INSTITUTE OF CORROSION

I·M3
Institute of Materials, Minerals & Mining

ICorr Aberdeen Branch Welcomes:

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.

Topic:

Sacrificial Anodes: Material Specifications, Manufacturing and Anode Design for Effective Cathodic Protection systems

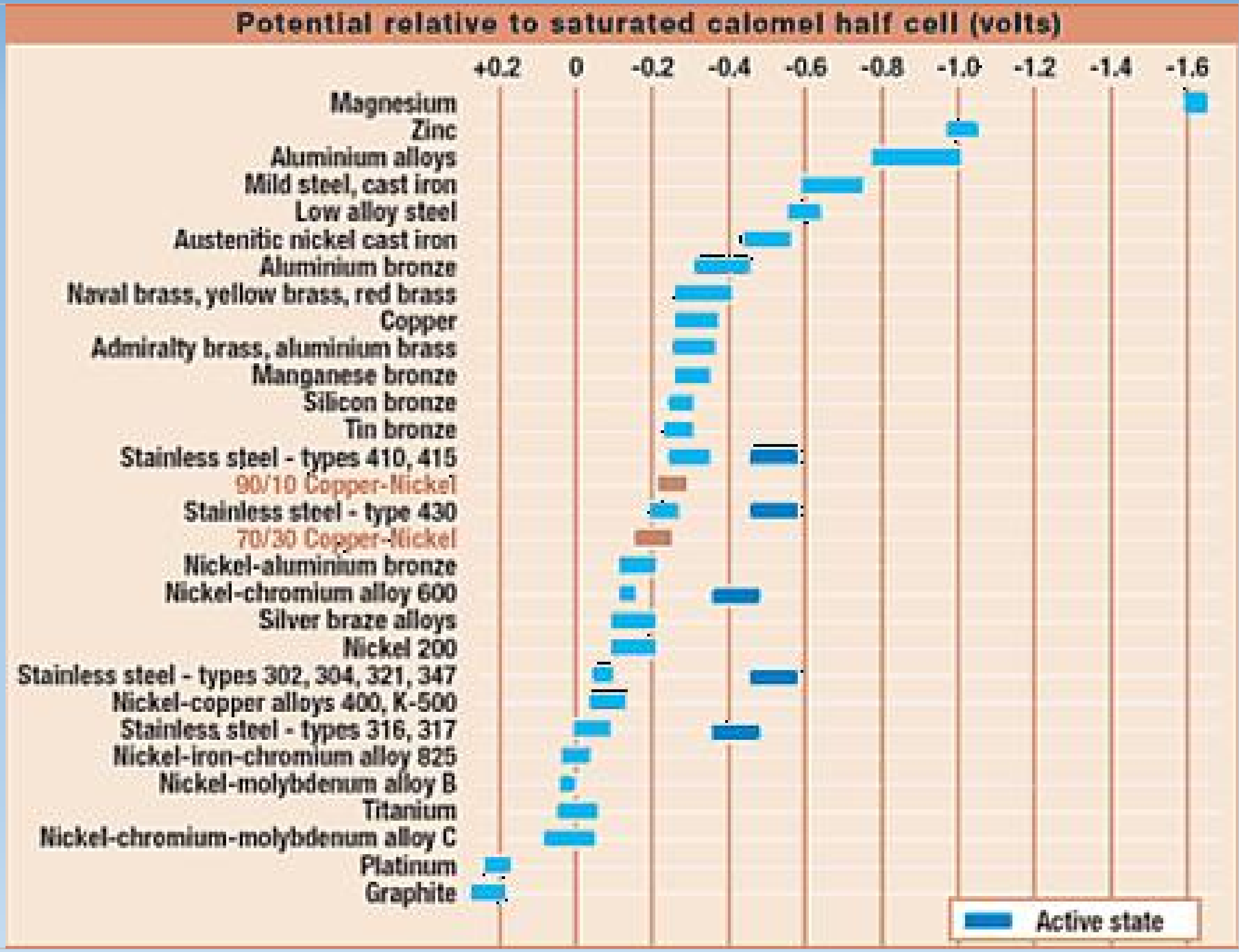
Sacrificial Anodes:
Alloys, manufacturing and design of Cathodic Protection installation

Scope

- Galvanic Table
- Alloys for Sacrificial Anodes
- Design, Manufacture and & Testing of Sacrificial Anodes
- Design of a CP system to protect a structure
- Installation of Sacrificial Anode

Corrosion

Sacrificial Anodes: The Galvanic Table



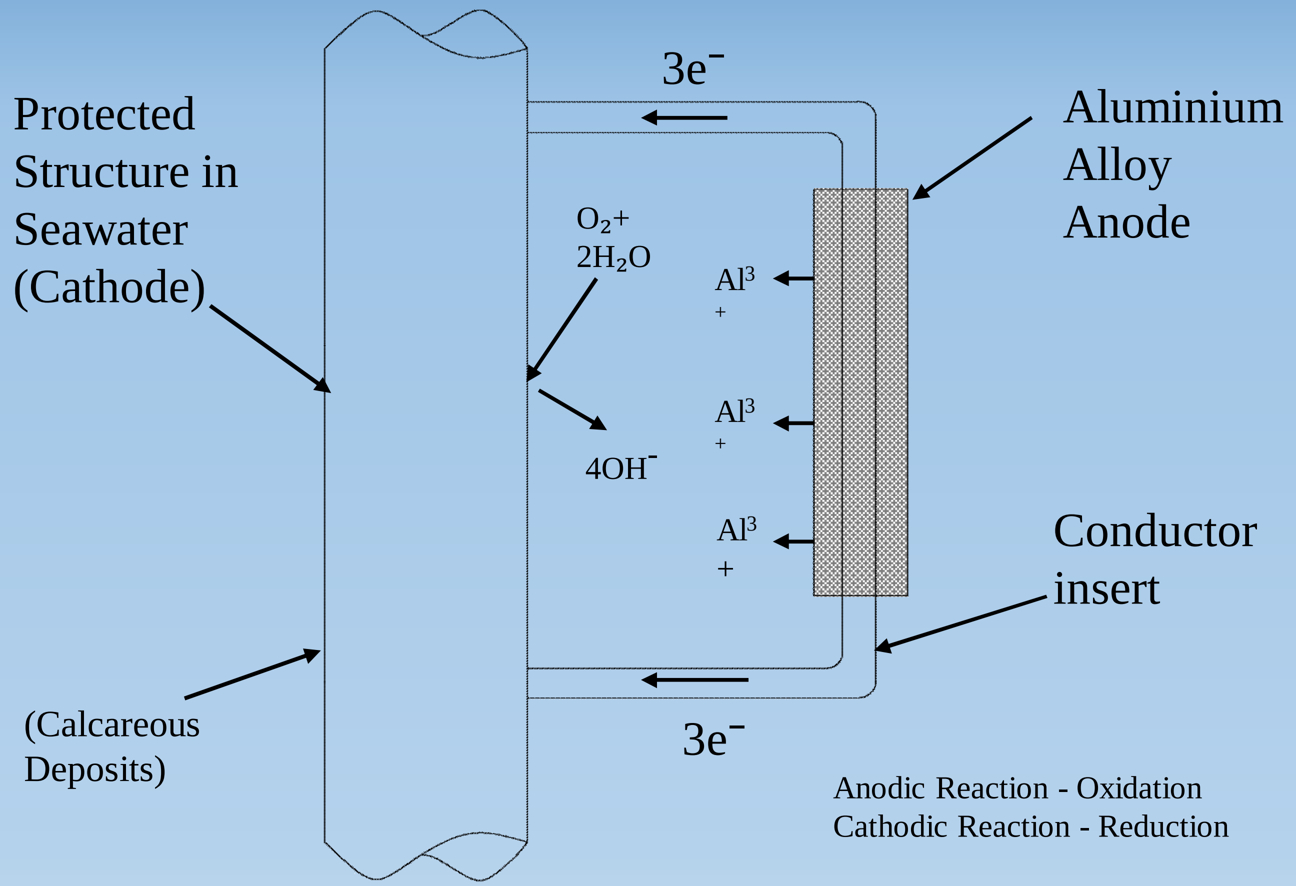
Sacrificial Anodes: A means of Cathodic Protection

