Australian Standard™

Cathodic protection of metals

Part 2: Compact buried structures

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Standards Australia

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Australian Electrolysis Committee
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Cathodic protection of metals

Part 2: Compact buried structures

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PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee MT-014, Corrosion of Metals, at the request of industry to supersede AS 2832.2—1991, *Guide to the cathodic protection of metals*, Part 2: *Compact buried structures*. After consultation with stakeholders in both countries, Standards Australia and Standards New Zealand decided to develop this Standard as an Australian, rather than an Australian/New Zealand Standard.

The objective of this Standard is to specify the technical requirements for the cathodic protection of compact buried structures.

This Standard is Part 2 of the AS and AS/NZS 2832 series of Standards, titled *Cathodic protection of metals*, currently comprising four parts. The other three parts are as follows:

AS or AS/NZS		
2832	Cathodic protection of metals	
2832.1	Part 1:	Pipes and cables
2832.3	Part 3:	Fixed immersed structures
2832.4	Part 4:	Internal surfaces

To enable this Standard to be referred to in regulations, it now contains requirements for cathodic protection and differs from the other Standards in the AS 2832 series which give guidelines for cathodic protection.

There are no International Standards (ISO) on the cathodic protection of metals.

The terms ‘normative’ and ‘informative’ have been used in this Standard to define the application of the appendix to which they apply. A ‘normative’ appendix is an integral part of a Standard, whereas an ‘informative’ appendix is only for information and guidance.

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FOREWORD

Corrosion of a metal is an electrochemical reaction between it and its environment which results in wastage of the metal. Thus, corrosion is a combination of chemical effects with an associated flow of electrical energy (corrosion current).

In many practical situations, where it is impossible to change the nature of the environment, corrosion may be prevented by employing cathodic protection 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. In practice, the electrical potential of the metal at risk is used to judge whether adequate protection is being achieved.

To employ cathodic protection, a circuit is established by connecting a suitable source of direct current to the structure to be protected.

Two types of cathodic protection systems are available, as follows:

(a) Galvanic anode systems, which employ metallic anodes that are consumed to provide the source of direct current for protection of the structure. The driving voltage for the protective current comes from the natural potential difference that exists between the structure and a second metal (the galvanic anode).

(b) Impressed current systems, in which the driving voltage for the protective current between the structure and the anode is supplied by an external direct current power source.

Corrosion control for a structure should be considered at the conceptual design stage. Factors that affect the corrosion of metallic structures are listed in Paragraph A3 of Appendix A. The practices recommended in this Standard relate to steps that need to be taken following a decision to apply cathodic protection to a structure. These steps are as follows:

(i) Designing the structure to be compatible with cathodic protection and including cathodic protection facilities during construction. For existing structures, determine the measures to be taken to apply cathodic protection effectively, and the facilities necessary for cathodic protection monitoring.

(ii) For new structures, deciding whether to coat, and if so, deciding which particular coating system should be employed. The nature and condition of any coating on existing structures needs to be considered when determining the requirements for the cathodic protection system.

(iii) Designing the cathodic protection system. If the structure is already installed, the design parameters may be measured and an optimum design provided. If the structure is not installed, a number of assumptions, especially in regard to interference, will be required for the estimation of design parameters.

(iv) Installing the cathodic protection system.

(v) Commissioning the cathodic protection system and achieving a balance of cathodic protection current to enable the entire structure to be protected with minimum current, and with as uniform a potential distribution as is practicable.

(vi) Monitoring cathodic protection at regular intervals, adjusting the system as necessary, and maintaining complete records of its operation.

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STANDARDS AUSTRALIA

Australian Standard
Cathodic protection of metals

Part 2: Compact buried structures

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE

This Standard specifies requirements for the cathodic protection of external surfaces of compact buried structures, including tank farms, service station tanks, tower footings, steel pilings (in soil), short well casings, compressor and pump stations and associated pipe work.

The Standard specifically covers the following subjects which relate to cathodic protection:

(a) Pertinent aspects of the design of structures requiring cathodic protection.

(b) Coatings for use on buried structures.

(c) Criteria for the cathodic protection of a structure.

(d) Measuring techniques and equipment.

(e) The design of cathodic protection systems.

(f) The installation of cathodic protection systems.

(g) The control of interference currents on foreign structures.

(h) The cathodic protection of structures subject to stray direct current.

(i) The operation and maintenance of cathodic protection systems.

(j) Electrical hazards.

NOTES:

1 Guidance on the general use and design of cathodic protection systems and factors affecting the corrosion of buried metallic structures are given in Appendix A.

2 This Standard employs conventional (positive) current flow, for consistency with accepted practice, and uses the potential sign conventions specified in AS/NZS 1852 (all parts). In order to understand the various electrochemical reactions that occur at electrodes during cathodic protection, it should be recognized that electron flow occurs in the opposite direction to conventional current flow.

3 Voltage and current referred to in this Standard is direct voltage and direct current, unless otherwise stated.

1.2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS
1100 Technical drawing
1100.401 Part 401: Engineering survey and engineering survey design drawing

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AS

1627	Metal finishing—Preparation and pretreatment of surfaces
1627.2	Part 2: Power tool cleaning
1627.4	Part 4: Abrasive blast cleaning
1697	Gas transmission and distribution systems (known as the SAA Gas Pipeline Code)
1768	Lightning protection
2239	Galvanic (sacrificial) anodes for cathodic protection
2374	Power transformers (all parts)
2430	Classification of hazardous areas
2430.1	Part 1: Explosive gas atmospheres
2885	Pipelines—Gas and liquid petroleum
2885.2	Part 2: Welding
3859	Effects of current passing through the human body
4321	Fusion-bonded medium-density polyethylene coating and lining for pipes and fittings
4799	Installation of underground utility services and pipelines within railway boundaries.

AS/NZS

1020	The control of undesirable static electricity
1518	External extruded high-density polyethylene coating system for pipes
1852	International Electrotechnical Vocabulary (all parts)
2430	Classification of hazardous areas
2430.3.1	Part 3.1: Examples of area classification—General
2430.3.4	Part 3.4: Examples of area classification—Flammable gases
2832	Cathodic protection of metals
2832.1	Part 1: Pipes and cables
3000	Electrical installations (known as the Australian/New Zealand Wiring Rules)
3008	Electrical installations—Selection of cables
3008.1.1	Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV—Typical Australian installation conditions
3008.1.2	Part 1.2: Cables for alternating voltages up to and including 0.6/1 kV—Typical New Zealand installation conditions
3100	Approval and test specification—General requirements for electrical equipment
3108	Approval and test specification—Particular requirements for isolating transformers and safety isolating transformers
3862	External fusion-bonded epoxy coating for steel pipes
4352	Tests for coating resistance to cathodic disbonding
4853	Electrical hazards on metallic pipelines
5000	Electric cables—Polymeric insulated
5000.1	Part 1: For working voltages up to and including 0.6/1 kV

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IEC
61024 Protection of structures against lightning
61024-1 Part 1: General principles
61024-1-1 Section 1: Guide A: Selection of protection levels for lightning protection systems
61024-1-2 Part 1-2: General principles—Guide B: Design, installation, maintenance and inspection of lightning protection systems

61312 Protection against lightning electromagnetic impulse
61312-1 Part 1: General principles
61312-2 Part 2: Shielding of structures, bonding inside structures and earthing
61312-3 Part 3: Requirements of surge protective devices (SPDs)
61312-4 Part 4: Protection of equipment in existing structures

1.3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

1.3.1 Anaerobic

Lacking free oxygen.

1.3.2 Anode (in general)

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

1.3.3 Anode screen

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

1.3.4 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.

1.3.5 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.

1.3.6 Backfill (anode)

Material surrounding, and in contact with, a buried anode for the purpose of maintaining or improving the performance of the anode.

1.3.7 Bond (electrical)

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

1.3.8 Bond (coating)

Adhesion between the coating materials and the substrate.

1.3.9 Cathode

The structure that is to be protected by cathodic protection.

1.3.10 Cathodic disbonding

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

1.3.11 Cathodic protection

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

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1.3.12 Cathodic protection unit

A unit which converts alternating or direct current by another energy source into cathodic protection current.

NOTE: This includes transformers, rectifiers, solid state converters and direct current input from batteries, thermo-electric generators, closed circuit vapour turbines and other sources of direct current.

1.3.13 Converter

A device that converts electrical energy to extra low voltage (ELV) direct current.

NOTE: A rectifier is considered to be a converter.

1.3.14 Copper/copper sulfate ($Cu/CuSO_4$) reference electrode

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

1.3.15 Corrosion

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

1.3.16 Corrosion cell anode

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

1.3.17 Corrosion current

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

1.3.18 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).

1.3.19 Current density (at anode)

Current output of anode divided by the anode surface area.

1.3.20 Current density (at cathode)

Current flowing into cathode divided by the cathode surface area.

1.3.21 Current density (at coated cathode)

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

1.3.22 Drainage (stray current)

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

1.3.23 Earth (noun)

The conducting mass of the general body of the earth.

1.3.24 Earth (verb)

The act of connecting any conductor to earth.

1.3.25 Electrode

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

1.3.26 Electrode potential

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

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1.3.27 Electrolyte

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

1.3.28 Extra low voltage (ELV)

Voltage not exceeding 50 V a.c. or 125 V d.c. (r.m.s.).

1.3.29 Ferrous metal structure

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

1.3.30 Foreign (secondary) structure

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

1.3.31 Galvanic action

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

1.3.32 Galvanic anode

An electrode used to protect a structure by galvanic action.

1.3.33 Galvanic isolator (polarization cell)

Device installed in series with the a.c. protective earthing conductor to block low-voltage d.c. galvanic current flow, but permit the passage of alternating current normally associated with the protective earthing conductor.

1.3.34 Ground bed

A group of buried anodes.

1.3.35 Half-cell

(See reference electrode)

1.3.36 Impressed current

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

1.3.37 Impressed current anode

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

1.3.38 Instantaneous off-potential

A potential substantially free of voltage gradients.

1.3.39 Isolating joint (insulation joint)

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

NOTE: Isolating joints include monolithic insulating joints, insulating flange assemblies and insulating couplings.

1.3.40 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.

1.3.41 Interrupter

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

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1.3.42 IR drop

(See resistance potential).

1.3.43 Loop resistance

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

1.3.44 Overprotection

The state that occurs when the cathodic polarization of a structure is at a level beyond that required for corrosion protection.

NOTE: Overprotection may cause effects that are detrimental to the structure.

1.3.45 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.

1.3.46 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.)

1.3.47 Primary structure

The structure that is subject to intentional cathodic protection.

1.3.48 Protective potential

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

1.3.49 Protective current

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

1.3.50 Reference 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.

1.3.51 Remote earth

A location sufficiently distant from the structure and the anode to be free from voltage gradients in the earth.

1.3.52 Ripple free d.c.

The ripple voltage content shall not exceed 1% of the d.c. output voltage.

1.3.53 Resistance potential

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

1.3.54 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.

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1.3.55 Shielding

A reduction in cathodic protection current to a section of a protected structure caused by either obstruction by adjacent insulating materials, such as disbonded coating, coating structures, or non-metallic structures or the electrical field from cathodic protection applied to an adjacent structure.

1.3.56 Silver/silver chloride reference electrode (Ag/AgCl)

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

1.3.57 Stray current

Current flowing through paths other than the intended circuit.

1.3.58 Structure

A metal surface in contact with an electrolyte.

1.3.59 Structure potential

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

1.3.60 Structure potential shift

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

1.3.61 Sulfate-reducing bacteria

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

1.3.62 Test point

A nominated point on a structure for electrical contact.

1.3.63 Transformer/rectifier (converter)

(See converter).

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SECTION 2 COMPETENCE OF PERSONNEL

The design, installation, operation, inspection, testing and maintenance of cathodic protection systems shall be carried out by, or under the direction of, persons qualified by experience and training in the appropriate aspects of corrosion mitigation in structures. Where the structure is influenced by stray electrical currents, the persons shall have had experience with mitigation of such current.

NOTE: The Australasian Corrosion Association provides training and accreditation for personnel in the corrosion prevention industry.

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SECTION 3 CRITERIA FOR CATHODIC PROTECTION

3.1 SCOPE AND GENERAL

3.1.1 Scope

This Section specifies the criteria for determining when the appropriate amount and distribution of direct current is being applied to the structure.

3.1.2 General

The corrosion of buried metal structures is controlled by the application of direct current to lower and maintain their potential at a sufficiently negative level with respect to the environment. The direct current is provided by the use of an impressed current system, galvanic anodes, or a combination of both.

Protection criteria based on potential measurement, and other references to potential in this Standard, use values relative to the copper/saturated copper sulfate reference electrode. Reference electrodes other than copper/copper sulfate may be used, provided that their relativity to copper/copper sulfate is established.

3.2 PROTECTION CRITERIA

3.2.1 General

The degree of protection shall be assessed by the use of one or more of the criteria set out in Clauses 3.2.2, 3.2.3 and 3.2.4. It is important that advice be obtained from a cathodic protection specialist to ensure that the criteria are correctly applied.

3.2.2 Potential criteria

3.2.2.1 *General*

The potential criteria specified in this Standard are applicable where the structure temperature is near ambient, and the electrolyte near the metal/electrolyte interface comprises natural soils and waters that are substantially free of active sulfate-reducing bacteria. If these conditions are not met, an evaluation of the conditions shall be carried out and an appropriate criterion determined.

The criteria given in Clauses 3.2.2.2, 3.2.2.3, 3.2.2.4 and 3.2.2.5 shall apply provided that there is not a significant voltage gradient in the electrolyte between the structure and the reference electrode. The criteria given in Clause 3.2.2.6 shall apply for structures subjected to variable stray current effects.

A method of preventing the cathodic protection electrolyte voltage gradient from affecting the measured potential readings is to measure an instantaneous off-potential, (see Appendix B).

3.2.2.2 *Ferrous structure*

The criteria for the protection of a buried ferrous structure shall be to maintain a potential on all parts of the structure equal to, or more negative than, −850 mV with respect to a saturated copper/copper sulfate reference electrode.

3.2.2.3 *Copper/copper alloy structure*

The criteria for the protection of a buried copper structure shall be to maintain a potential on all parts of the structure equal to, or more negative than −300 mV with respect to a copper/copper sulfate reference electrode.

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3.2.2.4 *Lead structure*

The criteria for the protection of a buried lead structure shall be to maintain a potential on all parts of the structure equal to, or more negative than, −650 mV with respect to a copper/copper sulfate reference electrode when the structure is in aerated conditions, and equal to, or more negative than, −800 mV with respect to a copper/copper sulfate reference electrode when the structure is in anaerobic conditions.

3.2.2.5 *Mixed metal structure*

The criteria for the protection of a buried mixed metal structure shall be to maintain a potential on all parts of the structure equal to, or more negative than, that required for the most anodic metal.

3.2.2.6 *Structures subject to variable stray current effects*

The response of a structure to anodic stray current excursions is dependent upon many factors including soil resistivity, degree of soil aeration, moisture content and the structure coating quality. The extent of depolarization is determined by the frequency, magnitude and the duration of anodic excursions.

Variable stray traction effects shall be evaluated when there is an indication that the structure potentials are varying and there is evidence that the potentials are positive of the protection criteria defined in Clauses 3.2.2.2 to 3.2.2.5 for a period of time, no matter how short that period may be.

The measured potential is the sum of the polarized structure potential and the potential from the voltage gradient in the electrolyte. When potentials are affected by stray current, it may not be possible to determine whether they are free of voltage gradients, and thus to compare the measured potential with the protection criterion. In such cases, an estimation of the electrolyte voltage gradient will suffice to determine the protection criterion. This measured potential is used to determine the magnitude and duration of anodic excursions.

3.2.2.7 *Traction current effects*

Where structures are required to be evaluated for traction stray current effects in accordance with Clause 3.2.2.6 the potential shall be recorded over a sufficient period of time to ensure that the maximum exposure to the stray current effects is encompassed. This period shall include the morning and evening usage peaks and is nominally twenty hours. If a data logger is used for the monitoring of potential, its frequency of sampling shall be not less than one sample per minute.

NOTE: For determining stray current effect see Appendix N.

The protection criteria for structures subject to traction current effects varies with the structure polarization time as follows:

(a) *Structures with short polarization times*

Structures with sound coating characteristics, or have otherwise been proven to polarize and depolarize rapidly in response to stray current, shall comply with the following criteria:

(i) The potential shall be not less negative than the protection criterion for more than 5% of the test period.

