AS 2832.2—1991

Australian Standard®

Cathodic protection of metals

Part 2: Compact buried structures

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- Aluminium Development Council
- Australasian Corrosion Association
- Australian Gas Association
- Australian Institute of Steel Construction
- Australian Zinc Development Association
- Austroads
- Bureau of Steel Manufacturers of Australia
- Confederation of Australian Industry
- Department of Defence
- Electricity Supply Association of Australia
- Engineering and Water Supply Department, South Australia
- Railways of Australia Committee
- States Electrolysis Committees
- Telecom Australia
- University of New South Wales

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- Corrosion consultants
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- Gas and Fuel Corporation of Victoria
- Hunter Water Board
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PREFACE

This Standard was prepared by the Standards Australia Committee on the Corrosion of Metals under the direction of the Metals Standards Board, at the request of industry, to provide a Standard for the guidance of owners of underground structures which are to be cathodically protected. It is not intended to be a complete cathodic protection design manual and those requiring further information should refer to the other Standards mentioned, to text books on the subject or to appropriate corrosion prevention specialists.

During preparation of this Standard, account was taken of the regulations of the various State Authorities, which differ in their approach to cathodic protection.

This Standard forms one of a proposed series of Standards which cover the cathodic protection of metals. The first in the series is AS 2832.1, *Pipes, cables and ducts*.

Other Standards which are in the course of preparation and provide guidelines on cathodic protection cover compact immersed structures such as offshore platforms and jetties, internal surfaces of items such as water storage tanks, and the design of cathodic protection systems for boats.

CONTENTS

FOREWORD

Corrosion of a metal is an electrochemical reaction between the metal 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. This is achieved by applying an appropriate direct current flowing in opposition to the original corrosion current, thus stopping 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 its protection is being adequately 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 system are available:

(a) Galvanic anode systems, which employ buried metallic anodes which sacrifice themselves to provide the source of direct current for protection of the structure.

(b) Impressed current systems, which employ an external electrical power source of direct current for the protection of the structure.

Corrosion control for a structure should be considered at the conceptual design stage. Factors which affect the corrosion of buried or partially buried 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) Decide whether the structure should be coated. If the decision is to coat, then decide what particular coating system should be employed. If the structure is already installed, a determination should then be made as to whether the nature and quality of the coating are compatible with cathodic protection.

(ii) Design the structure to be compatible with cathodic protection and to include cathodic protection facilities during construction. If the structure is already installed, determine the measures to be taken to apply cathodic protection effectively, and the facilities necessary for cathodic protection monitoring.

(iii) If necessary, design the cathodic protection system to include provisions for the mitigation of stray current effects. If the structure is already installed, the design parameters may be measured and an optimum design provided for the mitigation of stray current effects. If the structure is not installed, a number of assumptions will be required for the estimation of design parameters, and an adequate design for the mitigation of stray current effects may not be possible to achieve.

   During the cathodic protection design stage, consideration should be given to the possibility that interference with foreign structures in the area may occur. In some circumstances this interference may only be resolved by field testing subsequent to installation.

(iv) Install the cathodic protection system.

   NOTE: Legislation in some States requires that a permit be obtained prior to the installation of a cathodic protection system.

(v) Commission the cathodic protection system after achieving a balance of cathodic protection current, to enable the entire structure to be protected with minimum current, and with as uniform a potential over its surface as is practicable. Equipment installed for the mitigation of stray current effects should be balanced for optimum performance.

   Carry out interference testing and satisfy all parties involved that any interference problems have been resolved, giving attention to regulatory requirements (if any) of the State in which the system is installed.

(vi) Monitor cathodic protection at regular intervals, adjusting the conditions of operation as necessary, and maintain complete records of its operation.

STANDARDS AUSTRALIA

Australian Standard
Cathodic protection of metals

Part 2: Compact buried structures

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard provides guidelines 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 pipework.

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

(a) The design of structures requiring cathodic protection.

(b) Coatings for use on buried metal structures.

(c) Criteria for choice of cathodic protection potential.

(d) The design of cathodic protection systems.

(e) The installation of cathodic protection systems.

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

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

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

NOTES:

1 A different approach is required to achieve satisfactory protection of mounded installations to that for installations buried below ground.

2 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.

3 This Standard employs positive current flow, and uses the potential sign conventions specified in AS 1852.

1.2 REFERENCED DOCUMENTS The following documents are referred to in this Standard:

AS	
1020	The control of undesirable static electricity
1076	Code of practice for selection, installation and maintenance of electrical apparatus and associated equipment for use in explosive atmospheres (other than mining applications)
1076.1	Part 1: Basic requirements
1100	Technical drawing
1100.401	Part 401: Engineering survey and engineering survey design drawing
1518	Extruded high density polyethylene protective coating for pipes
1627	Metal finishing—Preparation and pretreatment of surfaces
1627.4	Part 4: Abrasive blast cleaning
1627.7	Part 7: Hand tool cleaning of metal surfaces
1768	Lightning protection
1852	International electrotechnical vocabulary
2043	Coal-tar and synthetic (fast dry) primers for steel pipes
2044	Coal-tar enamel for steel pipes
2045	Materials associated with the coating and lining of steel pipes with coal-tar primer/enamel systems
2046	Code of practice for the coating and lining of steel pipes with coal-tar primer/enamel systems
2239	Galvanic (sacrificial) anodes for cathodic protection
2430	Classification of hazardous areas
2430.1	Part 1: Explosive gas atmospheres
2518	Fusion-bonded low-density polyethylene coating for pipes and fittings
3000	SAA Wiring Rules
3100	Approval and test specification—Definitions and general requirements for electrical materials and equipment

3108 Approval and test specification—Isolating transformers and safety isolating transformers
3108.1 Part 1: General requirements
3108.2 Part 2: Supplementary requirements—Isolating transformers
3108.3 Part 3: Supplementary requirements—Safety isolating transformers

3147 Approval and test specification—Electric cables—Thermoplastic insulated for working voltages up to and including 0.6/1 kV

1.3 DEFINITIONS For the purpose of this Standard, the definitions given in Appendix B apply.

SECTION 2 DESIGN OF STRUCTURES FOR CATHODIC PROTECTION

2.1 GENERAL This Section provides guidance for the design of buried compact structures to accommodate cathodic protection.

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

The design of a compact structure should be as simple as possible, avoiding complex shapes with sharp crevices or edges, and shielded or screened areas that may give rise to localized underprotection.

2.2 STRUCTURE COATING Cathodic protection may be applied to bare or coated surfaces. The following factors should be considered when determining whether the surface should be coated or remain bare:

(a) The magnitude of the current required to achieve protection is considerably less for coated surfaces. When surfaces are coated the cathodic protection installation may be smaller and less complex than that which would be required to protect uncoated surfaces. Sacrificial anodes will have a longer life when used to protect coated surfaces.

(b) Uniformity of current distribution to an uncoated structure may be difficult to achieve, particularly if the structure contains deep recesses or shielded areas. Coating the structure may result in more uniform protective potentials.

(c) The ability to apply and maintain the coating.

NOTE: High levels of current can significantly increase the risk of causing interference to foreign structures. Legislation in some States prohibits the operation of cathodic protection installations which cause interference.

2.3 STRAY CURRENTS Three forms of stray current can affect the structure and its operations. These forms are as follows:

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

It is usually not possible to quantify the problem, or to design preventative procedures, until the structure is installed and the environment is stable. It may be possible to reduce or remove the problem at the design stage by locating the structure remote from sources of stray current.

(b) *Surge current* Surge current can pose a risk to both personnel and equipment. The surge current may arise from a fault in an adjacent high voltage power transmission line, or from a lightning strike. The high electrical surge can cause breakdown of insulating joints and transformer rectifiers, and can result in the fusion of cables and electric shock to personnel in contact with the structure.

Protection of personnel against the effects of surge current may be achieved by the following precautionary measures:

(i) By ensuring a suitable separation from high voltage power transmission support structure footings and earth electrodes.

(ii) By the installation of surge protection at insulating joints and at transformer rectifiers.

(iii) By adequate warning to all personnel of inherent dangers, especially of the dangers which occur during electrical storms.

(c) *Alternating current* Induced alternating current can arise where the structure is adjacent to high voltage power transmission lines, and can pose a risk to personnel.

Installation of insulating joints between the compact structure and connected pipelines and cables, or the selective use of low resistance earthing electrodes, can minimize induced voltages. In addition, installation of equipotential mats can minimize ‘step’ and ‘touch’ potentials.

Impressed current power sources may require special design features to prevent induced voltages.

NOTE: An induction level of less than 60 volts r.m.s. should not require special measures.

The induction conditions relating to zero sequence (single-phase earth) faults in electricity transmission lines should also be considered in relation to the surge suppression equipment and the cathodic protection systems of the structure.

2.4 TEST POINTS

2.4.1 General Test points provide facilities for monitoring compact structure potentials, and give information on the effectiveness of the cathodic protection.

2.4.2 Location Test points should 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 should 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 should be located where they are accessible and protected from damage, including vandalism, and are a minimum hindrance to site usage.

Test point cabling requirements are given in Section 5.

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

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

2.4.3 In-situ reference electrodes Consideration should 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 hardstanding. Such reference electrodes should either have a fixed and known potential, or should be capable of calibration before and after use.

2.5 INSULATING JOINTS To facilitate the use and control of cathodic protection systems, insulating joints are used to isolate electrically the structure or parts of the structure from external pipelines and cables. They may consist of flange assemblies, couplings, monolithic joints and other types of connection. The dielectric strength of such joints should be compatible with the system design.

The mechanical requirements for insulating joints should comply with the requirements of the appropriate design code.

Typical points where provision of insulating joints should be considered include the following:

(a) At ownership changeover points.

(b) At connection points to other structures.

(c) In stray current areas.

(d) At junctions of dissimilar metals.

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

(f) Where provision is made to minimize induced voltages.

(g) 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 which cannot cause an exposed arc during their operation, or in the event of their failure.

Surge protection should be considered in areas adjacent to high voltage transmission lines and in lightning-prone areas. In such cases, cable connections should be short, direct, and of a size suitable to carry short-term high current loading (see Clause 2.3(b)).

Installation of underground insulating joints should be avoided, except where both sides are cathodically protected. Where bolted-flange insulating joints are used underground, the bolts should be connected to the cathodically protected side, if only one side is cathodically protected. Insulating joints should be wrapped or coated to give the same standard of protection as is required for the structure. Separate test cables should be run from each side of the insulating joint, and be terminated suitably at a common test point.

NOTE: When designing an insulating joint, it may be necessary to specify that the joint be tested prior to installation, and also to specify that after coating, the assembly be inserted into the pipeline and welded using a controlled welding sequence to minimize stresses (see Clause 6.2.5).

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

Insulating joints located above ground in areas subject to high voltage surges, such as areas near high voltage power transmission lines or areas subject to electrical storms, should be provided with a system that will protect joint insulation, and protect 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 insulation over a sufficient length of the structure on either side of the joint.