To Mitigate Corrosion by Cathodic Protection

ÅMeans by imposing a current on the item of interest which will halt or reduce the corrosion level to one which is insignificant
ÅHow?

ÅEither by:
Åutilising the galvanic properties of 2 dissimilar metals when joined together in a conductive medium (electrolyte) to create Anode/Cathode
or
ÅImposing a current using an electrical system (Impressed Current) to achieve similar

Sacrificial Anode: Cathodic Protection



Sacrificial Anodes

Primary Requirements for Sacrificial Anode - Reasons for selection.
What makes the best anode material?

Å Potential sufficiently electronegative ï Galvanic Table vs your coupled material (driving potential)

Å Base material can be alloyed with other elements to make it more electronegative

Å Reactivity in Media - Conductivity (salinity)

Å Broad Active Temperature Range

Å High current output per Kg consumed

Å Low Metal Cost (Amps per Kg)

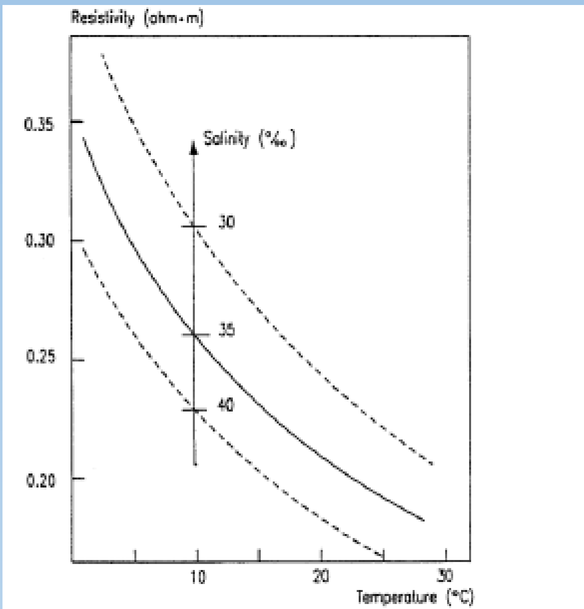


Figure 10-1
Seawater resistivity as a function of temperature for salinity 30 to 40 ‰.

* Chart From: DNV RPB401 Cathodic Protection Design 2010

Aluminium Anodes – Elements which raise potential

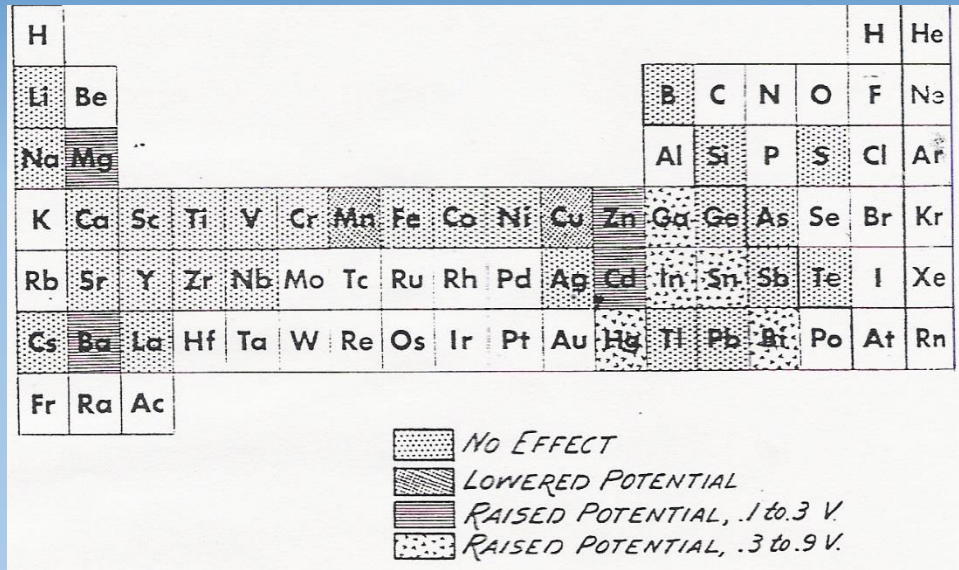


Figure 1—Elements screened in tests to determine the effects of various additions to aluminum anodes.

(0.1 to 0.3 V)

(large addition rates)

- Cadmium
- Zinc
- Mg
- Barium

(0.3 – 0.9V)

(max effect at low concentrations)

- Mercury
- Tin
- Indium
- Gallium
- Bismuth

Sacrificial Anodes: Historical Aluminium Anode Types

Nominal Alloy Composition Ranges for Anodes Tested (%)

	Al-Zn-Sn	Al-Zn-Hg	Al-Zn-In-Mg	Zinc (MIL-A-18001)
Zn	6.0 to 8.0	1.25 to 2.00	1.0 to 3.0	Remainder
Sn	0.10 to 0.20	—	—	—
Si	—	—	—	0.125 max.
Hg	—	0.030 to 0.08	—	—
Pb	—	—	—	0.006 max.
Mg	—	—	0.50 to 1.0	—
In	—	—	0.20	—
Fe	0.10 max.	0.10 max.	0.10 max.	0.005 max.
Cd	—	—	—	0.025 to 0.15
Cu	0.003 max.	0.003 max.	0.010 max.	0.005 max.
Al	Remainder	Remainder	Remainder	0.10 to 0.50

Table 2
Range of Evaluation Results

Alloy	Operating Potential (SCE[A]-mV)	Hydrogen Evolution (% Efficiency)	Impressed Current Capacity A-h/kg	A-h/lb
Al-Zn-Sn	940 to 1,176	70 to 94	1,014 to 2,711	460 to 1,230
Al-Zn-Hg	830 to 1,114	96	2,623 to 2,949	1,190 to 1,338
Al-Zn-In-Mg	1,032 to 1,140	90	2,354 to 2,742	1,068 to 1,244
Zinc	969 to 1,051	98	754 to 804	342 to 365

[A] Saturated calomel electrode.