(ii) The potential shall be not less negative than the protection criterion plus 50 mV, i.e. −800 mV for ferrous structures, for more than 2% of the test period.

(iii) The potential shall be not less negative than the protection criterion plus 100 mV, i.e. −750 mV for ferrous structures, for more than 1% of the test period.

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(iv) The potential shall be not less negative than the protection criterion plus 850 mV, i.e. 0 mV for ferrous structures, for more than 0.2% of the test period.

(b) *Structures with long polarization times*

The potential of structures that exhibit deteriorated coating characteristics, or have otherwise been proven to polarize and depolarize slowly in response to stray current, shall be not less negative than the protection criterion for more than 10% of the test period.

3.2.3 100 mV polarization decay criterion

The criterion for the protection of a buried structure shall be to maintain an instantaneous off-potential on all parts of the structure, which is at least 100 mV more negative than the depolarized potential (see Appendix B).

This criterion is not applicable if the structure is affected by stray current or significant galvanic corrosion couples.

3.2.4 Alternative criteria

3.2.4.1 *Coupon criterion*

When using coupons, the criterion for the protection of a buried ferrous structure is when the instantaneous off-potential on the coupon is either equal to, or more negative than, −850 mV with respect to a copper/copper sulfate reference electrode, or is at least 100 mV more negative than the depolarized potential.

Coupons shall be installed and used in accordance with the requirements of Appendix C.

3.2.4.2 *Resistance probe criterion*

When using resistance probes, the criterion for the protection of a buried ferrous structure is when the corrosion rate of the resistance probes does not exceed 5 μm per year, and the instantaneous off-potential on the probe element is either equal to, or more negative than, −850 mV with respect to a copper/copper sulfate reference electrode, or is at least 100 mV more negative than the depolarized potential. Resistance probes shall be installed and used in accordance with the requirements of Appendix C.

3.2.4.3 *Other criteria*

Other protection criteria may be used, provided that their validity can be demonstrated.

3.3 OVERPROTECTION

To ensure that overprotection does not cause accelerated disbondment of a coating or other deleterious effects, the potential corrected for soil voltage gradient error shall be measured or estimated. This may be achieved by measuring the instantaneous off-potential as described in Appendix B.

NOTES:

1 For ferrous, lead, copper and copper-alloy structures, this potential (which is free of voltage gradient potential) should not be more negative, with respect to a copper/copper sulfate reference electrode, than −1.2 V. Less negative values may be appropriate for coatings that are more susceptible to cathodic disbonding.

2 For tests to determine coating resistance to cathodic disbonding, refer to AS/NZS 4352.

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SECTION 4 MEASURING TECHNIQUES AND EQUIPMENT

4.1 GENERAL

All instruments and measuring equipment used for determining electrical values shall be of an appropriate type and accuracy and have a valid calibration certificate. Calibration of the equipment shall be carried out to the required level of accuracy, annually, or at intervals appropriate to its stability, or whenever service conditions may have resulted in loss of accuracy. Care shall be taken to ensure that the correct polarity is noted in all measurements.

Records shall be maintained to keep information on instruments used to conduct specific tests and any subsequent calibration adjustments.

The polarity of the test cables shall be checked to ensure that the correct sign is applied to the potential values.

The calibration and/or maintenance of reference electrodes shall be carried out as specified in Appendix D.

4.2 POTENTIAL MEASUREMENT AND EQUIPMENT

4.2.1 General

The influence of stray current shall be established on the structure by data logging over a nominal period of 20 hours or by other means as required. In areas free of significant stray current, potentials may be measured by a single observation.

The equipment used for potential measurements shall have the following characteristics:

(a) An input impedance of at least 10 MΩ, unless it can be verified that a lower impedance is adequate to contain errors to less than 10 mV at the point(s) being tested.

(b) An accuracy of better than ±10 mV.

(c) a.c. rejection of better than 60 dB, together with an ability to reject overload by a.c. signals of up to 30 V r.m.s., unless it can be verified that lesser a.c. rejection characteristics are adequate at the point(s) being tested.

(d) Errors in d.c. measurements, due to the presence of a.c. signals, of less than 10 mV.

NOTES:

1 The half cell or electrode resistance to earth may be assessed by shunting the voltmeter with a resistor of about one tenth of the input resistance of the meter. A variation of 10% or more between the unshunted and shunted voltmeter readings, indicates unsatisfactory reference electrode resistance conditions and corresponds to an error in the unshunted voltmeter reading of approximately 1%. Alternatively, a voltmeter with a selectable input impedance may be used for assessing the acceptability of reference electrode contact resistance.

2 Contact resistance due to dry soil surface conditions may be reduced by moistening the soil in contact with the reference electrode.

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4.2.2 Positioning of monitoring electrodes

When measuring potential, reference electrodes are preferably placed at locations of minimum soil voltage gradients, i.e. remote from anode beds and above and as close as possible to the structure. The effect of current flow from nearby impressed current ground-beds or sacrificial anodes shall be less than 10 mV, or be taken into account when determining potential readings. These considerations shall similarly apply when establishing the potential of fixed electrodes.

4.2.3 Off-potential measurements

Instantaneous off-potential measurements in areas that are not subject to the effects of stray currents shall be carried out in accordance with Appendix B ensuring that all current sources are interrupted synchronously. These current sources include galvanic anodes, earthing systems, cross-bonds and polarization cells. For measurement techniques in areas affected by stray currents refer to Clause 3.2.2.6 and 3.2.2.7.

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SECTION 5 DESIGN OF STRUCTURES TO ACCOMMODATE CATHODIC PROTECTION

5.1 SCOPE AND GENERAL

5.1.1 Scope

This Section provides requirements and guidance for the design of compact buried structures, to accommodate cathodic protection.

For protection to be achieved, a structure shall—

(a) be immersed or buried in an electrolyte; and

(b) be electrically continuous.

NOTE: Usually the structure should be electrically isolated from structures not requiring protection.

5.1.2 General

Because many aspects of design and construction of compact buried structures can interfere with the corrosion prevention process, cathodic protection has to become an integral part of the design stage. This will minimize unnecessary and sometimes costly modifications and help to ensure the safe operation of the structure and maximize its economic life.

NOTES:

1 Cathodic protection should be applied at the completion of the construction of the structure.

2 Additional information on structure design is given in Appendix E.

5.2 MATERIALS OF CONSTRUCTION

Careful consideration shall be given to the proposed materials to be used in a structure that is to be protected by cathodic protection.

Cathodic protection shall be applied with caution to structures that are made from materials which are subject to attack under alkaline conditions (e.g. lead, aluminium and zinc), due to the high pH levels developed at the cathode surface.

The effects of dissimilar metals and alloys on the structure shall be considered, in order to mitigate unintended bi-metallic corrosion and to select an appropriate protection criterion that recognizes the interaction that can occur between different metals (see Section 2).

5.3 COATED AND UNCOATED STRUCTURES

Most structures shall be coated prior to installation. Cathodic protection of uncoated structures requires the use of higher levels of current than coated structures and, generally, a greater number of cathodic protection installations. The higher levels of current could significantly increase the risk of causing interference with foreign structures. Legislation may require that cathodic protection installations that cause interference be turned off.

NOTE: Information on coatings for use with cathodic protection is given in Appendix F.

5.4 ELECTRICAL HAZARDS AND DISTURBANCES

There are a number of mechanisms that can give rise to electrical hazards in buried structures.

NOTE: Details of hazard mechanisms, their interaction with cathodic protection and advice on how to overcome hazards are given in Appendix G.

The following forms of stray current can affect the structure or its operation:

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(a) *Direct current*

Stray direct current can pose a corrosion hazard to a buried structure. A very rapid rate of corrosion can develop at the point where the current discharges from the structure surface. Such current can originate from railways, tramways, other cathodic protection installations or electrical distribution systems.

Generally it is not possible to quantify the problem or to design preventative procedures until the structure is installed and the environment has stabilized. It may be possible to reduce or remove the problem at the design stage by locating the structure away from sources of such current.

(b) *Surge current (short term conditions)*

Surge current (short term conditions) can arise from the following:

(i) *Lightning* The results of lightning can include direct flash contact to the structure or its ancillaries and to, exposed valves and test points (see Appendix G, Paragraph G2.1).

(ii) *Power transmission systems* The results of surge current in power transmission systems can include conductive coupling to the structure in the earth from power fault current to a nearby tower or electrical earthing system (see Appendix G, Paragraph G2.1).

In respect to the design of mitigative measures for hazards generated in accordance with Item (b) above, the attention of a specialist is required.

5.5 TEST POINTS

5.5.1 General

Test points shall be used to monitor structure potentials, and a sufficient number are needed to enable the assessment of the effectiveness of the cathodic protection.

5.5.2 Location

Test points shall be located to give an overall indication of the spread of protection, and encompass critical areas where problems are likely to be encountered or where extra precautions are required. Locations for test points shall include the following positions:

(a) Adjacent to insulating joints and at structure terminations.

(b) At likely sources of stray currents, and at discharge points for stray currents.

(c) Adjacent to air/electrolyte interfaces.

(d) Close to foreign structures.

(e) Adjacent to anode locations.

Test points may require to be located outside hazardous areas, or alternatively be enclosed in an intrinsically safe box if inside a hazardous area, for example, if they contain current carrying connections that may cause a spark hazard.

Test point cabling requirements are given in Clause 6.5.

All test point terminal boxes shall be of durable construction and be suitably identified.

NOTE: Where posts and identification signs are painted, non-toxic paints should be used.

5.5.3 In situ reference electrodes

Consideration shall be given to the installation of in situ reference electrodes, especially in areas where the structure is affected by stray direct current or where the structure is located under a hardstanding area. Such reference electrodes shall either have a fixed and known

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potential or should be capable of calibration at each time of use. Their potential should be stable during each period of use and shall not be polarized by current flow in the measuring circuit.

NOTE: Premature consumption of the electrode chemicals has been observed to occur where cells have been installed in direct current electric fields in permanently wet conditions, and care should be exercised in their placement to minimize early deterioration.

5.6 INSULATING JOINTS (ISOLATING JOINTS)

Insulating joints are used to electrically isolate parts of the structure to facilitate the use and control of cathodic protection systems. They may consist of flange assemblies, couplings or monolithic joints. The dielectric strength of such joints shall be compatible with the system design.

A structure containing a liquid electrolyte but requiring cathodic protection on the external surface may suffer serious corrosion at insulating joints or flanges. This may be minimized by coating the structure internally for a distance away from the flange. The coated length will depend on the conductivity of the electrolyte and shall be sufficient to ensure that the passage of cathodic protection current through the internal electrolyte does not adversely affect the integrity of the structure.

Mechanical requirements for insulating joints shall comply with the requirements of the appropriate design code.

Typical locations where the provision of insulating joints shall be considered include the following:

(a) At ownership changeover points.

(b) At connection points to other structures or piping.

(c) At inline measuring and/or pressure regulating stations.

(d) At compressor and pumping stations.

(e) In stray current areas.

(f) At junctions of dissimilar metals.

(g) Where it is necessary to isolate the structure from electrical earthing.

(h) At structure terminations.

Insulating joints should not be positioned in enclosed or defined hazardous areas where combustible gases may be present unless electrical surge protection is provided. Surge protection devices in such areas should be of a type that cannot cause an exposed arc.

Surge protection should be considered at isolating joints where incoming pipelines parallel high voltage transmission lines and in lightening prone areas.

NOTE: Cable connections should be short, direct, and of a size suitable for carrying short-term high-current loading.

Where an insulating joint is to be installed below ground and when both sides of the joint are to be cathodically protected, the joint shall be insulated from the electrolyte with a suitable coating.

NOTE: Where insulating joints are installed above ground, any gap between flanges should be filled with an electrically insulating compound and the outer faces of the flanges should be coated to minimize the possibility of accidental short-circuiting.

In hazardous areas where there is danger of sparks causing the ignition of flammable gases, the insulated joints should be suitably coated to prevent accidental short-circuiting.

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In areas subject to high voltage surges, such as near high voltage power transmission lines or areas subject to electrical storm activity, insulating joints should be provided with a system that will protect joint insulation, and safeguard personnel from electrical shock should they be in contact with both sides of the joint at the time of a surge. Such systems include polarization cells, insulating shrouds, properly rated surge protection devices and adequate insulation over a length of the structure to prevent personnel contact.

NOTE: Where possible all insulating joints should be electrically tested prior to installation. It is also advisable to electrically retest all insulating joints prior to backfilling.

5.7 ROAD AND RAIL CROSSINGS

From a corrosion protection viewpoint, uncased crossings are preferred to cased crossings. However, in practice, buried structures are often cased under railway lines and major roads; such casings shall be made of a conductive material, e.g. steel or concrete.

Where steel casings are used they shall be electrically isolated from the structure by insulating spacers. Cathodic protection of buried encased structures shall be in accordance with AS 4799.

5.8 ELECTRICAL ISOLATION

Buried structures shall be installed in a manner to ensure that they remain electrically isolated from all foreign buried metallic structures.

A separation of at least 300 mm shall be maintained between buried structures to prevent metallic contact, shielding and to minimize interference.

Specific items that require electrical isolation from a protected structure include the following:

(a) Metallic reinforcement in weights, anchors and weight coatings.

(b) Uncoated metal housings ancillary to a structure.

(c) A metal sleeve, when it is intended to maintain electrical isolation between the sleeve and the structure.

NOTE: If the sleeve remains in electrical contact with the structure, a loss of cathodic protection on the structure will occur within the sleeve area. Depending on design requirements this may be of little consequence.

(d) Electrical supply earth systems.

NOTES:

1 Possible connections may occur in the earthing systems of compressors, pumps, telemetry installations, and valves or in any other electrically powered equipment that is earthed.

2 Isolation of electrical earthing may be achieved by the use of galvanic isolators (polarization cell), subject to the agreement of the electrical distributor.

(e) Metal and metal reinforcing, together with associated earthing conductors and electrodes, on power transmission towers.

(f) Areas where there is a likelihood that cathodic protection will be adversely affected by contact with other metallic structures such as bridgework, pipe stanchions, tunnel enclosures, piling and reinforcing in concrete.

NOTE: Where structures are attached to bridgework, it is permissible to forego electrical isolation, provided that insulated joints are used at each end of the bridge at the air/ground interface, i.e. where the pipe enters the ground.

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5.9 ELECTRICAL CONTINUITY

For cathodic protection to be effective it is necessary to ensure that the structure, or each section of the structure, shall be electrically continuous. Bonds may be required to provide continuity of cathodic protection around sections isolated by insulating joints.

Care shall be taken to ensure electrical continuity in bolted structures.

NOTE: The use of electrically-continuous welded or fusion joints is recommended. Joints of high electrical resistance, e.g. flanges with elastomeric rings, or spigot or socket couplings, should be fitted with bonds.

The mechanical strength of a bond shall be adequate to withstand the effects of backfilling and maintenance, and the current-carrying capacity of a bond shall be sufficient for it to remain undamaged after the passage of a heavy surge current from an external source (see Clause 5.4(b)).

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SECTION 6 DESIGN OF CATHODIC PROTECTION SYSTEMS

6.1 SCOPE AND GENERAL

6.1.1 Scope

This Section provides requirements for the design of systems for cathodic protection.

6.1.2 General

The design requirements for cathodic protection systems shall comply with applicable regulatory requirements and the relevant requirements of AS/NZS 3000, AS/NZS 5000.1 and AS 2374 (all parts) for conductor current ratings, transformers (converters), circuit protection and personal safety.

NOTES:

1 The installation and operation of cathodic protection systems and/or traction drainage bonds may be subject to approval under legislation. In Australia, the control of stray currents from d.c. traction systems is co-ordinated by State Electrolysis Committees.

2 Detailed information for the design of cathodic protection systems is given in Appendix H.

6.2 SAFETY HAZARDS

As a matter of personnel safety, the open-circuit voltage of a cathodic protection power supply shall not exceed 50 V d.c.

NOTE: Appropriate safety precautions are required where voltages exceed 50 V d.c.

Consideration should be given to the possibility of unintended high voltages occurring on the structure caused by the following:

(a) Induced potentials and earth potential rise from neighbouring high voltage power lines (see Paragraph G2.2, Appendix G).

(b) Surge effects due to power systems component failure including voltages developed across insulated joints.

(c) Effects of lightning (see Paragraph G2.2(b), Appendix G).

(d) The effects of electric sparks on structures carrying products that are flammable and capable of forming explosive air/gas mixtures (see AS 2430.1).

