Assets Planning and Delivery Group
Engineering

DESIGN STANDARD DS 91

Standard for the Selection and Design of Cathodic Protection (CP) Systems

VERSION 3
REVISION 1

DECEMBER 2020

FOREWORD

Design Standards are prepared to ensure that the Corporation's staff, consultants and contractors are informed as to the Corporation's design standards and recommended practices. Design standards are intended to promote uniformity so as to simplify design and drafting practice and have as their ultimate objective the provision of safe and functional plant at minimum whole of life cost.

The Corporation design standards and recommended practices described in this design standard have evolved over a number of years as a result of design and field experience and these have been investigated and documented.

Deviation, on a particular project, from the design standards and recommended practices may be permitted in special circumstances but only after consultation with and endorsement by the Principal Engineer Cathodic Protection. Users are invited to forward submissions for continuous improvement to the Principal Engineer Cathodic Protection who will consider these for incorporation into future revisions.

Head of Engineering

This document is prepared without the assumption of a duty of care by the Water Corporation. The document is not intended to be nor should it be relied on as a substitute for professional engineering design expertise or any other professional advice.

It is the responsibility of the user to ensure they are using the current version of this document.

REVISION STATUS

The revision status of this standard is shown section by section below:

REVISION STATUS						
SECT.	**VER./ REV.**	**DATE**	**PAGES REVISED**	**REVISION DESCRIPTION (Section, Clause, Sub-Clause)**	**RVWD.**	**APRV.**
All	**3/0**	**29.09.17**	**All**	**Revise reference to MESB**	**RT**	**GP**

All	**3/0**	**29.09.17**	**All**	**Remove all relevant monitoring and maintenance pages and reference**	**RT**	**GP**

5.2	**3/0**	**29.09.17**	**17**	**Revise remote monitoring requirements in TRU**	**RT**	**GP**
5.2	**3/1**	**16.12.20**	**17**	**Include GPS built in current interrupter in TRU**	**RT**	**GP**

7	**3/0**	**29.09.17**	**26**	**Revise extent of protection and where it applies**	**RT**	**GP**

12	**3/0**	**29.09.17**	**33**	**Revise insulating flange joint requirements and reference DS21**	**RT**	**GP**

13.2	**3/0**	**29.09.17**	**34**	**Change electrical continuity bond type in line with modular construction specifications**	**RT**	**GP**

14	**3/0**	**29.09.17**	**35**	**Added drawing reference**	**RT**	**GP**

15	**3/0**	**29.09.17**	**36**	**Change section from monitoring to monitoring facilities**	**RT**	**GP**

16.5	**3/0**	**29.09.17**	**38**	**Change VM reference from DS20 to DS23**	**RT**	**GP**

17	**3/0**	**29.09.17**	**39**	**Change VM reference from DS20 to DS23**	**RT**	**GP**

18	**3/0**	**29.09.17**	**40**	**Incorporate Appendix F as part of Appendix A**	**RT**	**GP**

20	**3/0**	**29.09.17**	**49**	**Rename previous Appendix E to Appendix C and revise Appendix from CP Surveys to commissioning requirements**	**RT**	**GP**

DESIGN STANDARD DS 91

Standard for the Selection, Design and Monitoring of Cathodic Protection (CP) Systems

CONTENTS

Section *Page*

1 ABBREVIATIONS

AC	Alternating Current
AW	Anode Wastage
CD	Current Density
CP	Cathodic Protection
CPP	Cathodic Protection Potential
DC	Direct Current
ELV	Extra Low Voltage
EMF	Electro Motive Force
GAB	General Aerobic Bacteria
ICCP	Impressed Current Cathodic Protection
MMO	Mixed Metal Oxide
OSH	Occupational Safety and Health
RE	Reference Electrode
RRJ	Rubber Ring Joint
SA	Sacrificial Anode
SCP	Soil Corrosion Probe
SRB	Sulphate Reducing Bacteria
SC	Surge Current
TC	Telluric Current
TP	Test Point (Test Post)
TRU	Transformer Rectifier Unit

2 DEFINITIONS

Definitions used in this guideline are the same as those contained in Australian Standard AS 2832.1 - 2004, Guide to the Cathodic Protection of Metals.

Anaerobic

Lacking free oxygen.

Anode (in general)

An electrode, placed in the electrolyte, to apply cathodic protection to the structure.

Anode screen

A safety barrier surrounding a submerged anode for the prevention of electrical shock or shorting.

Anode shield

A protective covering of insulating material applied to a coated structure in the immediate vicinity of an anode to reduce local cathodic current density.

Back e.m.f.

An instantaneous open-circuit opposing voltage, between an anode and cathode of an operating cathodic protection system. NOTE: Back e.m.f. may have other definitions in other technologies.

Bond (electrical)

A metal connection between points on the same structure or on different structures.

Bond (coating)

Adhesion between the coating materials and the substrate.

Bond (drainage)

An electrical means, whereby stray current is removed from the structure, via a conductor.

Cathode

The structure that is to be protected by cathodic protection.

Cathodic disbonding

Detachment of a coating due to the effects of cathodic polarization.

Cathodic protection

The prevention or reduction of corrosion of metal by making the metal the cathode in a galvanic or electrolytic cell.

Cathodic protection unit

DC power supply controller for an impressed current, cathodic protection system.

Copper/copper sulphate (Cu/CuSO4) reference electrode

A reference electrode consisting of copper in a saturated solution of copper sulphate.

Corrosion

The deterioration of metal caused by its electrochemical reaction with its environment.

Corrosion cell anode

The electrode at which metal dissolution (corrosion) takes place.

Corrosion current

The current flowing in a corrosion cell and which is electrochemically equivalent to the anode and cathode reactions.

Coupon

A section of metal of similar size to a coating defect, used to monitor the corrosion of a coated structure that is subjected to cathodic protection (see resistance probe).

Current density (at anode)

Current output of anode divided by the anode surface area.

Current density (at cathode)

Current flowing into cathode divided by the cathode surface area.

Current density (at coated cathode)

Total current flow into cathode divided by the total surface area of the structure.

Earth (noun)

The conducting mass of the general body of the earth.

Earth (verb)

The act of connecting any conductor to earth.

Electrode

An electronic conductor that allows current to flow either to or from an electrolyte with which it is in contact.

Electrode potential

The measured potential of an electrode in an electrolyte relative to the potential of a reference electrode.

Electrolyte

A liquid or the liquid component in a composite material such as soil, in which electric current may flow by ionic charge transfer.

Extra low voltage (ELV)

Voltage not exceeding 50 V a.c. or 120 V d.c. (max 10% ripple see AS/NZS 3000).

Ferrous metal structure

A structure comprising an iron-based alloy containing more than 50% iron.

Foreign (secondary) structure

A buried or submerged structure that may be subject to interference arising from the cathodic protection of a primary structure.

Galvanic action

A spontaneous electrochemical cell reaction in which a metallic anode in a dissimilar metal couple corrodes.

Galvanic anode

An electrode used to protect a structure by galvanic action. Galvanic anode is also called as Sacrificial anode.

Half-cell

(See ‘reference electrode’)

Impressed current

Direct current supplied by an external power source to cathodically protect a structure.

Impressed current anode

The electrode connected to the positive terminal of an impressed current power supply.

Instantaneous off-potential

A potential substantially free of voltage gradients.

Insulating joint (isolating joint)

A joint that breaks electrical continuity in a structure, but does not affect the mechanical integrity of the structure.

Interference

A significant change in current density on a foreign structure caused by a cathodic protection system; it may be detected by a resultant potential change on the structure.

Interrupter

A timing device that permits a cyclic off/on interruption to the flow of cathodic protection current.

IR drop

(See ‘resistance potential’).

Loop resistance

The total external circuit resistance at the output terminals of the cathodic protection impressed current rectifier.

Overprotection

The state that occurs when the cathodic polarization of a structure is at a level beyond that required for corrosion protection. Overprotection may cause effects which are detrimental to the structure.

Polarization

A change in the potential of a corroding metal from its natural steady state value (the corrosion potential), as a result of current flow.

Polarization cell

A device which, at potential levels typical of cathodically protected structures, has low impedance to alternating current but high impedance to direct current.

Polarized potential

The potential of a structure at the structure-to-soil interface. (This potential is thus free of voltage gradients that may accompany current flow through the electrolyte.)

Primary structure

The structure that is subject to intentional cathodic protection.

Protective potential

The potential to which a metallic structure is lowered to achieve cathodic protection.

Protective current

The current made to flow into a metallic structure from its electrolytic environment, and which cathodically protects the structure.

Reference cell/electrode

An electrode that has a stable potential in one or more electrolytes at a given temperature, thus enabling it to be used for the measurement of other electrode potentials.

Resistance potential

That part of a measured electrode potential attributable to the passage of current through the resistance between cathode surface and reference electrode.

Resistance probe

A corrosion monitoring device, which functions by exposing an element of metal of which the structure is comprised, to the environment in which the structure is exposed. As the element corrodes, its cross-sectional area is reduced, thus increasing its longitudinal resistance. The change in resistance is measured with a very sensitive resistance measuring circuit.

NOTE: When monitoring a cathodically protected structure the element is connected to the structure to simulate a coating defect on the structure.

Silver/silver chloride reference electrode (Ag/AgCl)

An electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions.

Stray current

Current flowing through paths other than the intended circuit.