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

NOTE: Where insulating joints or flanges are used on lines containing water or other conducting liquids, there is a need to provide an insulating liner to prevent increased internal corrosion occurring at one side of the joint. The length of the liner required is dependent on the conductivity of the electrolyte. For highly conductive saline solutions such as seawater, the pipeline liner length is typically 8 diameters.

2.6 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 should preferably be made of an electrolytically conductive material.

Where steel casings are used, they require electrical isolation from the structure by the use of insulating spacers. The annular space between the casing and the structure requires treatment by one of the following methods:

(a) By filling the space with a dielectric material, e.g. a suitable grease.

(b) By filling the space with an electrolyte, e.g. bentonite clay or cement mortar.

NOTE: For both (a) and (b), the level of filling needs to be above that of the structure.

Method (b) is preferred, because the structure within the casing can be cathodically protected.

If there is no access to moisture, a third option is to leave the annular space untreated.

NOTE: In practice it is difficult to prevent the ingress of some moisture. Adequate end seals should be used, and casings preferably should be sloped to allow drainage.

Care should be exercised to ensure that the coating on the structure is not damaged during installation.

Steel casings should not be coated or lined, unless with a conductive material, e.g. cement, otherwise the structure within the casing may not be cathodically protected.

Casings should not be cathodically protected, because interference between the casing and the structure may cause corrosion to that part of the structure inside the casing.

2.7 ELECTRICAL ISOLATION Where possible, buried structures should be installed in isolation from all buried metallic foreign (secondary) structures and electrical earth.

It is recommended that a separation of at least 300 mm be maintained between buried structures, to prevent shielding from protective current and to minimize interference.

Specific instances which require electrical isolation from a cathodically protected structure include the following:

(a) Metallic reinforcement in pavements, buildings, concrete anchors and weight coatings.

(b) Uncoated metal housings ancillary to a structure.

(c) Where a metal sleeve is used, and where it is intended to maintain electrical isolation between the sleeve and the structure.

NOTES:

1 If a metal sleeve remains in electrical contact with the structure, a loss of cathodic protection of the structure will occur within the sleeve area.

2 Where electrical continuity is required for any other purpose, d.c. electrical isolation for the cathodic protection system may be achieved by the use of appropriately rated isolation or polarization cells. Subject to approval by local electricity supply authorities, these devices may be used to link the electricity supply earthing system to cathodically protected plant for electrical safety of personnel, without affecting the cathodic protection level.

3 Undesirable connections will occur in the earthing systems of compressors, pumps, telemetry installations or valves, or at any other electrically powered equipment which is earthed.

4 Where isolation is impractical, the use of zinc earthing electrodes instead of copper earthing electrodes may avoid the need for isolation.

(d) The area between buried structures and the earth of high voltage electrical transmission lines, e.g. steel transmission tower footings, reinforced concrete poles, and specific earthing systems including tower/pole connecting cables.

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

NOTES:

1 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.

2 Care is necessary to ensure that parallel structures such as pipe supports, cable trays and metallic conduit do not "short-out" these insulation measures.

2.8 EARTH POTENTIAL RISE CAUSED BY HIGH VOLTAGE POWER SYSTEM FAULTS The earth potential can rise by thousands of volts as the result of high voltage power system faults. This voltage can cause breakdown of the buried structure coating and perforation of the structure, and can expose personnel who may be working on the buried structure in the immediate vicinity of electrical authority installations to hazardous voltages. In this situation, the buried structure provides a remote earth connection to the area of high potential rise.

The separation required between the earths of high voltage power transmission lines and buried structures will depend on the type of line, its fault current parameters, and the soil resistivity.

Where the structure is adjacent to a high voltage electricity transmission tower, substation, or earthing system, a check should be made with the electricity supply authority to ascertain the extent of the electrical potential rise area, should a fault occur.

For a given fault current, the safe distance from such electrical installations varies inversely with soil resistivity. Typical distances may be as low as 1 m for some 11 kV systems, to over 100 m for major substations.

Equipment requiring access, e.g. joints, valves and test points, should not be sited within the potential rise area. If the structure is in such an area, special arrangements are required to provide a coating of suitable dielectric strength.

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

The use of welded or fusion joints which are electrically continuous is recommended. High resistance joints, e.g. flanges with elastomer rings require bonds to be fitted.

The mechanical strength of a bond should be adequate to withstand the effects of backfilling and maintenance, and its current-carrying capacity should be sufficient for the bond to remain undamaged after the passage of a heavy surge current from an external source (see Clause 2.3(b)).

2.10 GRAPHICAL SYMBOLS Graphical symbols used on drawings and plans to identify cathodic protection details should be in accordance with AS 1100 Part 401, and Figure 2.1.

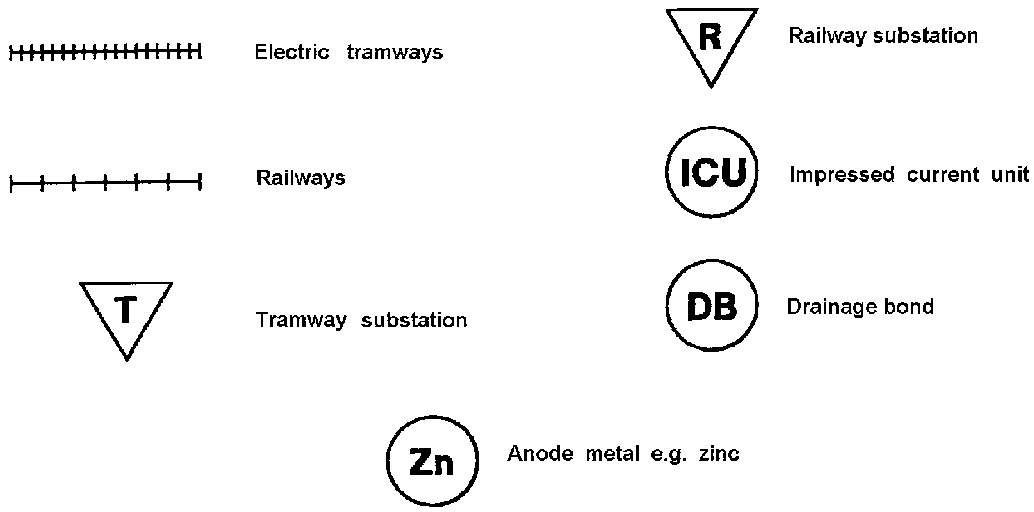


FIGURE 2.1 GRAPHIC SYMBOLS RELATING TO CATHODIC PROTECTION

SECTION 3 COATINGS FOR USE WITH CATHODIC PROTECTION

3.1 GENERAL This Section provides guidance on the types of coatings used on buried metal structures which are to be cathodically protected.

Coatings assist in the corrosion control of buried structures in two ways, as follows:

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

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

Although high costs are involved with the initial coating procedure, the application of coatings will lead to a considerable reduction in cathodic protection power consumption.

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

NOTE: In compact structures, many combinations of coating systems are used. *In-situ* repairability should be a significant factor in the selection of the coating system.

3.2 COATING PROPERTIES The prime function of a coating is to provide an electrically insulating barrier between the structure and its environment. Desirable features of coatings are as follows:

(a) Resistance to chemical degradation.

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

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

(d) Resistance to the transmission of water.

(e) Compatibility with the level of cathodic protection required (resistance to cathodic disbondment).

(f) Long-term adhesion to the structure.

(g) Resistance to entomological attack.

(h) Sufficient strength to resist service conditions including changes resulting from seasonal variations.

(i) Mechanical strength and resistance to pinholing, cracking 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 pipe anchors, if applicable.

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

3.3 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 availability and economic considerations.

Table 3.1 gives details of coating types which are commonly used for the protection of structures considered in this Standard, and lists typical properties of installed coating systems.

When a choice of coating has been made, the test requirements of the relevant product Standard should be invoked to ensure that the proprietary product chosen is of acceptable quality. Correct application techniques and requirements for appropriate field testing of the coated structure are normally specified in the product Standard.

NOTE: A loose plastic sleeve is not a satisfactory coating for use with cathodic protection.

TABLE 3.1
TYPICAL PROPERTIES OF REPRESENTATIVE COATING SYSTEMS FOR COMPACT STRUCTURES

Coating system*	Coating site	Ease of on-site application	Structure pretreatment (for steel)	Coating thickness mm	Susceptibility to damage from			Relevant Australian Standard
					Soil† stresses	Cathodic disbondment	Impact	
Coal tar enamel	Site and shop	Difficult	Wire brush or blast‡	2.5 to 5.0	Medium	Medium	Medium	AS 2043 to AS 2046 inclusive
Extruded polyethylene	Shop	—	Blast	0.6 to 1.8	Low	Low	Medium	AS 1518
Fusion bonded polyethylene	Shop	—	Blast	1.8 to 3.5	Low	Low	Low	AS 2518
Fusion bond epoxy	Site and shop	Difficult	Blast	0.3 to 1.0	Low	Low	Low	—
Bituminous enamel	Site and shop	Medium	Wire brush or blast‡	2.5 to 5.0	Medium	Medium	Medium	—
PVC, poly-ethylene backed laminated tapes	Site	Easy	Wire brush or blast‡	0.7 to 3.0	High	Medium	High	—
Petrolatum tapes	Site	Easy, highly conformable	Wire brush‡	3 to 6	High	Not applicable	Medium	—
Heat shrink sleeve§	Site	Medium	Blast	1.0 to 3.0	Low	Medium	Medium	—
Coal tar epoxy	Site and shop	Medium	Blast	0.3 to 0.6	Low	Medium	Medium	—
High build epoxy	Site and shop	Medium	Blast	0.75 to 3.0	Low	Medium	Low	—
Polyester	Site and shop	Difficult	Blast	0.8 to 4.0	Low	Low	Medium	—
Vinyl ester	Site and shop	Difficult	Blast	1.5 to 4.0	Low	Low	Medium	—

* Metalliferous primers should not be used in coating systems for structures requiring cathodic protection.

† Properties resulting from soils which produce stresses, e.g. clay.

‡ It is good practice to blast clean surfaces prior to coating application to ensure maximum adhesion. Wire brush pretreatment, which may leave millscale on a steel surface, may leave the structure in a condition susceptible to stress-corrosion cracking, and is inferior to blast-cleaned surfaces (see AS 1627.4 and AS 1627.7).

§ Used on site welded joints. Difficult to repair.

NOTE: The properties tabulated above relate only to the basic standard coating for each system. Coating performance can vary substantially from these values, and is dependent on the characteristics of the actual system used.

SECTION 4 CRITERIA FOR CATHODIC PROTECTION

4.1 GENERAL Many metals are protected from corrosion by the application of direct current which maintains the potential sufficiently negative with respect to the environment. Direct current is provided by the use of galvanic anodes, or by means of an impressed current system. The potential of a structure with respect to its environment can give a reliable indication of the degree of protection being provided.

The potential criteria to provide protection are given in Clauses 4.2 to 4.6, however other potential criteria may be used, provided that their efficacy has been established. This Standard recommends the use of copper/saturated copper sulfate reference electrodes for potential measurement.

Other reference electrodes may be used as alternatives to copper/saturated copper sulfate, provided that their relativity to this reference electrode has been established.

