AS 2832.3—1992

Australian Standard®

Cathodic protection of metals

Part 3: Fixed immersed structures

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Australian Gas Association
Australian Institute of Steel Construction
Australian Zinc Development Association
Austroads
Bureau of Steel Manufacturers of Australia
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Telecom Australia

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PREFACE

This Standard was prepared by the Standards Australia Committee on the Corrosion of Metals, at the request of industry to provide a Standard for the guidance of owners of immersed 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 the proposed AS 2832 series of Standards which cover the cathodic protection of metals. The first Standards in the series are as follows:

AS
2832 *Cathodic protection of metals*
2832.1 Part 1: *Pipes, cables and ducts*
2832.2 Part 2: *Compact buried structures*

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

CONTENTS

Page

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. The natural tendency of the metal to react with its environment is prevented by the application of an appropriate direct current to the structure surface.

Two types of cathodic protection system are available:

(a) Galvanic anode systems, which employ buried or immersed 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. 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 of 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.

    NOTE: Further literature, guidance and details of training courses on corrosion and its control can be obtained from the Corrosion Prevention Centre in Melbourne.

STANDARDS AUSTRALIA

Australian Standard
Cathodic protection of metals

Part 3: Fixed immersed structures

SECTION 1 SCOPE AND GENERAL

1.1 SCOPE This Standard provides guidelines for the cathodic protection of external surfaces of fixed immersed structures, including offshore platforms, wharves, jetties, pontoons, sewage treatment plants, water treatment plants, lock gates, dam gates, pump station piles in rivers, weirs, mooring buoys, piling, foundations and water inlet/outlet structures.

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 immersed metal structures.

(c) Criteria for the 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 Guidance on the general use and design of cathodic protection systems and factors affecting the corrosion of immersed metallic structures are given in Appendix A.

2 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
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
2052	Metallic conduits and fittings
2053	Non-metallic conduits and fittings
2239	Galvanic (sacrificial) anodes for cathodic protection
2430	Classification of hazardous areas
2430.1	Part 1: Explosive gas atmospheres
3000	SAA Wiring Rules
3100	Approval and test specification — General requirements for electrical equipment
3108	Approval and test specification — Particular requirements for isolating transformers and safety isolating transformers
3147	Approval and test specification — Electric cables — Thermoplastic insulated for working voltages up to and including 0.6/1 kV
3859	Guide to the effects of current passing through the human body

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

1.3.1 Anaerobic — lacking free oxygen.

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

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

1.3.4 Anode shield — a protective covering of insulating material applied to a structure in the immediate vicinity of an anode in order to reduce local cathodic current density.

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

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

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

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

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

1.3.9 Bond (drainage) — see Drainage (stray current).

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

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

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

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

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

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

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

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

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

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

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

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

1.3.22 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.

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

1.3.24 Galvanic action — a spontaneous electrochemical cell reaction in which a metallic anode corrodes in a dissimilar metal couple.

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

1.3.26 Ground-bed — a group of buried anodes.

1.3.27 Half-cell — see Reference electrode.

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

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

1.3.30 Informative — an appendix giving additional information, recommendations, guidelines or other non-mandatory statements.

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

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

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

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

1.3.35 Polarization — a change in the potential of a corroding metal from its natural steady state value, as a result of current flow.

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

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

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

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

1.3.40 Reference electrode — an electrode which has a stable potential in one or more electrolytes at a given temperature, thus enabling it to be used in the measurement of other electrode potentials.

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

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

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

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

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

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

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

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

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

SECTION 2 DESIGN OF STRUCTURES FOR CATHODIC PROTECTION

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

Because many aspects of the design and construction of fixed immersed structures can interfere with the corrosion prevention process, cathodic protection should become an integral part of the structure design. This will 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 fixed immersed structure should be as simple as possible, avoiding complex shapes with sharp crevices and shielded or screened areas that may give rise to areas of localized under-protection.

Typical provisions for cathodic protection installation include the following:

(a) Cable conduits and blockouts in concrete.

(b) Steel conduits and fittings welded to the structure during the building stage.

(c) Intrastructure bonding.

NOTE: Interpile bonding is especially important for wharves and bridges with a concrete deck or superstructure. The piles should be bonded with a material which has an electrical resistance suitable for the cathodic protection system. Welded reinforcing bar is frequently used for this bonding.

(d) Cable connection facilities to the bonded structure for both current carrying and monitoring facilities.

(e) Reinforcing bars in concrete structures. These bars need to be bonded together.