* Chart From: NACE TM0190-2012 Impressed Current Lab. Testing of Al &Zn Anodes

Alloys for Sacrificial Anodes

Magnesium Mg-Al-Zn- anode material composition

Fe	Si	Cu	Zn	Ni	Mn	Al	Mg
0.02 max.	0.3 max	0.05 max.	2 ï 4	0.003 max	0.2 min	5 -7	remainder

Potential **–1.5** Volts Ag/AgCl   Capacity 1230Amp Hrs per Kg min.   Density ~1725 kg/m^3

High Potential,   Low Life/High Consumption 7.3kg/A-Yr,   Soil/ Fresh Water

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Zinc Zn-Al-Cd Anode   Alloy: US Military Spec. 18001

Fe	Al	Cu	Cd	Pb	Others	Zn
.005 max	0.1-0.5	.005 max	0.025-0.070	0.006 max.	0.1 max	remainder

Potential ï 1.05 Volts Ag/AgCl   Capacity 780 Amp Hrs per Kg min.   Density 6900 Kg/m^3

Low Capacity,   High Consumption 11.5 kg/A-Yr,   Temp<50°C   Seawater/Seabed/ Brackish water

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Aluminium Al-Zn-In-Si anode alloy (Galvalum III)

Fe	Si	Cu	Zn	In	Others	Al
0.12 max.	0.08-0.21	0.006 max.	2.8 ï 6.5	0.01 ï 0.02	0.02 max	remainder

Potential ï 1.10* Volts Ag/AgCl   **Capacity (Amp Hrs) 2500** per Kg min   Density 2750Kg/m^3

Good Potential, Long Life/Low Consumption 4.2 kg/A-Yr, **High Temp 80-100°C**, Seawater /Seabed Mud

Alloys for Sacrificial Anodes

Å Magnesium

ï High Potential, -1.5 to -1.7V, (1200Amp.Hr/kg), Fresh water/Soil (5-100 ohm. m) , High cost/Kg., Low life.

ï Short term deployment in seawater

Å Zinc

ï -1.05V, Low capacity/ Kg (800), Limited Temp (50 ° C), Seawater to 30 ohm. M, Sea bed, Brackish water

ï Boats and vessels.

Å Aluminium

ï -1.10V, High Capacity/Kg (2500), High Temp (80-100 ° C), Seawater/Sea bed/ Mud to ~10 ohm. M

ï Large long life installations

Modern Aluminium Based Sacrificial Anodes

Elements	Alloy A1	Alloy A2	Alloy A3	Alloy A4
Zn	2.0 - 6.0	3.0 - 5.5	4.75 - 5.75	0.15
In	0.010 - 0.030	0.016 - 0.040	0.016 - 0.020	0.005 max
Ga				0.092 - 0.110
Fe	0.12 max	0.09 max	0.06 max	0.08 max
Si	0.12 max	0.10 max	0.08 -0.12	0.10 max
Cu	0.006 max	0.005 max	0.003 max	0.005 max
Cd	0.002 max	0.002 max	0.002 max	
Other Impurities (each)	0.02 max	0.02 max	0.02 max	0.02 max
Other Impurities (Total)	0.1 max	0.1 max	0.05 max	0.05 max
Al	Balance	Balance	Balance	Balance

Notes:	A1	A2	A3	A4
	Marine	Offshore	Deep/Cold Water	Low Driving Voltage

From: BS EN 12496:2013 Galvanic anodes for cathodic protection in Seawater and saline mud

Al Anodes: Materials for manufacture

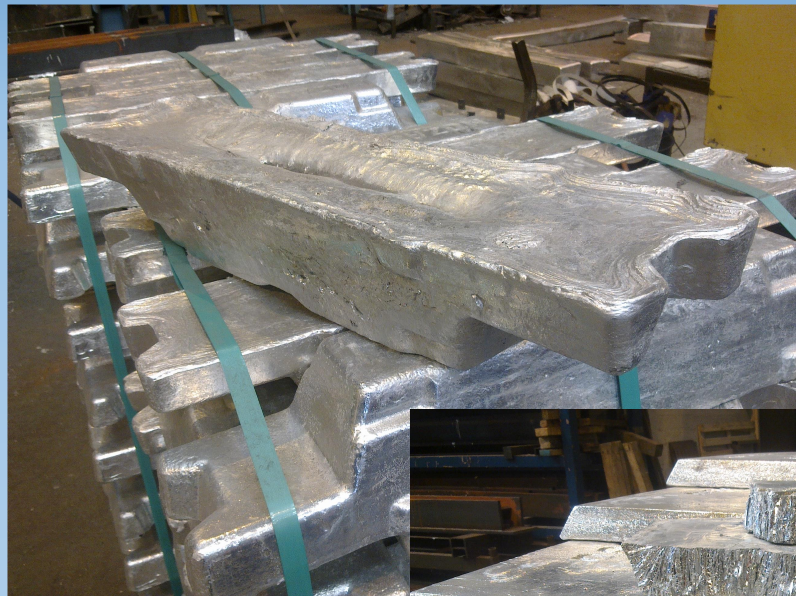
ÅAl-Zn-In Alloying -Base metals

Å Al (99.85%min)
- Å Fe, Si, Cu, Ga,
- Å Ingot Spec: PO610- (0.06%Si, 0.10%Fe)

Å Zn (99.99%)
- Å Fe, Cu,
- Å Ingot SHG (at ~ 5% addition)

Å Indium
- Å 99.99%
- Å (at a 0.010% addition)

