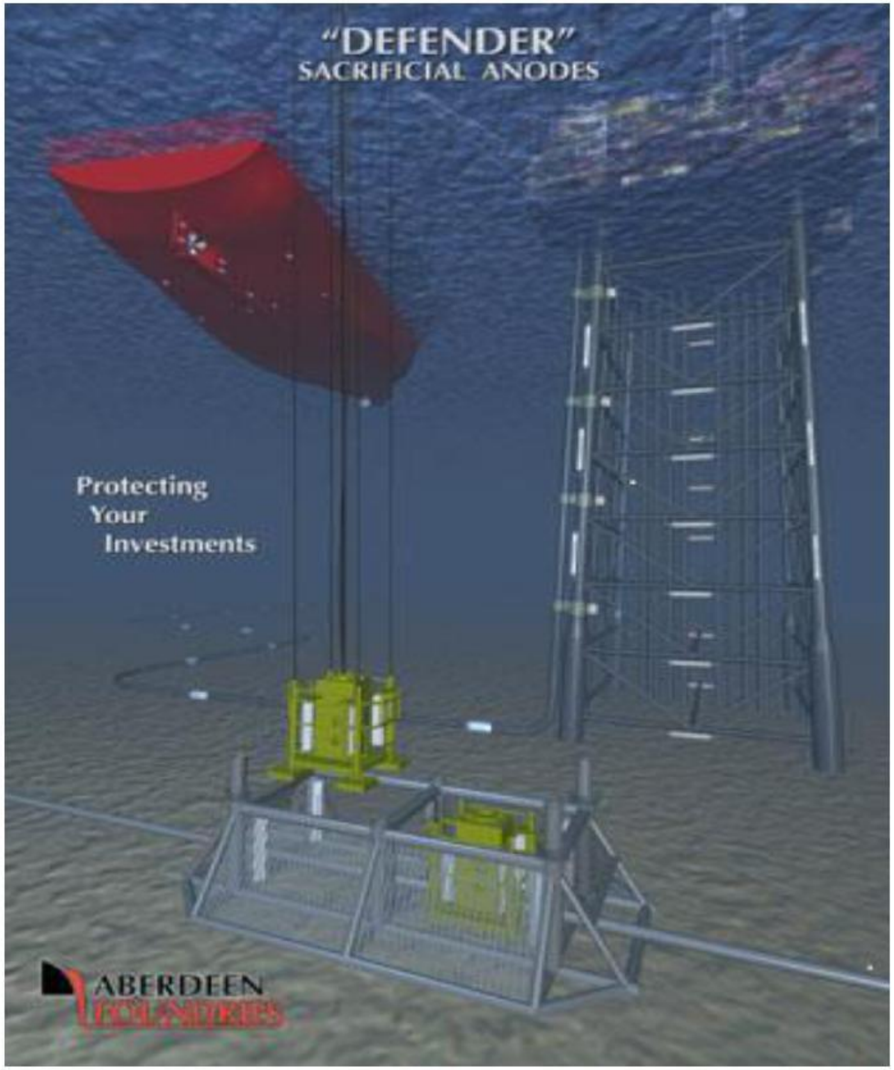
Anode system performance

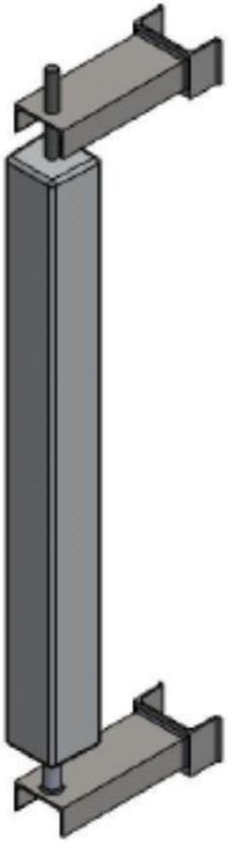


The aim of the CP design is to polarise the structure (period A) as quickly as possible and maintain the protection (period B) for the design life.
When depolarisation (period C) starts the CP system has reached its design life and leads to under protection (period D).

Sacrificial Anode Applications







Design Parameters may limit the use of Sacrificial Anodes or make them impractical.

- Conductivity / Resistivity of the environment
- Size of the areas to be protected by the system
- Location and water depth
- Availability of Power sources or personnel (operation & monitoring)
- Ability to install
- Design Life of the system short term submersion or 60-year lifespan

- Impressed Current Cathodic protection can be utilised to cover most other fields of protection where there are higher current requirements, but may cause interference issues to nearby foreign services.