NOTES:

1 AS 2430.1 defines the extent of hazardous zones in relation to various types of installations or items of equipment handling flammable liquids or gases; it is essential that there is no chance of a spark occurring within such a hazardous zone.

2 Conduit or ducting proceeding from a cathodic protection installation into hazardous areas, e.g. test boxes and transformer rectifier enclosures, should be sealed to prevent the flow of flammable substances.

3 It is also necessary in such circumstances to ensure control of static electricity (see AS/NZS 1020).

(e) Electrical gradients produced in water around fully and partially submerged anodes.

NOTE: Electric field strengths in water in excess of about 3 V/m when applied to the body at chest level can paralyse and cause respiratory failure. For design reasons, the field strength may sometimes be required to exceed this value. This will occur most frequently close to impressed current anodes, sometimes in sea water. In these situations, warnings should be given and access to such areas prevented by shielding or other means.

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6.3 DESIGN REQUIREMENTS

The cathodic protection system for a structure shall be designed to provide full protection for the specified life of the system. In particular the system shall—

(a) achieve a level of protection in accordance with the performance criteria and the protection criteria appropriate to the structure;

(b) comply with all relevant regulatory requirements;

(c) be compatible with the material of the structure;

(d) not cause detrimental anodic or cathodic interference to any foreign structure;

(e) not cause excessive negative potentials that may be harmful to the structure or to the coating of the structure (see Clause 3.3);

(f) incorporate a monitoring system to evaluate the levels of protection achieved;

(g) not cause excessive electrical noise in telecommunication or information technology circuits.

NOTES:

1 Noise is minimized by correct filtering of transformer/rectifier units.

2 For maximum allowable noise levels, refer to the relevant Telecommunications Act.

(h) not cause malfunctioning of railway signalling equipment; and

(i) be capable of adjustment during commissioning.

In areas subject to the effects of stray current from traction systems or other cathodic protection systems, the design shall allow for the mitigation of possible interaction on the structure.

The cathodic protection system shall be brought into operation as soon as possible following construction.

NOTE: Where delays to the achievement of permanent cathodic protection are unavoidable consideration should be given to temporary cathodic protection in particular areas that are corrosive.

6.4 DESIGN DATA

6.4.1 General

Data for the design of a cathodic protection system shall be collected, documented and retained for the life of the system.

NOTE: Structure factors that have a significant bearing on the design of a cathodic protection system are given in Appendix E and an example of cathodic protection system design documentation is given in Appendix I.

6.4.2 Structure layout

Details of the structure shall be collected and documented. All features that may affect the successful implementation of a cathodic protection system shall be documented and considered in the design.

6.4.3 Cathodic protection current requirements

The current requirements for cathodic protection shall be determined by trial or by calculation. All assumptions in the derivation of the total current requirement shall be clearly documented. Sufficient capacity shall be provided to allow for—

(a) structure coating deterioration over the life of the system; and

(b) mitigation of interference effects with any secondary structure.

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6.4.4 Environment resistivity

The environment resistivity at the site of each impressed current cathodic protection ground bed installation shall be determined by an appropriate method and shall be documented.

6.4.5 Anode characteristics

The performance characteristics of the anodes to be used for the system shall be determined and documented. In particular, the actual consumption rate of the anode in the operating environment shall be estimated and confirmation made that the anode array will achieve the system requirements in terms of current output and life.

6.5 MATERIALS

6.5.1 General

All materials specified in the design shall be suitable for installation in the proposed environment.

6.5.2 d.c. cables

6.5.2.1 *General*

The current carrying capacity and temperature ratings of cables shall comply with the requirements of AS/NZS 3008.1.1. Cables shall be appropriately sized for the maximum design currents and shall be appropriately insulated. Joints in cables shall be avoided wherever possible, but where installed they shall be located so as to be accessible and their location clearly documented. Particular care shall be taken with the insulation of positive cables as any damage or deterioration to the insulation can result in premature failure of the cable.

6.5.2.2 *Insulation*

Impressed current anode cables are particularly susceptible to failure from damage and insulation breakdown due to rapid anodic copper dissolution and the effects of chlorine gas (see Note to Clause 5.5.3).

Consideration shall be given to sources of environmental attack on cable insulation such as termites and other agents.

NOTES:

1 Colours for cable insulation on any one installation should comply with a uniform colour code. Where a colour code is not specified, the following insulation colours are recommended:

(a) Primary structure ..... black.

(b) Anode feeder cables ..... red.

(c) Reference electrodes ..... yellow.

(d) Earthing electrodes ..... green or green-yellow.

2 Cable colours coded with green and green-yellow spirals are to be used exclusively for safety earthing applications.

6.5.2.3 *Cable connections*

Cable connections shall be electrically sound and sealed to prevent the ingress of moisture. Typical connection processes comprise welding (including thermit welding), brazing and bolting.

NOTE: For details on thermit welding on hydrocarbon pipelines, refer to AS 2885.2.

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6.5.3 Test cables

Test cables shall be made of copper, be of stranded construction, have a minimum conductor size of 4 mm^2 and comply with AS/NZS 5000.1. Double-insulated cable is preferred.

6.5.4 Anodes

Anodes shall be fit for the intended purpose and conform to the relevant specifications. Sacrificial anodes shall comply with the requirements of AS 2239.

NOTE: The anode reactions of an impressed current cathodic protection installation in a saline environment result in the electrolytic formation of chlorine. Under stagnant conditions, the chlorine may be evolved as a gas and could present a hazard to cable insulation, e.g. PVC, and to inspection and maintenance personnel.

6.5.5 Reference electrodes

Permanently installed reference electrodes shall either be designed to last the life of the system, or provision shall be made for their replacement (see Clause 4.2.2).

Requirements for the calibration and maintenance of reference electrodes are set out in Appendix D.

6.5.6 Electrical isolation joints

Electrical isolation joints shall be designed to take account of the operating conditions of the structure in terms of maximum design pressure, vibration, fatigue, cyclic conditions, temperature, thermal expansion and construction installation stresses. The materials selected shall be resistant at the structure design temperature, to any fluids transported, including any corrosion inhibitors or flow modifiers that are added to these fluids.

6.6 TEST POINTS

Provision shall be made for the measurement of the structure potential at the structure to enable the effectiveness of the cathodic protection system to be verified. Test points shall be installed at all steel casings.

All cable attachments shall be made in a manner appropriate to the structure, and during connection any damage to the coating shall be repaired with an approved material that is compatible with the structure coating and the cable insulation.

6.7 REFERENCES

Where permanent references are installed they shall be located close to the structure and at a similar depth to the structure.

The potential of a reference electrode shall be able to be verified to detect any variations.

6.8 ELECTRICAL EARTHING

NOTE: Information on electrical earthing is given in Appendix G.

6.9 GRAPHICAL SYMBOLS

The graphical symbols used on drawings and plans to identify cathodic protection details shall be in accordance with AS 1100.401, as appropriate, and Appendix J.

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SECTION 7 INSTALLATION OF CATHODIC PROTECTION SYSTEMS

7.1 SCOPE

This Section outlines procedures for the installation of systems for the cathodic protection of compact buried metallic structures.

7.2 APPROVAL TO INSTALL

Where required by regulatory authorities, it shall be confirmed that approval to install and operate the system has been obtained. Approval will usually have required the identification and the interference testing of all nearby underground metallic structures.

Before any work is commenced, all necessary approvals shall be sought. Liaison with other authorities and other property owners may be required prior to installation. A thorough check shall be made by the installer to establish the existence of other nearby services so that steps can be taken to avoid mechanical damage to these services.

NOTES:

1 In some Australian States, a dial-before-you-dig underground plant referral service is available.

2 In most states or regions the installation and operation of cathodic protection systems require approval under legislation. The control of interference is coordinated by local Electrolysis Committees or the Regulatory Authority (see Appendix K).

If the installation is to be in a defined hazardous area, specific written approval to install the system shall be obtained and a check for hazardous atmospheres carried out immediately prior to commencing any work.

7.3 INSTALLATION PRACTICE

The installer shall be familiar with specification(s) for the works and shall ensure that all works are completed in accordance with good industrial practice. Additional requirements are as follows:

(a) Deviations from design specifications shall be permanently recorded for future reference and an as-installed plan prepared as works proceed.

(b) Installation of all electrical work shall be carried out in accordance with local electricity regulations, and relevant Standards.

Before dismantling, an insulated joint shall be shorted out (cross-bonded).

(c) Structures and test cable connection joints shall be clean, dry and free of damage at the time connections are made.

(d) Test point connections shall be mechanically secure and electrically conductive for the life of the structure.

(e) All test cable attachments to structures shall be coated with an electrically insulating material that prevents ingress of moisture. This coating shall be compatible with the structure coating and cable insulation, and have good adhesion to both.

(f) All ground surfaces that are disturbed shall be suitably reinstated.

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7.4 INSPECTION REQUIREMENTS FOR MATERIALS AND EQUIPMENT

7.4.1 General

Prior to shipment to site, materials and equipment shall be checked for compliance with the appropriate specification or Standard. On site, prior to installation, materials and equipment shall be checked to ensure that they are free from damage caused during transit and are fit and suitable for use. Clauses 7.4.2 to 7.4.5 specify checks and tests which shall be undertaken to avoid unnecessary and protracted delays if replacements are sought or repairs are undertaken.

7.4.2 Anodes

Galvanic and impressed current anodes shall be inspected for the following:

(a) Freedom from critical damage, i.e. damage that will affect the life or the operation of the anode.

(b) Integrity of mechanical and electrical connections.

(c) Correct dimensions.

(d) General compliance and identification of anodes (including anode backfill) with the purchaser's specification.

(e) Colour coding of cables.

(f) Insulation of all cable tails for nicks, cuts or other forms of damage, which for impressed current anodes may cause premature failure of the system.

7.4.3 Cables

Cables shall be inspected to ensure that cable runs can be achieved in the specified lengths in one take-off from a reel or drum and that the cable is of correct construction for the intended application.

7.4.4 Transformer-rectifier equipment

Testing shall be carried out prior to acceptance of a transformer-rectifier (converter) unit to confirm compliance with written specifications and to ensure that the equipment is suitable for the intended purpose. Electrical output, insulation and temperature rise tests shall be carried out in accordance with AS/NZS 3108.

The following tests shall also be carried out:

(a) Visual inspection to ensure that all rectifier and surge protection equipment, and all specified current outputs, have been provided.

(b) Polarity check to ensure that output terminals are correctly identified.

(c) Operational check of unit output against the calculated load, to ensure that a uniform control pattern is available.

(d) Functional tests of time switches, if installed.

(e) Functional tests of other special equipment to be fitted.

7.4.5 Prefabricated insulated joints

Where appropriate, each joint shall be electrically tested. Where supplied for welding into position, the lengths of associated pipe pieces shall be sufficient to prevent the joint insulation from being damaged by heat transfer during the welding process.

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7.5 INSTALLATION OF GALVANIC ANODE SYSTEMS

Before an anode is buried or immersed, any waterproof wrapping material shall be removed.

Suitable backfilling materials for use around buried sacrificial anodes as given in AS 2239, Section 4. These are selected to have an electrical resistance as low as, or lower than, that of the surrounding soil.

Packaged anodes shall be inspected to ensure that backfill completely surrounds the anode. Where anodes and backfill are provided separately, anodes shall be centred in the backfill and the backfill shall be compacted before any additional backfill soil is added.

Preliminary electrical testing shall be carried out to ensure that continuity of anode to structure connection has been achieved, while work crews are still on site. This will enable remedial action to be readily carried out.

NOTE: To enhance the initial operation of the anode, the backfill should be thoroughly wetted after installation.

7.6 INSTALLATION OF IMPRESSED CURRENT ANODE SYSTEMS

7.6.1 Cabling

All cables shall be carefully unreeled to avoid kinks, knots and damage to the insulation.

Care shall be exercised to ensure that cable insulation and connections are not damaged during backfilling. Sufficient cable slack shall be provided to avoid strain. Damaged cable shall be replaced or repaired in an approved manner.

All buried cables shall be laid centrally in a trench with at least 75 mm of suitably graded backfill, or ‘in’ conduit, to a minimum depth of 300 mm, to prevent damage to cables.

Cable joints shall be completely waterproofed using an appropriate cable jointing compound. Waterproofing is particularly important on the positive (or groundbed) side of an impressed current cathodic protection system to prevent localized rapid corrosion at the joint and consequent failure of the whole system.

Thorough cleaning (degreasing and abrading) of the insulation shall be carried out to ensure that a watertight bond is achieved between the insulation and the cable-jointing compound. Where repairs are carried out, a minimum of 50 mm of cable insulation on each side of the repair, shall be contained within the repair.

NOTE: It is recommended that marker posts, cable tiles or marker tape be used to identify the presence of buried cables

7.6.2 Anodes and groundbed

Because anodes are often brittle, care shall be exercised to ensure that they are not damaged during handling. Anodes shall not be suspended or lowered by their cable tails unless this practice is specifically approved.

Anodes shall be installed in the centre of any backfill which shall then be consolidated to prevent anode damage.

Deep well anodes shall be lowered down the hole using either a prefabricated anode holder or suspension system. Sufficient backfill shall then be added to completely cover the anodes.

On completion of the installation of a groundbed, the earth resistance shall be measured and compared with the design resistance. It may be necessary to provide watering facilities to lower anode groundbed resistance.

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7.6.3 Cathodic protection unit

Requirements of relevant standards and local authorities shall be observed during the installation of the transformer-rectifier with regard to provision of earth stakes, a.c. input, cabling and positioning.

After installation of a converter, the following shall be checked or verified:

(a) Correct polarity and groundbed resistance.

(b) Fuse and circuit breaker ratings and residual current device operation, if fitted.

(c) Oil level, if the converter is oil cooled.

7.7 INSTALLATION OF INSULATED FLANGES, JOINTS AND COUPLINGS

All insulated flanges, joints and couplings shall be installed in accordance with the requirements of the manufacturer. Care shall be taken to ensure that the temperature rating of the joint is not exceeded during welding operations.

NOTE: Care should be taken during the installation of a pre-assembled insulated flange to ensure that it is not damaged.

When bolted insulated flanges are buried, the bolts shall either be electrically isolated from both flanges or isolated from the one side only. In the latter case, the bolts shall be included as part of the cathodic protection system. In all cases, the joints shall be suitably wrapped with a protective coating.

Complete flanges shall be coated in accordance with design specifications.

After installation, insulated joints shall be further checked for isolation integrity by measurement of a potential difference across the joint using a high input impedance voltmeter.

NOTES:

1 A potential difference across the joint usually indicates adequate isolation. If there is no potential difference, apply a cathodic protection current to one side and remeasure the potential. If there is still no potential difference, then either the joint is not functioning adequately or an alternative metallic path is acting as a bridge across the joint.

2 In some instances, a potential difference in itself may not indicate that the joint is adequate for the purpose for which it is intended, and other measurements may be required, e.g. in stray current areas it may be necessary to measure the amount of current leakage through the joint to determine if the joint is adequate for purpose.

Where insulated flanges are installed in accessible structures, shrouds of suitably rated insulation, or surge diversion equipment, shall be installed.

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SECTION 8 CONTROL OF INTERFERENCE WITH FOREIGN STRUCTURES

8.1 SCOPE AND GENERAL

8.1.1 Scope

This Section gives methods for protecting foreign structures from the effects of current flowing from the cathodically protected primary structure.

8.1.2 General

Interference is a specific form of stray current wherein cathodic protection current applied to a primary structure flows to a foreign structure and causes corrosion of that structure by altering its potential.

Interference may be detected by a change in the potential of the foreign structure when the system current is interrupted. This procedure provides qualitative results which indicate the magnitude of the corrosion hazard to the foreign structure.

8.2 STATUTORY REGULATIONS

Most cathodic protection systems are installed in areas where statutory requirements covering interference exist and permits to install and/or operate are required. In these areas, discussions with owners of foreign structures are necessary to decide if testing is required to determine the extent of any interference.

Testing shall be carried out as soon as possible after the commissioning of the cathodic protection system.

Testing shall be carried out at the system operating level or higher, and agreed remedial action should be taken to correct adverse effects to foreign structures. Follow-up testing is necessary especially when increased cathodic protection current is applied to the primary structure.

Changes to cathodic protection current levels can arise from—

(a) deterioration of the structure coating; and

(b) alterations to the size or geometry of the primary structure.

Apart from causing the corrosion of foreign structures, interference can also cause specific problems such as—

(i) noise in telecommunication cables; and

(ii) malfunctioning of railway signalling equipment.