Å Si (Al-20% Si)-hardener



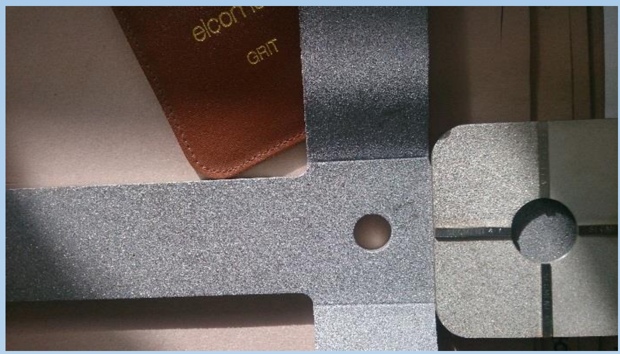
Sacrificial Anodes: Manufacturing

Melting, Pouring & Finishing

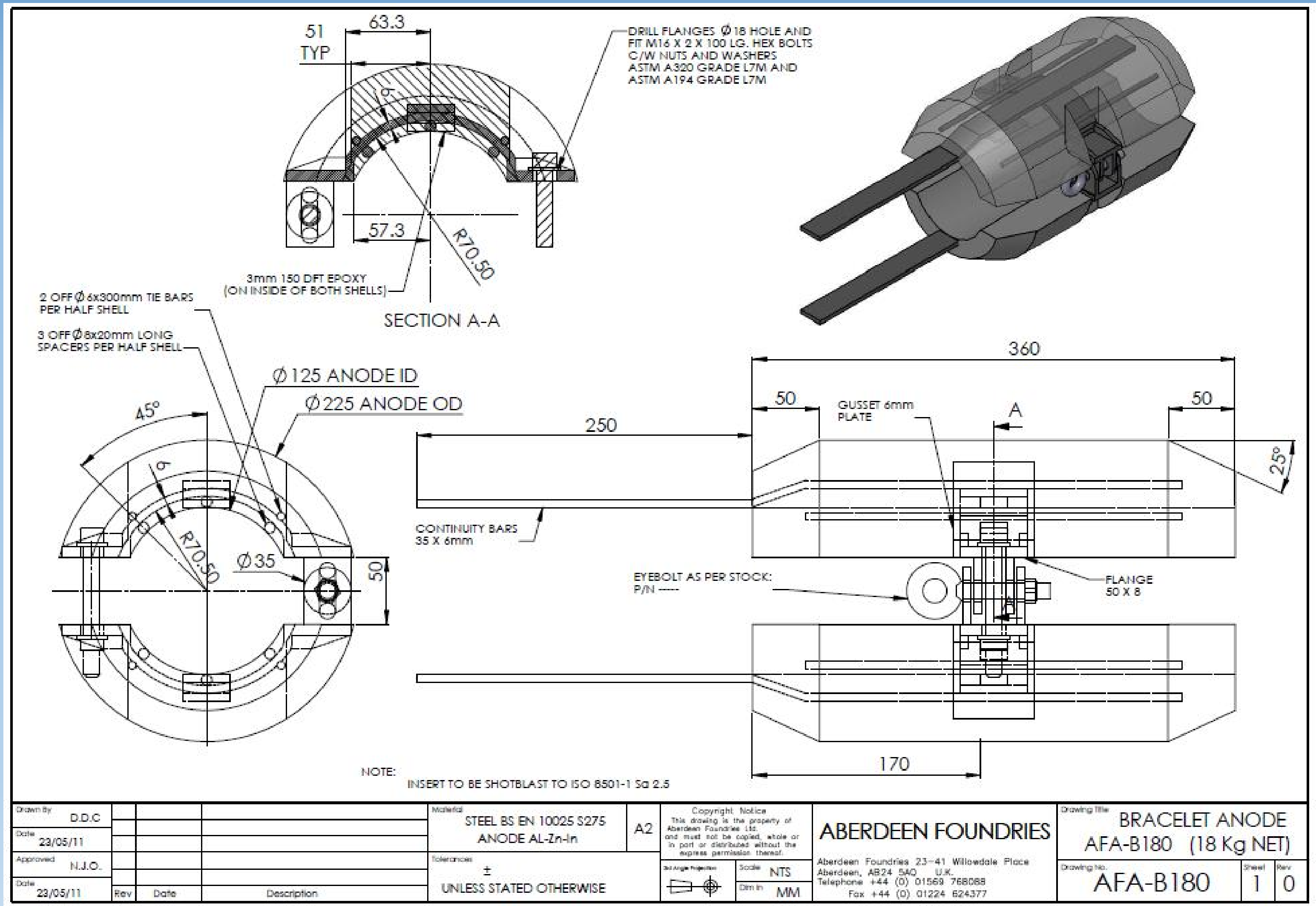
- Melt Base Metal
- Zinc Addition
- Indium Addition
- Silicon
- Heat to Molten, (760-880°C) stir, prepare
- Sample (chilled disc)
- Test - Spectrometry OES
- Pour

Sacrificial Anodes: Manufacturing

- Å Alloy constituents-Heat melt-
- Å Prepare and manufacture steel insert
- Å Select & Assemble mould
- Å Cast into mould and top up
- Å Fettle /tidy
- Å Mark identification on anode



Anode Bracelet - Construction



Anode Manufacture
-Pipeline Bracelet Anode

Sacrificial Anodes : Manufacturing & Testing

Principal Tests

Å Composition

Å Dimensions (body/insert)

Å Cracks / sinks/ finish

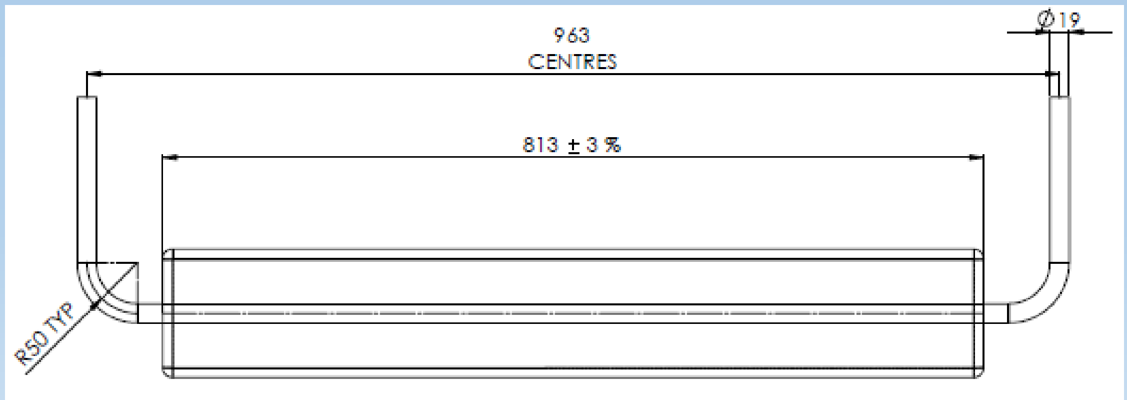
Å Integrity (porosity/Holes)*

Å Insert position

Å Shape (straightness/Fit)

Å Electrical Continuity

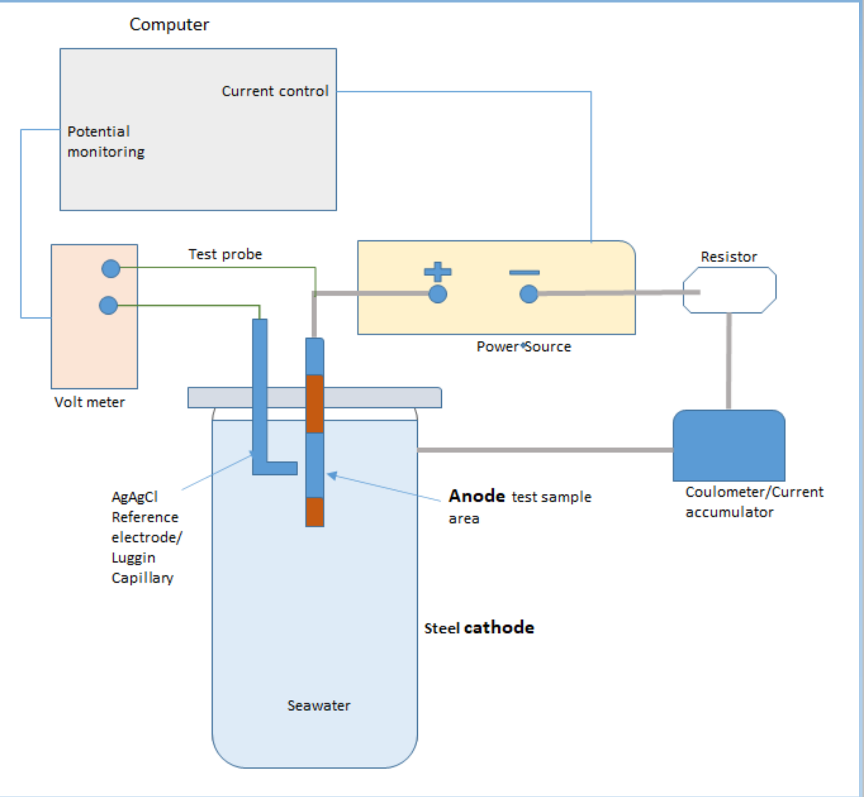
Å Electrochemical test



Sacrificial Anodes: Manufacturing& Testing

Electrochemical Testing
DNV
ï 1 test per 15 Tonnes production
Comparative Test
- Galvostatic Control Current (density), 4 x 1 day
- At set ambient temp (20° C)
- Accelerated at ~ x 20 field current density