4.2 FERROUS STRUCTURES

4.2.1 Buried structures The accepted practice for the protection of buried ferrous structures is to maintain a potential on all parts of the structure equal to, or more negative than, –850 mV with respect to a copper/copper sulfate reference electrode.

NOTE: Where sulfate-reducing bacteria are active, a more negative potential may be required for protection.

4.2.2 Alternative protection criteria An alternative practice for the protection of a buried ferrous structure is to maintain the polarized potential on all parts of the structure at a level of at least 100 mV more negative than the natural potential, or the potential which exists after the structure has been allowed to fully depolarize. This practice is only applicable where there are no significant amounts of mixed metals present on the structure.

NOTES:

1 This alternative protection practice may result in a less negative polarization potential than that described in Clause 4.2.1, particularly in soils of low moisture and low oxygen content found in arid conditions.

2 Care is required when measuring polarized potential, as errors due to the presence of soil voltage gradients can occur (see Clause 4.7.1).

4.3 COPPER/COPPER ALLOY STRUCTURES The accepted practice for the protection of a buried copper structure is 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.

NOTE: In some situations, potentials for copper alloys as large as –650 mV may be required for protection.

4.4 LEAD STRUCTURES For aerated conditions, the accepted practice for the protection of a buried lead structure is 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. For anaerobic conditions, the potential to be maintained is equal to, or more negative than –800 mV with respect to a copper/copper sulfate reference electrode.

A precaution is necessary with lead structures to prevent damage should the polarizing energy be removed. If the structure is maintained at a maximum level of protection (i.e. at approximately –1.8 V to ensure adequate potential at extremities), the pH surrounding the structure will usually be raised to a high level (approximately pH 12). Adequate provision to maintain continuity of protection is necessary as the dissolution of lead will occur if the protection is disabled.

To prevent damage to lead structures by the formation of gaseous lead hydride, the potential of the structure with respect to a copper/copper sulfate reference electrode should not be more negative than –2.5 V.

4.5 MIXED METALLIC STRUCTURES The accepted practice for the protection of buried mixed metallic structures is to maintain a negative (cathodic) voltage, at least equal to that required for the most anodic metal, between all structure surfaces and a copper/copper sulfate reference electrode.

4.6 STRUCTURES SUBJECT TO STRAY DIRECT CURRENT Where structures are subject to stray direct current, it may be necessary to record potential measurements over a given time to ascertain the maximum exposure to the stray current. With d.c. traction systems, this period would be typically 24 h.

The structure should be protected if the potential is equal to, or more negative than the values stated in Clauses 4.2, 4.3, 4.4 and 4.5 for 90 percent of the time period, provided that, during the remaining 10 percent of the period, the anodic peaks do not occur continuously, but are separated by frequent excursions of potential more negative than the stated limits.

4.7 MEASUREMENT OF POTENTIAL

4.7.1 Polarized potential measurement When a cathodic protection system is energized, the measured potential includes both the polarized potential and the soil voltage gradient, which is caused by the flow of cathodic protection current and other direct currents in the electrolyte. The error of measurement of the polarized potential caused by the voltage gradient is small in low resistivity electrolytes, but can dominate the reading in high resistivity electrolytes. It is more pronounced under conditions of high levels of polarization, and is particularly pronounced near the anode bed of a cathodic protection system. If the soil voltage gradient is ignored, the structure may not be protected even though the appropriate potential reading is obtained. There are a number of methods of eliminating or reducing the effect of the soil voltage gradient on the potential measurement, however each method has constraints on its applicability. Some of these methods are outlined as follows:

(a) *Structure-off potential method* The structure-off potential method requires measurement of the potential almost immediately (typically 1 second) after the cathodic protection systems have been switched off. During this short delay, the voltage gradient resulting from the cathodic protection system will have dissipated. This technique requires that all protection systems, both impressed and galvanic, together with any other sources of direct current to the structure such as earthing beds and electrical bonds, be interrupted simultaneously. This method has limitations in applicability where stray direct current and mixed metal systems exist.

(b) *Coupon-off potential method* The coupon-off potential method requires measurement of the potentials of metal coupons which are connected to the structure via test points, at the instant they are temporarily disconnected from the structure. These coupons simulate coating defects on the structure and the potential measured is the polarized potential which is indicative of that of a coating fault, the same size as the coupon, on an adjacent section of the structure.

    It is important that significant gradients are not present between the reference electrode and the coupon when the measurement is taken.

(c) *Polarization probe method* A polarization probe is connected to the structure via a test point, and comprises a metal coupon of similar material to the structure and an adjacent reference electrode, both positioned in such a manner that measurement errors due to soil voltage gradients are negligible. Typically, the reference electrode is positioned in the centre of the coupon. The potential thus measured approximates the polarized potential obtained when using the 'coupon-off' method.

4.8 OVERPROTECTION To ensure that overprotection does not cause accelerated disbondment of the coating, or other deleterious effects, a potential corrected for soil voltage gradient error should be measured. For coated structures, the polarized potential should not be more electro-negative with respect to a copper/copper sulfate reference electrode than –1200 mV.

SECTION 5 DESIGN OF CATHODIC PROTECTION SYSTEMS

5.1 GENERAL This Section includes guidelines for the design of cathodic protection systems for localized structures of limited surface area. Such structures may be completely isolated from all other structures, e.g. fuel tanks, or may be linked to other areas, e.g. the individual process areas in a chemical production complex. For simple structures, the variation of potential over the structure is usually small, however large variations of potential can occur as a result of shielding and the presence of mixed metals.

NOTE: In addition to the recommendations of this Standard, compliance with the Regulations for applying the Statutes and Ordinances of State and Local Governments is necessary. Also the requirements of AS 2239, AS 3000, AS 3100, AS 3108.1, AS 3108.2, AS 3108.3 and AS 3147 are applicable in respect of conductor current rating, and the protection of circuits and transformers.

5.2 SAFETY PRECAUTIONS For personnel safety, the open-circuit voltage of a cathodic protection power supply should not exceed 50 V d.c. Consideration should be given to the following resultant effects of unintended high voltages which may occur on the structure:

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

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

In addition, the following hazards should be considered:

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

NOTES:

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

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

3 Connection of copper earthing electrodes for control of static electricity may induce corrosion of the structure in the event of a failure of the cathodic protection system, and will increase the current requirement to provide cathodic protection. The use of zinc electrodes or series polarization cells may overcome this problem.

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

NOTE: Paralysis and respiratory failure may result if the body extremities of a person come in contact with electric field strengths greater than 3 V/m in water. Should the design result in the electric field strength exceeding this value in areas of saline and non-saline waters frequently located close to impressed current anodes, warnings should be given and access to such areas prevented by shielding or by other means.

5.3 CHOICE OF SYSTEM—IMPRESSED CURRENT OR GALVANIC ANODES The decision on the type of cathodic protection system to be installed requires careful consideration. Parameters which may affect the decision include the following:

(a) *Coating effectiveness* The more effective the protective coating, the lower will be the cathodic protection current requirements. Low cathodic protection current requirements favour the use of galvanic anodes. High current requirements favour the use of impressed current.

(b) *Economic considerations* It is generally more economic to protect a large structure by impressed current. However, specific civil engineering requirements, maintenance problems, or operational needs may override primary cathodic protection economics in favour of specially designed, high capacity galvanic systems. Standard economic methods such as net present value (NPV) analysis can be used to determine the most cost effective system for the structure.

(c) *Soil resistivity* Galvanic anodes have a fixed, low driving voltage which in high resistivity soils may not produce sufficient current output to protect the metal adequately. The use of an impressed current system may be more practical for such soils.

Galvanic anodes are infrequently used in soils where the resistivity is in excess of 75 Ω.m unless the components are effectively coated.

(d) *Interference* A large impressed current system can create in the soil, voltage gradients sufficiently high to cause interference to foreign structures, especially if the foreign structures are in the vicinity of the groundbed and the protected structure. Interference to an isolated foreign structure may be minimized by placement of the groundbed in a location remote from the foreign structure. The use of a galvanic anode system can minimize such problems, because of its lower driving potential.

(e) *Availability of anode sites* A remotely-located impressed current cathodic protection system may be required for structures where access is prevented by physical obstructions, e.g. a concrete slab or a building. If a sacrificial anode system is selected, access for replacement of the anode during the life of the structure is required.

(f) *Stray current* A galvanic anode system earths the structure. This can be of advantage in overcoming stray current effects, e.g. those from the operation of d.c. traction systems.

A disadvantage of the use of sacrificial anodes occurs when a steep potential gradient is present, causing anodes sited to one side of the structure to pick up current, and this may result in consequent corrosion of the remote side of the structure.

(g) *Control* An impressed current system has the advantage of increased flexibility of location and ease of control. With such a system, anodes can be located remotely from the structure, allowing problems arising from coating defects and short circuits to be more readily traced. In contrast, a galvanic anode system generally requires less frequent monitoring, and is self-regulating.

5.4 CONTROL OF INTERFERENCE CURRENTS Systems should be designed to minimize the following effects of interference currents resulting from a cathodic protection system —

(a) corrosion of other metallic structures;

(b) electrical interference to railway and tramway signalling equipment; and

(c) noise interference to telecommunication circuits.

To minimize the presence of interference currents, anodes should be located in sites where they are electrically isolated as much as possible from other structures. The following minimum spacings of anodes from other structures are recommended —

(a) for galvanic anode systems . . . . 3 m; and

(b) for impressed current systems . . . . 20 m to 500 m. (The separation increases with increasing current output and soil resistivity—see Clause 5.8.2).

Where it is not possible to locate anodes at or near a remote earth, consideration should be given to the following alternative means of reducing interference currents:

(a) The use of cooperative designs where other owners have structures in the vicinity, and agree to share a common system.

(b) Reduction of current output from each anode by increasing the number of anode systems.

(c) The replacement of sections of foreign structures which are susceptible to severe interference with structure sections which have been given additional protective coatings, e.g. at crossover points of structures.

Further guidance on the detection and control of interference currents is given in Section 7.

5.5 CABLES

5.5.1 Cable joints and protection All cable joints and anode cable tail connections to the groundbed header cable, or to the structure cable, should be designed to be of crimped, bolted, welded or soldered construction.

Because long-term electrical integrity is necessary, all buried or immersed cable joints are required to be totally waterproofed. This is also required for joints in impressed anode cables.

5.5.2 Types of cables The types of insulated cables used for cathodic protection systems include the following:

(a) Test cables connected as follows —

   (i) to the structure;

   (ii) to reference electrodes; and

   (iii) to foreign structures, if any (see Clause 2.4).

(b) Impressed current anode cables to carry d.c. positive supply.

(c) Primary structure (cathode) cables to carry d.c. negative supply.

(d) Cables to galvanic anodes.

(e) Interference mitigation cables.

NOTE: Cables colour-coded with green and green/yellow spirals are to be used exclusively for safety earthing applications in impressed current cathodic protection systems.

5.5.3 Test cables

5.5.3.1 *Construction* Test cables should be manufactured from copper or from a material with similar properties to copper, should comply with AS 3147, and should have a minimum conductor cross-sectional area of 6 mm^2. Specific environments may dictate the use of alternative materials.