NOTE: Regulatory (Statutory) authorities recognize the right of foreign structure owners not to have their structures connected to the primary structure. The permit to operate a cathodic protection installation that causes interference to a foreign structure can be suspended after a complaint, until interference is brought under control.

8.3 MINIMIZATION OF INTERFERENCE CURRENT

8.3.1 Design of the system

With few exceptions, cathodic protection systems shall be designed (and adjusted) to protect the primary structure from corrosion using the minimum practical current. By minimizing the cathodic protection current, interference to any foreign structure is kept to a minimum and is thus easier to control.

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NOTE: Some degree of interference cannot be prevented in areas with a multiplicity of metallic underground services. Detection and control of such interference currents are discussed in Clause 8.3.3 and Clause 8.3.4.

8.3.2 Methods of minimizing interference currents

Methods for minimizing ground potential gradients include a consideration of the following:

(a) Coating the primary structure to the highest possible standard and thereby minimizing current requirements.

(b) Using distributed anodes.

(c) Positioning impressed current anodes as far from any foreign structures as is practicable.

(d) Using deep well anodes.

(e) Using a large number of distributed small output protective systems in preference to a small number of large output protective systems.

(f) Strictly controlling current outputs and primary structure voltages.

(g) Siting groundbeds in soil of low resistivity.

8.3.3 Detection of interference levels

Quantitative assessment of probable damage is difficult because any current discharge from a foreign structure and the surface area from which it discharges are difficult to assess, particularly in built-up metropolitan areas with their multitude of underground services.

The extent of foreign structure testing, therefore, depends on a number of factors, including the following:

(a) The proximity of the protected structure to the foreign structure.

(b) Soil resistivity and variations therein.

(c) Conductivity per unit length of all structures concerned.

(d) Anode current.

(e) Condition of coatings on all structures concerned.

(f) The type of foreign structure, e.g. rubber ring-jointed cast iron and welded high pressure steel.

Field experience and consideration of the above factors make it possible to estimate likely interference and the length of the foreign structure(s) that needs to be tested.

The extent of interference, which is caused by the electrical gradient around the protected structure, is usually only a matter of a few metres radial distance. However, interference, which is caused by the electrical gradient field around the anode, may extend for some hundreds of metres, with the resultant effect occurring on foreign structures up to a kilometre or more away.

As interference is usually assessed by checking the potential shift of the foreign structure, it is common practice to temporarily install a cyclic interrupter to the cathodic protection power source to provide a switching sequence, typically 20 s on, 10 s off. Foreign structures are then systematically tested for potential shifts in sequence with interruption of the cathodic protection, by taking measurements between the foreign structure and a suitable testing electrode.

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8.3.4 Control of interference

8.3.4.1 *General*

Where testing of a cathodic protection installation indicates that interference exists at a level which may result in corrosion of the foreign structure, control of interference may be achieved by the following measures:

(a) Installing galvanic anodes on the foreign structure.

(b) Bonding the foreign structure to the primary structure through control resistance, if appropriate.

(c) Insulating the foreign structure.

(d) Using distributed cathode points on poorly coated structures to reduce the average potential shift on the protected structures.

(e) Relocating foreign structures away from the interfering field or relocating the interfering field away from the foreign structures.

Where the foreign structure is electrically discontinuous, as may occur on a cast iron pipeline with elastomer ring joints, some bonding of the insulated joints may be necessary before these measures can be adopted.

8.3.4.2 *Control by using galvanic anodes*

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

Advantages and disadvantages of this method are as follows:

(a) *Advantages:*

  (i) The owner of the foreign structure has control over the anodes and thus can be assured of their continued operation.

  (ii) Galvanic corrosion, or complication of stray current problems as may occur with bonding, does not result.

(b) *Disadvantages:*

  (i) If the interference is extensive, the foreign structure bare, and/or the soil is of high resistivity, the limited driving voltage of the galvanic anodes may not provide sufficient protection current.

  (ii) The owner of the foreign structure is required to either monitor the performance of the anodes or have others monitor their performance on his behalf.

  (iii) In areas where stray traction current exists, the presence of galvanic anodes may accentuate stray current pick-up onto the secondary structure, thus possibly causing more problems than it solves.

8.3.4.3 *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 cathodic protection system. In the former case, an appropriate resistor is inserted in series with the bond to control current flow to the level required to just offset the interference. In the latter case, a diode and a resistor are inserted into the circuit.

Diodes are used to prevent the following problems from occurring:

(a) Where the foreign structure and the primary structure are of dissimilar metals, interruption to the cathodic protection current could lead to galvanic corrosion.

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(b) Where structures are located in a stray current area, the overall stray current flows could be affected by flows from one structure to the other.

The advantages and disadvantages of control by bonding are as follows:

(i) *Advantages:*

(A) It is an economical solution to have the structure access points close together.

(B) The existing bond should deal automatically with a subsequent increase in output of the cathodic protection unit, if required.

(ii) *Disadvantages:*

(A) Bonding can lead to galvanic corrosion and stray current problems where the foreign structure is remote from the cathodic protection installation.

(B) The owner of the foreign structure does not have control of both ends of the bond.

(C) The bond requires monitoring to ensure that it is not accidentally broken, cut, disconnected, or fused.

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SECTION 9 COMMISSIONING OF CATHODIC PROTECTION SYSTEMS

9.1 SCOPE AND GENERAL

9.1.1 Scope

This Section specifies the minimum requirements and procedures for the commissioning of a cathodic protection system installed on compact buried structures.

9.1.2 General

Commissioning is divided into the following three steps representing the three stages of the process:

(a) Pre-energization tests.

(b) System operation and adjustment to satisfy protection criteria (see Section 2), including, where applicable, interference testing to comply with relevant regulatory requirements (see also Note 1 of Clause 5.1.2). Before this step is carried out, it may be necessary to forward an application form to the appropriate authority.

(c) Post-energization tests.

Where any additional tests and measurements are carried out, the exact details of such tests and measurements shall be defined and the reason for their execution described.

9.2 PRE-ENERGIZATION TESTING

The following tests shall be conducted prior to the connection of galvanic anodes or the energization of impressed current systems:

(a) Measurement of the natural potential of galvanic anodes, permanent references and negative structure cables at all test points and power units, to confirm that correct installation has occurred, refer AS/NZS 3008.1.2.

NOTE: These pre-energization tests may not be possible where temporary or permanent galvanic anodes are connected during the course of construction.

(b) Checking of the polarity of electrical circuits and confirming that the positive connections are to the anode and the negative connections are to the structure.

(c) Visual inspection for mechanical damage and faults, e.g. checking for missing fuses and damaged cables.

9.3 SYSTEM OPERATION AND ADJUSTMENT

After connection of sacrificial anodes, or energization of transformer rectifiers (converters), the following shall be checked or carried out:

(a) Maximum output current, d.c. voltage of power unit and loop resistance (if applicable).

(b) Transformer/rectifier (converter) unit meters.

(c) Individual anode currents, if practicable.

(d) Current flow in bond cables.

(e) Structure potential at test points, casings and insulating joints.

(f) Adjustment of protection levels to comply with specified criteria or design values (see Section 2).

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(g) Interference testing in accordance with statutory requirements.

(h) Adjustment of stray current control equipment.

9.4 POST-ENERGIZATION TESTS

Following system energization, a full system survey shall be conducted including—

(a) Structure potential surveys to ensure compliance with specified criteria or design values (see Section 2).

NOTE: Some structures require substantial periods of time to achieve full polarization. It may be necessary to conduct a survey some months after initial energization to check the potential on such structures.

(b) Equipment operation and adjustment checks.

(c) Casing and insulating joint testing.

(d) Earthing system resistances (if applicable).

(e) Structure/system visual inspection.

9.5 RECORDS

All tests, inspections and statutory approvals, where applicable, shall be documented identifying the date of the test, equipment used, results and any adjustment or remedial action taken.

Fully detailed written reports shall be provided to the structure owner/client following initial energization of the system and the survey. These reports shall include the ‘as found’ results, any adjustments or modifications and test results showing the consequence of the changes.

9.6 OPERATION MANUALS

Detailed system manuals shall be provided following commissioning and shall be updated after any modifications. These manuals shall include:

(a) Detailed description of the system and its components.

(b) Detailed as-built drawings to show—

(i) transformer/rectifier (converter) wiring schematic (if applicable);

(ii) anode ground bed/support details;

(iii) test point arrangements and locations; and

(iv) locations and details of insulating joints, casings, earthing and electrolysis/stray current devices.

(c) Transformer rectifier (converter) operation instructions.

(d) System adjustment and control procedures.

(e) Alarm conditions and fault finding.

(f) Recommended routine inspection schedule and tests required.

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SECTION 10 OPERATION OF CATHODIC PROTECTION SYSTEMS

10.1 SCOPE AND GENERAL

10.1.1 Scope

This Section specifies procedures and practices to be followed when cathodic protection systems are in operation.

10.1.2 General

Electrical measurements and inspections shall be carried out to ensure that protection of the structure has been established in accordance with the applicable criteria, and that each part of the cathodic protection system is operating satisfactorily.

System checks shall be carried out to ensure that the structure remains protected and, if changes are noted, action is taken to restore the specified levels of protection.

In areas where stray traction currents occur, the potential shall be measured and recorded during times when adverse effects of the stray current on the structure are extreme.

NOTE: In some instances the extent and nature of records to be kept are described in statutory regulations.

10.2 SYSTEM OPERATION CHECKS

10.2.1 Impressed current systems

Impressed current systems shall be monitored at regular intervals not exceeding two months to ensure that each system is operating correctly. Inspection shall confirm the operating level of the system. Inspection may include measurement of the protected potential of the structure.

NOTE: The monitoring interval should not exceed 2 months.

10.2.2 Galvanic anode installations

Galvanic anode installations, where accessible, shall be inspected at agreed intervals.

NOTE: It is good practice to measure anode current at intervals not exceeding 5 years.

The following parameters should be measured and recorded:

(a) Anode output current.

(b) Anode-to-soil potential.

10.2.3 Current drainage systems

Buried structures may depend on a combination of cathodic protection, cross-bonding and stray traction current drainage systems to achieve full protection against corrosion. All systems shall be examined to ensure correct operation and to record the conductance/resistance of the bond and drainage systems.

10.3 STRUCTURE INSPECTIONS

The structure system relies on the correct operation and integrity of many aspects of the cathodic protection system. At the time of conducting potential surveys it is also necessary to confirm that all elements contributing to cathodic protection are operating satisfactorily. Correct operation of the following items shall be verified before or during the survey:

(a) All cathodic protection system equipment.

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(b) Insulating joints and fittings.

(c) Casing isolation and protection, where applicable.

(d) Continuity bonds, where accessible.

(e) Earthing systems installed to control induced voltages.

(f) Foreign structure bonds and stray current drainage bonds.

(g) Electrical equipment, including rectifiers, transformers and switchgear. This equipment shall be kept clean to ensure adequate cooling.

Whenever the structure is exposed for any purpose it shall be examined for corrosion, and, if coated, the condition of the coating shall be assessed. The coating shall be repaired where necessary.

NOTE: Additional advice on the inspection of structures is given in Appendix L.

10.4 CATHODIC PROTECTION POTENTIAL SURVEYS

Periodic survey checks are necessary to assist in assessing the effectiveness of the cathodic protection system to ensure that it continues to protect the structure from corrosion. Typical maximum time intervals between cathodic protection potential surveys are given in Table 10.1.

TABLE 10.1

TYPICAL MAXIMUM TIME INTERVALS BETWEEN CATHODIC PROTECTION SURVEYS

Structure type	Maximum interval, years	
	Suburban	Rural
(a) Structures containing hazardous fluids	0.5	1
(b) All other structures	1	1

NOTE: The figures in this Table are provided for guidance only. Actual intervals will vary from structure to structure and are determined after consideration of the design lives of the cathodic protection system and structure, cathodic protection operation history, operator experience and an assessment of the consequence and probability of any failure of the system.

10.5 SYSTEM RE-APPROVAL

In some Australian States there are requirements to carry out periodic retesting of cathodic protection and current drainage systems. This retesting is normally conducted by arrangement with State Electrolysis Committees or cathodic protection regulators (see Appendix K for details). Re-approval testing includes interference testing of neighbouring structures.

10.6 RECORDS

Details for recording purposes shall be taken at the time of a survey. Records associated with cathodic protection of a structure provide background data for assessing causes of system failure and determining appropriate remedial action. Records of the following items shall be retained for the life of the structure:

(a) Date and results (at least in summary form) of periodic surveys and checks.

(b) Date and location of any test points added to the structure.

(c) Date, location and type of any anode replacements.

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(d) Details of any repairs, replacements, or additional cathodic protection equipment.

(e) Details of any repairs, replacements or additional earthing systems.

(f) Details of any alterations made to the structure.

(g) Details of any structure corrosion observed, including where possible the cause of the corrosion.

(h) Any damage to the structure, and the nature and extent of repairs carried out.

(i) The condition of coating at the time of any examination, and the details of any coating repair.

(j) Agreements made with the owners of foreign structures or systems.

(k) Relevant correspondence with regulatory authorities.

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SECTION 11 DOCUMENTATION OF CATHODIC PROTECTION SYSTEMS

11.1 SYSTEM DESIGN DOCUMENTATION

Following the design of the cathodic protection system, suitable documentation shall be prepared.

Appropriate documentation shall include the following:

(a) Report of proposed design and layout. The report shall include design calculations, assumptions made in the design, an explanation of any deviations from normal practice and plans of the proposed system drawn using appropriate signs and symbols (see AS 1100.401). Plans shall consist of the following:

  (i) A diagram of the structure to be protected in which the following are identified:

    (A) Significant accessible points of the structure, e.g. valves, vents and insulating joints.

    (B) Access roads.

    (C) Power supply points.

    (D) Topographical features such as creeks and rivers.

    (E) Location of adjacent metallic structures, where applicable.

  (ii) Location of anode(s) and anode and cathode cable routes.

  (iii) Location of d.c. power supplies and power supply extensions specially provided.

  (iv) Test points, suitably identified.

  (v) List of owners of foreign neighbouring structures that may affect or be affected by the proposed system(s).

  (vi) Location of any bonding to others structures, including any insulation or isolation of structure sections.

(b) Documentation required by regulatory authorities, as appropriate.

NOTE: An example of system design documentation is given in Appendix I.

11.2 COMMISSIONING DOCUMENTATION

A commissioning report comprising a complete record of all data recorded at all test points during the commissioning survey shall be prepared. The report shall include documentation required by regulatory authorities, as appropriate, and when issued, approval documentation.

The approving regulatory authority may require regular retesting to be carried out and may re-issue approval documentation. Approval documentation shall be retained for the life of the system.

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APPENDIX A

GUIDANCE ON THE GENERAL USE OF CATHODIC PROTECTION

(Informative)

A1 SCOPE

This Appendix describes the basic components of both the galvanic and the impressed current cathodic protection systems, and lists the factors that may affect the rate of corrosion of buried metallic structures.

A2 GENERAL COMPONENTS OF CATHODIC PROTECTION INSTALLATIONS

The general components of a cathodic protection system, employing galvanic anodes as the current source, are shown schematically in Figure A1.

The general components of an impressed current cathodic protection system are shown schematically in Figure A2. The system shown employs a mains-operated current source with relatively permanent anodes. Other power systems may be employed, e.g. solar and thermal-electric generators.

In the impressed current system, correct polarity is required to achieve protection of the structure. With proper design and operation, both systems are capable of completely preventing the corrosion of any metallic surface in contact with a bulk of soil or water for as long as sufficient current flow is maintained. In both systems the anodes will be consumed, and will require replacement at intervals dependent upon system design.

A3 FACTORS AFFECTING THE CORROSION OF BURIED OR PARTIALLY BURIED METALLIC STRUCTURES

All metal surfaces in contact with soil or water are subject to corrosion. Factors that affect the rate of corrosion of a given buried, or partially buried, metal or metallic structure include the following:

(a) *The environment surrounding the structure* The characteristics of the environment surrounding the structure are affected by the following soil properties:

  (i) Resistivity.

  (ii) pH value.

  (iii) Composition of dissolved salts.

  (iv) Moisture content.

  (v) Presence of sulfate-reducing and other bacteria, and their state of activity.

  (vi) Degree of aeration.

(b) *Abnormal constituents present in the surrounding soil* Under abnormal circumstances, the surrounding soil may contain the following constituents or contaminating substances:

  (i) Mineral ores.