Issues
- Sampling, cut/machine/as-cast bars
- Performance is preparation/rig dependant
- Accelerated parameters & High Capacities
- Not to be used as test of field condition performance
- Anode Performance Composition dependant & controlled by analysis of predetermined properties



- Alternative Production test method NACE, 14 Day procedure
- Long Term 1 year Free Running Test (Type Approval)

Design of Sacrificial Anode cathodic protection system

System Parameters

ÅDesign Life : Years or months
ÅExposed surface Areas of the materials (cathode)
    ÅBare, Painted, Plated & immersed in mud
    ÅType of materials. (Carbon Steel, Stainless, Duplex, Aluminium etc)
    ÅAll materials <u>Conductive</u> and have <u>Continuity</u> to the main unit

ÅDesign Current Densities
    ÅInitial mean and final (for bare surfaces)
    affected by Geographic region and depth
    ÅCoating Breakdown factors (discounts applied for coating integrity)

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

C.P. Design: Capacity and Protection

Design Solution

ÅSelect sacrificial anode material (Al, Zn or Mg base)

Material has properties of Amp Hr/ Kg and Potential

ÅMultiply areas of materials and Current density required with coating factors ï

Calculate mean current Demand

Then 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):

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

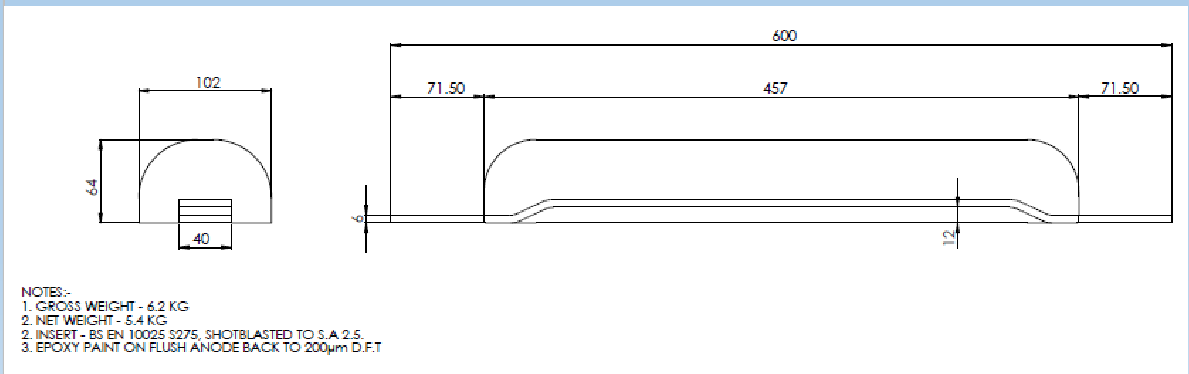
In (2), 8760 refers to hours per year. u and ε (Ah /kg) are to be selected based on (6.8) and (6.5), respectively.

*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 Current output <u>area</u> and 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



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

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

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

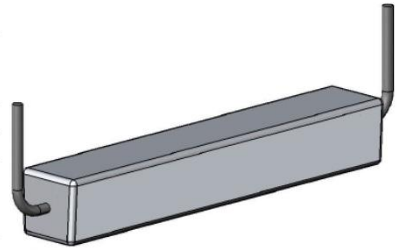
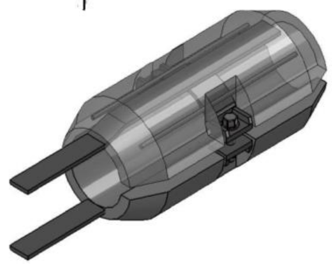


Table 10-8 Recommended Anode Utilisation Factors for CP Design Calculations.

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

Sacrificial Anodes: Design

ANODE MATERIAL: EFFECT OF ANODE TEMPERATURE ON PERFORMANCE

Anode type	Anode surface temperature[a]	Immersed in seawater		Buried in seawater sediments[d]	
		Potential	Electrochemical capacity	Potential	Electrochemical capacity
		Ag/AgCl/ seawater	ε	Ag/AgCl/ seawater	ε
	°C	mV	A·h/kg	mV	A·h/kg
Aluminium	< 30	− 1 050	2 000	− 1 000	1 500
	60	− 1 050	1 500	− 1 000	800
	80[b]	− 1 000	900	− 1 000	400
Zinc	< 30	− 1 030	780	− 980	750
	> 30 to 50[c]			− 980	580

Electrochemical capacity for a given alloy is a function of temperature and anode current density. Reference is made to Annex A for guidance on CP design for variations in anode current densities.

For non-buried pipelines, the anode surface temperature should be taken as the external pipeline temperature and not the internal fluid temperature. For buried pipelines, the anode surface temperature shall be taken as the internal fluid temperature.

[a] For anode surface temperatures between the limits stated, the electrochemical capacity shall be interpolated.

[b] For aluminium anodes, the anode surface temperature shall not exceed 80 °C unless the performance has been demonstrated in tests and has been documented.

[c] For zinc anodes, the anode surface temperature shall not exceed 50 °C unless satisfactory performance has been demonstrated in tests and has been documented.