2.2 STRUCTURE COATING Structures should always be coated in areas where cathodic protection is not effective, e.g. in and above the intermittently wetted or splash zone area of the structure. The remainder of the structure may be either coated or bare.

The following factors should be considered when determining whether a structure situated below water level should be coated:

(a) The geometry of the structure, and the presence of shielded areas.

(b) The magnitude of the current demand required to achieve protection; the coating will reduce the current requirement and thus reduce the mass of any galvanic anode system installed.

(c) The proximity of foreign structures; the coating will reduce the total applied current and thus reduce any interference caused to foreign structures.

(d) The ability to maintain the coating on the structure.

2.3 TEST POINTS Fixed testing points should be established on the structure to monitor the effectiveness of the cathodic protection. The use of in-situ reference electrodes in association with various test points enables potentials to be measured in particular areas remote from the test points. Examples of such areas are:

(a) Remote and shielded areas of the structure where the least protection potentials are likely to occur. In the case of platforms or jetties these points are likely to be in the throats of nodal joints. Such a reference can establish a correlation between normally measured potentials and the least protection potential.

(b) Close to anodes to ensure that maximum polarization will not cause rapid cathodic disbonding of any coating system.

(c) Surfaces which are warmer and which have different cathodic protection requirements than the remainder of the structure.

2.4 ISOLATION OF STRUCTURE Isolation/polarization devices may be used to isolate the structure or parts of the structure electrically to facilitate the use and control of cathodic protection systems. They may consist of flange assemblies, couplings, monolithic joints or custom-designed insulation. The dielectric strength of such devices should be compatible with the system design.

The mechanical requirements for isolation/polarization devices should comply with the requirements of the appropriate design code.

Typical points where provision of isolation/polarization devices should be considered include the following:

(a) Pipeline risers.

(b) Connections to shore-based metallic structures.

(c) Dissimilar metal connections.

(d) Connections to earthed structures.

(e) Connections to other cathodically protected structures.

Where isolation/polarization devices are installed, any gap between metal surfaces should be filled with an electrically insulating compound and the outer faces coated.

All monolithic joints should be electrically tested prior to installation.

NOTE: Where monolithic joints or flanges are used in water pipes or oil pipes left standing and containing water, special precautions are necessary to prevent internal corrosion.

To facilitate the application and control of the cathodic protection system, it is recommended that the primary structure be isolated from any other electrically connected metallic structures. It may be impractical to isolate certain systems, e.g. wharf or material handling gantries. In such situations, the cathodic protection system should be designed to cope with the additional load.

If the superstructure shares a common a.c. power or static electrical earthing system with shore-based structures, problems may be avoided by isolating items of electrical equipment from the superstructure, and earthing these directly to the shore-based system without contact with the superstructure, or by using polarization devices or isolating transformers (see also Clause 5.2 for safety design precautions).

The cathodic protection current consumed by onshore foreign structures in electrical contact with cathodically protected offshore immersed structures is usually low if the offshore structure is immersed in low resistivity water, e.g. seawater, and the onshore structure is buried in relatively high resistivity soil.

If the immersed structure is in electrical contact with onshore structures, the relative consumption of cathodic protection current should be considered in the system design. If it is electrically isolated from onshore structures which are in close proximity to the cathodic protection system, testing is required to determine the magnitude of any interference to the onshore structure, and appropriate measures then taken to mitigate that interference (see Clause 5.4).

2.5 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 to isolated sections, e.g. around bolted connections, in sheet piling where the degree of metallic contact is uncertain, and in tubular piling.

The design of the bond should be sufficient to withstand installation and maintenance procedures. Bonds are required to carry the full current and to have low electrical resistances in accordance with the cathodic protection circuit design parameters.

SECTION 3 COATINGS FOR USE WITH CATHODIC PROTECTION

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

Coatings assist in the corrosion control of immersed structures in several ways, as follows:

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

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

(c) Their use can be extended to provide corrosion protection to intermittently immersed parts of the structure.

As noted in Item (b), coatings can result in considerably lower current and anode requirements for cathodic protection than would be necessary for an uncoated structure. However, unless the coatings can be maintained, they will deteriorate with time, leading to increasing cathodic protection requirements. Coating deterioration needs to be considered when specifying coatings for structures designed to last 20 or more years.

The decision to coat is primarily an economic one, based on considerations of the combined costs of coating and cathodic protection, versus the cost of cathodic protection alone. In general, it is less economic to coat structures with long lifetimes (since they cannot economically be recoated when necessary), and structures exposed to high conductivity environments, such as seawater.