Where the cable is fully protected, e.g. by a surrounding conduit or duct, the conductor cross-sectional area may be reduced, but, for durability, should be not less than 2.5 mm^2 in cross-sectional area.

Cable insulation should be resistant to attack by rodents and by insects.

5.5.3.2 *Insulation colour* Colours for test cable insulation on any one installation should be permanently identified and should preferably comply with a uniform colour code. Where this is not specified, it is recommended that insulation colours be as follows:

(a) To primary structure . . . . black.

(b) To reference electrode . . . . yellow.

(c) To foreign structures and for other uses . . . . blue or white.

(d) To galvanic anodes . . . . red.

5.5.4 Impressed current anode cables

5.5.4.1 *Construction* Impressed current anode cables should comply with the requirements of AS 3147 for double insulated cable.

Because anode cables may be subject to attack from a high chlorine environment found near most anodes, it is important that the cable insulation and sheathing be resistant to such an environment, or otherwise be suitably oversheathed or protected.

Recommended insulants include the following:

(a) PVC cable insulation complying with AS 3147, containing no filler and a minimum of colourant and plasticizer.

Sheathing should be of similar material and be not less than 1.5 mm thick.

(b) Polyethylene cable insulation not less than 1.5 mm thick; this should have an outer PVC sheathing in accordance with item (a) above.

(c) Polyethylene cable insulation not less than 1.5 mm thick; this should have an outer sheathing of a black, ultraviolet light-resistant grade of polyethylene.

(d) Other insulants; these should have a black, chlorine-resistant outer sheathing.

5.5.4.2 *Cable identification* It is important that anode cables have a different colour, preferably with red insulation, or constructional appearance from that for cathode cables, and that all cables in a system can be identified by differences of construction, insulation, sheathing, or permanent marking.

5.5.5 Galvanic anode cables Cables are supplied with galvanic anodes in accordance with the requirements of AS 2239.

5.6 CHECK LIST FOR INITIAL SURVEYS The following check list is applicable to new and existing structures, and sets out information which should be available for the design of a cathodic protection system, before initial surveys and tests are carried out:

(a) Complete layout plans and specifications of structure and materials of construction. The location and position of survey marks and test points. Full details of any insulating joints or sections that may require bonding, or special consideration.

(b) Details of any foreign structures, including water, gas and telephone service lines, and the presence of any other cathodic protection systems in the vicinity of the structure to be protected.

(c) Details of any product to be stored or handled in the structure, such as gas or liquid, including details of their flammability, pressure and toxicity, if applicable.

(d) Type and resistivity of the soil in which the structure is sited. Details of the corrosion history of other structures in the area.

(e) Details and location of any previously installed cathodic protection systems on the structure. This includes details of test points and the positions of anodes.

(f) Full technical details of the type and quality of coatings used on structures, and of the results of any tests carried out to assess their integrity.

(g) Ability of the owner of the structure to maintain the cathodic protection system, especially where it is intended to use civil, electrical or mechanical staff to operate the system.

(h) Nature and location of any existing or proposed electrical earthing, electrical bonding to nearby structures for stray current drainage, electrical surge control, and potential equalization.

(i) Any known hazardous areas, as defined in AS 2430.

(j) Availability of commercial electricity.

(k) Relevant Local Government regulations.

5.7 DETERMINATION OF CATHODIC PROTECTION CURRENT REQUIREMENTS

5.7.1 General The current capacity of an installed cathodic protection system is dependent on the achievement and maintenance of the appropriate criteria for protection, as described for all discrete modules of the structure in Section 4. In complex structures, the effects of bonding on operational safety, telemetry and incidental corrosion control may require careful consideration.

To minimize interference effects, overprotection should be avoided (see Clause 4.8).

5.7.2 Prediction of current requirement from design parameters The current required for cathodic protection is related to the following parameters:

(a) The nature of the environment.

(b) The temperature of the structure surface.

(c) The oxygen availability at the structure surface.

(d) The oxygen and moisture permeability of the coating.

(e) The effective area of exposed bare structure metal.

Based on experience, the above parameters may often be jointly assessed to estimate the current density required to give protection. Allowance should be included for coating deterioration. For shielded situations, e.g. pipes in tank farms, guidance can be obtained from the average current density figures used for a similar area of structure.

The current density estimation, when multiplied by the total buried area of the structure, can give an approximation to the likely total current required. This practice is limited to designs where the parameters noted are sufficiently well known.

5.7.3 Determination of current requirement by field testing of existing structures Where the structure is installed prior to cathodic protection design, the following test procedure to measure the condition of the coating can be carried out:

(a) Set up a temporary cathodic protection installation with test connections to the structure at the point of application of the test current, and also at other points on the structure distant from the point of application. From a measurement of the potential changes on the structure for a given current, extrapolate the total current required, to achieve a specified shift of potential difference at all measured points.

(b) If necessary, re-position the test circuit installation to a number of locations on the structure so that a value of the shift in potential difference can be determined to achieve the optimum current, and the optimum anode locations. Alternatively, make the cathode connection at multiple points to achieve a more uniform spread of potential.

The procedure for the determination of the current requirement to achieve the potential differences recommended in Section 4 is as follows:

(i) Make a durable connection to the structure at a point determined from the above tests.

NOTE: The test cable may become the permanent cathode cable, and may therefore justify the installation of a permanent conductor connection box. Any such installations should be in a permanent location where they will not be damaged by structure usage.

(ii) Attach a separate insulated test cable to the structure adjacent to the cathode test cable.

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

(iii) Install a temporary test anode, preferably where the anode may ultimately be sited.

NOTE: Earth stakes may be driven into soils and used as temporary anodes. It may be expedient to install a permanent anode and use it for the test, if no alternative anode sites are available.

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

Application of cathodic protection current to a structure will result in its potential becoming more negative over time. The period before the potential stabilizes will vary between minutes, for a well-coated buried structure, to months, for a poorly coated or bare buried structure. Thus the current requirement determined by this technique tends be conservative. Also, where a number of different metals or alloys are involved, the time required to stabilize the potential will be different for each metal and alloy.

(iv) Determine the current required to achieve the specified potential at the most distant test point, and at those test points that are most effectively screened from the anode by the shape of the structure.

5.8 ANODE ARRANGEMENTS

5.8.1 General Anodes should be placed where they will achieve the desired spread of protection for all the surfaces of the primary structure, and will cause minimal interference to secondary structures. The placement of anodes will depend upon a number of factors, including the following:

(a) Site accessibility and availability.

(b) Soil resistivity.

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

(d) Structure coating, if present.

(e) Geometric layout of the structure.

(f) The need to avoid excessive potential variations in the structure by maintaining appropriate anode separation.

(g) Whether any parts of the structure require a higher level of protection (e.g. the presence of more electropositive metals).

5.8.2 Calculation of appropriate anode/structure separation Anodes or anode groundbeds should be located at a sufficient distance from the structure to ensure that potential differences in the soil adjacent to the primary structure surfaces do not become excessive.

In a homogeneous electrolyte, the relationship between soil potential and distance from an operating anode is given by the following equation:

$$D = \frac{I\varrho}{2\pi V} \qquad \text{... 5.8(1)}$$

where

D = distance from anode to primary structure, in metres

I = current output of anode, in amperes

ϱ = soil resistivity, in ohm. metres

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

NOTE: This equation will give only approximate results when the electric field is distorted by the physical shape of the primary structure, or when the electrolyte is not homogeneous.

The minimum desirable separation of an anode from a structure can be calculated from this equation by substituting a maximum allowable value for V. The value of V should not exceed 0.2 V at the closest point of a foreign structure, or 1.0 V at the primary structure. Where a potential of 0.2 V adjacent to the foreign structure is exceeded for design reasons, protective measures may be required (see Section 7).

In some situations the anodes are required to be placed deliberately close to the primary structure to provide very localized protection.

Example: Where the anode current is 10 A and the soil resistivity is 30 Ω.m, the minimum spacing from the anode to the primary structure (for a maximum soil potential of 1 V) is calculated as follows:

$$D = \frac{10 \times 30}{2 \times \pi \times 1} = \textbf{48 m (approx.)} \qquad \text{... 5.8(2)}$$

5.8.3 Anode positioning and burial

5.8.3.1 *Positioning of 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, and at a level below that of the base of the primary structure (see Clause 5.8.2). Exceptions may occur where insufficient space is available, or where a variation in current density is required.

5.8.3.2 *Positioning of impressed current anodes* Anodes for impressed current systems may be installed singly or in arrays called ‘groundbeds’. Groundbeds may be shallow or deep in relation to the ground level. Depending on the site layout, multiple anodes are normally arranged in shallow groundbeds (see Clause 5.8.3.3), but if proximity of other structures or buildings prevents this, or for other reasons, deep well groundbeds may also be used (see Clause 5.8.3.4). Groundbeds are normally backfilled with selected material (see Clause 5.13). Anode-to-structure separation may be calculated using Equation 5.8(1).

5.8.3.3 *Burial of anodes in shallow groundbeds* Shallow groundbeds are installed by laying the anodes in a trench 1 m to 3 m deep and containing backfill, or in shallow vertical holes surrounded with backfill (see Clause 5.13).

Lateral spacing of the groundbed from the structure should be calculated using Equation 5.8(1). Spacing should be such that the soil voltage shift due to anode operation should not exceed 1 V at the structure.

A distributed anode system may be used where underground structures require the use of widely dispersed anodes strategically placed to overcome shielding, to ensure that the maximum area of structure is protected, and to minimize the flow of interference current to foreign structures.

The costs of distributed anode systems are generally higher than for compact groundbeds because anodes distributed over large areas require the use of lengthy anode cables, possibly with individual anode current adjustment, and require more extensive excavation.

5.8.3.4 *Burial of anodes in deep well groundbeds* Deep well groundbeds provide the following features:

(a) Access to lower resistivity soil.

(b) Reduced site and right-of-way requirements.

(c) Lower interference to foreign structures.

The depth of anode placement below the ground surface is often a compromise between the cost and the feasibility of drilling to a depth to reach soils of required resistivity, and the distance between the anodes and structure to maintain the potential shift in the soil around the structure at an acceptable level. Although the prime intent is to position anodes in soils of the appropriate resistivity, Equation 5.8(1) may not apply for deep well groundbeds located in soils having different resistivities from that adjacent to the structure site.

5.8.3.5 *Use of non-conductive casing* Where a non-conductive casing is used, it should be designed to stop short of the anode, to allow the passage of current to earth.

5.8.3.6 *Mechanical support of anodes* Anodes may require to be mechanically supported to maintain clearance during backfilling. In some cases, the connecting cable may be designed to serve also as the anode support. Appropriate steps should be taken to allow gas venting.

5.9 ANODE MATERIALS, APPLICATIONS AND OPERATING CHARACTERISTICS Anode materials are classified according to their end use, as impressed current anodes, or as galvanic (sacrificial) anodes.

Typical environments and operating characteristics of anodes are given in Table 5.1.