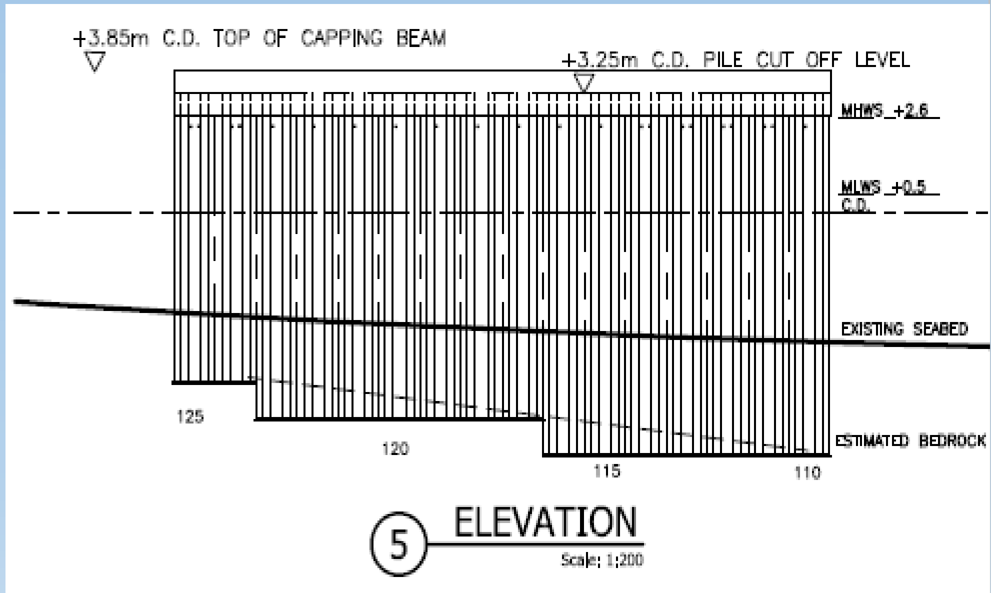
[d] Pipelines which are rock-dumped shall be considered as buried in seawater sediments.

*Text From: BS EN ISO 15589-2: 2012 Petroleum, Petrochemical & Natural Gas Ind. ï C.P. of Pipeline Transportations Systems

Sacrificial Anodes: Installation

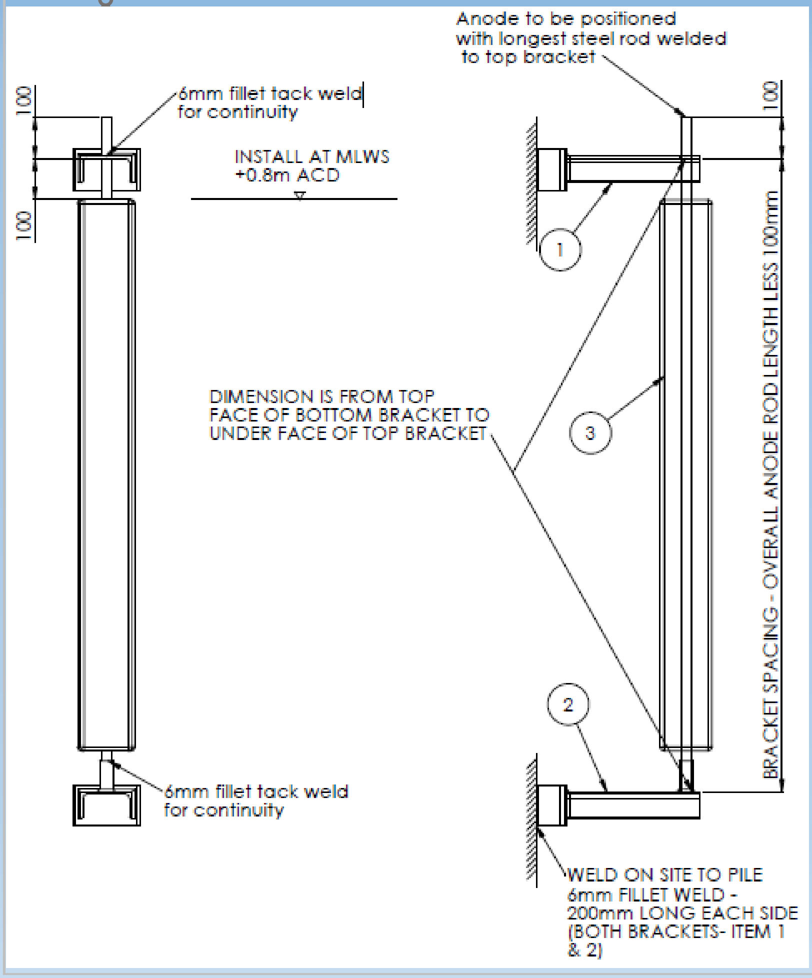
Example of a project to Design install a Sacrificial CP system