  (ii) Ash, cinders or other corrosion-inducing substances.

  (iii) Sewage effluents.

  (iv) Termites, rodents and other pests.

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(c) *Alternating and direct current* Outside sources may cause the following interfering currents to be present:

(i) Stray direct current from traction systems or other man-made sources.

(ii) Alternating current arising from conductive or inductive sources such as power lines or electrical earthing systems.

(d) *Climatic factors* Climatic factors that affect corrosion include:

(i) Rainfall.

(ii) Temperature.

(iii) Lightning strikes.

(iv) The presence of a water table and its fluctuation.

(e) *Operating conditions of the structure* Factors that affect operating conditions of the structure include the following:

(i) Minimum, maximum and average temperature of the metal surface.

(ii) Magnitude and frequency of temperature fluctuations.

(iii) Stress level of the structure, and magnitude and frequency of stress variations.

(f) *Other factors* Other factors that affect the corrosion rate of a metal or metallic structure include the following:

(i) Deterioration of any protective coating in its environment.

(ii) Dissimilar metals in contact.

(iii) Abrasion.

(iv) Erosion.

The total effect of these factors on the corrosion rate, generally, cannot be assessed until the structure has been installed and the backfill consolidated. Even then, a complete assessment may not be possible because the corrosive effects of many of these factors may vary daily or seasonally, and the variation may not be repeatable or predictable. Potential readings relating to these factors may vary over short distances along the structure and at different depths, so that different conditions may exist at the top and the bottom of the structure. Some of the factors can have combined effects greater than the sum of individual effects. The uncertainty of individual results, and the complexity in making an accurate assessment of the combined results, may give rise to an inaccurate evaluation of corrosion rates.

Therefore, it is recommended that, unless an accurate assessment has demonstrated that cathodic protection is not required, a cathodic protection system should be installed and its operation monitored, to ensure protection of the structure.

Cathodic protection systems are frequently complex. Their application requires the services of a trained and experienced corrosion specialist.

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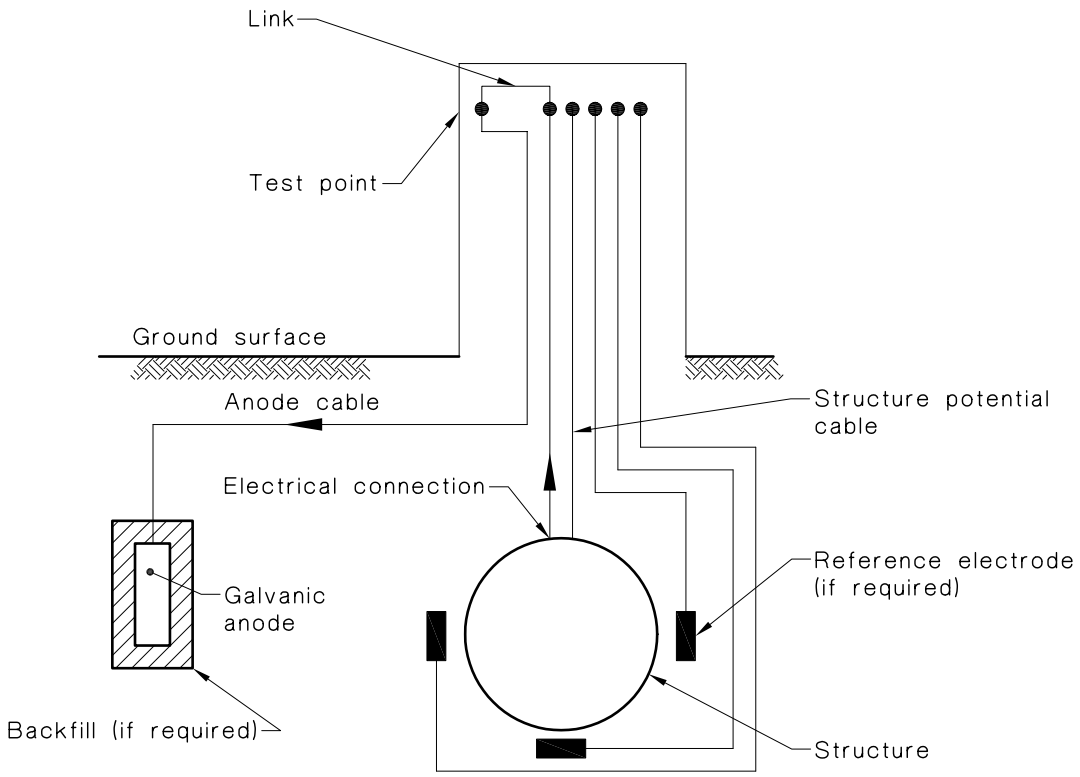


FIGURE A1 SCHEMATIC OF THE CATHODIC PROTECTION OF A COMPACT BURIED STRUCTURE USING A SACRIFICIAL GALVANIC ANODE SYSTEM

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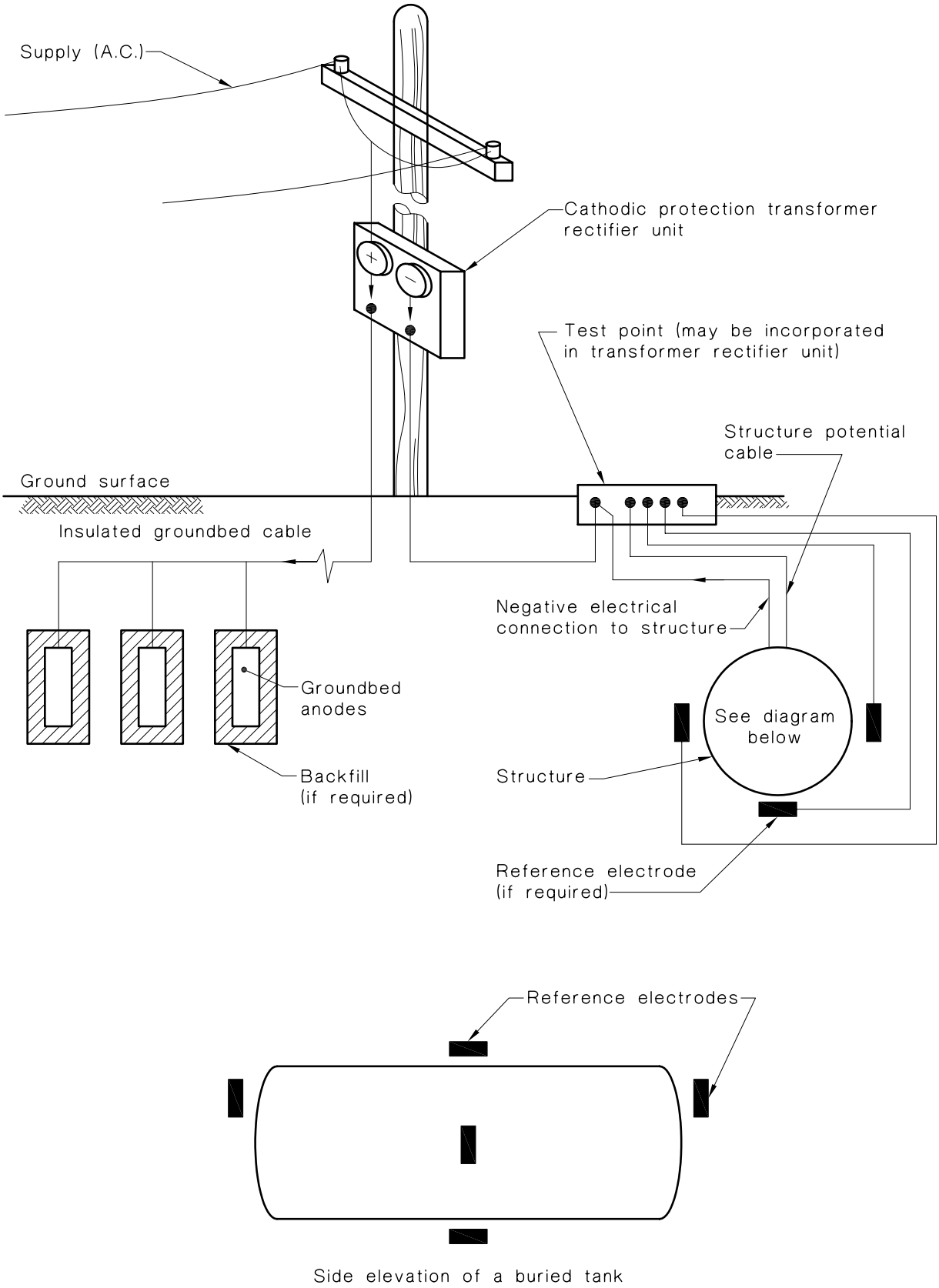


FIGURE A2 SCHEMATIC OF THE CATHODIC PROTECTION OF A COMPACT BURIED STRUCTURE USING AN IMPRESSED CURRENT SYSTEM

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APPENDIX B

THE MEASUREMENT OF STRUCTURE POTENTIALS USING THE INSTANTANEOUS OFF-POTENTIAL METHOD

(Normative)

B1 GENERAL

When the potential of a cathodically protected metal surface is measured with the current on, the measurement includes a component originating from the passage of protective current through the electrical resistance between the metal surface and the reference electrode. The magnitude of the resistance potential (IR drop) is, for all practical purposes, proportional to the current and is also substantially greater in high-resistivity soils and in fresh water. This potential may vary from millivolts to volts.

When the current is switched off the resistive component of the potential will collapse immediately whilst the polarized component will decay. Hence, if the structure-to-soil potential is measured immediately after the protective current is interrupted, the reading will include the polarized potential, excluding the resistive component, and will indicate whether or not protection has been achieved.

The rate of change of decay of the polarized potential after switching off the protective current will depend on a number of factors including—

(a) the nature of the soil;

(b) the coating condition;

(c) the amount of oxygen present;

(d) any current flow in the surrounding environment; and

(e) the period of time the cathodic protection system has been operational.

These factors will influence the time that is available for obtaining an accurate measurement of the polarized potential. Excessive time delays will allow depolarization to progress and consequently readings will be lower than the ‘true’ level of polarization occurring when the current is flowing.

Periods during which satisfactory measurements of polarization can be taken will vary from within a few milliseconds to several minutes following interruption of current flow.

For structures with short depolarization times, readings taken within 100 to 200 milliseconds after current interruption are usually satisfactory.

For structures with long depolarization times, a satisfactory reading will be obtained within 1 to 4 seconds.

NOTE: There can be an error in this reading if the primary structure is not fully electrically isolated from foreign structures. For example, an error can result from partial to full loss of electrical isolation across insulating flanges.

B2 MEASUREMENT OF POLARIZATION POTENTIAL

In order to measure polarized potential, cathodic protection current sources shall be interrupted (switched off) whilst readings are taken. To facilitate surveys involving readings at multiple sites, the current sources may be switched on and off continuously during the survey at intervals that do not significantly reduce the level of polarization. A typical interval is 5 s off and 25 s on.

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Where there is more than one source of a cathodic protection current then all sources that could influence the readings shall be switched simultaneously using synchronized switching.

Coating defects (holidays) of different sizes and orientations may have different levels of polarization. When the cathodic protection current is interrupted there may, therefore, be a current flow between the defects resulting in resistive voltage drop errors when taking potential readings. These errors are generally small but may still require consideration when assessing protection levels.

B3 MEASUREMENT OF STRUCTURE POTENTIAL BY POLARIZED POTENTIAL TECHNIQUES

When a cathodic protection system is energized, the measured potential includes both the polarized potential and the electrolyte voltage gradient, which is caused by the flow of cathodic protection current and other direct currents in the electrolyte. The magnitude of the error in the measurement of the polarized potential is proportional to the electrolyte resistivity and the electrolyte current density, and so will be more pronounced in high resistivity areas or where the current density is large, e.g. in the proximity of an anode bed. If the soil voltage gradient is ignored, the structure may not be protected even though the appropriate potential reading is obtained.

Approximate voltage gradient-free readings may be obtained using the instantaneous off-potential technique. This technique involves taking the structure potential reading the instant the cathodic protection system and any other direct current sources are interrupted. Additionally, polarization probes or coupons may be installed at test points, and voltage-free readings taken by measuring the polarization probe potential or the instantaneous off-coupon potential. The polarization probes and coupons shall be of a size and shape to represent typical coating defects on the pipeline and shall be buried in the same backfill as the pipeline.

NOTE: When the structure is subjected to significant voltage gradients in the electrolyte, monitoring of stray currents (see Clause 3.2.2.6) should be carried out using a data logger graph to obtain optimum resolution of voltage peaks.

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APPENDIX C

COUPONS AND RESISTANCE PROBES

(Normative)

C1 GENERAL

Coupons and resistance probes provide a measure of the effectiveness of a cathodic protection system on a well-coated structure. They are applicable to structures when the structure—

(a) is well coated so that it can be modelled as a structure with an insulating coating, except where small defects occur in the coating;

(b) is subject to significant levels of induced alternating current, which can reduce the effectiveness of the cathodic protection and can affect the accuracy of potential monitoring techniques;

(c) is in dry or very high resistivity soils where soil voltage gradient errors can be very high; or

(d) traverses soils of varying resistivity where a structure off-potential can give an optimistic evaluation of protection status.

NOTE: This is because a coating defect that dominates the potential reading is that with the lowest circuit resistance to the reference electrode. It is not necessarily the closest coating defect to the reference electrode, but is most likely the coating defect in the lowest resistivity environment. If this defect is in the lowest resistivity environment, it will also tend to be the most protected defect.

C2 COUPON

A coupon is a section of metal of similar size to a typical coating defect. It is exposed to the same environment as the structure, and is electrically connected to the structure so that it experiences the same cathodic protection environment as the structure. Measurement of coupon potential may be achieved either by—

(a) using a reference electrode on the soil surface and taking off-potentials by open-circuiting the coupon; or

(b) using an in-situ reference electrode, or a shielded electrode bridge, adjacent to the coupon.

NOTE: With this configuration the on-potential will usually adequately represent the off-potential.

C3 RESISTANCE PROBE

The resistance probe element is a section of metal, of a size similar to a typical coating defect, of very thin cross-section. It is exposed to the same environment as the structure, and is electrically connected to the structure so that it experiences the same cathodic protection environment as the structure. If the probe element corrodes it loses cross-sectional area and as a result its electrical resistance increases. This increase in resistance can be determined from measurements made using an instrument designed for the purpose. The resistance probe method is very sensitive and can monitor very low rates of corrosion.

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C4 COUPON AND PROBE USE

The design of a cathodic protection monitoring system based on coupons and probes, shall be carried out by a cathodic protection specialist. The following factors and requirements apply when designing a coupon or probe-based monitoring system:

(a) The coupon or probe element should be of a metal of similar composition to the structure being monitored.

(b) The size of the element (coupon or probe) shall be similar to that of the typical coating defect that the cathodic protection system is expected to protect.

(c) The element shall be buried at the same depth as the structure so that it is subject to the same moisture content in the backfill and the same cathodic protection field as the structure.

(d) The elements shall be provided with the same backfill material as the structure.

(e) Coupons or probes shall be located around the structure at positions that are anticipated to be the most corrosive and the most remote from cathodic protection installations. Coupons or probes shall be located in each of the soil types around the route, at induction nodes from power transmission cables, at the ends of the structure at intervals along the route determined by an evaluation of the route by a cathodic protection specialist.

(f) Coupons and probes shall be used with caution when monitoring sections of structures operating at elevated temperatures, as they may not be at the same temperature as the structure.

C5 INSTALLATION

The coupons or resistance probes shall be installed such that the following parameters can be measured and monitored at the test point:

(a) For resistance probes, the loss of metal section, measured with the resistance probe instrument, and by inference, the amount of corrosion occurring on the structure.

(b) The cathodic protection current to the coupon or probe element, and by inference, the cathodic protection current density that would flow onto a coating defect on the structure in that area.

NOTE: This may be achieved by the installation of a shunt in the element connection to the structure.

(c) On-potentials and off-potentials on the coupon or probe element.

NOTES:

1 Off-potential measurements may not be required for coupons when using an in-situ reference electrode positioned so that its diaphragm is adjacent to the coupon.

2 The measurement of off-potentials can be achieved by the installation of a switch at the element connection to the structure. A magnetically operated reed switch can work effectively. When measured in this manner, an off-potential on a coupon or probe represents the off-potential at the location. The reading is not distorted by other coating defects, which may be in lower resistivity environments and are thus more protected, as can occur with structure off-potentials.