5.10 CALCULATION OF GALVANIC ANODE MASS The mass of anode material required to provide a protection current for a given period of time can be calculated using the following equation:

$$m = \frac{ZIt}{\eta u} \qquad \text{... 5.10(1)}$$

where

m = mass of anode, in kilograms

Z = theoretical anode consumption rate, in kilograms per ampere.year (see Note 1)

I = anode output current, in amperes

t = time, in years

η = anode current efficiency (see Note 2)

u = anode utilization factor (see Note 3).

NOTES:

1 Theoretical anode consumption rates, in kg/A.year, are as follows:
 (a) Magnesium . . . . 4.0.
 (b) Zinc . . . . 10.7.

2 Anode current efficiency is the useful charge which may be obtained from the metal in practice, compared with the theoretical value of the charge.
 Anode current efficiency is dependent on such factors as anode alloy composition, output, output current density, and environment.
 Typical anode current efficiency values are as follows:
 (a) Magnesium . . . . 0.2 to 0.5.
 The anode current efficiency value for magnesium is typically 0.5 when the anode is operating at its maximum output as limited by its resistance to ground. The efficiency may be considerably lower if the output is reduced to below this level owing to resistance or polarization of the cathode.
 (b) Zinc . . . . 0.85 to 0.95.

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

TABLE 5.1
TYPICAL ENVIRONMENTS AND OPERATING CHARACTERISTICS OF ANODES FOR CATHODIC PROTECTION (CP)

Description of anode	Typical environment for CP application	Typical environment resistivity* Ω.m	Typical current density A/m²	Approximate consumption kg/A.year†	Relevant reference Standard
GALVANIC ANODES Zinc	Waters and soils	0.2 to 15	Controlled by total circuit resistance	12	AS 2239
Magnesium	Waters and soils where a high current output is required	5 to 75		7	AS 2239
IMPRESSED CURRENT ANODES Platinized titanium/niobium	Seawater, sea bed‡ or soils with coke bed backfill	0.2 to 2	100 to 1000	1×10^{-5}	—
Silicon iron§	All waters, sea bed and soils with coke bed backfill	0.2 to 10	5 to 40	0.3 to 1	—
Magnetite	As for silicon iron	0.2 to 10	3 to 60	< 0.1	—
Scrap steel	As for silicon iron	10 to 200	0.1 to 1	10	—
Graphite	With coke backfill	10 to 100	10 to 30	—	—

* The need for backfill will be determined by the combination of soil resistivity, anode material and current requirements. However, backfill is desirable for high current buried anodes. To reduce the effect of electro-osmosis in high current zones, it may be necessary to water-in the backfill (see also Clause 5.13).

† 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 current density figures are exceeded, or environment conditions are unsuitable. For platinized titanium, voltages across any bare titanium/electrolyte interface should not exceed 8 V in chloride environments.

‡ Low current density only on sea bed.

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

NOTE: Aluminium anodes are used as galvanic anodes in aqueous environments, but are not suited to structures buried in soil.

5.11 CALCULATION OF GALVANIC ANODE OUTPUT CURRENT 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 by using Equation 5.11(1) (which applies to anodes with a ratio of L/d > 10, buried or immersed vertically to a depth at least equal to the anode length), as follows:

$$R = \frac{\varrho}{2\pi L}\left(\ln\frac{8L}{d} - 1\right) \quad \textbf{(Modified Dwight equation)} \qquad \text{... 5.11(1)}$$

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.

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

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

$$I = \frac{E_s - E_a}{R} \qquad \text{... 5.11(2)}$$

where

I = output current, in amperes

E_s = structure polarized potential, in volts

E_a = anode closed circuit potential, in volts

R = resistance of anode to earth, in ohms.

Typical properties of galvanic (sacrificial) anodes are given in Table 5.2.

5.12 POWER SUPPLY FOR IMPRESSED CURRENT SYSTEMS

5.12.1 Sources of direct current Where impressed current systems are being considered, it is necessary to have a direct current power supply which may be obtained from such sources 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.

TABLE 5.2
TYPICAL PROPERTIES OF GALVANIC ANODES

Anode type	Open circuit potential, V		Typical anode consumption rate in seawater kg/A.year
	Reference electrode type		
	$Cu/CuSO_4$	Ag/AgCl	
Zinc	-1.1	-1.05	12
Magnesium:			
—high potential	-1.7	-1.65	7
—low potential	-1.5	-1.45	7

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

The equipment and wiring is required by regulatory authorities to comply with AS 3100, AS 3108.1, AS 3108.2, AS 3108.3, AS 3147 and AS 3000, as appropriate.

NOTES:
1 Smoothing may be required for such special purposes as the suppression of electrical interference to telecommunication lines, data or signalling circuits.
2 Smoothing may be required where using platinized titanium anodes.
3 Surge protection should be fitted to power sources as appropriate.

Where anode/cathode resistance varies, current control may vary from manual voltage adjustment to control by 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 five times the current requirements, and twice the output voltage requirements (see Clause 5.7).

5.12.3 Calculation of voltage requirements The approximate d.c.voltage required can be calculated by multiplying the total loop resistance by the required current, and then by adding the back e.m.f. to the value obtained.

NOTE: For safety reasons, the d.c. output voltage should not exceed 50 V (see Clause 5.2).

5.13 BACKFILL The following two types of backfill are used to surround buried anodes:

(a) *Electronic conduction backfill* Electronic conduction backfills are used with impressed current anodes to—
   (i) decrease the anode-to-soil resistance; and
   (ii) increase the current capacity of the anode system.

   Materials used for electronic conduction backfills include magnetite, calcined coke and graphite.

(b) *Electrolytic conduction backfill* Electrolytic conduction backfills are mainly used for galvanic anodes, to retain moisture, and to lower the anode-to-soil resistance.

   Care should be taken with electrolytic backfills of bentonite/gypsum around impressed current anodes, to prevent the possibility of the system drying out the backfill during operation. Natural or artificial water feeding may be effective in some cases.

5.14 PROVISION FOR STRAY CURRENTS The possible effect of stray current pick-up and discharge should be considered (see Clause 2.3 and Section 8).

5.15 SYSTEM DESIGN DOCUMENTATION Following the design of the cathodic protection system, it is necessary that suitable documentation be prepared to provide a permanent record.

Documentation for the proposed system should be drawn up in the form of plans to acceptable engineering standards using appropriate signs and symbols (see Clause 2.10).

Appropriate documentation may include the following:

(a) A report of the proposed design and layout, including soil resistivity and current drainage surveys, if applicable. The report should include 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 information:
   (i) A properly scaled diagram of the structure to be protected in which the following points and features are identified:
      (A) Significant points of the structure.
      (B) Power supply points.
      (C) Topographical features, e.g. road and river access.
   (ii) The location of anode(s) and anode and cathode cable routes.
   (iii) The d.c. source.
   (iv) The location of test points, individually identified.
   (v) A list of owners of all structures that may affect, or be affected by, the proposed system(s).
   (vi) The location of any bonding to other structures.
   (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) The location of any reference electrodes, and their type(s).
   (ix) Installation instructions.
   (x) The location of insulating joints, and any insulation of structure sections in the protected area, or in other structures.

   NOTE: Documentation may need to be updated in light of changes which may occur during construction (see Section 9).

(b) Documentation required by State and Local Government Regulatory Authorities, as appropriate.

(c) Request to owners of neighbouring structures to seek their co-operation. Such a request is required to comply with statutory requirements, if applicable.

(d) Advice to Local Government Authorities, Main Roads Authorities, and Harbour Boards, giving details of road openings and attendant civil works required.

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

SECTION 6 INSTALLATION OF CATHODIC PROTECTION SYSTEMS

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

Where required by regulatory authorities, it should be confirmed that approval to install and operate the scheme has been sought and obtained. Liaison with other authorities may be required during the installation.

The installer should be thoroughly familiar with the specifications for the works, and should ensure that all works are completed in accordance with good industrial practice and the relevant specifications.

Deviations from design specifications should be approved by the Regulatory Authority and permanently recorded for future reference.

The following points should be observed during installation of a cathodic protection system:

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

(b) Before any work is carried out on or near an insulated flange, the area should be checked for hazardous atmospheres.

(c) To avoid risk of electric shock and the possibility of sparking, it is advisable that insulating joints be cross-bonded before being disassembled. This precaution is essential for hydrocarbon product lines.

(d) Structures and test cable connection joints are required to be clean, dry, and free of damage and foreign materials at the time connections are made.

(e) Test point connections are required to be installed with care, to ensure that they remain mechanically secure and electrically conductive.

(f) Care should be exercised to ensure that cables and connections are not damaged during backfilling. Sufficient cable slack should be provided to avoid strain.

    Examples of suitable backfilling materials for use around anodes are given in Clause 5.13. The selected materials should have an electrical resistance equal to, or lower than, that of the surrounding soil. The use of high resistance material, such as sand, should be avoided.

(g) All test cable attachments to structures should be coated with an electrically insulating material. This coating should be compatible with the structure coating and cable insulation, and have good adhesion to both.

(h) As part of the general overall procedure of installation, insulating joints need to satisfy the guidelines given in Clause 2.5, and the location of test points should comply with advice given in Clause 2.4.

(i) All ground surfaces that are disturbed should be suitably reinstated.

6.2 MATERIALS AND EQUIPMENT ACCEPTANCE TESTS

6.2.1 General Because of the inaccessible nature of much of the cathodic protection equipment in service, it is advisable to confirm, prior to shipment to site and prior to installation, that materials and equipment comply with the appropriate specification or Standard. Clauses 6.2.2 to 6.2.5 indicate the types of checks and tests which should be undertaken to avoid the possibility of protracted delays while replacements are sought or repairs are undertaken.

6.2.2 Anodes Galvanic and impressed current anodes should be inspected to ensure that the following criteria are met:

(a) Freedom from critical damage.

(b) Electrical security and continuity of connections.

(c) Anode-to-core continuity.

(d) Correct metal mass.

(e) Correct profile.

(f) Compliance of galvanic anodes (including anode backfill) with AS 2239.

Insulation of all cable tails is required to be inspected for the presence of nicks, cuts or other forms of damage which, for impressed current anodes, will cause premature failure of the system.

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

6.2.4 Transformer-rectifier equipment Testing should be carried out prior to acceptance of a transformer-rectifier unit, to confirm compliance with the written specification and to ensure that the equipment is suitable for the intended purpose. Electrical output and insulation tests should be carried out in accordance with AS 3108.1, AS 3108.2 and AS 3108.3.

The following tests should also be carried out on transformer-rectifier equipment:

(a) Polarity checks to ensure that output terminals are correctly identified.

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

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

(d) Functional tests of any time switches installed.

(e) Functional tests of any other special equipment fitted.

6.2.5 Prefabricated insulating joints Where appropriate, each insulating joint should be electrically tested, pressure tested, and finally electrically re-tested. Where supplied for welding into position, the associated pipe pieces should be of sufficient length to prevent the joint insulation from being damaged by heat transfer during the welding process. A documented welding sequence should be available to the fabricator to ensure that stresses resulting from the welding process can be kept to a minimum.

6.3 INSTALLATION OF GALVANIC ANODE SYSTEMS Before an anode is buried, it is important that any waterproof wrapping material be removed.