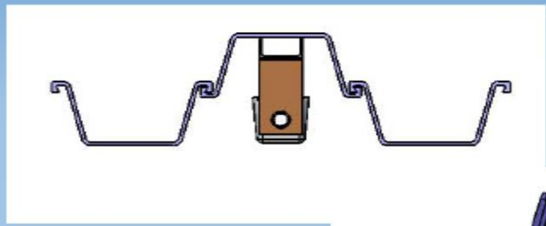
- Harbour wall CP protection system



Long standoff anodes for harbour wall installation

Design & Install Anodes

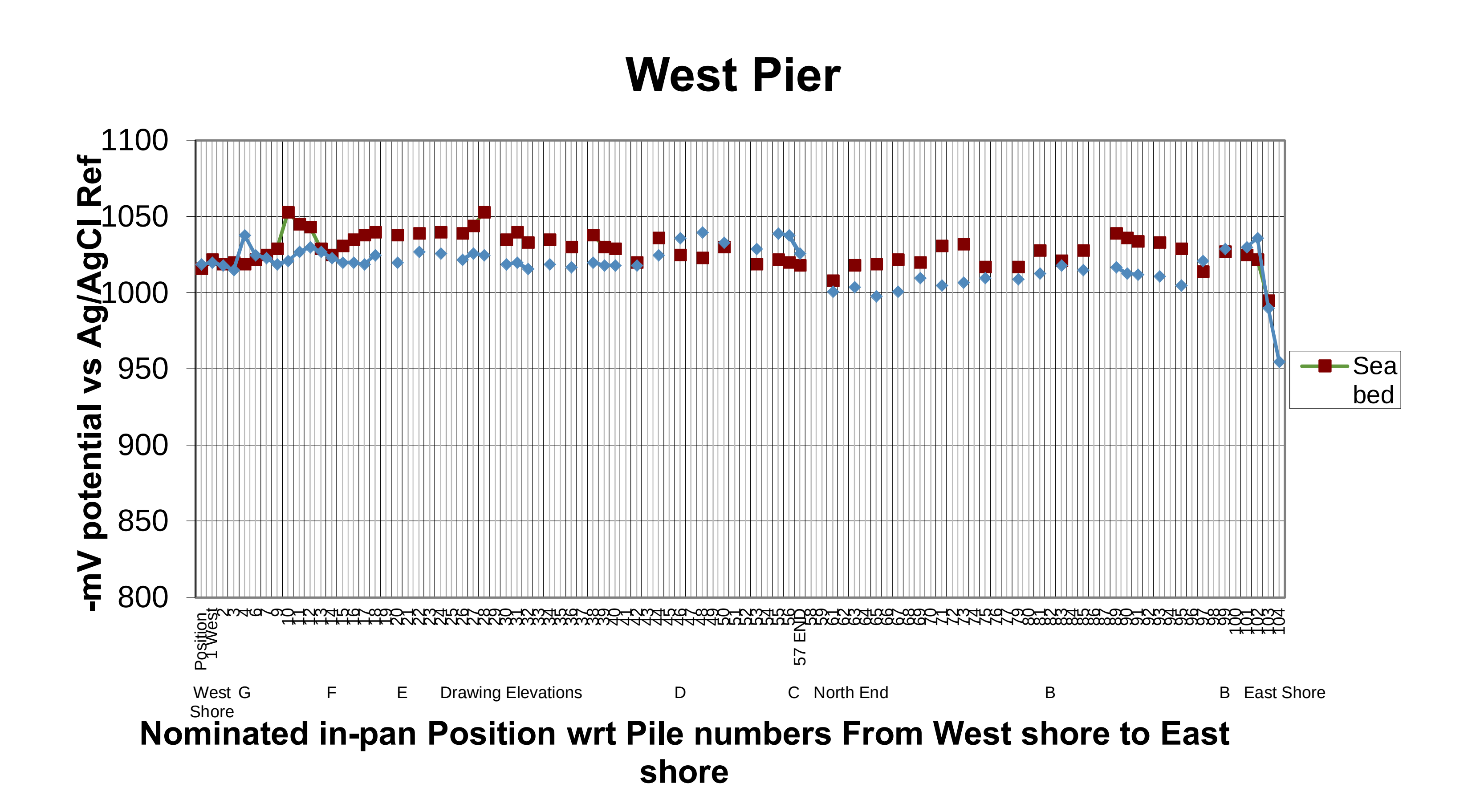




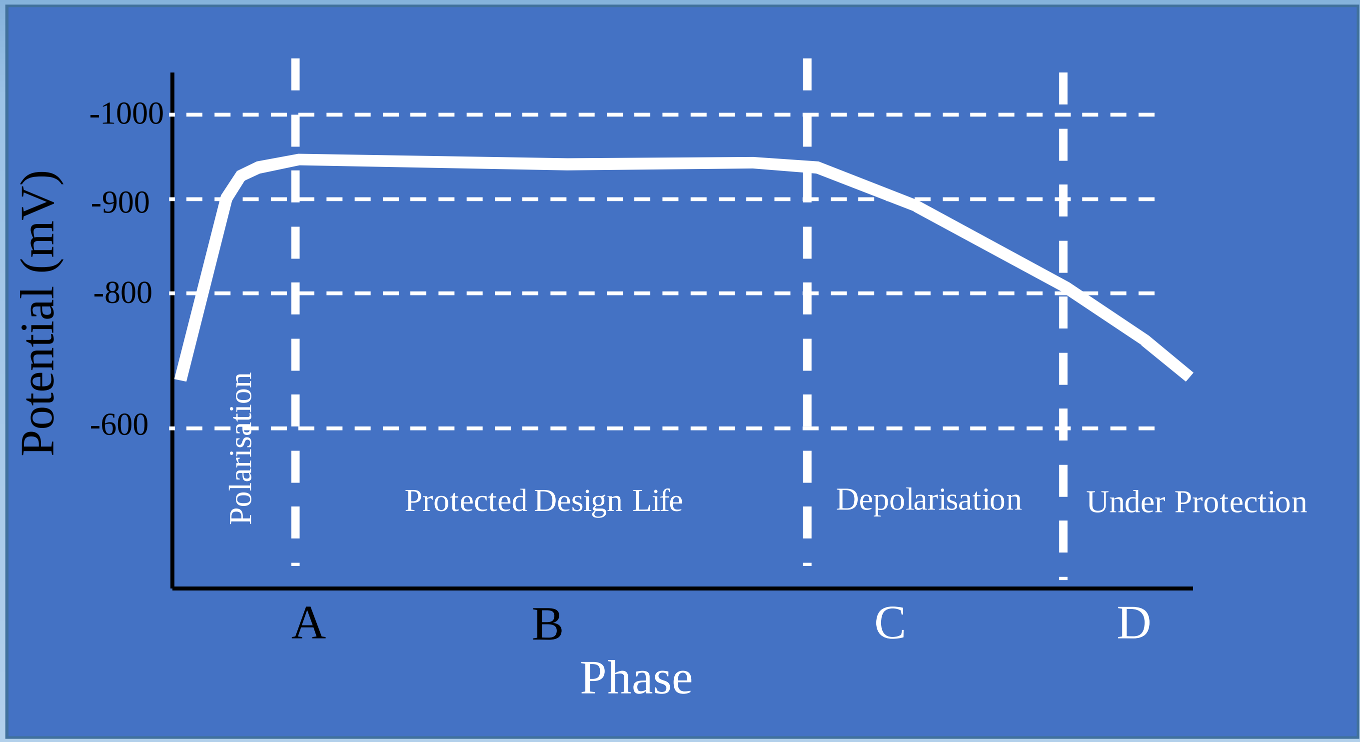
ÅInstall Anodes

Jetty Anodes installed

CP Site Survey

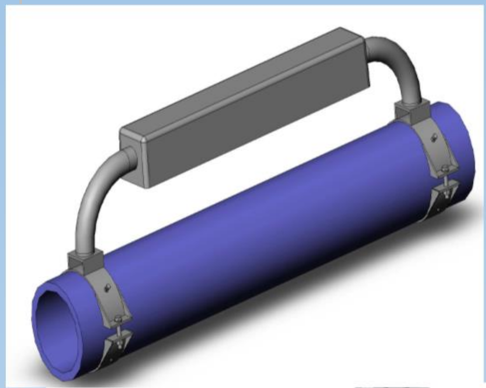


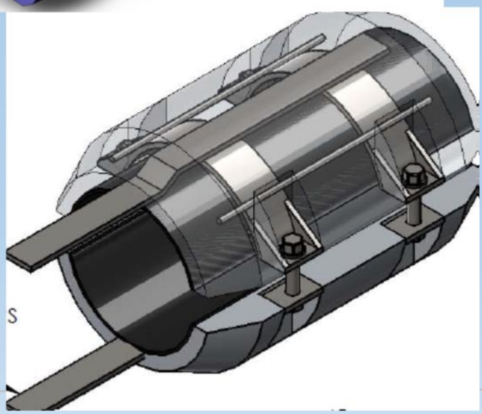
Anode system performance

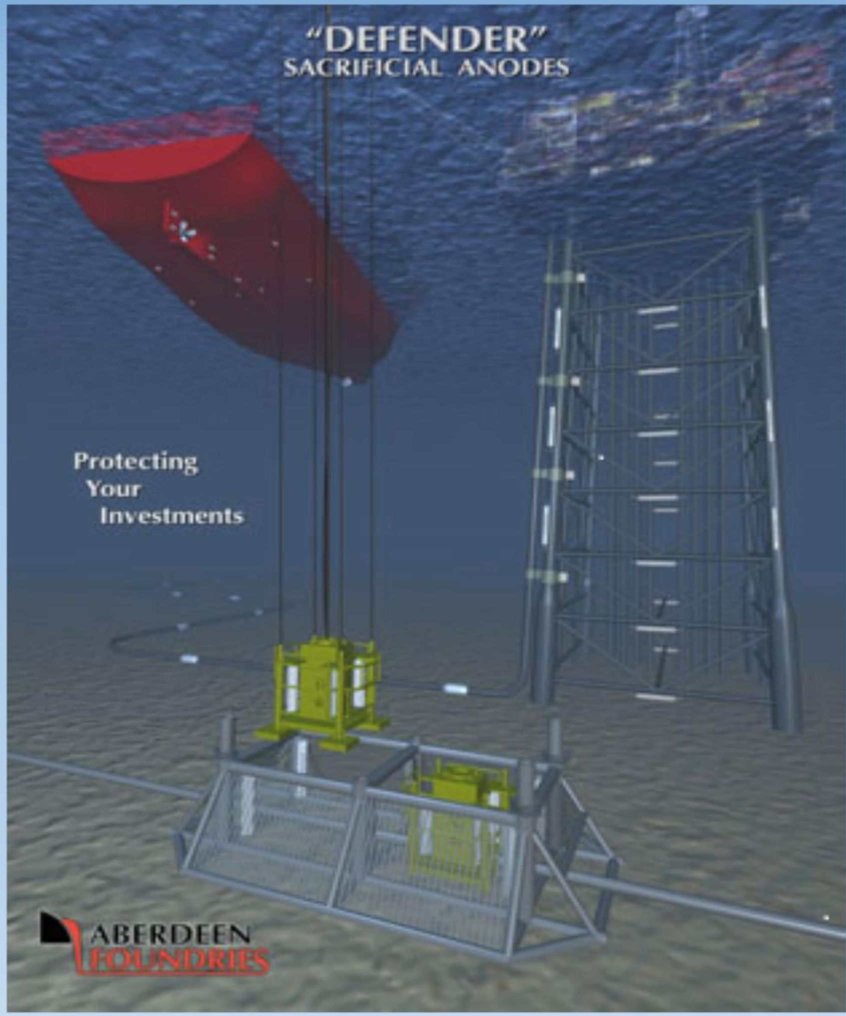


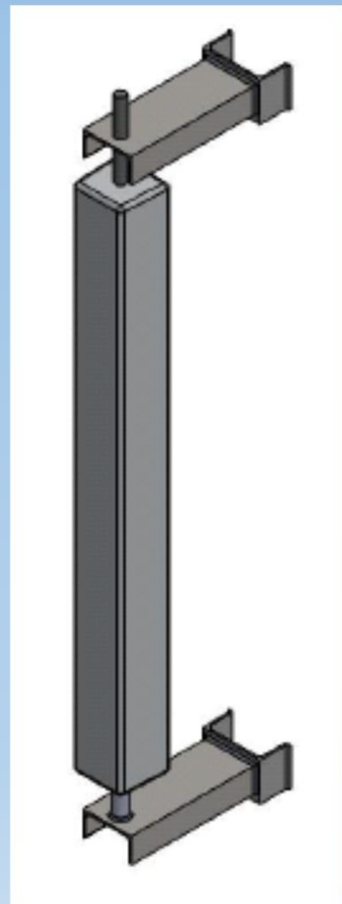
The aim of the CP design is to polarise the structure (period A) as quickly as possible and maintain the protection (period B) for the design life.
When depolarisation (period C) starts the CP system has reached its design life and leads to under protection (period D).

Sacrificial Anode Applications









Sacrificial Anode Applications

Zinc Hull Anodes

Sacrificial Anode Applications

Sacrificial anodes in Zinc for flush fit (Hulls & steelwork)

Sacrificial Anode Applications