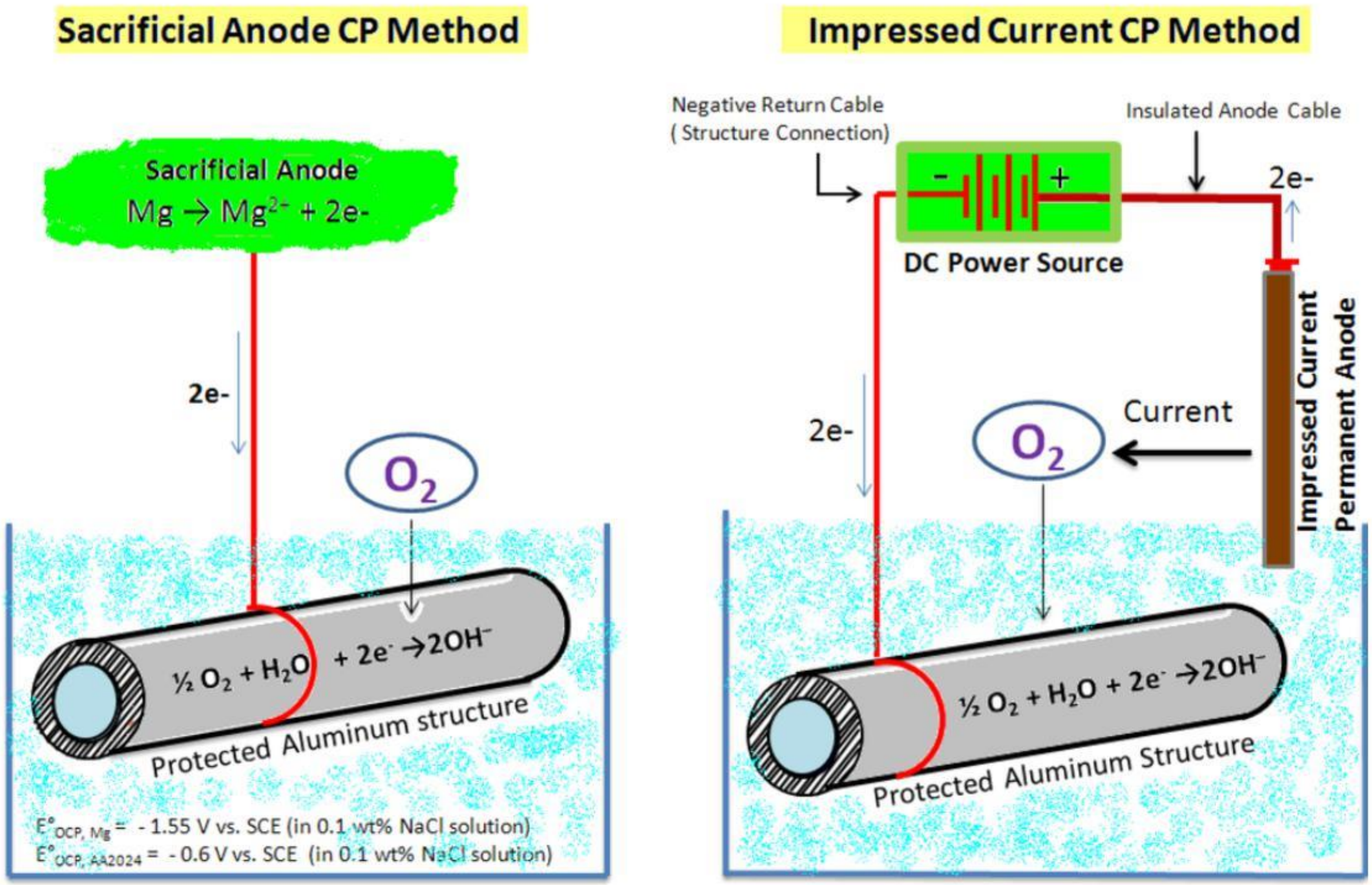
Sacrificial Protection vs Impressed Current

Sacrificial Anode Impressed Current

- Simple
- Short term (Days to 30 years)
- Low/no maintenance
- Welded, secure installation
- Conductive environments (seawater)
- Restricted by anode material
- No adverse effects on structures, coatings etc
- Doesn't overprotect

- Anodes are not consumed (inert)
- Use for long term systems (20-50 yrs)
- Requires regular maintenance
- Remote anodes & wiring
- Complex - has to be accurately set up
- Works in Low conductivity water areas (& onshore buried pipelines & Concrete)
- Can cause:
  - Coating de-bonding
    - Hydrogen embrittlement of steel piles
  - Cathodic corrosion of Al (hulls etc) – Stray current corrosion