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

After positioning the anode and compaction of the backfill, the backfill should be thoroughly wetted.

It is recommended that while the work crews are still on site, preliminary electrical testing, including the testing of anode current output, be carried out to ensure that continuity has been achieved. This will enable repairs and adjustments to be more readily carried out. It should be noted that the value of anode current measured during installation will differ from the value obtained after a period of stabilization.

6.4 INSTALLATION OF IMPRESSED CURRENT ANODE SYSTEMS

6.4.1 Cabling To avoid kinks and knots, all cables should be carefully unreeled, and the cable should be laid directly into the prepared trench. Where cables are reeled on drums, the drums should be mounted on jacks or other supports which enable the cable to pay off freely.

In rocky terrain, cable trenches should be lined with a 75 mm deep appropriately graded fill, to protect the cable sheath from rock damage.

After laying and before covering, all cables should be examined for cuts, nicks and any other form of damage. All damaged cables should be repaired before burying.

NOTE: To identify the presence of a buried cable, the use of marker posts, tiles or marker tape on buried cable runs is recommended (see AS 3000).

Cable joints should 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 and subsequent failure of the cable.

NOTE: Proper cleaning (degreasing and abrading) of the insulation is necessary 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, should be contained within the repair.

6.4.2 Groundbed Care should be exercised to ensure that anodes are not damaged by handling. Unless especially designed with high strength connections, anodes should not be suspended or lowered by their cable tails.

Anodes should be installed in the centre of any backfill and the backfill should be gently tamped into place around the anode; care being taken to prevent anode breakage.

Deep well anodes should be lowered down the hole using either a prefabricated anode holder or a rope. Sufficient backfill should then be added to cover the anode array completely. Adequate venting should be provided.

6.5 INSTALLATION OF REFERENCE ELECTRODES If the installation of the metallic structure is likely to obstruct correct electrode placement, reference electrodes should be installed immediately prior to construction. For large structures, consideration should be given to installation of reference electrodes and associated cabling prior to the laying of foundations. Cabling should be laid with sufficient free play to allow for foundation movement and structural loading.

Reference electrodes should be installed as close as possible to the buried structure without touching or shielding the surface. The backfill around the electrode should have a resistivity no greater than that of the soil surrounding the buried structure. Allowance should be made for foundation settling when locating reference electrodes.

Where reinforced concrete foundations are to be laid, care should be taken to ensure that all reference and test point cabling and equipment are electrically isolated from metallic reinforcement materials.

Reference electrodes, associated cabling and connections should all be checked for damage prior to installation. Correct operation and electrical isolation of the system should be confirmed prior to final reinstatement of backfill material.

The actual location of reference electrodes and cabling should be accurately documented on the as-built drawings.

6.6 INSTALLATION OF INSULATING FLANGES, JOINTS AND COUPLINGS All insulating flanges, joints and couplings should be installed in accordance with the recommendations of the manufacturer.

The assembly of an insulating flange requires particular care, to ensure that insulation is not lost due to mechanical failure of the components.

NOTE: The use of resistance methods to determine the integrity of insulating flanges in the field can produce unreliable results.

Completed flanges should be coated in accordance with design specifications.

6.6.1 Test for insulation integrity Insulating joints should be checked for insulation integrity by measurement of structure-to-soil potential on each side of the joint, with the reference electrode in the same location. Different potential readings indicate adequate insulation. If the potential readings are the same, a cathodic protection current (or changed cathodic protection current) should be applied to one side of the joint, and the potential remeasured. If the potentials remain the same on both sides, the joint is not adequately insulating.

SECTION 7 CONTROL OF INTERFERENCE CURRENTS FROM CATHODIC PROTECTION SYSTEMS TO MINIMIZE THEIR EFFECT ON FOREIGN STRUCTURES

7.1 GENERAL Interference from cathodic protection systems arises where a foreign structure intersects the direct current path between the anode and cathode. Where the current enters the structure the effect is cathodic. Where it leaves the structure the effect is anodic, and the rate of corrosion at that position may be increased.

Interference may be detected by a change in the potential of the foreign structure when the system current is interrupted. The result of this test indicates whether the foreign structure is being subjected to an increased or a decreased corrosion hazard.

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

(a) noise in telecommunication cables; and

(b) malfunctioning of railway signalling equipment.

7.2 REGULATORY REQUIREMENTS Most cathodic protection systems are installed in areas subject to the requirements of Regulatory Authorities covering interference. In some States it is required that formal approval be obtained prior to installation of a cathodic protection system. In these areas it is mandatory that owners of cathodic protection systems inform the appropriate authority, in writing, that a system has been, or is being, installed. The authorities may have a standard application form that should be used for this purpose. The authorities, in consultation with concerned parties, will decide if interference testing is required, and interested parties will usually be informed through the local electrolysis committee.

NOTE: A list of administering authorities is given in Appendix C.

Regulatory Authorities usually specify that a cathodic protection system shall not be operated, other than for the purpose of agreed interference testing, unless the Authority has specifically approved operation. Therefore, testing should be carried out as soon as possible following installation of the cathodic protection system, and before the system is put into continuous operation.

As a matter of good engineering practice, consultation with foreign structure owners should be undertaken whether required by regulation or not.

Testing should be carried out at or above the system operating level, and agreed remedial action should be taken to correct adverse effects to foreign structures. Follow-up testing is necessary, especially when there is an increase in cathodic protection current applied to the primary structure. Increases in current above that originally approved may require re-approval by the authority.

Changes to cathodic protection current levels can arise from—

(a) deterioration of the structure coating;

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

(c) environmental changes.

NOTES:

1 All regulatory authorities recognize the right of owners to safeguard their foreign structures. In the event of any complaint, the permit to operate a cathodic protection installation which causes interference to a foreign structure can be withdrawn until interference is brought under control.

2 Most regulatory authorities make no attempt to assess the degree of risk to a foreign structure. They are concerned with the fact that interference exists, and with obtaining a resolution of interference problems to the satisfaction of the affected parties.

3 In some States, electrolysis committees and technical subcommittees are established to provide a suitable venue for discussion and resolution of interference problems, from the point of view of both the owners of affected structures and the authorities.

7.3 MINIMIZATION OF INTERFERENCE CURRENT

7.3.1 Design of the system With few exceptions, cathodic protection systems should be designed (and adjusted) to protect the primary structure from corrosion with the use of the minimum practical current. By minimizing the cathodic protection current, interference to any foreign structure is kept to a minimum. It also follows that undetected interference will be minimized.

The designer and installer of a cathodic protection system should use the design information given in Clause 5.4 and the advice given in Clause 7.3.2 to avoid interference currents.

Some degree of interference cannot be prevented in areas having a multiplicity of metallic underground services. Electrolysis committees can usually work out a compromise between competing interests where a low level of continuing interference is acceptable to the parties, including the Authority. The detection and control of such interference currents are discussed in Clause 7.3.3.

7.3.2 Actions for minimizing interference currents Ground potential gradients, and hence interference currents, should be minimized by taking the following actions:

(a) Coating the primary structure to the highest possible standard.

(b) Installing a galvanic protection system.

(c) Using distributed anodes.

(d) Positioning impressed current anodes as far from any secondary structures as is practicable.

(e) Using deep well anodes.

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

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

(h) Siting groundbeds in soil of low resistivity.

7.3.3 Detection of interference levels Quantitative assessment of probable damage is difficult because any current discharge from a foreign structure is difficult to measure, and the extent of surface area from which it discharges is difficult to estimate, particularly in areas where there is a multitude of underground services.

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

(a) The relative positioning of the protected structure and foreign structures.

(b) Soil resistivity variations.

(c) Electrical conductivity per unit length of all structures.

(d) Anode current.

(e) Condition of coatings on all structures.

Field experience and application of the above factors enables estimation of the likely degree of interference, and the extent of foreign structure testing required.

The interference caused by the electrical gradient around the protected structure usually only extends for a radial distance of a few metres from the structure. However, the extent of interference caused by the electrical gradient field around the anode may extend for some hundreds of metres, with the result that foreign structures up to a kilometre or more away may be affected.

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

7.3.4 Control of interference

7.3.4.1 *General* Where testing of a cathodic protection installation indicates that there is interference at a level which may result in corrosion of the foreign structure, control of the interference may be achieved by taking the following actions:

(a) Installing galvanic anodes or an impressed current system on the foreign structure.

(b) Bonding the foreign structure to the primary structure through a current controlling resistance, if appropriate.

(c) Insulating the foreign structure.

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

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

(f) Reducing the cathodic protection system current.

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

In practice, it is sometimes found that reducing the system current can reduce the interference on foreign structures to a level acceptable to all concerned, while maintaining a satisfactory level of protection on the protected structures.

7.3.4.2 *Control by the use of galvanic anodes* Interference may be controlled by installing galvanic anodes on the foreign structure, to make the potential at least as electro-negative 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 problems arising from complex stray currents should not occur.

(b) *Disadvantages:*

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

(ii) The performance of the anodes requires to be monitored.

(iii) Galvanic anodes sited in areas where there are steep potential gradients resulting from a foreign cathodic protection system, may accentuate the pick-up of stray current which may discharge at the remote side of the structure, and cause corrosion.

7.3.4.3 *Control by the use of impressed current cathodic protection* In special circumstances, interference can also be controlled by installing impressed current cathodic protection on the foreign structure. 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 problems arising from complex stray currents should not occur.

(iii) If interference is significant, the foreign structure bare, or the soil resistivity high, the high driving voltage of impressed current cathodic protection may be required to provide adequate protection.

(iv) In stray current areas, an impressed current cathodic protection system is less likely to accentuate stray current pick-up than a galvanic system.

(b) *Disadvantages:*

(i) Interlocks between the interfering cathodic protection system and the second cathodic protection system may be required to control adverse effects should failure of the first cathodic protection system occur.

(ii) The interference suppression current will require to be monitored for proper operation.

(iii) Power supplies for the transformer/rectifier may be difficult to arrange at isolated locations.

(iv) The impressed current interference suppression system may itself cause additional interference, and it may require registration with, or approval by, the relevant Authority.

7.3.4.4 *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 the current flow to the level required to just offset interference. In the latter case, a diode and a resistor are inserted into the impressed current 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.

(b) Where structures are located in a stray current area, current flow from one structure to the other could affect the overall stray current flow.

NOTE: This is particularly important where stray current drainage from more than one structure is involved.

Advantages and disadvantages of the bonding method are as follows:

(i) *Advantages:*

(A) It is an economical solution where the structure access points are close together.

(B) The existing bond may be capable of automatically coping with an increase in output of the cathodic protection unit.

(ii) *Disadvantages:*

(A) Where the foreign structure is remote from the cathodic protection installation, bonding may lead to galvanic corrosion and stray current problems should failure of the cathodic protection system occur.

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

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

SECTION 8 CATHODIC PROTECTION OF STRUCTURES SUBJECT TO STRAY DIRECT CURRENT

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

Stray current may be detected as a change in potential on the structure corresponding to the changing current loadings on the traction system. Fully isolated compact structures will usually experience only minor stray current effects. However, many compact structures are directly or indirectly connected to larger conducting networks, e.g. via associated pipelines or electrical earthing systems. Under these circumstances, increased stray current effects may be experienced.