Structure

A metal which has a surface in contact with an electrolyte.

Structure potential

The potential of a structure relative to that of a specified reference electrode situated in the electrolyte immediately adjacent to the structure.

Structure potential shift

A change in the measured voltage of a metallic structure caused by the application of current from an external source.

Sulphate-reducing bacteria

A type of bacteria, which is capable of reducing sulphate to sulphide in anaerobic, near-neutral soils and natural waters.

Telluric current (Geomagnetic Current)

The current induced by the variations in the earth’s magnetic field that intersects the structure.

Test point

A nominated point on a structure for electrical contact.

Transformer/rectifier

A form of cathodic protection unit.

3 SCOPE

The scope of this standard is to provide Water Corporation personnel and Design Consultants with information to assist with the selection and design of CP systems for buried pipelines, tanks and other infrastructures.

The standard is intended to:

Ensure consistency in the application of CP system on all relevant classes of assets.

Ensure that designs meet Water Corporation requirements and comply with relevant Australian Standards

Promote co-operation between all interested parties through a common understanding of the complex principles and practices associated with the CP.

4 INTRODUCTION

4.1 Introduction

Corrosion is the destruction of a metal by a chemical or electrochemical reaction of the metal with its environment. In all electrolytes, such as soil, water and wastewater, metal atoms go into solution as electrically charged atoms (ions). This process results in rapid loss of metal commonly known as corrosion.

Cathodic Protection (CP) is defined as "reducing or eliminating" corrosion by making the metal a cathode by means of an impressed direct current (DC) or an attachment to a sacrificial anode (usually magnesium, aluminium or zinc).

When CP is applied, there is an exponential decrease in the rate of corrosion with increasing negative (cathodic) potential. When a certain level (protection potential) is reached, the rate of corrosion becomes negligible. So corrosion may be prevented by employing CP on a buried or submerged structure. This is achieved by applying an appropriate direct current flowing in opposition to the original corrosion current, thus preventing the natural tendency of the metal to react with its environment. CP is a system utilized to inhibit corrosion of structures, such as buried pipes, structures, tanks, etc.

To employ CP, a circuit is established by connecting a suitable source of Direct Current (DC) to the structure to be protected. It is well known that the current flows due to potential difference between the anode and cathode. For example, in soil with low resistivity, current would leave the pipeline at the anode site, pass through the soil, and re-enter the pipeline at a cathode site. The total system – anode, cathode, electrolyte, and metallic connection between anode and cathode is termed a corrosion cell.

NOTE : Design of any CP system using DS 91 should be read in conjunction with DS 20, Design Process for Electrical Works and DS 21, Major Pump Station – Electrical, to satisfy both Cathodic Protection and Voltage Mitigation requirements.

4.2 Corrosion

For corrosion to occur the following conditions must exist:

Electrodes:	An anode and cathode must be present; and
Conductive Path:	A metallic conductive path electrically connecting the anode and cathode must exist. In the case of a metallic pipeline, the pipe itself is this conductive path.
Electrolyte:	The anode and cathode are immersed in an electrical conductive media (electrolyte).
Electrical Potential:	An electrical potential between the anode and cathode must be present.
Current:	When these conditions exist, an electric current will flow, and where the current leaves a metallic object, corrosion take place.

CP reverses this current flow and inhibits corrosion.

5 TYPES OF CP SYSTEMS

5.1 Sacrificial CP Systems

A Sacrificial CP system makes use of the corrosive potentials for different metals. A much less inert object (more negative potential, e.g. magnesium) corrodes preferentially to the structure to be protected, such as a pipeline (less negative potential) when a metallic connection (insulated wire) is installed between the magnesium and the structure. The magnesium will become the anode and the entire structure will become the cathode and will be protected.

Magnesium or Zinc anodes are usually used in sacrificial CP systems. Zinc anodes are typically used in electrolyte mediums below 2 ohms-meter. Magnesium alloy anodes are typically used in electrolyte medium between 2 and 75 ohms-meter. The site of lowest resistivity will normally be used for anode location to minimize anode-to electrolyte resistance. Aluminium anodes are not commonly used in buried environments.

The datasheets for anode specification should include anode weight, anode dimensions, composition and package dimensions (anode plus backfill). The materials used for Magnesium, Aluminium, Zinc anodes shall comply with Australian Standard AS 2239.

Factors affecting the design of sacrificial anode systems are shown in Figure 1.

FACTORS TO BE CONSIDERED FOR SELECTION OF
SACRIFICIAL (GALVANIC) ANODE SYSTEM FOR BURIED STRUCTURES

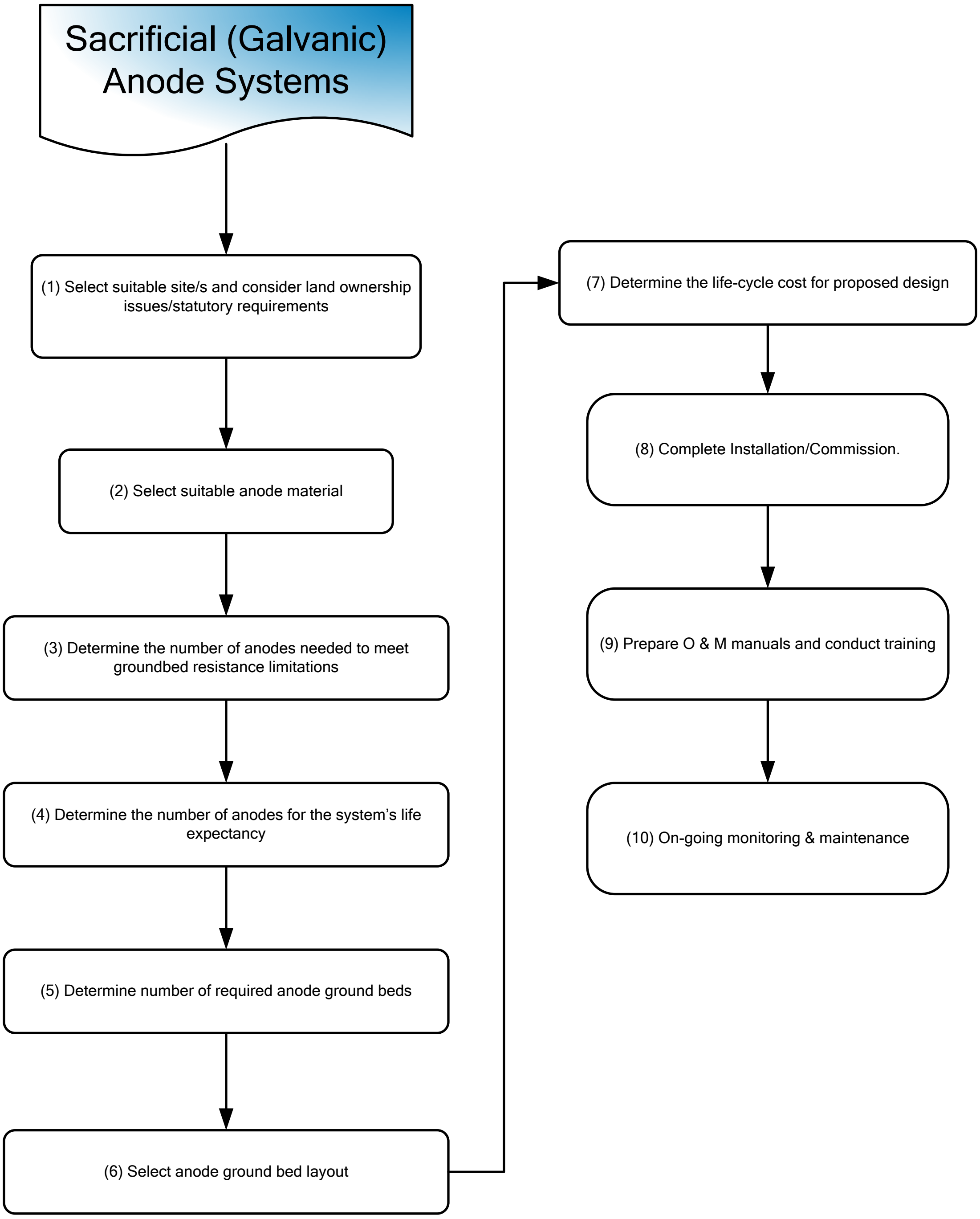

Figure 1 – Factors Affecting the Design of Sacrificial Anode Systems.

5.2 Impressed Current Cathodic Protection (ICCP) Systems

Impressed Current Cathodic Protection (ICCP) systems use the same elements as the sacrificial protection system. The structure is protected by applying a current to it from an anode. The anode and the structure are connected by an insulated wire. Current flows from the anode through the electrolyte onto the structure, just as in the sacrificial system.

The main difference between a sacrificial and an impressed current system is that the sacrificial system relies on the difference in potential between the anode and structure, whereas the impressed current system uses an external power source to drive the current.

The primary advantage of ICCP systems over sacrificial anode CP systems is that the driving potential of the impressed current systems is not limited by the corrosion potential of an active metal. The ability to select appropriate driving potentials, and to adjust the driving potential after system installation, gives the designer and operator of ICCP systems additional flexibility to compensate for changing environmental conditions.

The external power source is usually a rectifier that changes input Alternating Current (AC) power to the Direct Current (DC) power. The Transformer Rectifier Unit (TRU) can be adjusted, so that proper output can be maintained over the system's life. The ICCP system anodes typically are Mixed Metal Oxide (MMO), High-Silicon Iron or Magnetite. Scrap iron is also used when available.