3 If a resistance probe element is drawing a very high cathodic protection current, the current flow in the probe cable can affect the corrosion reading measured with the resistance probe instrument. This can be avoided by open circuiting the resistance probe element from the structure while the reading is being taken. This can be achieved by operating the switch installed at the probe connection to the structure.

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APPENDIX D

CALIBRATION AND MAINTENANCE OF REFERENCE ELECTRODES

(Normative)

D1 SCOPE AND GENERAL

D1.1 Scope

This Appendix provides requirements on the calibration and maintenance of reference electrodes used in the measurement of potentials on cathodically protected structures.

D1.2 General

A reference electrode consists of a metal rod immersed in an electrolyte containing one of its salts. A known reversible chemical reaction occurs between the metal and its environment. At equilibrium, the reaction rate in both directions is equal, and the potential established is constant under constant conditions and can be used as a stable reference for measurement. When using such a reference, it should be noted that the following factors affect this potential:

(a) Temperature.

(b) Electrolyte concentration.

(c) Electrolyte contamination.

(d) Electrolyte photosensitivity.

D2 CALIBRATION

Reference electrodes should be calibrated regularly against a known stable reference to ensure that potentials measured are within acceptable limits.

In the laboratory or workshop, a calomel electrode makes a useful reference for checking the calibration of field units; however, any other reliable reference can be used. Comparative measurements can be made under the same conditions with the reference electrode positions interchanged over a short period whilst measuring the potential of a metal object, for example, that has been immersed in the same electrolyte. The measurements taken should be within 10 millivolts of each other for similar reference cells.

NOTE: For different cells, readings may be compared with Figure M1 and Table M1 in Appendix M to determine their relative potentials.

In the field, where the use of more rugged references is required, comparison of readings can be made with similar type reference cells. If readings are not within a few millivolts of each other then a problem is indicated and action is required. Generally, if reference cells are properly stored and well maintained, they give very good performance.

D3 MAINTENANCE

There are two basic types of reference cells: those which have their own reservoir of electrolyte, e.g. copper/saturated copper sulfate electrodes, and those which rely on the environment into which they are placed (the electrolyte), e.g. silver/silver chloride/sea water electrodes. Details for the maintenance of these cells are as follows:

(a) *Cells with their own reservoir of electrolyte* Where the half-cells have a reservoir of electrolyte, the electrolyte should be checked regularly to ensure that it has not dried up or has not become contaminated whilst in usage. These cells have a porous plug at one end, which completes the electrical path to the environment in which the

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measurement is taken. This plug needs to be kept moist and when not in use shall be either covered with a cap or immersed in a solution of the electrolyte. With usage, the electrolyte will gradually leak out through the porous plug and so needs periodic replenishment. In the same way, contaminants can leach in through the plug.

Specific maintenance details for a copper/saturated copper sulfate reference electrode, to be carried out at least monthly, are as follows:

(i) If possible, dismantle the cell and clean the central copper rod with emery, garnet or other non-metallic abrasive paper.

(ii) Check the electrolyte level. A few crystals of copper sulfate present in the solution indicates that the solution is saturated. If copper sulfate crystals are not present, the entire electrolyte shall be discarded and replaced with fresh saturated copper sulfate solution, and a few crystals introduced.

If the electrolyte is cloudy or milky, contamination has occurred. The entire electrolyte should be discarded, the cell rinsed with distilled water and a fresh replacement solution of copper sulfate and free crystals prepared.

(iii) Check the cell for damage and leaks. If the porous plug contains cracks or the plug leaks, it shall be replaced; otherwise, replace the cell.

This type of reference cell is designed for portable usage and is not suitable for permanent installation. For electrodes intended for permanent usage, gelling agents are added to the electrolyte to overcome the problem of leakage. Such electrodes need no maintenance but have a finite life as they can dry out; they should be re-calibrated periodically.

(b) *Cells that do not have a reservoir of electrolyte* For reference electrodes that do not have a reservoir of electrolyte, place the rod directly in the electrolyte to be measured. These types of electrodes rely heavily on the chemistry of the electrolyte into which they are placed to form a stable reference potential. They are otherwise quite rugged but must be stored carefully to prevent contamination of the rod which is often coated with a fused layer of the metal's salts. If contamination occurs, this type of reference can be ruined. The reference potential of this type of cell changes with the logarithm of the concentration of active species in the solution into which it is immersed. Such electrodes shall only be used in electrolytes that have a consistent composition.

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APPENDIX E

INFORMATION FOR THE DESIGN OF STRUCTURES TO ACCOMMODATE CATHODIC PROTECTION

(Informative)

In order to design a cathodic protection system, details of the structure and its location should be gathered, documented and considered. As a minimum, the following should be known:

(a) *Structure details* Description of structure, its extent, materials of construction, coating system(s), expected design and service life and importance of structure.

(b) *Coating details* The type and quality of coating used, including the coating used for field joints and repairs, has a significant bearing on the effectiveness of cathodic protection and on the amount of current that needs to be provided to protect the compact buried structure. In addition, the impact of handling on the coating and the nature of the structure backfill (i.e. the material immediately in contact with the structure) needs to be understood so that an assessment of coating integrity can be made.

(c) *Structure isolation points* For cathodic protection to be successfully applied, the compact buried structure to be protected needs to be electrically continuous and electrically isolated from other structures. Certain fittings and joint couplings are naturally isolating, and these may need to be electrically bonded to allow the cathodic protection to extend to the whole structure. Additionally, isolating joints or insulating flanges may need to be installed to limit the cathodic protection to the compact buried structure and prevent its effect being dissipated to other underground structures.

(d) *Road, rail and water channel crossings* Details of crossings need to be considered to ensure that effective cathodic protection is provided. Steel casings may shield the structure from the cathodic protection, and so measures to electrically insulate the casing from the structure need to be implemented. Bridged crossings may need to be electrically insulated from the support structure to prevent excessive current drain to the support structure. In all cases, provision for test connections needs to be included in the design.

(e) *Structure location* Features of the structure location which may affect the cathodic protection system need to be identified and provision incorporated in the design. Typical features include the following:

  (i) Variations in soil types and soil resistivity.

  (ii) The location of other metallic structures.

  (iii) The presence of abnormal backfill material such as cinders, ashes or highly acidic soils.

  (iv) The presence of a.c. or d.c. transmission systems within close proximity to the structure.

  (v) The proximity of d.c. traction systems.

  (vi) The proximity of other cathodic protection systems.

(f) *Water levels* Any fluctuation of water levels, both short term and seasonally, should be noted and possible effects on cathodic protection determined.

(g) *Structure operating conditions* Elevated temperatures result in increased rates of corrosion and may alter the nature of the backfill.

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APPENDIX F

COATINGS FOR USE WITH CATHODIC PROTECTION

(Informative)

F1 GENERAL

This Appendix gives guidance on the types of coatings used on compact buried structures that are to be cathodically protected.

Coatings are considered to be an integral part of any cathodic protection system. In most situations, coatings provide the primary corrosion protection system, with cathodic protection providing back-up corrosion protection to the structure at points where failure of the coating or damage to the coating has occurred.

A secondary but important function of coatings on buried structures is to reduce the current flowing, thereby reducing the potential gradients in the surrounding soil and decreasing interaction with neighbouring buried structures.

Coatings assist in the corrosion protection of buried structures in several ways, as follows:

(a) They inhibit corrosion by providing a protective film with high resistance to ionic transport.

(b) They reduce the current requirements for cathodic protection by providing an electrically insulating film.

(c) They extend the effective coverage provided by a given anode.

A coating will lead to a considerable reduction in the cathodic protection power consumption, offsetting the initial high application cost.

F2 COATING PROPERTIES

The prime function of a coating is to provide a non-conductive barrier between the structure and its environment. Desirable features of coatings are as follows:

(a) Resistance to chemical, biological and microbiological attack in service.

(b) Resistance to deterioration in the operating temperature range of the structure.

(c) High electrical resistance and dielectric strength under continuous service.

(d) Resistance to permeation of water.

(e) Compatibility with the level of cathodic protection required (resistance to cathodic disbondment and alkalinity (see AS/NZS 4352).

(f) Long term adhesion to the structure and resistance to blistering or disbonding.

(g) Resistance to entomological attack.

(h) Sufficient strength to resist soil stress caused by changes in the environment resulting from seasonal variations.

(i) Mechanical strength and resistance to pinholing, erosion and spalling.

(j) Ability to be repaired in the field.

(k) Resistance to degradation by ultraviolet light for the period of exposure during transport, storage and installation.

(l) Resistance to damage by weight coatings and structure anchors, if applicable.

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(m) Resistance to mechanical damage from handling, field bending, installation and backfilling procedures.

Suitable backfill, free of stones, should be considered to reduce damage to the coating.

F3 COATING CHOICE

The choice of a coating for a particular application is necessarily a compromise between physical and chemical property requirements, compatibility with cathodic protection, and other factors including repairability, availability and economic considerations.

It is not possible to nominate any one type of coating as being inherently more suitable for a given use than any other.

Table F1 gives coating types that are commonly used for the protection of buried structures, and lists the typical environmental behaviour of installed coating systems.

When a choice has been made, the test requirements of the relevant product Standard should be utilized to ensure that the proprietary product chosen is of acceptable quality. Correct surface preparation, application techniques and performance requirements should be specified. Appropriate field testing of the coated structure should be specified.

Concrete should not be considered to be a substitute for an insulating coating, which should be provided in addition to concrete, whenever possible.

F4 COATING LIFE

Coatings subject to cyclic soil stress and cyclic immersion will deteriorate with time and factors that influence their rate of deterioration include the following:

(a) Surface preparation.

(b) Composition and temperature of water and soil.

(c) Pollution and microbiological organisms.

(d) Mechanical damage by a third party.

It is usually impractical to provide effective coating maintenance to buried areas. Cathodic protection systems provide for coating deterioration by having reserve current capacity available. This capacity should be based on the estimated current requirement for the expected useful life of the structure or the cathodic protection system.

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TABLE F1

TYPICAL PROPERTIES OF COATING SYSTEMS FOR COMPACT BURIED STEEL STRUCTURES

Coating system	Coating site	Structure treatment	Coating thickness mm	Probability of damage by			Maximum operating temperature °C	Relevant Australian Standard
				Soil stresses	Cathodic disbondment	Impact		
Extruded polyethylene	Shop	Blast	0.6 to 1.8	Low	Low	Medium	50	AS/NZS 1518
Fusion bonded (medium density) polyethylene	Shop	Blast	1.6 to 2.3	Low	Medium	Low	60	AS 4321
Ultra high build epoxy	Site and shop	Blast	1.0 to 3.0	Low	Variable*	Low	60	—
Fusion bonded epoxy	Shop	Blast	0.4 to 0.8	Low	Very low	Medium	80	AS/NZS 3862
Asphaltic enamel (reinforced)	Shop	Blast†	2.5 to 5.0	Medium	Medium	Medium	40	—
Butyl-laminated tapes	Site and shop	Blast†	0.7 to 3.0	High	Medium	High	40	—
		Wire brush†			High			
Petrolatum tapes	Over ditch	Wire brush†	1.4 to 5.0	High	High	High	40	—
Heat shrink sleeve‡	Over ditch	Blast	1.0 to 3.0	Low	Medium	Medium	60	—
Trilaminate	Shop	Blast	1.2 to 2.0	Low	Very low	Low	80	—

* The cathodic disbondment performance of ultra-high build epoxy coatings can vary between low and high depending on formulation and application.

† It is good practice to blast clean surfaces prior to coating application to ensure maximum adhesion and resistance to cathodic disbondment. Wire brush pretreatment, which leaves mill scale on surfaces and may leave the structure in a condition susceptible to stress-corrosion cracking, is inferior to blast-cleaned pretreatment for good adhesion of the coating (see AS 1627.2 and AS 1627.4).

‡ Due to the complexity in the application, heat shrink sleeves should only be applied by accredited applicators. Such accreditation may be gained through the Australasian Corrosion Association.

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APPENDIX G

ELECTRICAL HAZARDS—CATHODIC PROTECTION ON COMPACT BURIED STRUCTURES

(Informative)

G1 SCOPE

This Appendix lists the several electrical hazards that can arise from the application of cathodic protection to compact buried structures. Whilst it does not provide prescription for overcoming such hazards, it does indicate general principles and other Standards which address these matters.

G2 CATEGORIES OF HAZARD

G2.1 General

There are two categories of electrical hazards, as follows:

(a) *General electrical hazards* This arises from the use of electrical energy to power cathodic protection converters, and is equally applicable to this use in other industries or in domestic conditions.

The electrical wiring from the point of supply to the input of the converter constitutes fixed wiring, and must be installed in accordance with AS/NZS 3000. Such work must be performed by a licensed electrical contractor, or, in some cases, by a limited licence holder, certified to perform specific electrical installations.

The converter itself must be in accordance with a *type* 'certificate of suitability, issued by the Electrical Safety Regulator in the various states. The titles of the various regulators are given in Paragraph G3.

This certificate requires compliance with AS/NZS 3100, which specifies essential safety requirements for approval and test purposes.

This certificate covers earthing, protection from inadvertent contact with live parts, prevention of water ingress and like matters.

(b) *Hazard arising from the cathodic protection (CP) technology in compact structures* This is described in Paragraph G2.2.

G2.2 Electrical hazard relating to use of cathodic protection (CP) converters in compact structures

Examples of electrical hazards relating to CP converters are as follows:

(a) *External electrical influences* Compact structures are frequently associated with or sited at the terminals of long structures such as pipelines or metal-sheathed cables. In consequence, electrical surges on these longer structures pass to the terminal equipment and to the converters protecting this equipment. Such surges may be either of meteorological origin (lightning flash contact or lightning electromagnetic induction (LEMP)) or from low frequency induction due to parallel siting of, for example, pipelines with power transmission lines. This is detailed in AS/NZS 4853, and also described briefly in AS/NZS 2832.1. The effective way to protect both personnel and CP equipment at the terminal structure is to fit an isolating joint in the pipeline, or metal cable sheath, at the entry to the terminal structure. Earthing of the pipeline side of the isolating joint is also advisable, particularly to provide protection from lightning conditions, which might otherwise arc across the joint. Such earthing should be of 5 ohms, preferred, and 10 ohms maximum electrode resistance to earth.

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The lightning earth cable in such cases should be provided by 2 parallel 16 mm^2 conductors, coloured green/yellow in insulation.

(b) *Lightning (excluding external electrical influences (see Item (a))* Lightning rarely is of direct flash concern to converters in compact structures. If concern is felt for some reason, such as siting in high altitude, high lightning flash density areas, specialist advice should be sought.

Usually lightning damage results from surges received from the low voltage (L.V.) power mains (see AS 1768). Other information is given in IEC 61024, Parts 1, 1-1 and 1-2 and IEC 61312, Parts 1 to 4, the former Standards applying to general principles and the latter Standards to LEMP protection. Design of protection equipment for converters should be discussed with the manufacturer acting on specialist advice.

(c) *Hazardous situations (combustible or explosive atmospheres)* Attention is drawn to the provision of AS/NZS 2430 series of Standards which determine the classification of situations requiring electrical equipment to be intrinsically safe. In general CP converters should not be installed in hazard zones (0, 1, 2), and the anode and cathode leads and installation associated should not permit a situation leading to sparking in the zones. See AS 1697, AS 2430.1, AS/NZS 2430.3.1 and AS/NZS 2430.3.4.

(d) *Earth potential rise (EPR)* When an earthing system discharges electric current to earth, it results in an electric field producing a voltage in the ground. At the surface, the voltage E, at a distance d, is given by:

$$E\ (volts) = \frac{\rho \times I}{2\pi d} \qquad \ldots \text{G1}$$

where

ρ = soil resistivity, in ohm metres

I = electrical current, in amperes

d = distance, in metres

Cathodic protection anodes should not, in consequence be installed near electrical earthing systems. This is to avoid both the EPR voltage being injected to the converter positive outlet, likely causing damage, and also to avoid interference corrosion damage to part of the earthing system. The severity of this effect may be partially calculated from Equation G1, which does not allow for the resultant current caused by voltage E. For general guidance, separation between anode and earth system electrodes should not be less than 15 m. Actual current discharge, and soil resistivity may modify this.

Earth potential rise should also be considered when a compact structure is located in the vicinity of an electrical earthing system. Excessive voltage (under fault conditions) may cause damage to the structure or its coating, and present a hazard to personnel who may be in contact with the structure.