Assessment of the level of cathodic protection on 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 4.6.

NOTE: The State electrolysis committees, where such bodies exist, are the appropriate technical bodies for coordination and consultation regarding stray current problems and mitigation systems.

8.2 MINIMIZATION OF STRAY CURRENT EFFECTS

8.2.1 General The effects of stray current on underground structures can be minimized in two ways, as follows:

(a) By minimization of the track leakage current at its source (see Clause 8.2.2).

(b) By mitigation of current pick-up and discharge from the structure (see Clause 8.2.3).

8.2.2 Minimization of track leakage current 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) Reduction of the leakage current from the rail track by cleaning or replacing the track ballast and ensuring good water drainage, particularly at road crossings.

(c) The careful balancing of traction load between railway substations, to reduce rail potentials to earth, particularly adjacent to the substation.

(d) The careful inspection of the track and the removal of any fortuitous metallic connections between rail, soil or an adjacent metallic structure.

8.2.3 Mitigation of stray current pick-up and discharge 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. The return path may incorporate the control equipment. Such drainage should be arranged through the State electrolysis committee, where one exists.

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

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

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

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

(c) Installation of cathodic protection.

(d) Electrical isolation of parts of the structure.

NOTE: Caution is needed with insulating joints because stray currents frequently cross them, causing extreme local corrosion to one side of the joint.

SECTION 9 OPERATION AND MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

9.1 GENERAL This Section outlines procedures and practices for operation and maintenance of cathodic protection systems.

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

It is important for subsequent system checks to be carried out to ensure that the structure remains protected and, if changes are noted, that action is taken to return the system to a protected condition.

Whenever the surface of a structure is exposed, the condition of the coating should be noted, and the coating repaired appropriately.

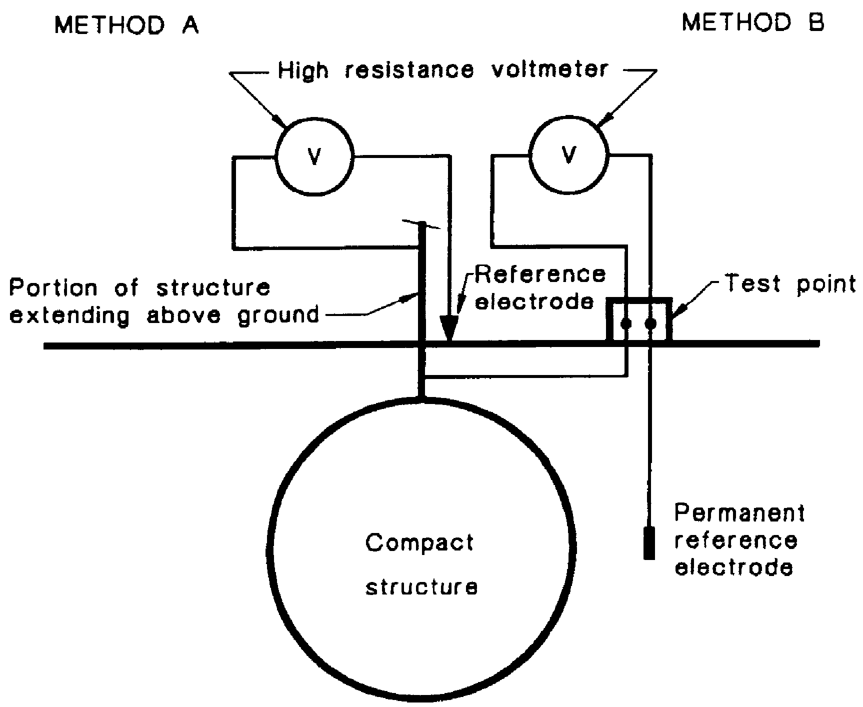
9.2 MEASURING TECHNIQUES All instruments used for determining electrical values should be of an appropriate type and be of the required accuracy. They should be maintained in good working condition at all times.

Where fluctuations in the electrical measurements are noted, it may be necessary to substitute recording instruments for meters during surveys.

Electrodes other than copper/copper sulfate and silver/silver chloride may be used, provided that their relationship with these electrodes is either known or established prior to each measurement.

The structure potential is measured by connecting the positive terminal of a high input impedance (at least 1 megohm) voltmeter to the structure, usually through a test point, and connecting the negative terminal to a reference electrode placed as near as practicable to the structure. Figure 9.1 demonstrates two methods for measuring structure potentials, which employ either an external reference electrode or a permanent reference electrode.

In dry conditions, it may be necessary to moisten the soil in contact with the reference electrode.



NOTES:

1 Method A employs a portable reference electrode.

2 Method B employs a permanent reference electrode.

FIGURE 9.1 ALTERNATIVE METHODS FOR MEASURING STRUCTURE POTENTIALS

9.3 COMMISSIONING SURVEY To ensure that the structure is protected in accordance with the design criteria, and that all equipment is correctly installed and functioning correctly, the commissioning survey should consist of the following tests and measurements:

(a) A check for correctness of polarity of electrical circuits, i.e. positive to anode and negative to structure.

(b) Measurement of structure potential at all test points, both before and after energisation of the cathodic protection system.

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

(c) A functional test of all test points (if installed), to ensure correct installation/operation.

(d) Assessment of the effectiveness of the following items:

(i) All insulating joints.

(ii) The continuity of bonds.

(iii) The isolation of the structure from electrical earths and secondary structures in accordance with the design.

(e) Measurement of the coating resistance (structure-to-earth resistance).

(f) For impressed current systems, the measurement of circuit resistance.

(g) The current required to provide protection.

(h) The voltage output of impressed current system.

(l) A test for interference current flow in bonds.

The survey should also identify the following points:

(i) The negative swing of the structure potential due to polarization occurring over a given time.

(ii) Locations where future measurements (current, source voltage, structure/electrolyte potential) can be taken to provide a representative view of the operation of the system.

(iii) Need for any additional test points or cathodic protection facilities.

Data from the survey should be recorded and retained for future reference.

9.4 CATHODIC PROTECTION POTENTIAL SURVEYS Cathodic protection potential surveys should be carried out at time intervals determined from a consideration of the system parameters, including the type of cathodic protection system, the nature of the environment, the presence or absence of stray currents and the structure operating conditions. Structures which are protected by sacrificial anode systems and which are remotely situated in uniform environments and isolated from other structures, may be surveyed as infrequently as every five years. The frequency at which it is necessary to re-check any system depends ultimately upon the history of the structure and similar structures in the same locality.

9.5 EQUIPMENT MAINTENANCE CHECKS

9.5.1 For impressed current systems Equipment checks for impressed current systems should be carried out at regular intervals, typically monthly.

Functional checks on equipment should be carried out to determine changes in the following parameters:

(a) Rectifier current output and voltage.

(b) Drainage point potentials.

Electrical equipment, including rectifiers, transformers and switchgear, should be kept clean to ensure adequate cooling. More comprehensive electrical maintenance checks may be needed on an annual basis, e.g. unit efficiency checks and resistance checks on all joints.

9.5.2 For galvanic anode installations For galvanic anode installations, it is difficult to specify detailed procedures for maintenance because of the variety of structures involved.

The frequency and extent of inspection will depend upon such considerations as the likelihood of disturbance by other agencies, and the possibility of additions and alterations to the structure.

Wherever practical, link boxes should be included in the installation to permit current measurements to check anode operation.

9.6 STRUCTURE INSPECTIONS Where the structure is exposed for any purpose, it should be examined for corrosion and, if coated, the condition of the coating should be assessed and recorded as part of the history of the system.

Any coating damage should be made good prior to reburial of the structure.

9.7 RECORDS Records can be used to demonstrate the operational history at any time during the working life of a cathodic protection system. For this reason, it is recommended that records be retained for the life of the structure.

Information should be recorded for the following operations:

(a) *Commissioning and installation* The information should include the following items:

(i) Design documentation as listed under Clause 5.15.

(ii) Results of periodic survey checks (see Clause 9.4).

(iii) Results of equipment checks (see Clause 9.5).

(iv) Agreements made with owners of foreign structures.

(v) Location of any test points added to the system.

(vi) Coating material and application procedures.

(vii) Correspondence with statutory authorities.

(b) *Inspections* The following information should be included:

(i) Dates of surveys and current control procedures applied.

(ii) For anode replacements: types, location and date of replacement.

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

(iv) The condition of coating at failure points, and remedial action taken.

(v) The location(s) of any structure corrosion observed and, if possible, the cause(s) of corrosion.

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

(c) *Equipment maintenance* The following information should be included:

(i) Details of any repairs to, or replacement of, any cathodic protection equipment.

(ii) Location and identification of any new equipment added to the system.

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 which 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. This system employs a mains-operated current source with a relatively permanent anode.

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 which 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 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) Certain sulfate-reducing and other bacteria.

    (v) Termites, rodents and other pests.

(c) *Alternating and direct currents* 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.

(d) *Climatic and tidal factors* Climatic and tidal factors affecting corrosion include:

    (i) Rainfall.

    (ii) Temperature.

    (iii) Velocity of water, e.g. for partially buried wharf piles.

    (iv) Lightning strikes.

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

(e) *Operating conditions of the structure* Factors which 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 which 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 can generally not 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 engineer. Additional specialist expertise is required to design cathodic protection systems for structures subject to the effects of stray currents.