TRU based on combined digital control and monitoring systems for ICCP systems which are vendor only serviceable are not acceptable. For conformity with existing Water Corporation TRU's it is recommended that the panel layout be similar to that specified in Drawing No. LL33-054-014. There should be sufficient space within the TRU enclosure to physically locate a Cyplex remote monitoring unit for monitoring output voltage, output current and structure potential. These 3 sets of outputs shall be wired onto DIN mounted terminal blocks located on the same DIN rails for the DC outputs for ease of Cyplex unit hookup. TRU shall incorporate a built in GPS current interrupter for synchronised potential testing.

Factors affecting the design of ICCP system are shown in Figure 2.

Safety issues:

Warning notices advising of the danger of electrical gradients near the anodes and the need to switch off the system prior to diving shall be prominently displayed at all entry points to the water body. The system must be turned off and properly isolated and tagged, prior to the commencement of any underwater diving inspection or maintenance activity.

Signs shall be displayed indicating the presence of any immersed cables or anode supports which are not physically protected.

The contractor should be thoroughly familiar with the specifications for the works, and shall ensure that all works are completed in accordance with good industrial practice and the relevant specifications. Departures from design specifications shall be approved only by the Durability Section and shall be permanently recorded for future reference.

Installation of all electrical work is required to be carried out in accordance with AS 3000 and AS 3100 as appropriate, local electricity regulations and other relevant Standards.

It is necessary that precautions be taken in combustible atmospheres to prevent sparking due to potential differences between protected and unprotected structures (Refer: AS 2430.1). The CP system shall be switched off (isolated and tagged) and insulated joints cross-bonded before being separated.

Effects of lightning, both on the protected structure and via the electricity distribution system (personnel protection aspects are specifically covered in AS 1768).

Effects of induced voltages and fault currents on the protected structure as defined in AS4853.

In addition the following hazards shall be considered:

The effects of electric sparks on structures containing products which are flammable or capable of forming explosive air/gas mixtures (Refer: AS 1076.1 and AS 2430.1). It is also necessary, in such circumstances, to ensure control of static electricity; this may conflict with the insulating joint requirements of the CP system (Refer: AS 1020).

NOTES:

The extent of hazardous zones for various types of installation or for items of equipment which are used to handle flammable liquids or gases is defined in AS 2430.1. It is essential that there is no chance of a spark occurring within such a hazardous zone.

Conduit or ducting leading from a CP installation into hazardous areas, e.g. test boxes and transformer rectifier enclosures, shall be sealed to prevent the flow of flammable substances.

Where electrical continuity is required for any other purpose, D.C. electrical isolation of the CP system may be achieved by the use of appropriately rated isolation or decoupling devices. These devices are subject to approval by local electrical supply authorities and may be used to link the electricity supply earthing system to cathodically protected plant without affecting the level of CP or the level of personnel safety.

Electrical gradients occurring in water around fully and partially submerged anodes and in waterways adjacent to anodes, resulting from impressed current systems.

Paralysis and respiratory failure may result if the body extremities of a person come in contact with electric field strengths greater than 3 V/m in water (Refer AS 3859)

Should the design result in the electric field strength exceeding this value in areas of saline and non-saline waters frequently located close to impressed current anodes, warnings shall be given and access to such areas prevented by shielding or by other means.

FACTORS TO BE CONSIDERED FOR SELECTION OF IMPRESSED CURRENT SYSTEM

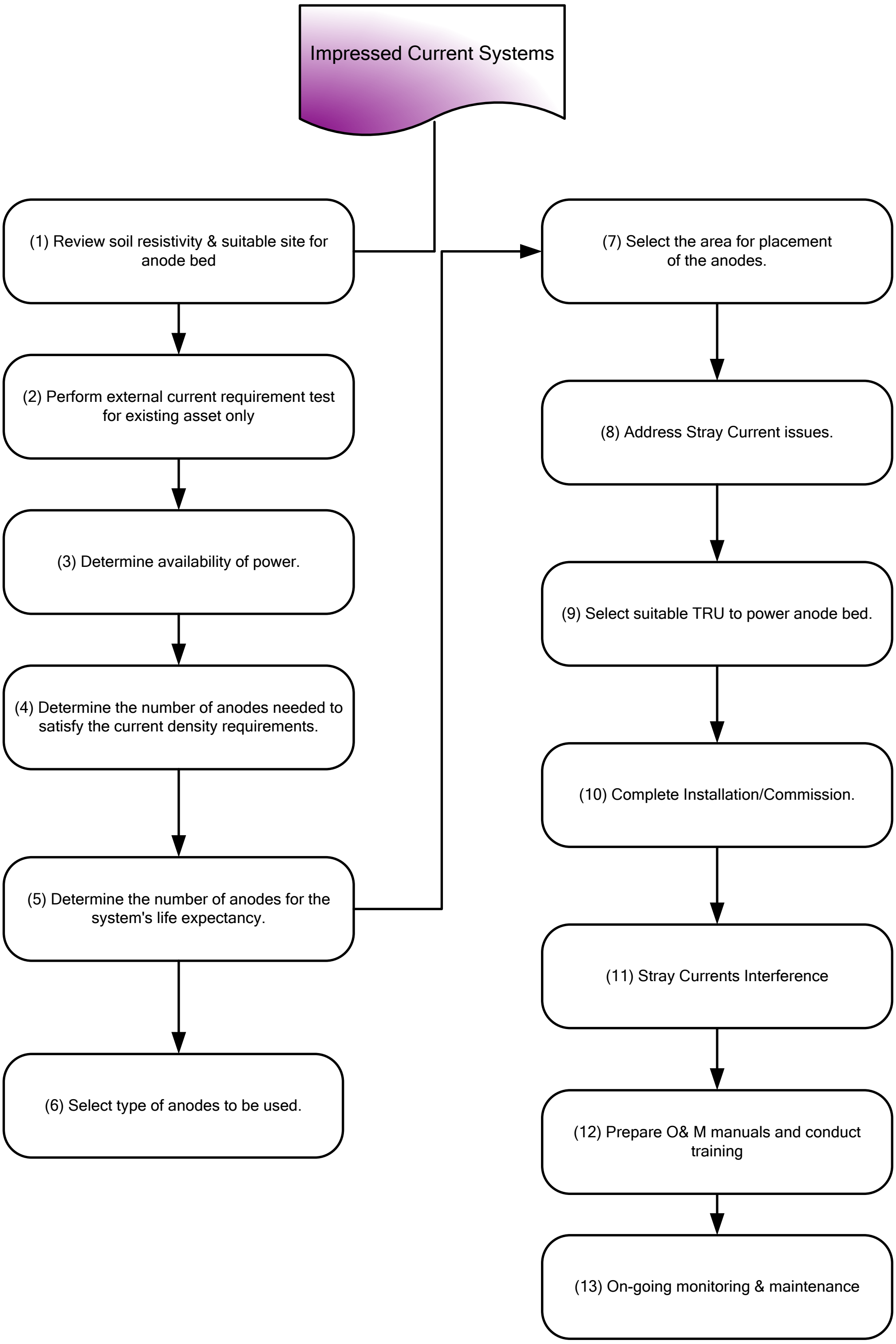

Figure 2 – Factors Affecting the Design of Impressed Current Systems.

5.3 Advantages and Disadvantages

Table 1 – Advantages and Disadvantages of Various Types of CP System

	Impressed Current System	Sacrificial System
Advantages	Longer anode life. Current can be controlled.	Inherently simple in design.
	Significantly larger areas can be protected. Suitable for high resistivity areas.	External power not required.
	Anode current delivery is independent of surrounding environment.	Minimum interference to foreign structure. No Occupational Safety & Health (OSH) issues.
Disadvantages		
	External power is required. Possible interference to foreign structure.	Only smaller areas can be protected. Shorter anode life. Anode current delivery is dependent on anode chemistry and surrounding environment.
	OSH issues in submerged environments.	Not suitable for high resistivity area. Not suitable for high current demand. High recurring anode replacement cost in remote areas or in areas where safety and environmental access may be an issue.

6 SELECTING THE APPROPRIATE SYSTEM

6.1 Guidelines for Selection of CP

The selection of CP system depends on a number of factors including a site investigation to provide information on the location of all structures (above and below ground), and geographical features in the vicinity of the structures to be protected and land ownership (for statutory requirements). A summary of the key CP selection criterion for buried pipework is shown in Figure 3.