Coatings are essential where it is necessary to provide protection to the structure in the region of the water/air interface (splash zone), since cathodic protection is not effective in this region. In addition, a coating may be necessary for the protection of immersed areas of a structure that are shielded from cathodic protection due to the configuration of the structure. Cathodic protection can only give partial protection to areas of a structure which are located in a tidal zone.

The purpose of a coating is to provide the corrosion protection for the system, whereas cathodic protection provides backup protection for the structure should failure or damage to the coating occur.

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 in an immersed or marine environment 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 permeation of water.

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

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

(g) Resistance to attack by marine or freshwater organisms.

(h) Sufficient strength to resist service conditions including changes in environment caused by tidal movement, fluctuating fluid levels and 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 service.

(l) Resistance to mechanical damage and abrasion from handling, installation or service conditions.

(m) Where applicable, suitability for use with potable water.

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 repairability, availability and economic considerations.

Table 3.1 gives details of coating types which are commonly used for the protection of the types 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 Standard should be utilized to ensure the proprietary product chosen is of acceptable quality. Correct application techniques and requirements for appropriate field testing of the coated structures are normally specified in the product Standard.

TABLE 3.1
TYPICAL PROPERTIES OF REPRESENTATIVE COATING SYSTEMS FOR IMMERSED STRUCTURES

Coating system*	Coating site	Ease of on-site application	Structure pretreatment (for steel)	Coating thickness mm	Susceptibility to damage from	
					Cathodic disbondment	Impact
Coal tar epoxy	Site and shop	Medium	Blast	0.3 to 0.6	Medium	Medium
High-build epoxy	Site and shop	Medium	Blast	0.3 to 3.0	Medium	Medium
Fusion bonded epoxy	Site and shop	Difficult	Blast	0.4 to 0.6	Low	Low
Polyester	Site and shop	Difficult	Blast	0.8 to 4.0	Low	Medium
Vinyl ester	Site and shop	Difficult	Blast	1.5 to 4.0	Low	Medium
Laminated tapes	Site and shop	Easy	Wire brush†	0.7 to 3.0	Medium	High
Petrolatum tapes	Site and shop	Easy	Wire brush†	3 to 6	Not applicable	Medium

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

† It is good practice to blast clean surfaces prior to coating application to ensure maximum adhesion. Wire brush pretreatment, which may not remove millscale from 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).

NOTES:

1 Additional mechanical protection may be required for certain systems for areas subject to abrasion damage such as the splash zone.

2 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.

3.4 COATING LIFE Coatings undergoing cyclic immersion will deteriorate with time, and factors influencing the rate of deterioration include the following:

(a) Surface preparation.

(b) Coating characteristics.

(c) Water composition and temperature.

(d) Water pollution, e.g. floating oil films, domestic waste.

(e) Marine fouling and microbiological organisms.

(f) Abrasion and mechanical damage.

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

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 its environment to prevent corrosion. 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 4.5. These criteria are with reference to either a copper/copper sulfate electrode or a silver/silver chloride electrode. This latter electrode is commonly used in marine and brackish water conditions, whereas the former is used on land and in fresh water conditions. Either electrode can be used in both situations; however, the copper/copper sulfate electrode can become rapidly contaminated by chloride ions whereas the silver/silver chloride electrode gives differing readings, depending on the concentration of the chloride in the environment.

Other reference electrodes may be used as alternatives to copper/copper sulfate and silver/silver chloride, provided that their relativity to these reference electrodes has been established.

Criteria other than those listed may be used, if their efficacy has been established.

NOTE: Where a silver/silver chloride reference electrode is of the type which has the central billet directly exposed to the electrolyte in which it is immersed, rather than being encapsulated in a chloride ion-rich electrolyte, the protection criteria will vary with the change in concentration of chloride ions present, requiring appropriate correction to the measured value. This type of silver/silver chloride reference electrode is mainly used in seawater where the chloride ion concentration is substantially constant.

4.2 FERROUS STRUCTURES

4.2.1 Immersed structures The accepted practices for the protection of ferrous structures are as follows:

(a) *For structures submerged in seawater* Maintain a potential on all parts of an immersed ferrous structure equal to, or more negative than, −800 mV with respect to a silver/silver chloride reference electrode.

NOTE: This potential is equivalent to −850 mV with respect to a copper/copper sulfate reference electrode.