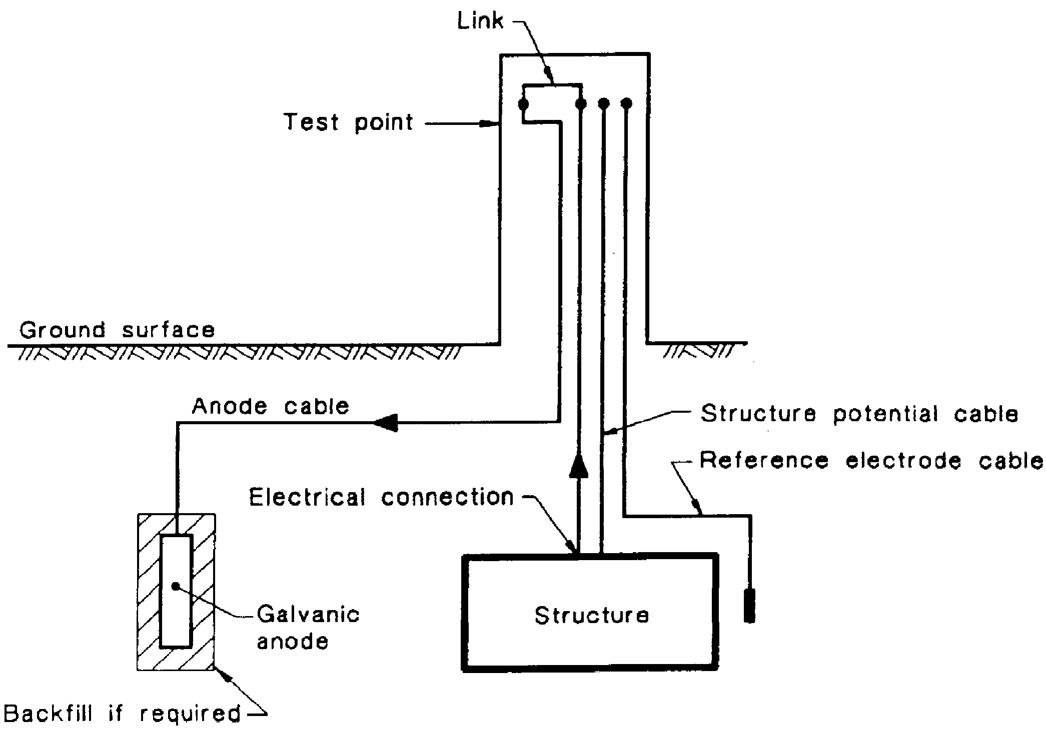


FIGURE A1 SCHEMATIC OF THE CATHODIC PROTECTION OF A BURIED STRUCTURE USING A SACRIFICIAL GALVANIC ANODE SYSTEM

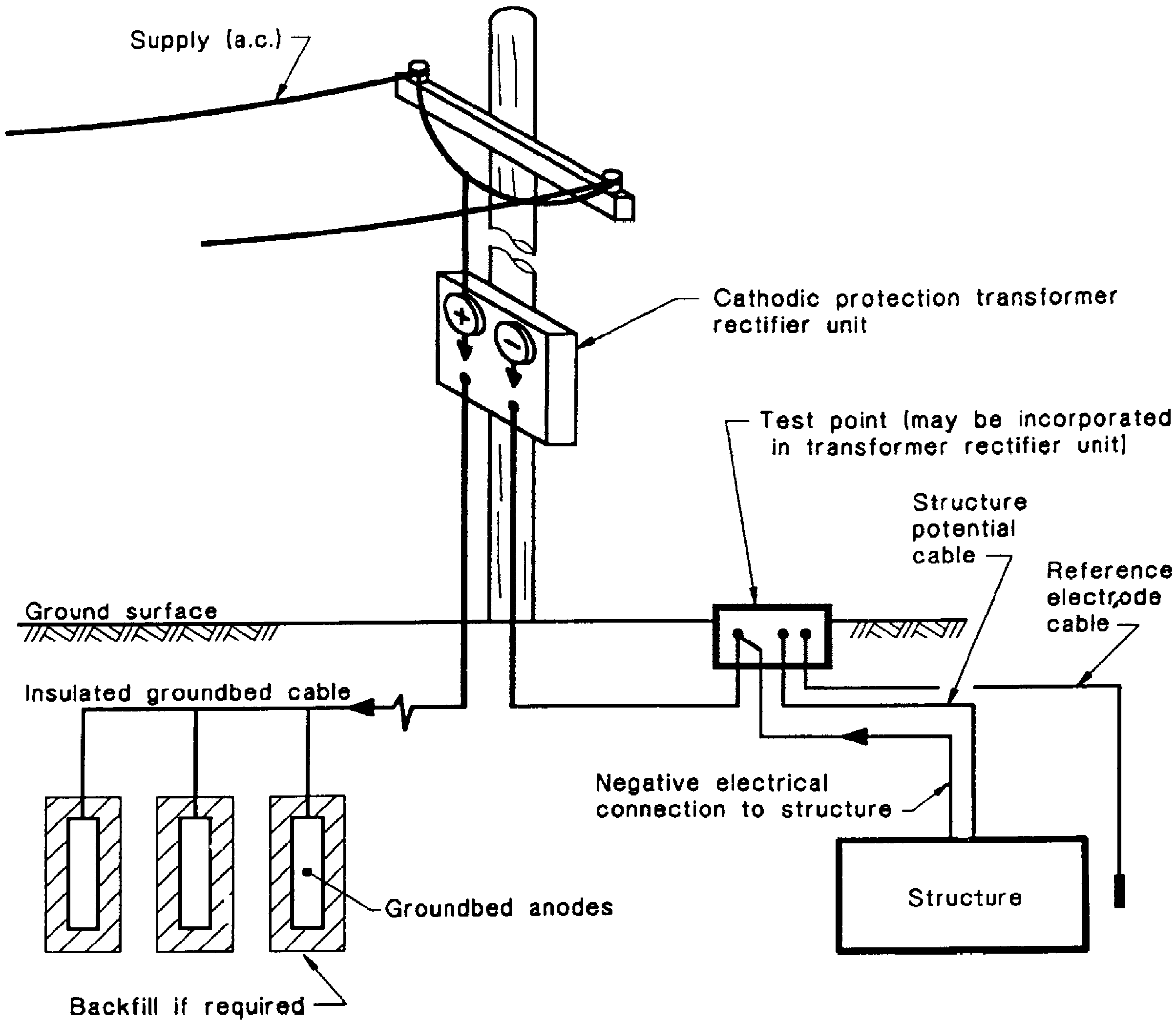


FIGURE A2 SCHEMATIC OF THE CATHODIC PROTECTION OF A BURIED STRUCTURE USING AN IMPRESSED CURRENT SYSTEM

APPENDIX B

LIST OF DEFINITIONS
(Normative)

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

B1 Anaerobic—lacking free oxygen.

B2 Anode (in general)—an electrode through which direct current enters an electrolyte causing oxidation reactions to take place.

B3 Anode screen—a safety barrier surrounding a submerged anode for the prevention of electrical shock or shorting.

B4 Back e.m.f—an instantaneous open circuit opposing voltage between an anode and cathode of an operating cathodic protection system.

NOTE: A back e.m.f may have other definitions in other technologies.

B5 Backfill (anode)—material surrounding, and in contact with, a buried anode for the purpose of maintaining or improving its performance.

B6 Bond (electrical)—a metal connection between points on the same structure or on different structures.

B7 Bond (coating)—adhesion between the coating materials and the substrate.

B8 Bond (drainage)—*see* Drainage (stray current).

B9 Cathode—the electrode through which direct current leaves an electrolyte causing reduction reactions to take place.

B10 Cathodic disbonding—detachment of a coating due to the effect of cathodic polarization.

B11 Cathodic protection—the prevention or reduction of corrosion of metal by making the metal the cathode in a galvanic or electrolytic cell.

B12 Copper/copper sulfate reference electrode ($Cu/CuSO_4$)—a reference electrode consisting of copper in a saturated solution of copper sulfate.

B13 Corrosion—the deterioration of metal caused by its electrochemical reaction with its environment.

B14 Corrosion cell anode—the electrode at which metal dissolution (corrosion) takes place.

B15 Corrosion current—the current flowing in a corrosion cell, electrochemically equivalent to the anode and cathode reactions.

B16 Drainage (stray current)—an electrical means whereby stray current is removed from the structure via a conductor.

B17 Earth (noun)—the conducting mass of the general body of the earth.

B18 Earth (verb)—the act of connecting any conductor to earth.

B19 Electrode—an electronic conductor that allows current to flow either to or from an electrolyte with which it is in contact.

B20 Electrode potential—the measured potential of an electrode in an electrolyte relative to the potential of a reference electrode.

B21 Electrolyte—a liquid, or the liquid component in a composite material such as soil, in which electric current may flow by the movement of ions.

B22 Foreign (secondary) structure—a buried or submerged structure that may be subject to interference arising from the cathodic protection of a primary structure.

B23 Galvanic action—a spontaneous electrochemical cell reaction in which a metallic anode corrodes.

B24 Galvanic anode—an electrode used to protect a structure by galvanic action.

B25 Groundbed—a group of buried anodes.

B26 Half-cell—*see* Reference electrode.

B27 Impressed current—direct current supplied by an external power source to cathodically protect a structure.

B28 Impressed current anode—the electrode connected to the positive terminal of an impressed current power supply.

B29 Insulating joint—a joint which breaks electrical continuity in a structure, but does not affect the mechanical integrity.

B30 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.

B31 Interrupter—a timing device which permits a cyclic on/off interruption to the flow of cathodic protection current.

B32 Loop resistance—the total external circuit resistance at the output terminals of the cathodic protection impressed current rectifier.

B33 Polarization—a shift in the potential of an electrode from an equilibrium value, as the result of current flow through its surface.

B34 Polarization cell—an electrochemical device which, at potential levels typical of protected structures, has high impedance to direct current, but low impedance to alternating current.

B35 Polarized potential—the potential that exists at the metal-soil interface, when this interface is free of all soil voltage gradients.

B36 Primary structure—the structure which is subject to intentional cathodic protection.

B37 Protective potential—the potential to which a metallic structure is reduced to achieve cathodic protection.

B38 Protective current—the current made to flow into a metallic structure from its electrolytic environment, and which cathodically protects the structure.

B39 Reference electrode—an electrode which 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.

B40 Remote earth—a location sufficiently distant from the structure and anode to be free from voltage gradients in the earth.

B41 Silver/silver chloride reference electrode (Ag/AgCl)—an electrode consisting of silver, coated with silver chloride, in an electrolyte containing chloride ions.

B42 Stray current—current flowing through paths other than the intended circuit.

B43 Structure—a metal surface in contact with an electrolyte.

B44 Structure potential—the potential of a structure relative to that of a specified reference electrode situated in the electrolyte immediately adjacent to the structure.

B45 Structure potential shift—a change in measured voltage of a metallic structure caused by the application of current from an external source.

B46 Sulfate-reducing bacteria—a type of bacteria which is capable of reducing sulfate to sulfide in anaerobic, near-neutral soils and natural waters.

B47 Test point—a nominated point on a structure for electrical contact.

B48 Weight coating—the coating, usually concrete, applied to a structure to provide negative buoyancy.

APPENDIX C

CONTROL OF INTERFERENCE CURRENTS—LIST OF ELECTROLYSIS COMMITTEES
(Informative)

STATE	STATE ELECTROLYSIS COMMITTEE
A.C.T.	ACT Electrolysis Committee C/- ACTEW, PO Box 366, Canberra City, A.C.T. 2601
N.S.W.	New South Wales Electrolysis Committee Sydney Electrolysis Technical Committee Newcastle Electrolysis Technical Committee (All) C/- Department of Minerals and Energy, P.O. Box 536 St Leonards, N.S.W. 2065
N.T.	The Managing Director, The Power and Water Authority, PO Box 1921, DARWIN 5794
Qld	Queensland Electrolysis Committee C/- Queensland Electricity Commission, 61 Mary Street, BRISBANE Qld 4000 (GPO Box 10, BRISBANE Qld 4001)
S.A.	South Australian Electrolysis Committee Inc. C/- Box 206, KILKENNY S.A. 5009
Tas.	The Chief Electrical Inspector The Hydro-Electric Commission, 4-16 Elizabeth Street, HOBART Tas. 7000
Vic.	Victorian Electrolysis Committee Electrolysis Technical Sub-Committee (both C/- State Electricity Commission of Victoria, Box 2765Y, MELBOURNE Vic. 3001)
W.A.	None at present—refer to: State Energy Commission of Western Australia, 365 Wellington Street, PERTH W.A. 6000 (GPO Box L921, PERTH W.A. 6001)