The following additional factors shall be taken into consideration before installing a CP system:

a) Age of structure;

b) Type of structure – MSCL, RRJ;

c) As constructed information (for identifying adjacent structures);

d) Materials of construction;

e) Dimensions;

f) Nature of the soil;

g) Any external electric influences (stray currents and geomagnetic currents);

h) Effectiveness of the protective system;

i) Composition and level of the groundwater;

j) Type and thickness of protective coatings;

k) Type of backfill;

l) Soil conditions (pH, resistivity, ASS, SRB);

m) History, frequency and location of bursts/failures;

n) Protective current requirement;

o) Availability of power - Mains, Solar, Wind, Gas and Hydro Electric;

p) Electrical continuity of structures;

q) Interaction with other installations – foreign structure, high voltage towers;

r) Installation and maintenance cost;

s) Consideration should also be given to anode beds which will also have a significant effect on the decision process

t) Decoupling earthing on pipes;

u) Isolation of offtakes and copper services;

v) Encumbrances such as heritage, aboriginal sites, Swan River etc.; and

w) Proximity to High Voltage AC Power lines (induce fault current)

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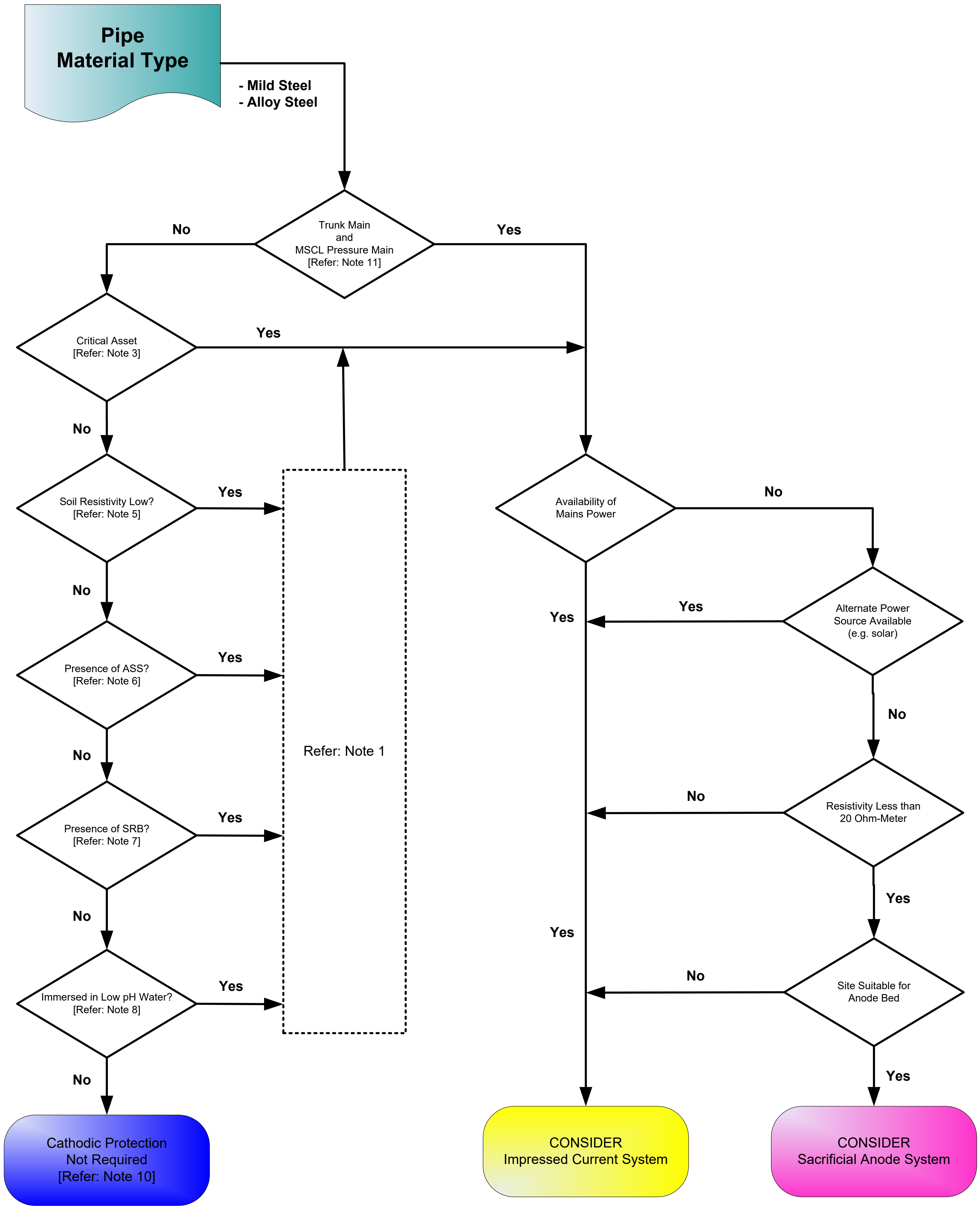
CATHODIC PROTECTION SELECTION CRITERIA FOR BURIED PIPEWORK



Notes:

1) Where criteria for CP requirement is not uniform throughout the entire length of the pipe, consideration should be made to only protect sections of pipe meeting the CP installation requirements if the required section(s) can be effectively and economically isolated electrically.
2) For Sintakote, MSCL Rubber Ring Jointed pipe, a decision to use CP will require joints to be electrically bonded for sections with common attributes.
3) Refer to asset owner for asset criticality.
4) Refer to list of additional factors in Section 3, that may have to be taken into consideration.
5) If the soil resistivity is < 50 ohm-m, then CP should be considered.
6) If the ASS level is > 150 ppm, then CP should be considered. ASS tests should be carried out in accordance with Water Corporation Environmental Branch, Acid Sulphate Soil Management Plan document No. TBA.
7) Based on the testing carried by SaniCheck SRB test kits. Refer to Appendix F for testing procedure.
8) If the pH < 5.5 i.e. acidic then CP should be considered.
9) Stainless Steel or copper pipes and fittings must be insulated from MSCL, Ductile or Cast Iron pipework. Cathodic Protection are generally only applied to Mild Steel pipes.
10) Consider possible effects of stray current interference from other CP systems (e.g. gas mains)
11) CP system to be applied to MSCL pressure mains in “sensitive and highly sensitive areas’. Examples of ‘Sensitive areas” are permanent creeks, rivers and lakes. Example of “Highly sensitive areas” are Dry season pools in seasonal (intermittent) creeks, rivers and wetlands.

6.2 Buried Structures

6.2.1 Pipelines

For pipelines, it would generally be more economical to install sacrificial anode system in the following circumstances:

- Short buried section
- Protective coating in good condition
- No access to power and
- Suitable low soil resistivity soils for the installation of anodes

For longer and larger diameter pipelines it may be more economical to install impressed current systems. Pipelines with poor or deteriorated coatings require a substantial amount of electric current to ensure adequate protection. The impressed current system is very efficient, provided it is installed in a suitable environment. In general, soil conductivity is not a problem, since the impressed current system can have a driving voltage up to 50 volts. Anode bed locations and proximity of foreign structures are very important considerations when designing an impressed current system.

Where environmental approval is required for any excavation, or the cost of labour for recurring sacrificial anodes replacement is high, consideration should be made for the use of low cost solar powered impressed current system even for short buried pipe sections.

The Net Present Value (NPV) of an asset must be calculated to determine which type of system (sacrificial or impressed) is the most suitable. The Asset Manager would assess the financial and risk analysis of the structure in the calculations.

6.2.2 Other Structures

- Road crossing casings and steel reinforcement
- Outfalls
- Buried /bypass valves
- Tank floor plates (external)
- Pipe supports and trestle legs

6.3 Immersed Structures

6.3.1 Tanks

Due to the high cost associated with replacement of sacrificial anodes, impressed current CP shall be installed.

Note:

- The taste of potable water in tanks, clarifiers and pipelines can be affected by excessive use of sacrificial anodes. Also contamination can occur from the waste products.
- For further information, reference should be made to current CP standards AS 2832 parts 1-3 and AS 2239.
- The high cost of sacrificial anode maintenance arises from the requirement to use either a diving team or a rope access team to remove and install new anodes every 3-5 years to comply with Water Corporation's confined space entry and prevention of falls requirements.
- The anodes used in an impressed current system have no detrimental effect on the water quality and may provide an additional benefit to the water supply from the chlorine formed at the anode.

6.3.2 Other Structures

- Piles or caissons
- Reinforcing in concrete tanks
- Pressure vessels
- Structural steel and pipework within concrete tanks and clarifiers
- Vacuum tanks
- Chlorinators

7 EXTENT OF PROTECTION

7.1 Overview

For pipeline CP systems the extent of protection shall typically be the two extremes of the constructed pipeline scope of work.

Where the pipeline terminates at an installation where there are extensive earthing systems, like pump stations, storage complex, etc, the extent of protection shall be up to the last length of pipe at the farthest isolation valve away from the extensive earthing system. This is to ensure improved reliability of the CP system from future accidental bond to earth which compromise CP systems.

Where the extent of protection is only at road and river crossings, the pipeline shall not be CP protected unless the pipework at the crossing is completely electrically isolated at both ends of each crossing.

For storage tanks, only steel tanks larger than 200m^3 shall be CP protected. Steel tanks with waterproof liners shall not be CP protected as the steel is not in contact with the electrolyte. Steel pipeworks in concrete tanks shall only be protected after proper assessment to determine its necessity.

8 GROUND BED SELECTION

8.1 Overview

The following are some factors affecting the selection of ground beds. For further details refer to **Appendix A**.

In selecting the ground bed sites, the most important consideration from a design standpoint is determination of effective soil resistivity. The soil resistivity measurement techniques and interpretation are discussed in Appendix A 14.2.1. However, other considerations must be taken into account when selecting a site. Often these will rule out locations where soil resistivity measurements indicate a highly desirable construction site.