(e) *Anode field hazard* The voltage of CP systems is limited by this Standard and also by statute in some States, generally to 50 V. This figure aligns with AS 3859 as ‘not a proven hazard’. However, CP is one system which has an earth behind both positive and negative converter leads. Thus, personnel may intercept this CP electrical field either adjacent to anode or cathode, though usually the latter is of very small current density. It is important to note that a 50 V field is more than sufficient to cause muscular paralysis and in immersed, or in mud saturated conditions, may cause drowning or asphyxia. The use of unfiltered d.c. output causes a much greater risk in such an environment than does filtered d.c.

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G3 LIST OF ELECTRICAL SAFETY REGULATORS

N.S.W.	Department of Fair Trading
VIC.	Office of the Chief Electrical Inspector
QLD	Electrical Safety Office
S.A.	Office of the Technical Regulator
W.A.	Office of Energy
TAS.	Office of Electricity Standards and Safety
N.Z.	Ministry of Consumer Affairs

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APPENDIX H

INFORMATION FOR THE DESIGN OF CATHODIC PROTECTION SYSTEMS

(Informative)

H1 SCOPE

This Appendix provides information for the design of cathodic protection systems.

H2 DETERMINATION OF CATHODIC PROTECTION CURRENT REQUIREMENTS

H2.1 General

The current capacity of an installed cathodic protection system should be such that the appropriate criterion for protection specified in Section 2 is achieved and maintained.

Overprotection should be avoided because of possible damage to the structure itself or to any protective coating, and to minimize interference.

Some coatings suffer damage in the presence of high alkalinity and/or in the presence of hydrogen, both of which can inhibit the application of the full capacity of the corrosion protection system.

Some types of steel, e.g. prestressed steel and post-tensioned cables, can be embrittled by hydrogen.

Lead dihydride is formed when lead reacts with hydrogen formed at high negative potentials (approximately 2.5 V), thereby causing damage to lead structures.

As a basis for the design of the electrical capacity of the proposed system, the current requirement may be predicted by calculation taking into account the size and other design parameters of a proposed structure (see Paragraph H2.2), or, for an existing structure, it may be determined by a suitable field trial (see Paragraph H2.3).

H2.2 Prediction of current requirement from design parameters

Current required for cathodic protection is controlled by the following factors:

(a) Oxygen availability at the structure surface.

(b) Oxygen and moisture permeability of the coating.

(c) Effective bare area of structure metal exposed.

In some instances, based on experience, the above factors may be considered jointly and then expressed as an estimated current density figure in milliamperes per square metre required to give protection. Allowance for coating deterioration should be included in this figure.

This estimated current density value is multiplied by the total buried area of the structure to give an approximation of the likely total current required.

In practice, uncertainty of the environmental characteristics and of structure current density requirements may limit the applicability of this method, unless previous experience with similar structures is available.

H2.3 Determination of current requirement by field test on existing structures

Where the structure is installed prior to cathodic protection design, the following tests can give an indication of the condition of the coating:

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(a) A temporary cathodic protection installation, similar to that shown in Figure A2 (see Appendix A), is used. Test connections to the structure are required at the point of application of the test current, and on at least one other point on the structure some distance away. From a measurement of the potential changes on the structure and of the applied current, it is possible to calculate the resistance of the structure to ground, and thus to determine the spread of any applied current along the structure and the magnitude of the current required from a permanent installation.

(b) If necessary, on larger structures such as tank farms, the test circuit installation may be repositioned at a number of locations along the structure so that a polarization value can be progressively measured along the length of the whole structure.

The procedure for the determination of current requirement to achieve the potential specified in Section 2 is as follows:

(i) Make a durable connection to the structure at a point near the selected anode site. In many instances the test cable will become the permanent cathode cable and may therefore justify installation of a permanent durable conductor housing or connection box. Such installations should be in a permanent location where they will not be damaged.

(ii) Attach a separate insulated potential test cable to the structure adjacent to the cathode test cable (see Figure A2, Appendix A).

NOTE: The coating on the structure should be made good at this stage, i.e. prior to reinstatement of the excavation or other access work.

(iii) Install a temporary test anode.

NOTE: Earth stakes may be driven into soils and used as a temporary anode; however, in isolated locations it may be expedient to install a permanent anode and use it for testing.

(iv) Arrange the test circuit in accordance with Figures A1 and A2 (see Appendix A).

NOTES:

1 A circuit interrupter may be used to interrupt the flow of protective current in a recognizable sequence, e.g. 20 s on, 10 s off. Corresponding shifts of potential on the structure can then be measured.

2 Application of cathodic protection current to a structure will result in its potential becoming more negative over a period of time. The time before the potential stabilizes will vary between minutes on a well-coated buried structure to months on a poorly coated or bare submerged structure. Thus, the current requirement determined by this technique tends to give a conservative value.

(v) Determine the current required to achieve the specified potential at the most distant test point.

H3 ANODE ARRANGEMENTS

H3.1 General

Anodes should be placed where they achieve the desired spread of protection along the primary structure with minimum interference to secondary structures. The actual longitudinal and transverse placement of anodes will depend upon a number of factors such as the following:

(a) Site accessibility and availability.

(b) Soil resistivity, including seasonal variations.

(c) Structure layout and location, and presence of any foreign structures.

(d) Structure coating.

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(e) Longitudinal conductivity of the structure.

(f) Resistance of the structure to earth.

(g) Minimum anode/structure separation necessary to avoid excessive local structure potential change (overprotection or interference). The separation required is related to the anode current output.

H3.2 Calculation of appropriate anode/structure separation

Anode or anode groundbeds should be located at a sufficient distance from the structure to ensure that soil potentials at neighbouring structure surfaces do not become excessive.

The relationship between soil and distance from an operating anode is complex and depends on several variables such as depth of anode and variation in soil resistivity in both the horizontal and vertical planes. See Equation H1.

NOTE: Equation H1 may only be used as an indicative guide.

$$D = \frac{I\rho}{2\pi V} \quad \ldots \text{H1}$$

where

D = distance from anode, in metres.

I = current output of anode, in amperes.

ρ = soil resistivity, in ohm metres.

V = soil potential in volts at a distance of D metres from the anode, relative to remote earth.

H3.3 Anode positioning

H3.3.1 *Galvanic anodes*

Galvanic anodes should be buried at a horizontal distance of not less than 0.3 m and preferably 2 m to 3 m from the structure to be protected (see Paragraph H3.2), and at a level below that of the primary structure. Exceptions may occur where insufficient space is available or where a deliberate variation in current density is desirable. Anodes may be immersed in adjacent waterways when suitable sites are available.

H3.3.2 *Impressed current anodes*

Anodes for impressed current systems may be installed singly or in arrays called groundbeds. These may be shallow or deep in relation to the ground level. Anode structure separation may be calculated using Equation H1.

H3.4 Anode positioning details

H3.4.1 *General*

For simple systems, anodes are positioned as indicated in Paragraph H3.3.1, allowance being made for the ground voltage requirements. Depending on the site layout, multiple anodes are normally arranged in shallow arrays (groundbeds), but if this is prevented by proximity of other structures and/or buildings or for other reasons, deep well groundbeds may also be used.

H3.4.2 *Shallow groundbeds*

Shallow groundbeds are installed by laying anodes in a trench 1 m to 3 m deep with backfill, or in shallow vertical holes surrounded with backfill (see Paragraph H8).

Distributed anode systems may be used where underground structures require the use of widely dispersed anodes strategically placed to overcome shielding, to ensure that the

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maximum area of structure is protected, and/or to minimize the flow of interference current to foreign structures.

Distributed anode systems costs are generally higher than compact groundbed costs because anodes distributed over large areas require lengthy anode cables, often with individual anode current adjustment.

H3.4.3 *Deep-well groundbeds*

Deep well groundbeds are installed in vertical holes. Features of deep well groundbeds are as follows:

(a) They can access lower resistivity soil.

(b) They reduce site and right of way requirements.

(c) They reduce interference to foreign structures.

Groundbeds are normally backfilled with suitable material (see Paragraph H8).

The deep well hole may be steel or plastic-lined. Where a plastic casing is used, it is important that the casing stops short of the anode to allow the passage of current.

Anodes may need to be mechanically supported to maintain clearance during backfilling. In some cases the connecting cable may be designed to also serve as the anode support. Appropriate steps should be taken for gas venting.

The actual positioning, i.e. the depth below the ground surface, may be a compromise between cost and feasibility of drilling to a depth to reach soils of required resistivity, and an isolation or distance requirement to reduce anode operation soil potential shift around the structure to an acceptable level. Although the prime intent is to position anodes in soils of the correct resistivity, Equation H1 given in Paragraph H3.2 may not apply because of changed conditions at the structure site.

H4 ANODE MATERIALS AND APPLICATIONS

Anode materials are classified according to their end use as impressed current anodes or as galvanic (sacrificial) anodes.

Typical properties and uses of anodes are given in Table H1.

H5 GALVANIC ANODES

The mass of anode material required to provide protection current for a given period of time may be calculated using the following equation:

$$m = \frac{ZIt}{Du} \quad \ldots \text{H2}$$

where

m = mass of anode, in kilograms

Z = theoretical anode consumption rate, in kilograms per ampere per year

I = anode output current, in amperes

t = time, in years

D = anode current efficiency

u = anode utilization factor

NOTES:

1 Anode current efficiency is the useful charge in ampere hours, which may be obtained from the metal in practice compared with that theoretically obtainable. Anode current efficiency depends on factors such as anode alloy composition, current output density, and environment.

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Typical figures for anode current efficiency are as follows:

(a) Aluminium ..... 0.85.

(b) Magnesium ..... 0.50.

(c) Zinc ..... 0.95.

2 Theoretical anode consumption rates in kilograms per ampere year, are as follows:

(a) Aluminium ..... 2.94.

(b) Magnesium ..... 3.97.

(c) Zinc ..... 10.68.

3 The utilization factor is applied to take account of material that is not consumed at the end of the useful life of the anode. Typical values range between 0.8 to 0.9.

H6 CALCULATION OF ANODE OUTPUT CURRENT

H6.1 General

Anode output current can be determined from a knowledge of the anode resistance to earth and its potential relative to the structure.

The resistance of an anode to earth can be determined using a suitable equation.

H6.2 Modified Dwight formula

The modified Dwight formula (see Note), an equation applying to anodes with a length to diameter ratio greater than 10, and which are buried or immersed vertically to a depth at least equal to the anode length, is as follows:

$$R = \frac{\rho}{2\pi L}\left(\ln\frac{8L}{d} - 1\right) \quad \ldots \text{H3}$$

where

R = resistance of anode to earth, in ohms

ρ = soil resistivity, in ohm metres

L = anode length, in metres

d = anode diameter, in metres

NOTE: The modified Dwight formula applies to long slender anodes buried or immersed to a depth at least equal to the anode length.

H6.3 Anode output current

Anode dimensions will decrease during service life, and to ensure adequate output at the end of life it may be necessary to base the calculation on decreased dimensions. A common practice is to allow 90% radial consumption and 10% to 20% longitudinal consumption.

Anode output current can then be determined using the following equation:

$$I = \frac{E_s - E_a}{R} \quad \ldots \text{H4}$$

where

I = output current, in amperes

E_s = structure potential, in volts

E_a = anode potential, in volts

Typical ($E_s - E_a$) values based on a steel structure potential of −850 mV with respect to a copper/copper sulfate reference electrode are as follows:

(a) Aluminium ..... 0.25 V.

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(b) Magnesium ..... 0.65 V (low potential alloy) or, 0.85 V (high potential alloy).

(c) Zinc ..... 0.25 V.

H7 POWER SUPPLY CONSIDERATIONS

Where impressed current systems are being considered, it is necessary to have a direct current power supply, which may be obtained from sources such as the following:

(a) Mains power supply.

(b) Internal combustion-driven generators.

(c) Solar cells (with storage).

(d) Thermoelectric generators.

(e) Wind driven generators (with storage).

(f) Closed circuit vapour-turbine-driven generators.

Equipment and wiring shall comply with AS 2374 (all parts), AS/NZS 3000 and AS/NZS 5000.1, as appropriate.

The driving potential source used should provide sufficient cathodic protection current, but for safety reasons should not exceed 50 V d.c.

The simplest system may involve the use of a transformer with a suitably matched rectifier to produce a fixed voltage of unfiltered output, the current depending upon the total circuit resistance and the back e.m.f.

NOTE: Smoothing may be required for special purposes, such as suppression of electrical interference.

Where anode/cathode resistance varies, current control may vary from manual voltage adjustment to a fully automated system.

To allow for unknown factors such as stray current effects, increased ground resistance, coating damage and plant extensions, it is recommended that equipment be capable of providing at least twice but not more than 5 times the current requirements and twice the output voltage (see Paragraph H2) as determined initially.

An approximate d.c. voltage requirement can be calculated by multiplying the total circuit resistance by the required current and adding the back e.m.f.

H8 BACKFILLS

H8.1 Electronic conduction backfills

Electronic conduction backfills are used with impressed current anodes to—

(a) decrease anode-to-soil resistance; and

(b) increase current capacity of the anode system.

Materials used include magnetite, calcined coke and graphite (see AS 2239).

H8.2 Electrolytic conduction backfills

Electrolytic conduction backfills are mainly used for galvanic anodes to retain moisture and lower the anode-to-soil resistance.

Care should be taken with electrolytic backfills of bentonite/gypsum that surround impressed current anodes, to prevent the possibility of the operation of the system drying out the backfill.

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H9 PROVISION FOR STRAY CURRENTS

The important consideration in stray current areas is to locate where stray current pick-up occurs and/or is discharged from the structure (see Section 3 and Section 7).

H10 SYSTEM DESIGN DOCUMENTATION

Following design of the cathodic protection system, it is necessary to prepare suitable documentation for the record.

Documentation of the proposed system should be drawn up in the form of plans and acceptable engineering standards using appropriate signs and symbols (see Appendix J).

Appropriate documentation may include the following:

(a) A report of the proposed design and layout including design calculations, assumptions made in the design and an explanation of any deviations from normal practice. It should also include full and adequate drawings and specifications to allow construction to proceed. The report should typically include the following:

  (i) A properly scaled diagram of the structure to be protected in which the following are identified:

    (A) Accessible locations on the structure.

    (B) Access roads.

    (C) Power supply points.

    (D) Topographical features such as creeks and rivers.

  (ii) Location of anode(s) and anode and cathode cable routes.

  (iii) Location of d.c. power supplies and power supply extensions specially provided.

  (iv) Test points, suitably identified.

  (v) A list of owners of foreign neighbouring structures, which may affect or be affected by the proposed system(s).

  (vi) Location of any bonding to other structures, including any insulation of structure sections.

  (vii) A detailed plan of anode installations, including anode type, mass, dimensions, type of backfill and pattern of grouping in a groundbed, if applicable.

  (viii) Location of reference electrodes.

  (ix) Installation instructions.

    NOTE: Documentation may need to be updated in light of changes that occur during construction.

(b) Documentation required by statutory or regulatory approval authorities, as appropriate.

(c) Advice to owners of neighbouring structures to seek cooperation. Such advice should comply with statutory requirements, if applicable.

(d) Advice to local government authorities, including main roads authorities and harbour boards on road openings and attendant civil work required.

(e) Advice to the electricity supply authorities regarding the need for power supply.

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TABLE H1

TYPICAL PROPERTIES AND USES OF ANODES FOR CATHODIC PROTECTION

Description of anode	Typical application	Typical environment resistivity* Ω.m	Typical current density A/m^2	Approximate consumption kg/A.Y	Relevant Standard
GALVANIC ANODES Zinc	All waters and soils of low resistivity	0.2 to 10	Controlled by total circuit resistance	12	AS 2239
Magnesium	All waters and soils of higher resistivity	5 to 30†		7	AS 2239
Aluminium	Sea water	0.2 to 1		3.5	AS 2239
IMPRESSED CURRENT ANODES‡ Platinized titanium/niobium§	Sea water, sea bed or soils, with calcined petroleum coke backfill	0.2 to 2	100 to 1000	10^{-5}	—
Mixed metal oxide			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.

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APPENDIX I

EXAMPLE OF CATHODIC PROTECTION SYSTEM DESIGN DOCUMENTATION FOR COMPACT BURIED STRUCTURES

(Informative)

Structure details

Materials of construction:.....

Structure dimensions:.....

—Diameter, mm:.....

—Wall thickness, mm: .....

—Length, m:.....

Field joint type (e.g. fully welded, spigot and socket, etc): .....