(b) *For structures submerged in other waters (including potable waters)* Maintain a potential on all parts of an immersed ferrous 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 an immersed 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 waters having low oxygen content.

2 Care is required when measuring polarized potential, as errors due to the presence of voltage gradients can occur (see Clause 4.6.1).

4.3 COPPER/COPPER ALLOY STRUCTURES The accepted practice for the protection of copper structures 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 negative as −650 mV may be required for protection.

4.4 ALUMINIUM STRUCTURES The accepted practice for the protection of a submerged aluminium structure is to maintain a potential on all parts of the structure equal to, or more negative than, −950 mV, but not more negative than −1.1 V with respect to a copper/copper sulfate reference electrode.

If the potential is lowered too far, aluminium will be corroded by a build-up of alkalinity around the structure.

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

4.6 MEASUREMENT OF POTENTIAL

4.6.1 Polarized potential measurement When a cathodic protection system is energized, the measured potential of the structure includes both the polarized potential and the 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 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 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 s) 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 voltage gradients are minimized. 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.

4.7 OVERPROTECTION To ensure that overprotection does not cause accelerated disbondment of the coating, or other deleterious effects, a potential corrected for voltage gradient error should be measured. For coated structures, the polarized potential should not be more electronegative 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 fixed immersed structures.

The object is to design a cathodic protection system to meet the criteria specified in Section 4 and aim for uniform potentials over the entire surface of the structure. However, in practice, wide variations are acceptable.

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 and AS 3147 are applicable in respect of conductor current ratings 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 system 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 the flow of flammable substances.

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

(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 (see AS 3859). Should the design result in the electric field strength exceeding this value in areas of saline and non-saline waters frequently located close to impressed current anodes, warnings 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. Where coatings on structures designed for long life cannot be maintained, the effects of coating breakdown require consideration.

(b) *Size of protected structure* It is generally more economical 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.

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

NOTE: Galvanic anodes are infrequently used in electrolytes where the resistivity is in excess of 75 Ω.m.

(d) *Interference* A large impressed current system can create, in the electrolyte, voltage gradients sufficiently high to cause interference to foreign structures, especially if the foreign structures are in the vicinity of the anodes and the protected structure. Interference to an isolated foreign structure may be minimized by placement of the anodes 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* Anodes for either sacrificial or impressed current systems are normally distributed adjacent to the structure. However, where this is not possible, they may be located at sites remote from the structure; in this case, the use of impressed current systems which have a larger driving voltage is generally favoured.

(f) *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 remote 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 corrosion caused by interference currents resulting from a cathodic protection system, particularly to adjacent or mobile metal structures.

Guidance on the suppression of interference currents is given in Section 7.

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 from other structures are recommended —

(a) for galvanic anodes, 3 m; and

(b) for impressed current systems, 5 m.

The separation required increases with increasing electrolyte resistivity (see Clause 5.8.2).

Where it is not possible to locate anodes at positions which are electrically isolated from other structures, consideration should be given to the following alternative means of reducing interference currents:

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

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

(iii) 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.

(iv) The design of facilities for bonding the protected structure to the foreign structure.

5.5 CABLES

5.5.1 General All cables should comply with the requirements of AS 3147. Where additional protection from mechanical damage is required, cables may be located in conduit complying with AS 2052 or AS 2053, or be armoured cabling. Specific environments may dictate the use of alternative cable materials.

Cable insulation should be resistant to attack, in general, by rodents and insects and, in marine installations, attack by marine organisms.

All cable terminations and joints should be designed to be of brazed, crimped, bolted, welded or soldered construction.

Joints in cables should be kept to a minimum, and avoided if possible, in buried or immersed cable runs. Because long-term electrical integrity is necessary, all buried or immersed cable joints are required to be totally waterproofed to prevent the ingress of moisture. This is particularly important for joints in impressed current anode cables.

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

(a) Impressed current anode cable to carry d.c. positive supply.

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

(c) Cables to galvanic anodes.

(d) Test cables connected as follows—

  (i) to the structure (see Clause 2.3);

  (ii) to reference electrodes; and

  (iii) to foreign structures, if any.

(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.

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.

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

5.5.3.2 *Insulation colours* 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.

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 required to resist attack from the 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 sheathing of a black, ultraviolet light resistant grade of polyethylene.

(c) Other insulants that possess adequate performance characteristics; these should have an ultraviolet and chlorine resistant outer sheathing.