Cathodic Protection (CP) Methods



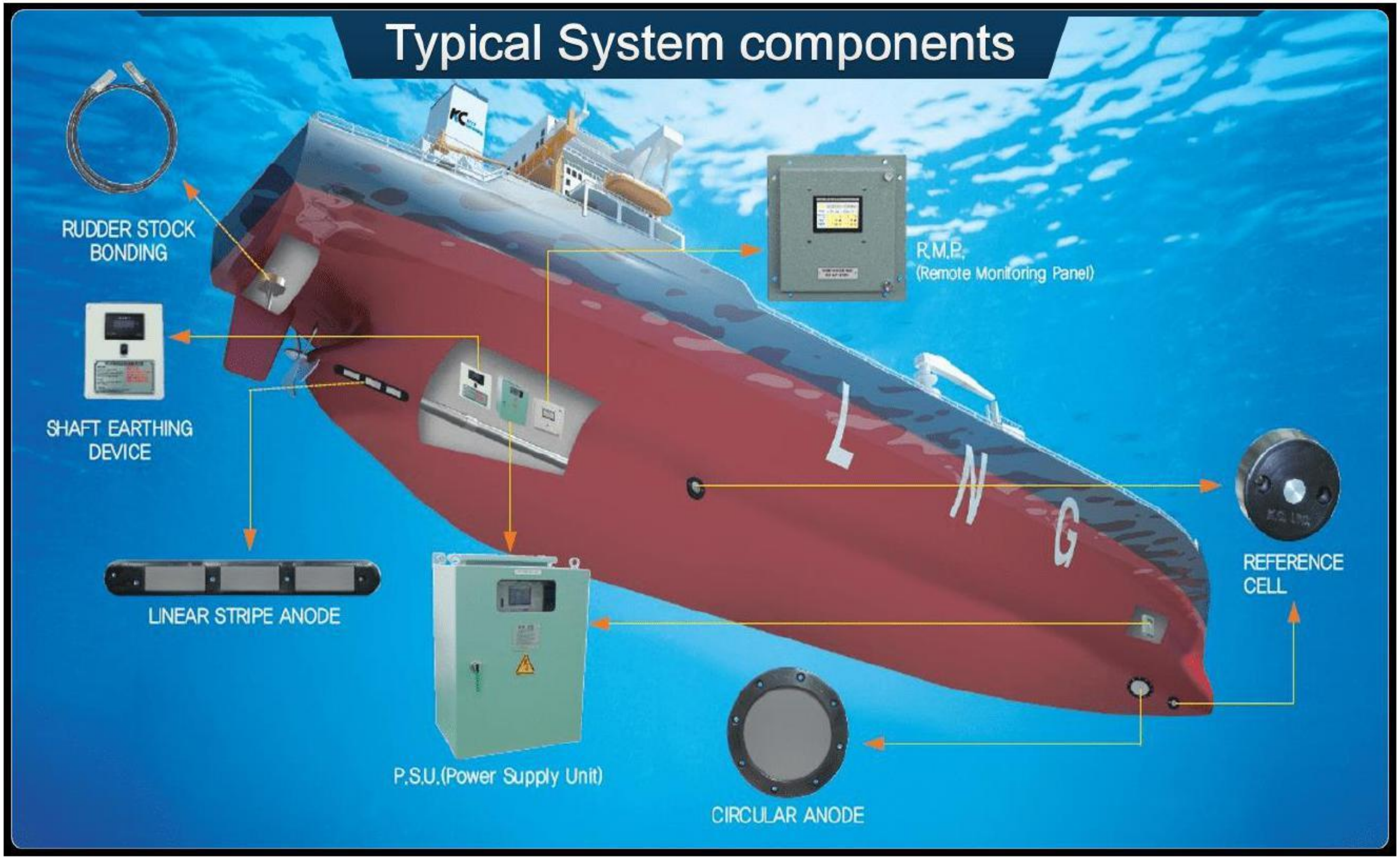
Cathodic Protection (CP) Methods

Cathodic Protection Overview/Impressed Current Systems

Common applications of IP systems

- Large ships, crude oil tankers
- Long-distance pipelines
- Highways/bridge foundations
- Loading jetties
- Bases of storage tanks
- Protection of reinforced concrete

Corrosion Awareness



Cathodic Protection Overview/Impressed Current Systems

Whitecart Viaduct Glasgow Airport and Tay Road Bridge Dundee both have CP – foundations and RC Concrete Supports, as do M9 Bridges

Protection of reinforced concrete

The End!

- More Anodes Please!

Thank you for your attention.

Any Questions?

Thank you for your attention...

Q & A