Slender Anodes for Subsea Manifold Frame

Sacrificial Anode Applications

Manifold Anodes

Sacrificial Anode Applications

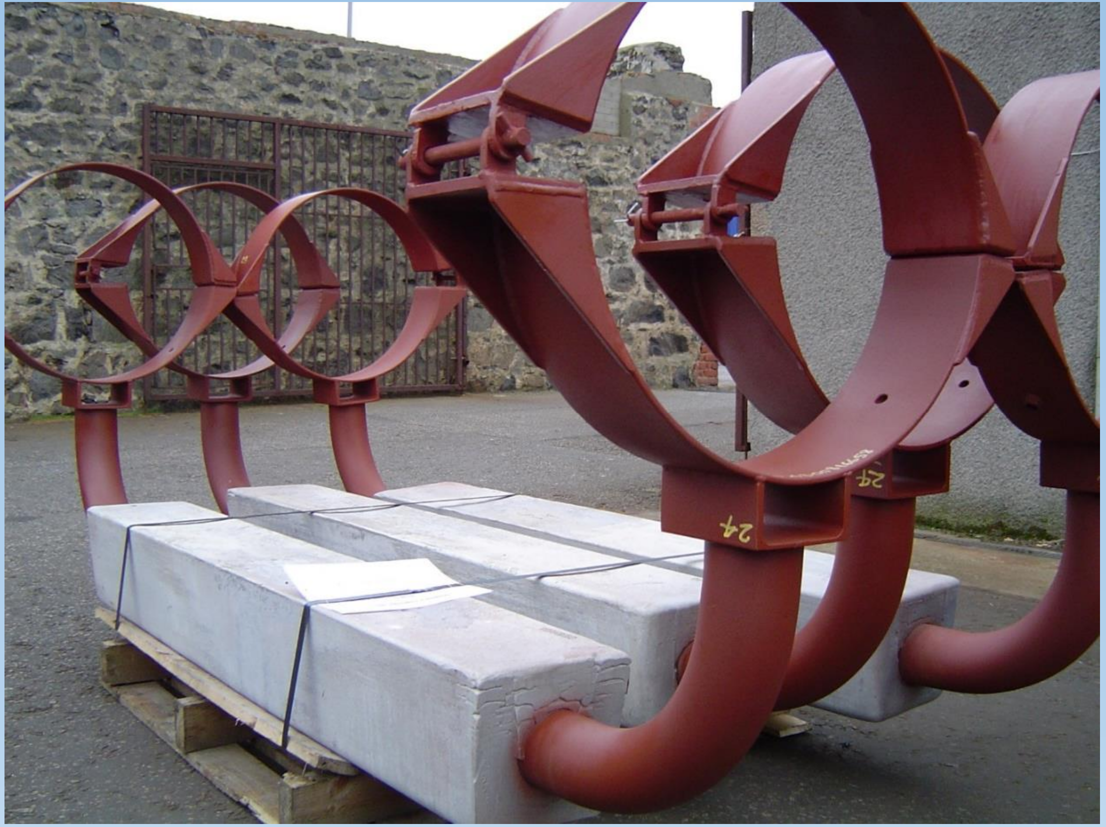
Frame
Anodes

Sacrificial Anode Applications

Retrofit Anodes

Sacrificial Anode Applications

Retrofit Anodes



Sacrificial Anode Applications

Anode Skids for Remote Retrofit of Manifold

Sacrificial Anode Applications

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

- **Conductivity / Resistivity /Temperature of the environment**
- **Size of the areas to be protected by the system**
- **Location and water depth**
- **Design Life of the system 20-30+ year lifespan (retrofit)**
- **Ability to install…… and forget!**

- **Impressed Current Cathodic protection can be utilised to cover most other fields of protection.**

-Availability of Power sources or personnel (operation & monitoring)
- Additional maintenance /survey for functionality

Anode Autopsy

Sacrificial Anode Applications

ÅTHE END

ÅMore Anodes Please!