The following points shall be considered in the design of a ground bed:

1. Are other underground metallic structures within the area of influence surrounding the ground bed? If so they may pick up current from the ground bed and create a stray current interference problem that will require corrective measures if the site is used.
2. Anode to protected pipeline separation distance.
3. Anodic and Cathodic field effects.
4. If a rectifier-powered impressed current system is to be installed, is there a power line present? If not, is a power line extension from the nearest source practicable? Has solar power been considered?
5. Is the site reasonably accessible for construction and maintenance purposes?
6. Are there plans for building construction (new pipelines, highway development or other similar work) that will make the site untenable in the near future?
7. Environmental issues?
8. Aboriginal heritage and native title issues?

8.2 Sacrificial Ground Beds

In most cases, locations for sacrificial ground beds are easier to select than those for impressed current ground beds because they do not require external power and are relatively free of interference with foreign underground structures.

8.3 Impressed Current Ground Beds

Deep ground beds can be described as one in which the anodes are located adjacent to the structure at an average depth of approximately 40 meters.

Deep well ground beds are effective in areas where soil resistivity is high or where obtaining suitable easements may be an issue. Deep well ground beds generally reduce the risk of stray current interference to adjacent structures. Refer to **Appendix A** for typical Impressed Current ground bed design details.

8.3.1 Anode Groundbed Drilling

8.3.1.1 General

The anode borehole shall be drilled using reverse circulation (RC) techniques to the minimum required depth.

A surface casing shall be grouted in to facilitate drilling of the main hole.

The hole shall be logged at intervals of 2m or at major changes in strata type.

The logging shall include completion of the 'Geological Survey of Western Australia particulars of completed borehole' form.

The Contractor shall be responsible for the supply of all water and consumables as necessary to complete the works.

The Contractor shall have available or access to equipment and materials to grout subsurface strata as necessary to prevent contamination of different water strata. The determination of these requirements will be as directed by the Principal.

The Contractor shall be responsible for provision of security around the borehole during non-working hours to prevent vandalism and debris being put down hole.

The Contractor shall provide suitable capacity open top tank(s) for containment and separation of drilling mud and cuttings. The use of temporary on-site pits is not permitted.

8.3.1.2 Aquifer Sealing

The Contractor shall be responsible for ensuring aquifers intersected during drilling are sealed to minimize flow to the surface or between aquifers.

The Contractor shall verify with the Water Corporation the approximate depth intervals of aquifers and obtain approval for the proposed aquifer sealing technique before proceeding. The Contractor shall advise the drilling sub-contractor of the agreed aquifer sealing technique prior to commencement of the works.

Sealing shall be effected using a conventional drilling bentonite slurry (wall cake) in the following two (2) zones:

Zone 1 - Natural ground surface to bottom of PVC surface casing.

The annulus space between the PVC surface casing and borehole shall be left filled with a bentonite slurry either from the drilling process or pumped in separately.

Zone 2 - Active Anode Interval (conductive carbon column)

The installation methodology shall ensure that a bentonite slurry is displaced by the carbon backfill from the bottom to the top of the column interval.

The bentonite slurry density shall meet the following specification:

30 – 40kg Bentonite/1000L water + additives depending on actual site drilling conditions.

8.3.1.3 Anode/Backfill

The Contractor shall liaise with the calcined coke backfill supplier on the recommended procedure for the anode/backfill installation. Key issues to be considered include:

Fluidisation ratios

Intake/delivery pump rate(s) and pressure(s)

Wetting agents

Backfill volume and loss determinations

The vent and backfill delivery pipe(s) shall be installed the full depth of the borehole.

These pipe(s) can be used to facilitate the installation of the anode assemblies.

Under no circumstances shall the anode cable be used to support the vent or fill pipe; the cable shall remain un-tensioned during the entire installation process and 24 hour settling period.

Following completion of backfilling, the Contractor shall check the borehole after 24 hours have elapsed, check and top up as necessary to ensure the backfill level stabilizes at the specified RL.

Extreme care shall be taken at all times to ensure the anode cable insulation and electrodes are not damaged during handling or the installation.

Construction plastic sheeting shall be laid out for the anode assembly to facilitate installation and prevent abrasion.

9 CP PROTECTION CRITERIA (SIZING THE SYSTEM)

9.1 General CP Protection Criteria

In general all structures generate natural static potential (i.e. without CP). This potential is used to establish the required protection potential depending on soil type, galvanic couples or interference caused by others.

The prime objective of the CP process is to ensure that the correct amount of current flows into the structure to be protected. Determination of the current requirement helps determine the number of CP systems required, design and layout of the ground beds and the design of the power supply equipment.

The magnitude of the current requirement is dependent upon the environment, areas of exposed metal, quality of the coating, the relative positions of various metals on the galvanic series and structure geometry.

The best way to accurately determine the CP current requirement for a structure is to measure it in the field. An indication of the current requirement can be obtained by applying a temporary CP system and adjusting it to obtain an indication of the level of protection required. Due to depolarising agents, coating and anode deterioration, a margin of at least 2 - 3 times over the estimated current (from field measurements) should be applied.

The criteria for the protection of a buried ferrous structure is to maintain a potential on all parts of the structure equal to, or more negative than, -850 mV *instant off* with respect to a saturated Copper/Copper Sulphate (Cu/$CuSO_4$) reference electrode. More negative potentials will be required to counteract the effects of Sulphur Reducing Bacteria (SRB).

100 mV negative shift from depolarized potential can also be used as a criteria for protection. In some areas where the above criteria may not be feasible because of adjacent structures a level of protection can be achieved using a soil corrosion probes as a measure of the cessation of corrosion.

Consideration must also be given to the additional CP current requirements where electrical isolation from offtakes, plant and equipment is not feasible.

9.2 Effects of Overprotection

Overprotection may cause accelerated disbondment of a coating and other deleterious effects. For ferrous, lead, copper and copper-alloy structures, the overprotection potential shall not be more negative than -1.2 V *instant off* with respect to a Cu/$CuSO_4$ reference electrode.

10 SELECTION OF ANODES – REFER APPENDIX A

10.1 Overview

There are significant differences between the types and expected life of anodes used in sacrificial and impressed current systems.

Refer **Appendix A** for further information on the different types of anodes.

11 REFERENCE CELL

11.1 Overview

A Reference Cell can be defined as an electrode immersed in a suitable electrolyte, designed for measurements of electrode potential. A pure metal in contact with a solution of known concentration of its own ion, at a specific temperature develops a potential which is characteristic and reproducible. When coupled with another half cell, an overall potential develops which is the sum of both half cells.

Reference cells are a vital part of the corrosion monitoring system. Reference-cell testing estimates the electrical half-cell potential of the structures for the purpose of determining the potential for corrosion activity at the time of testing.

Depending upon the environment, various types of reference cells are used for corrosion measurements including:

Copper/Copper Sulphate [$Cu/CuSO_4$]

Silver-Silver Chloride [Ag/AgCl]

Zinc [Zn]

Refer **Appendix B** for further information on Reference Cells.

12 INSULATED FLANGED JOINTS

12.1 Overview

Insulating flanged joints where required for dissimilar metals interfaces, for electrical isolation of cathodic protection systems and instrumentation (magnetic flow meters) shall comply with the requirements of Design Standard DS38-2. All insulating flanged joints installed shall be provided with surge protection devices to prevent damage to the flange during lightning or fault conditions and for personnel safety as per DS21 Section 11.6.2 unless it is across a bypass pipeline where the surge protection device has already been provided across the insulating flanged joint on the main pipeline. Surge protection device used are to comply with DS21 Section 11.8. In addition, insulating flanged joints shall be provided with test facilities in accordance with drawing LL33-054-004 for insulating flange integrity testing.

Insulating flange joints shall be adequately wrapped in accordance with drawing JZ39-91-10 to ensure no water ingress which may compromise the insulating flange integrity.

13 ELECTRICAL CONTINUITY

13.1 Overview

For CP System to work, asset within the scope of protection has to be made electrically continuous. This can be made by welding or tack welding using the rebar within the concrete for jetty piles or by electrical bonding straps for rubber ring jointed pipes.

13.2 Methods

For all metallic non welded pipes, continuity shall be delivered by CP continuity cables in accordance with Drawing LL33-054-042 or LL33-054-041.

All crimped connectors shall comply with AS 4325.1 and be subjected to batch testing in accordance with an AQL of 2.5%, single sampling plan, general inspection level 1 as specified in ISO 2859.

Quality control document shall be kept during installation, of continuity bonds installed, detailing bond serial numbers (if any), data and person installing the bond and bond location or pipe chainage. The continuity bonds quality control document is to be forwarded to the *Superintendent* weekly for review and an electronic copy of this document will form part of the commissioning documentation. The *Superintendent* will forward a copy of the continuity bonds quality control documents to the Durability Team.

14 SLEEVED/CASED CROSSINGS

14.1 Overview

Where metallic sleeves or stainless steel overwrap is used to protect the carrier pipe, care should be taken to ensure that these sleeves or overwrap are not in direct electrical contact with the carrier pipe. Non-metallic spacers **ONLY** should be used to separate the metallic sleeve from the carrier pipe. A Cathodic Protection test point should be installed for every metallic sleeve installed to ensure that the metallic sleeve remains electrically isolated from the carrier pipe as per drawing LL33-054-006.

NOTE: Design of any CP system using DS 91 should be read in conjunction with DS 60, Water Supply Distribution Standard Pipelines Other Than Reticulation, to satisfy both Cathodic Protection and Sleeved Crossings requirements.