5.5.4.2 *Cable identification* It is important that anode cables have a different colour or constructional appearance to that of 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 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 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) The resistivity, temperature, velocity and depth of the electrolyte. 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 position 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 a cathodic protection system is dependent on the achievement and maintenance of the appropriate criteria for protection, as described for all modules of the structure in Section 4.

To minimize interference effects, overprotection should be avoided (see Clause 4.7).

5.7.2 Basic procedures The following steps should be followed in the design of any cathodic protection system:

(a) Determine the wetted surface area requiring cathodic protection (see Clause 5.7.3).

(b) Select the required current density to be applied to achieve the nominated protection criteria specified in Section 4 (see also Clause 5.7.4).

(c) From the two values determined in Items (a) and (b), calculate the capacity requirement of the cathodic protection system (see Clause 5.7.5).

(d) For a distributed anode system, calculate the resistance of the anode or anode array to the electrolyte (see Clause 5.7.7), calculate the current output of one anode (impressed current or galvanic, see Clause 5.7.8), and determine the total number of anodes required to supply the calculated current (see Clause 5.7.6).

(e) For a remote anode system, design the ground-beds to supply the required current.

(f) For a galvanic anode system, calculate the galvanic anode mass requirements (see Clause 5.7.9).

(g) Complete the detailed engineering design of the system.

5.7.3 Determination of exposed surface area The total wetted surface area of the structure is calculated from structural drawings and should take into account electrolyte level fluctuations. The calculations should also take into account all additional immersed metallic appurtenances in electrical contact with the structure, since these will also draw current from the designed system. Examples of appurtenances are earthing systems, weld reinforcement gusset plates, pump caissons and vortex breakers.

At the completion of the calculation, the surface area should be increased by an appropriate factor to account for items including missed areas, surface roughness, weld beads and clamps, and for minor design changes affecting new structures. This factor may be of the order of 10 percent.

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

(a) The nature of the environment.

(b) The temperature of the environment.

(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.

(f) The velocity of the electrolyte.

(g) The resistivity of the electrolyte

(h) Tidal range.

Based on experience, the above parameters should be considered when estimating the current density (CD) required to give protection. For bare structures, particularly those in marine environments, there is no single average current density figure that can be assumed, as the current density required for the maintenance of protection changes with time, with a greater current being required to achieve protection than is necessary to maintain it. This is partly due to the potential change that occurs at the cathode, and partly to the effect of chemical species precipitated at the cathode. Fouling, particularly in the marine environment, may act to some extent as a coating, thus reducing the current density requirements. In addition, once a stable value has been reached, the current density for protection continues to vary, owing to seasonal temperature changes of the water, and variation in dissolved oxygen levels. This change in the current density requirement over the life of a structure is illustrated in Figure 5.1.

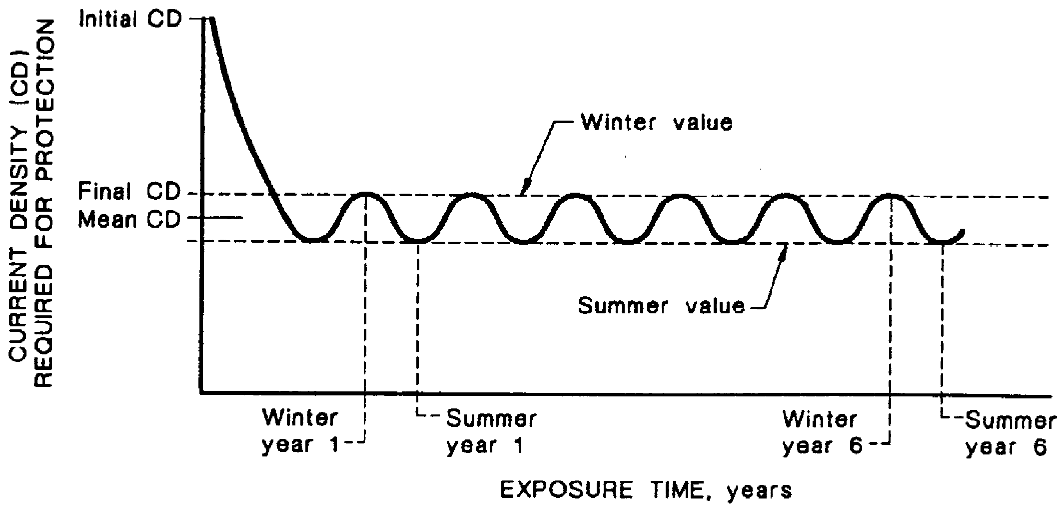

FIGURE 5.1 TYPICAL REPRESENTATION OF CURRENT DENSITY REQUIREMENT VARIATIONS WITH TIME FOR IMMERSED BARE STRUCTURES

In marine environments, the following current densities should be estimated -

(i) the initial current density required to achieve polarization;

(ii) the average current density over the life of the structure; and

(iii) the maximum required current density (for winter) at the end of the life of the structure.