Design Life: .....

Coating .....

—Type: .....

—Surface preparation:.....

—Application method: .....

—Joint coating:.....

Temperature: .....

—Design: .....

—Operational: .....

Unintended isolations:.....

Structure continuity: .....

Cathodic protection design details

Protection criterion: .....

Design life:.....

Coating holiday/breakdown: .....

Initial:. . . . . Mean:. . . . . Final:. . . . .

Current density:

Initial:. . . . . Mean:. . . . . Final:. . . . . From CD test/Reference*

Surface area to be protected:.....

Total current demand: .....

Insulated flange/joint locations:.....

Impressed current systems	*Sacrificial anodes*
Cathodic protection site details	**Individual site details**
Location:.....	Location: .....
Resistivity:.....	Resistivity:.....
Cables (core size, length, insulation):	Anode
Groundbed feeder:	Material: .....
Structure negative:.....	Size: .....
Anode header:	Installation details: .....
Anode	Connection details:.....
Material:	Backfill type: .....
Design life:	Design current:.....
Backfill	Design life: .....
Type:	
Resistivity:.....	
Layout	
Anode orientation:.....	
Anode spacing:.....	
Length:	
Design resistance:.....	
Actual resistance:	
T/R	
Capacity:.....	
Size:	
Power source:.....	
Surge protection:	

* Delete as necessary.

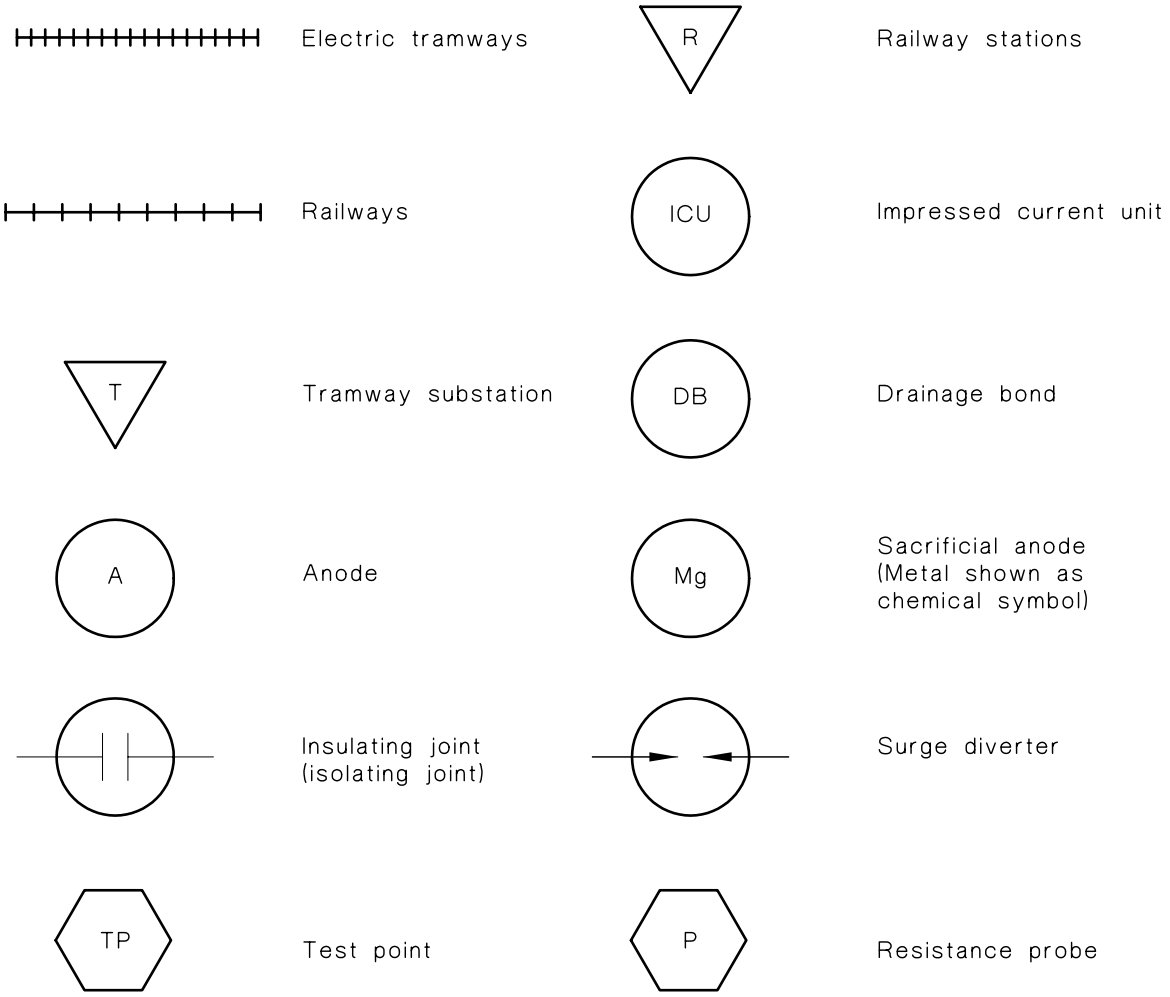
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APPENDIX J

GRAPHICAL SYMBOLS RELATING TO CATHODIC PROTECTION

(Normative)



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APPENDIX K

CONTROL OF INTERFERENCE CURRENTS— LIST OF ELECTROLYSIS COMMITTEES/REGULATORY AUTHORITIES

(Informative)

State	State Electrolysis Committee
A.C.T.	A.C.T. Electrolysis Committee C/- ACTEW PO Box 366 CANBERRA CITY A.C.T. 2601
N.S.W	New South Wales Electrolysis Committee C/- Ministry of Energy and Utilities PO Box 536 ST LEONARDS N.S.W. 2065
N.T.	The Managing Director The Power and Water Authority PO Box 1921 DARWIN N.T. 0800
Qld.	Department of Industrial Relations Electrical Safety Office LMB 2234 BRISBANE QLD 4001
S.A.	South Australian Electrolysis Committee C/- PO Box 206 KILKENNY S.A. 5009
Tas.	The Chief Electrical Inspector Work Place Standard Tasmania 30 Gordon Hill Road ROSNEY TAS. 7018
Vic.	Victorian Electrolysis Committee Office of the Chief Electrical Inspector PO Box 262, Collins Street West MELBOURNE VIC. 8007
W.A.	Electrolysis Subcommittee (ACA) Water Corporation Western Australia 629 Newcastle Street LEEDERVILLE W.A. 6007

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APPENDIX L

STRUCTURE INSPECTIONS

(Informative)

L1 FACTORS AFFECTING THE REGULARITY OF STRUCTURE INSPECTIONS

The following factors affect the regularity of structure inspections:

(a) Statutory agreements.

(b) The probability of corrosion failure, which depends on a number of factors, including—

  (i) wall thickness of the structure;

  (ii) presence of stray current, particularly stray traction current;

  (iii) corrosive nature of the environment;

  (iv) structure operating conditions (e.g. the transmission of hot oil);

  (v) seasonal changes in soil moisture content;

  (vi) quality and integrity of coatings; and

  (vii) effectiveness of the cathodic protection system.

(c) The consequence of any corrosion failure, which depends on a number of factors, including—

  (i) material contained by the structure (e.g. material heavier than air, such as flammable gas);

  (ii) location of the structure (e.g. in urban areas); and

  (iii) size of structure and its operating conditions.

(d) Other factors, including—

  (i) alternative structure inspection techniques, e.g. ultrasonics;

  (ii) whether an impressed current or a sacrificial anode system is used;

  (iii) the degree of difficulty of access to, and the consequent cost of inspections; and

  (iv) whether the system is partially or fully monitored by telemetry of key data.

L2 LOCATION OF TEST POINTS

Test points should be located on the structure at positions so as to provide a full representation of the levels of cathodic protection, e.g. at structure extremities, isolation joints and casings.

Test points that are located close to high voltage electricity substations or high voltage transmission towers may be subject to hazardous voltages under fault conditions (see Appendix G).

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APPENDIX M

COMPARISON OF STRUCTURE/ELECTROLYTE POTENTIALS OBTAINED WHEN MEASURED WITH VARIOUS REFERENCE ELECTRODES

(Informative)

Figure M1 and Table M1 may be used to enable a comparison to be made between the potentials of a number of reference electrodes.

NOTE: For cathodic protection criteria, see Section 3.

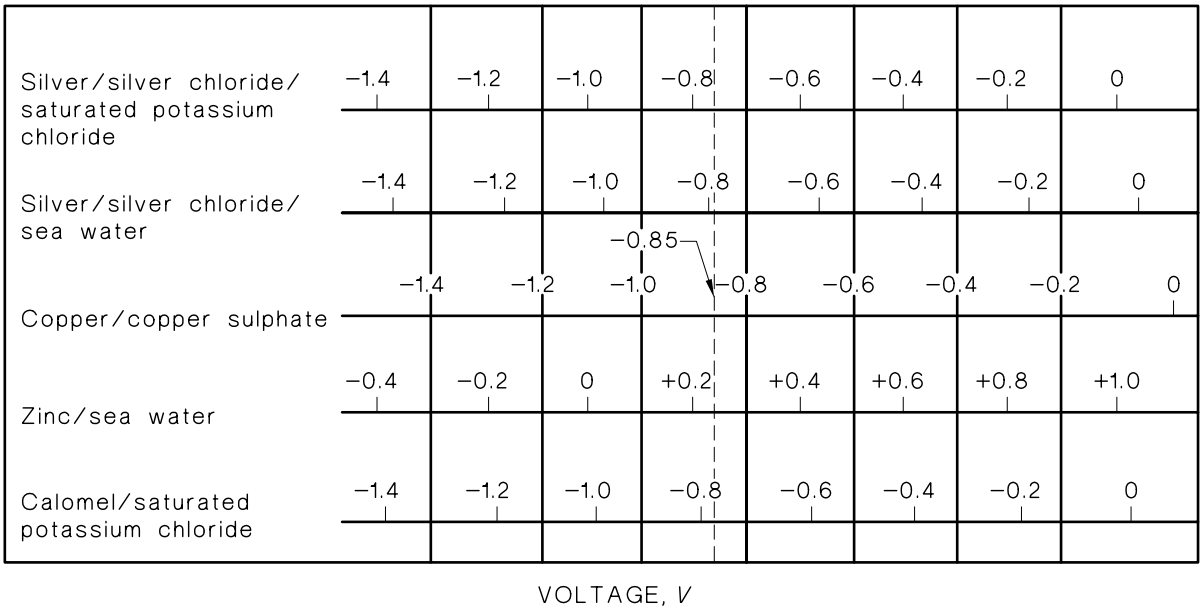


FIGURE M1 COMPARISON OF STRUCTURE/ELECTROLYTE POTENTIALS (V) MEASURED WITH VARIOUS REFERENCE ELECTRODES

TABLE M1

POTENTIALS OF VARIOUS ELECTRODES MEASURED AGAINST A SATURATED $Cu/CuSO_4$ ELECTRODE

Type of electrode	Potential at 25°C mV
Ag/AgCl/Sea water	−66
Ag/AgCl/KCl (saturated)	−91
Zinc/Sea water	−1 106
$Hg/Hg_2Cl_2/KCl$(saturated)	−74

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APPENDIX N

CATHODIC PROTECTION OF STRUCTURES SUBJECT TO STRAY DIRECT TRACTION CURRENT

(Informative)

N1 SCOPE AND GENERAL

N1.1 Scope

This Appendix gives information on minimizing the impact of stray traction direct currents and methods that may be employed to protect structures.

N1.2 General

The main source of stray current experienced in the ground is track leakage current from d.c. rail return railway and tramway systems.

Stray traction current may be detected as rapid fluctuations in potential on the structure corresponding to the changing current loadings on the traction system. Current pick-up will occur at some points on the structure whilst current discharge will take place at separate points. The pick-up points will normally alter in position on the structure as the motor carriage moves.

The assessment of the level of cathodic protection for a structure will be influenced by the level of stray current effects. Criteria for cathodic protection of structures subject to stray current are given in Clause 3.2.2.6 and 3.2.2.7.

NOTE: The relevant State Electrolysis Committee, where it exists, is the appropriate technical body for coordination and consultation regarding stray current problems and mitigation systems, see Appendix K.

N2 MINIMIZATION OF STRAY CURRENT EFFECTS

N2.1 General

Although compacted structures are usually much less affected by stray current than are pipelines and cables, this can still occur in stray current areas. The effects of stray current on underground structures can be minimized in two ways, as follows:

(a) Minimization of track leakage current at its source (see Paragraph N2.2).

(b) Mitigation of current pick-up and discharge from the structure (see Paragraph N2.3).

N2.2 Minimization of track leakage current at its source

Track leakage current may be minimized by the following methods:

(a) Obtaining maximum conductance in the rail return by ensuring that the rails form an electrically continuous conductor.

(b) Obtaining maximum electrical resistance between the track system and earth by cleaning or replacing the track ballast and ensuring good water drainage, particularly in station pits and at road crossings, and by isolating poorly maintained sidings.

(c) Maintaining railway structure safety devices, such as spark gaps, in good working order.

(d) Regular inspection and removal of fortuitous metallic contacts between the track and earthed structures.

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N2.3 Mitigation of stray current pick-up and discharge from the structure

Stray current pick-up and discharge may be reduced in severity by means of the following:

(a) Coating of the structure to the best possible standard, with particular attention paid to the coating near likely current pick-up points.

(b) Avoidance of anode or earthing bed placement in current pick-up regions.

(c) Consideration of stray current pick-up and discharge regions in the selection of the structure route.

(d) Installation of current drainage bonds, including automatically controlled drainage systems, at discharge points within practicable distance of the stray current source. (See Paragraph N2.4)

(e) Positioning of in-line insulation in locations where it will not disrupt the effectiveness of stray current mitigation measures.

NOTE: Caution is needed with insulation because stray currents frequently cross such joints causing extreme local corrosion to occur at one side of the joint.

(f) Use of automatic, controlled output, impressed current cathodic protection units in stray current areas, and in particular, installation of cathodic protection at discharge points that are remote from the stray current source.

NOTE: The effect of controlled units will depend upon whether they are located in the stray current pick-up or discharge areas. Controlled units in the pick-up area will minimize negative-going excursions in this region, but cause little reduction of corresponding positive excursions in the discharge zone. Controlled units in the discharge area will minimize or eliminate positive excursions, but will accentuate negative peaks in the pick-up zone. (Short term negative peaks are of relatively minor significance.)

N2.4 Mitigation of stray current discharge using traction current drainage

N2.4.1 *Reduction of discharge to soil*

In many instances, it is practicable to reduce the discharge of stray current from structure to soil by providing a metallic return path (drainage cable) to the traction system. Such drainage should be arranged through the relevant local Electrolysis Committee.

Traction authorities will usually provide electrical drainage to reduce, as far as practicable, any anodic potentials to the level existing when the traction system is not in operation.

N2.4.2 *Maximizing effectiveness of drainage bonds*

In many instances the positioning of drainage bond connection points will be governed by practical considerations. However, when practicable, drainage effectiveness may be improved by the following measures:

(a) Making the structure connections near points that exhibit maximum adverse potential from stray current effects.

(b) Making structure connections at points where rail and structure potentials show correlation, so that drainage current peaks occur at the same instant as adverse structure potential peaks.

(c) Designing the drainage bond to carry peak currents with minimal voltage drop. The potential difference between structure and rail may be only about 1 V.

(d) Using relay contact type devices rather than diodes to block reverse currents, where there is little potential difference between rail and structure. (Diodes tend to be more reliable, but introduce a voltage drop of 0.5 V to 1.5 V in the circuit.)

N2.4.3 *Drainage bond operation*

Where stray current problems exist, the local Electrolysis Committee should be consulted.

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Drainage bonds should be connected and adjusted to achieve the following results:

(a) The reduction of positive potential excursions on the drained structure to the level existing when the traction system is not in operation, and/or compliance of the structure potential with the criteria for acceptable corrosion protection; (this is usually achieved by cathodic protection).

(b) Where several structures are connected to a common drain, satisfactory drainage of the current to each structure. (Reverse current flow should be prevented by means of blocking relays, or diodes in series with each structure bond.)

(c) Structures not included in the system are unaffected.

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Standards Australia

GPO Box 5420 Sydney NSW 2001
Administration Phone (02) 8206 6000 Fax (02) 8206 6001 Email mail@standards.com.au
Customer Service Phone 1300 65 46 46 Fax 1300 65 49 49 Email sales@standards.com.au
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