15 CP MONITORING FACILITIES

15.1 Overview

All CP system designs incorporate monitoring facilities to provide a continual assessment of the condition of the asset. Adequate monitoring and testing to ensure that the required level of protection is provided forms an integral part of the CP system process. Test Point shall be constructed as per drawing LL33-054-001 and LL33-054-002.

Monitoring methods, testing programs and CP adjustment procedures will be provided to the Asset Manager as part of Operations and Maintenance Manuals (O&M) when the CP system is commissioned.

15.2 Potential Monitoring Test Points

Potential monitoring test points are required for CP protection level measurements as per drawing LL33-054-003. The Spacing of potential monitoring test point shall be based on AS 2832.1 Section 4.5.2, typically every 500m for suburban and build up areas and every 2000m for semi-rural areas. Future land zoning and development should be considered when selecting the appropriate test point spacing to apply.

15.3 Insulating Flange Test Points

Insulating flange test points as per drawing LL33-054-004 are required across every insulating flange for testing electrical isolation integrity. In addition, all insulating flange would also require a solid state decoupler installed across the flange for insulating flange protection and electrical safety unless the insulating flange is across a by-pass line and a solid state decoupler has already been installed across the main pipeline.

15.4 Foreign Structure Test Points

Foreign Structure test points as per drawing LL33-054-005 are required across every foreign pipeline crossings including in some cases, different Water Corporation metallic pipelines. These test points are required for interference testing and possibly interference bonding. Where foreign pipeline runs parallel in close proximity and may interfere with Water Corporation metallic pipelines, interference test points at every 500m intervals are required.

15.5 Cased Crossing Test Points

Cased Crossing test points as per drawing LL33-054-006 are required at one end of each cased crossing. Where the cased crossing is over 100m, a cased crossing test point at each end of the cased crossing is recommended. Cased crossing test points are needed for metallic pipes installed in metallic casings only. They are required to test that the metallic casing remains electrically isolated from the metallic pipes.

16 STRAY CURRENT INTERFERENCE & AC VOLTAGE MITIGATION

16.1 Overview

Stray current corrosion (interference corrosion) is corrosion caused by direct current from an external source that travels through paths other than the intended circuit. Accelerated corrosion will result if the current is collected by a foreign structure and leaves to enter the soil. This may result in catastrophic failure of the foreign structure at the point where the stray current exits into the soil. Stray currents can be caused in two ways, either by direct connection or through a soil gradient.

The corrosion resulting from stray currents (external sources) is similar to that from galvanic cells (which generate their own current) but different remedial measures may be required. Soil and water characteristics affect the corrosion rate in the same manner as with galvanic-type corrosion.

16.2 Detection of Interference Levels

A quantitative assessment of probable damage caused by interference currents is difficult because the extent of current discharge from a foreign structure and the surface area from which it arises are usually unknown.

Interference is normally evaluated by checking the change of potential of the foreign structure by taking measurements between the foreign structure and a suitable reference electrode.

16.3 Stray Current - Mitigation

16.3.1 Control by Sacrificial Anodes

Interference may be controlled by installing sacrificial anodes on the foreign structure, to make the potential at least as electronegative as that which existed prior to the interference.

16.3.2 Control by Bonding

Interference may be controlled by bonding the foreign structure to the primary structure, or by connecting the foreign structure directly into the impressed current CP system.

Further details on minimization of stray current effects on underground structures are described in Section 6.2, AS 2832.2, Cathodic Protection of Metals, Part 2: Compact Buried Structures.

16.4 Alternating Current Effects from High Voltage Electrical Powerlines - Overview

Modern pipelines are usually coated with high quality anti-corrosion coatings that have highly effective electrically insulating properties. Pipelines are often laid in roadway easements that also have high voltage electricity distribution lines alongside.

The overall result is that pipelines are now much more prone to being subject to electrical effects as a result of the powerlines. Significant voltage may be induced under normal steady-state powerline operating conditions and more substantial effects may occur under fault conditions when surges of very high currents could flow.

Electrical fault conditions may occur at frequencies ranging from less than once per year up to several times per year depending on factors such as location and type of powerline construction. They may cause electric shock to personnel working on pipelines adjacent to the powerlines and may present a number of possible hazards to the pipelines, as follows:

- Damage to electrical insulation in devices such as monolithic isolation joints, isolating flanges, isolating couplings and isolating unions.
- Damage or puncture of protective coatings.
- Damage to electrical and electronic equipment.
- Electrical arcing which can fuse the pipeline steel or can act as a source of ignition for escaping product.

16.5 AC Voltage Currents - Mitigation

Mitigative measures employed to control or minimize the effects of powerlines include:

(a) Earthing decoupling devices such as surge diverters coupled with:

  - Electrical earthing in the form of discrete electrodes, earthing beds or lengths of earthing cable or ribbon
  - Earth safety mats or grids to limit step and touch potentials adjacent to accessible points on the structure

(b) Measures that restrict access to direct contact with the structure or its appurtenances.

The protective measures employed need to be appropriate to the specific circumstances and to the level of exposure. Although most electrical hazards arise under powerline fault conditions, effects that can cause risk to integrity of structures or safety of personnel may also arise during normal powerline operation. Further information on requirements for electrical safety on pipelines subject to power system influences may be found in AS 4853, Electrical Hazards on Metallic Pipelines and Water Corporation Design Standard DS 23, Pipeline AC Interference & Substation Earthing.

NOTE : Design of any CP system using DS 91 should be read in conjunction with DS 23, Pipeline AC Interference & Substation Earthing and DS 21, Major Pump Station – Electrical, to satisfy both Cathodic Protection and Voltage Mitigation requirements.

16.5.1 Surge Protectors

Many buried pipelines are protected from corrosion by CP systems. To maintain the insulation integrity of the pipe at metering and telemetry stations, insulating joints are inserted into the pipe and those sections between insulating joints are grounded at the station.

With long lengths of pipelines, induced voltages in the pipe caused by local lightning or power line faults activity can be in the order of tens of kilovolts. The result is that insulated joints failure is almost inevitable, with flange type insulated joints particularly susceptible.

To protect against insulated joint break-down, surge diverters are normally connected directly across the joint. The type of surge diverters must be approved by the Water Corporation, Electrical Section of IDB.

When the insulated joint voltage starts to rise due to transients, the surge diverters will conduct and safely pass the transient current to ground, limiting the voltage stress across the joint. After conduction the surge diverter will automatically reset to its inactive state.

17 REFERENCES

Principles and Prevention of Corrosion, D.A. Jones, MacMillan Publication, USA.

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Cathodic Protection, Part 1. Code of practice for land and marine applications, BS 7361

AS 2239, Sacrificial (Galvanic) anodes for Cathodic Protection.

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Control of Pipeline Corrosion, A.W. Peabody, NACE Corrosion Association, Houston, Texas, USA.

Marshall E. Parker & Edward G. Peattie, Pipeline Corrosion and Cathodic Protection, NACE Publication.

Cathodic Protection – An Introduction, NACE Publication, 1987.

MC Miller, How to use and maintain Cu/$CuSO_4$ Reference Electrodes datasheet.

ETS-CP-008, Water Corporation Procedure on maintaining Reference Electrode.

Electrical Installations (Australian,/New Zealand Wiring Rules)

AS 3008, Electrical Installations – Selection of Cables.

Guide for Measurement of Interference Caused by Cathodic Protection and Railway Drainage Systems, NSW Electrolysis Committee, NSW Department of Energy, PO Box 536 St Leonards, 2065, October 1998.

CP Handbook for Technicians, Adelaide Electrolysis Investigating Committee.

AS 4853, Electrical Hazards on Metallic Pipelines.

DS 21, Water Corporation Design Standard, Major Pump Station – Electrical.

DS 23, Water Corporation Design Standard, Pipeline AC Interference & Substation Earthing.

DS 38-2, Water Corporation Design Standard, Flange Connections.

DS 38-3, Water Corporation Design Standard, Flange Bolting.

DS 60, Water Corporation Design Standard, Water Supply Distribution Standard Pipelines Other Than Reticulation.

18 APPENDIX–A: DESIGN OF CP SYSTEMS

18.1 Qualification of Designers

CP systems must be designed by a suitably qualified professional. The “corrosion expert” responsible for design of the system must have a minimum of five years’ experience in the design of CP systems and the design experience must be type specific. For instance, a CP engineer who only has experience designing water tank systems shall not design the CP system for an underground water pipe.

18.2 Factors Affecting Design

18.2.1 Soil and/or Water Resistivity

Resistivity is used to determine the aggressiveness of the medium in which the structure is located and will help to determine whether the CP system should be impressed current or sacrificial anode. Resistivity is one of the most important factors in selecting a ground bed location. The number of anodes required, the length and diameter of the backfill column, the voltage rating of the rectifier and power cost are all influenced by soil resistivity. In general, the lowest and most uniform soil resistivity location with respect to depth should be utilized for a deep ground bed site. Consideration should be given to perched water tables that affect corrosivity assessment due to summer and winter cycle. A number of methods are available for determining resistivity, depending on the type of instrument used, these include:

- four pin method;
- soil box method; and
- soil conductivity method

Reference should be made to instrument supplier instruction booklet for calibration and usage of the instrument. Table 3 provides guidelines for the soil resistivity which is classified as follows:

Table 3 – Interpretation of Soil Resistivity and Corrosion Rate in a Marine Environment [Ref: BS 7361 PI1: 1991]

Resistivity (Ohm-m)	Classification
0-10	Severely Corrosive
10-50	Corrosive
50-100	Moderately Corrosive
100 and above	Slightly-corrosive

18.2.2 PH, Chlorides and Sulphates

The major constituents that accelerate soil corrosion are chlorides, sulphates, and the acidity (pH) of the soil. The degree of corrosivity due to chlorides, sulphates and pH is shown in Table 4. As a general rule, if the concentration of Chlorides > 500 ppm, Sulphates > 150 ppm and pH <5.5, then CP should be considered.

Table 4 - Effect of Chlorides, Sulphates, and pH on the Corrosion of Buried Steel Pipelines

Concentration (ppm)	Degree of Corrosivity	Comments
Chloride		
>5,000	Severe	Chloride concentration is automatically considered when taking the resistivity measurements
1,500–5,000	Considerable	
500–1,500	Corrosive	
<500	Threshold	
Sulphate		
>10,000	Severe	
1,500–10,000	Considerable	
150–1,500	Positive	
0–150	Negligible	
pH		
<5.5	Severe	Considered to be critical in deciding CP installation.
5.5–6.5	Moderate	
6.5–7.5	Neutral	
>7.5	None (alkaline)	

Notes:

Bicarbonates are not typically detrimental to buried metallic structures. However, high concentrations of bicarbonates found in soils/groundwater tend to lower the resistivity without the resulting increase in corrosion activity. Soil samples should be taken at the depth of the pipeline in areas where soil resistivity data may indicate corrosive conditions.

If soil samples are not measured “on location” but are collected for later measurement, they shall be kept in air-tight containers to preserve the normal moisture content. In some instances, abnormally dry surface soils may be moistened with distilled water to obtain their resistivity under wet conditions.

18.2.3 Sulphate Reducing Bacteria - SRB

If the measured SRB level is $\geq 10^3$, then SRB could be viewed as a significantly increasing risk to corrosion probability and CP should be considered for mitigation.

Sulphate Reducers/ml	Interpretation
10^5 (100,000) or more/ml	Heavy
10^3-10^4 (1,000 - 10,000)/ml	Moderate
10^2-10^3 (100 - 1,000)/ml	**Low**
10^1-10^2 (10 - 100)/ml	Very Low
10^1(10) or less/ml	Generally Insignificant

18.2.4 Current Requirement

If field testing is not practical then current requirements can be estimated from the following Table 5:

Table 5 – Typical Current Density (CD) Requirements for the Protection of Bare Steel Immersed in Various Environments

Environment	Resistivity Ω.m	Initial CD mA/m^2	Mean CD mA/m^2	Final CD mA/m^2
Fresh water (potable)	>20	≥50 ≤80	≥50 ≤80	≥50 ≤80
Brackish water	≥0.3 ≤20	≥80 ≤120	≥80 ≤120	≥80 ≤120
Brackish water and sewage	0.5-20	50-100	20-100	20-100
Seawater	<0.3	120	90	90
Seabed mud	----	20	20	20

NOTE: These values may need to be increased for structures immersed in environments warmer than 25°C and they should be reduced if the structure is coated.

Approximate CP current requirements can also be determined according to the formula:

$$I = \left[\frac{10^5}{\rho}\right]^{0.3}$$

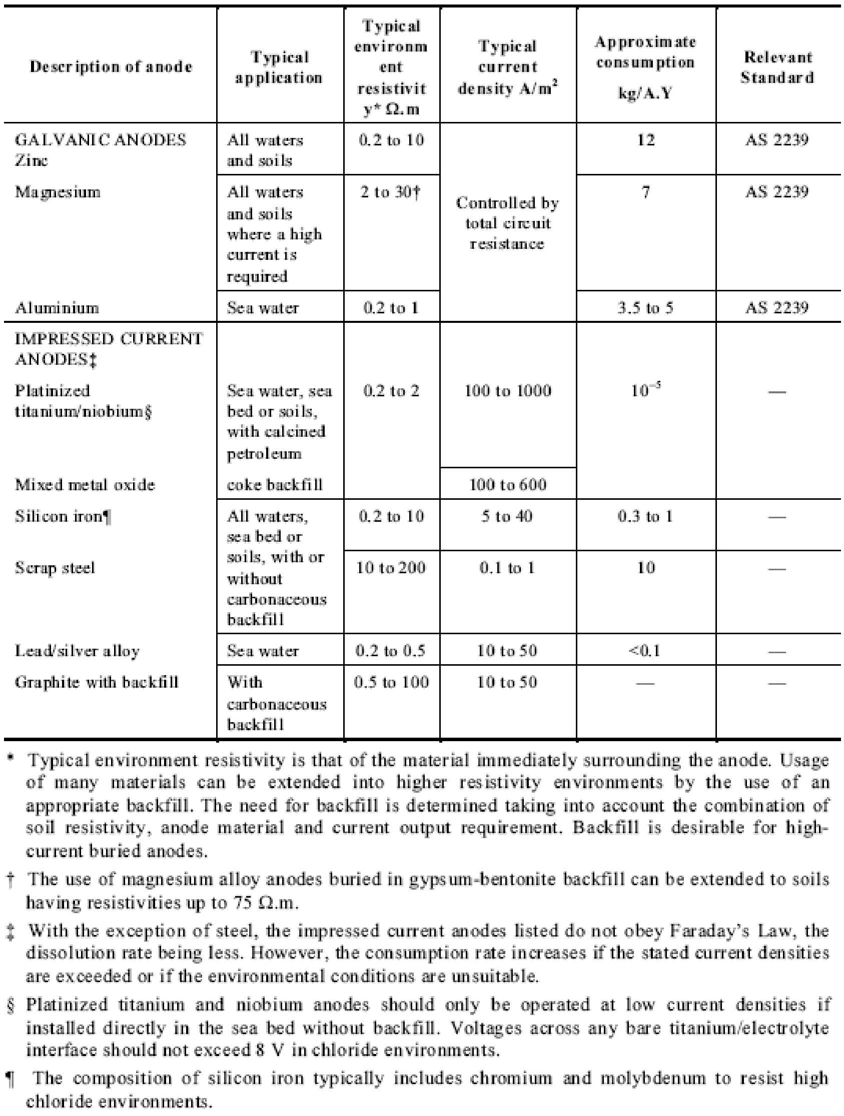
where

I = current density in mA/m^2

ρ = soil or water resistivity in ohm-cm

The major difference between a sacrificial and impressed current system is the driving voltage attainable and therefore the current output. A sacrificial CP system has a driving voltage limited by the Electro Motive Force (EMF) of the galvanic cell (e.g. -1.7 Volts for Magnesium anodes connected to a steel structure); whereas an impressed current system can achieve any driving voltage required (up to 50 Volts). The effective EMF of the galvanic cell is proportional to several factors in the operating environment including resistivity, pH and temperature. Current requirements for coated structures will increase over time due to coating deterioration and other factors. For safety reasons, the driving voltage shall not exceed 50 V DC.

18.3 Anode Selection – Typical Properties and Uses of Various Types of Anodes for Sacrificial and Impressed Current Systems



Description of anode	Typical application	Typical environment resistivity* Ω.m	Typical current density A/m²	Approximate consumption kg/A.Y	Relevant Standard
GALVANIC ANODES Zinc	All waters and soils	0.2 to 10	Controlled by total circuit resistance	12	AS 2239
Magnesium	All waters and soils where a high current is required	2 to 30†		7	AS 2239
Aluminium	Sea water	0.2 to 1		3.5 to 5	AS 2239
IMPRESSED CURRENT ANODES‡					
Platinized titanium/niobium§	Sea water, sea bed or soils, with calcined petroleum	0.2 to 2	100 to 1000	10^{-5}	—
Mixed metal oxide	coke backfill		100 to 600		
Silicon iron¶	All waters, sea bed or soils, with or without carbonaceous backfill	0.2 to 10	5 to 40	0.3 to 1	—
Scrap steel		10 to 200	0.1 to 1	10	—
Lead/silver alloy	Sea water	0.2 to 0.5	10 to 50	<0.1	—
Graphite with backfill	With carbonaceous backfill	0.5 to 100	10 to 50	—	—

* Typical environment resistivity is that of the material immediately surrounding the anode. Usage of many materials can be extended into higher resistivity environments by the use of an appropriate backfill. The need for backfill is determined taking into account the combination of soil resistivity, anode material and current output requirement. Backfill is desirable for high-current buried anodes.

† The use of magnesium alloy anodes buried in gypsum-bentonite backfill can be extended to soils having resistivities up to 75 Ω.m.

‡ With the exception of steel, the impressed current anodes listed do not obey Faraday's Law, the dissolution rate being less. However, the consumption rate increases if the stated current densities are exceeded or if the environmental conditions are unsuitable.

§ Platinized titanium and niobium anodes should only be operated at low current densities if installed directly in the sea bed without backfill. Voltages across any bare titanium/electrolyte interface should not exceed 8 V in chloride environments.

¶ The composition of silicon iron typically includes chromium and molybdenum to resist high chloride environments.

Note:

The above Table is an extract from AS 2832.1, Cathodic Protection of metals, Part 1: Pipes and Cables.

For further details on Anode type and the arrangements, refer Water Corporation Drawing No. MWB 17557-40-010 and 17557-41-1.

18.4 Other Factors to be Considered

18.4.1 Sacrificial Anode Systems

Sacrificial Anodes are normally produced by casting the Aluminium or Magnesium or Zinc alloy around a steel core or insert which is then attached directly or indirectly to the structure to be protected. Some anodes may be produced by extrusion with or without steel core. Cores are prepared prior to casting to ensure maximum electrical contact with the sacrificial anode alloy. The inserts will project outside the body of the anode to provide means for attaching the anodes to the structure by welding or bolting.

Sacrificial anodes are infrequently used where resistivity is in excess of 20 ohms-meter. Sacrificial anodes have a low driving voltage with respect to the protected metal. In high resistivity soils, such low driving voltages cannot produce sufficient current output from the anode. Therefore, in high resistivity soils, an impressed current system may be more economic. For guidance on the application of anodes refer to Appendix C - Australian Standard AS 2239.

18.4.1.1 Sacrificial Anode Selection

Alloys used for sacrificial anodes are based on Magnesium, Zinc or Aluminium. Certain alloys may produce toxic products and it shall be ascertained whether the particular alloy proposed is permitted under the intended conditions of use. The selection of anodes for a particular application can be a complex process, requiring a thorough knowledge of:

- The environment
- Anode composition
- Anode consumption rate
- Anode mass and shape

Table 6 - Typical Properties of Sacrificial Anode Alloys

Anode alloy type	Open Circuit potential, Ea Reference Electrode Cu/CuSO$_4$	Typical anode consumption rate in soil (Kg/A. year)
Aluminium	-1.05 to -1.1 V	Not used
Magnesium		
• High potential	-1.7 V	7
• Low potential	-1.5V	7
Zinc	-1.1 V	12

NOTES:

Magnesium alloys are not suitable for long term protection in saline environments as they self-corrode rapidly. The indicated consumption rate for magnesium can be significantly higher for lower soil resistivities.

Copper sulphate reference electrodes are not recommended for prolonged use in seawater.

Silver chloride reference electrodes are not recommended for freshwater use.

18.4.1.2 Typical Masses, Dimensions and Shapes of Sacrificial Anodes

Anodes are normally cast or extruded.

Cast anodes are usually in the form of a rectangular prism shape

Extruded anodes are usually in the form of rod up to 3 meters long containing a mild steel core 3 to 5 mm in diameter.

The typical masses and dimensions are shown in Appendix B in Australian Standard AS 2239. The selection of anode type and mass depends on various factors. It is highly recommended that designers refer to the manufacturer's data sheet for further details including composition, dimensions, throwing power (efficiency), mass etc of the various types of anodes, to ensure that the system provides the required level of protection without the negative consequences of over protection (refer Section 8.2).

18.4.2 Impressed Current Systems

Design of Impressed Current Deep Well Ground beds should include consideration of the following factors:

- DC continuous rating
- Maximum anode current density
- Anode design service life
- Backfill material requirements (preferred backfill material is Calcined petroleum coke Loresco SC3 for full length of the anode column)
- Typical water resistivity
- Impact of expected down hole anodic reaction products including chlorine, hypochlorous acid and carbon oxides
- Possible development of highly acidic conditions

18.4.2.1 Anode Fabrication

Various types of anodes can be used as per Table H1, AS 2832.1. Where Mixed Metal Oxide (MMO) anodes are specified they shall comply with the following:

- The anodes shall be MMO coated titanium tubes or wires
- The tubes are to be manufactured from Grade 1 Titanium per ASTM B338 (or approved equivalent)
- The wires are to be manufactured from Grade 1 Titanium per ASTM B348 (or approved equivalent)
- The coating composition shall be iridium based with a final thickness to suit the manufacturer’s proprietary information on consumption rates with respect to rated output.
- The anode assembly shall be constructed in a continuous string configuration; the final number of individual anode tubes, diameter and length shall be determined on the basis of the manufacturer’s proprietary design information.

18.4.2.2 Anode Cable

Cables shall consist of the following:

- Core shall consist of flexible copper cables
- The cable primary insulation shall be fabricated from proprietary Halar/Kynar or approved chlorine resistant material.
- The sheath shall be high molecular weight polyethylene (HMWPE) or approve equivalent
- The minimum cable cross section shall be 16 mm^2.

18.4.2.3 Anode Backfill

Various types of backfills are used including:

- Calcined Coke and
- Coke Breeze (Coke Breeze is usually only used for shallow groundbeds)

Where Calcined Coke is specified it shall comply with the following:

Resistivity:	Max. 10 ohm-cm
Fixed carbon content:	Minimum 97%
Max. Particle size:	1 mm
Bulk density:	Nominal 1120 kg/m^3

The material shall be supplied dust free.

18.4.2.4 Anode Vent Pipe

Vent pipe shall be installed to the full depth of the well to allow the release of gas generated by the deep well anodes.

- The vent pipe shall be constructed from slotted DN 20 UPVC Class 12 (minimum) pressure pipe.
- The nominal slot width shall be 1.2 mm with coverage not exceeding 50% of the pipe circumference. The Spacing shall be nominally 10 mm.
- The pipe shall be wrapped in geofabric.

18.4.2.5 Anode Casing

The upper borehole casing shall be constructed using 150NB Class 9 (minimum) UPVC (or approved equivalent).

The active anode zone casing where required, shall be slotted 150NB Class 9 (minimum) UPVC (or approved equivalent).

18.4.2.6 Anode Well Head Arrangement

Refer Drawing no. LL33-054-021 for typical details of well head arrangement.

19 APPENDIX–B: REFERENCE CELLS/ELECTRODES

19.1 General

Reference cells, other than copper/copper sulphate, may be used provided their relationship with copper/copper sulphate reference electrodes is either known or established prior to each series of measurements.

Permanent reference cells shall be checked regularly against an independent or master reference cell to ensure that their potential has not drifted from their standard value.

Accurate readings of the structure potential can then be related to readings taken with a reference cell placed adjacent to the structure. Care shall be taken to ensure that the structure component to which the measuring voltmeter is connected is not carrying a substantial CP current.

With impressed current systems, in particular, parts of the structure may be carrying a large current and hence may cause a significant voltage drop error in the measurement.

19.1.1 Maintenance of Cu/CuSO4 Reference-Cells

Copper in saturated copper sulphate solution will maintain stable potentials within reasonable limits, under practical field conditions. However, with regular use in different soil conditions, copper/copper sulphate ($Cu/CuSO_4$) reference-cells may become contaminated and the potential may deviate.

To maintain a stable potential the reference cell should always be kept in good condition. This is achieved by replacement of the copper sulphate solution, cleaning the copper rod with fine grade emery paper, washing of all components in distilled or demineralised water, and adding crystals of copper sulphate to ensure solution saturation. Distilled or demineralised water shall be used for the cell electrolyte. For consistent results, it is highly recommended to use highest purity $CuSO_4$.

The reference cell should be checked for calibration in accordance with **Water Corporation Procedure No. CP-MESB-CAL-001.**

19.1.2 Measurement of Structure Potential

To obtain reliable results in monitoring CP potentials there must be a conductive path between the reference cell and the structure under test. The reference cell must therefore be placed in intimate contact with the soil. Good results in different environments are achieved as follows:

1. Moist sand and soil - ensure intimate contact between reference cell and sand/soil.
2. Dry soil - dig a small depression and fill with water with small amount of wetting agent.
3. Dry sand - pour water around the reference cell.
4. Concrete – saturate sponge with water or water with wetting agent and place between the concrete and reference cell.
5. Bitumen - Use $Cu/CuSO_4$ reference cells; with saturated sponge above cracks to facilitate contact to the underlying soil.
6. Salt and Brackish Water - use Silver/Silver Chloride (Ag/AgC1) reference cells.

19.1.3 Reference Cells – Common Sources of Error

Voltmeters used in conjunction with reference cells shall be of sufficiently high impedance (10 MΩ or greater) so that contact resistance, which can occur between cell and soil, does not affect readings.

When taking readings, the porous tip of the reference cell must come in contact with the soil. Grass or other items will add resistance and result in inaccurate readings. Prolonged use of reference cells will result in the porous plug assembly being contaminated by foreign materials or becoming worn or cracked. If this occurs the porous plug should be replaced.

If the $CuSO_4$ solution within the cell becomes cloudy, reverse osmosis has occurred and the solution should be replaced.

20 APPENDIX-C: COMMISSIONING

20.1 CP System Commissioning

The commissioning survey should include the following tests and measurements to ensure that the structure is protected in accordance with the design criteria and that all equipment is correctly installed and functioning correctly:

- Measurement of structure potential at all test points, both before and after energisation of the CP system.

***NOTE**: Following the application of cathodic protection, the potential level of the structure may change with time owing to polarization. To ensure that the structure potential is in the desired range, it may be necessary to carry out several potential measurements over a given time.*

In tanks and pipelines *instant off* potentials are measured to minimize voltage gradient effects. The following reading should be taken:

- A check for correctness of polarity of electrical circuits, i.e. positive to anode and negative to structure.
- A functional test of all test points, to ensure correct installation/operation.
- For impressed current systems, the measurement of circuit resistance.
- Current required to provide protection.
- Voltage output of the impressed current system.
- A test for electrical continuity on pipelines.

20.2 Documentation

Records shall include the following items:

- Design documentation - As constructed, O & M manuals
- GPS Co-ordinates
- Results of potential surveys.
- Results of interference mitigation
- Results of soil corrosion probes
- Results of equipment checks.
- The location of any test points added to the system.
- The coating material and application procedures.

END OF DOCUMENT