For existing structures, the current densities required to achieve protection can be established by a field test or, where this is not possible, by estimation. Typical current densities used in designs for bare steel at ambient temperature are given in Table 5.1.

TABLE 5.1
TYPICAL CURRENT DENSITY (CD) REQUIREMENTS FOR THE PROTECTION OF BARE STEEL IMMERSED IN VARIOUS ENVIRONMENTS

Environment	Resistivity Ω.m	Initial CD mA/m^2	Mean CD mA/m^2	Final CD mA/m^2	Typical location of environment
Fresh water (potable)	>20	≥50 ≤ 80	≥50 ≤ 80	≥50 ≤ 80	—
Brackish water	≥0.3 ≤20	≥80 ≤120	≥80 ≤120	≥80 ≤120	—
Seawater	<0.3	120	90	90	South-eastern Australia
	<0.3	120	65	65	North-western Australia
Seabed mud	—	20	20	20	—

NOTE: These values may need to be increased for structures immersed in environments warmer then 25°C and they should be reduced if the structure is coated. The current density required to protect exposed metal which has resulted from breakdown of a coating may be estimated using Equation 5.7 (1):

$$CD_{\text{coated}} = CD_{\text{bare metal}} \times \text{percentage of surface (effectively bare)} \qquad \ldots.5.7\,(1)$$

The amount of coating breakdown that will occur is related to the type of coating, the service conditions and the length of time in service. It is probable that no better than a 99 percent perfect coating is achievable on a new structure. In general, the thicker the coating, the lower the amount of breakdown that will occur within a given period. Values for coating breakdown with time are best obtained for the particular environment in which the structure is to be placed.

5.7.5 Calculation of the current capacity The current capacity for a cathodic protection system is the product of the calculated surface area and the required current density.

Where a structure is coated, an estimate of likely coating deterioration (as a percentage) for the required structure life is made and the corresponding system current determined by multiplying the end-of-life current density by the structure surface area.

5.7.6 Anode layout design Anodes for protecting compact immersed structures may be installed in one of the following two main ways—

(a) singly and distributed about the structure, called distributed anode systems; or

(b) grouped in arrays at a smaller number of locations around the structure and more electrically remote from the structure.

Distributed anode systems are typically used for galvanic anode systems or, where there is a need, because of structure geometry, to protect against areas of shielding. In marine environments, because of the low anode to electrolyte resistances, single impressed current anodes are capable of generating large amounts of current and thus are often distributed about the structure. However, in high resistivity environments it may be necessary to group anodes in arrays to achieve the required current output.

In marine environments, it is usual to position anodes in the water rather than to bury them in the seabed, to take advantage of the lower resistivity of the water that results in a higher current output for the anode. In fresh water applications, where the anodes are not located directly on the structure, they may be buried to provide some degree of mechanical protection and to access lower resistivity environments.

The distance of each anode or ground-bed from the structure should be sufficient to ensure that potentials at the structure surface do not become excessive.

In a homogeneous electrolyte, the relationship between structure potential and distance from an operating anode or anode array is given in Clause 5.8.2.

The design of both distributed and remote ground-bed anode systems is similar, because in each case it is necessary to calculate the resistance of each anode or anode array to the electrolyte, and thus determine the amount of current that can be provided by the anode or anode array.

5.7.7 Determination of resistance of the anode or anode array to the electrolyte The resistance of the anode or anode array to the electrolyte is determined from the electrolyte resistivity and the anode dimensions, using a suitable equation. For example, for a long slender anode buried or immersed to a depth equal at least to the anode length, the following equation applies (modified Dwight equation):

$$\boldsymbol{R} = \frac{\varrho}{2\pi L}\left(\ln \frac{8L}{d} - 1\right) \qquad \ldots\ldots 5.7(2)$$

where

R = resistance of anode to electrolyte, in ohms

ϱ = electrolyte resistivity, in ohm metres

L = anode length, in metres

d = anode equivalent diameter, in metres

$= \frac{\sqrt{(4ab)}}{\pi}$

and where

a = anode width, in metres

b = anode depth, in metres

For a slab anode:

$$\boldsymbol{R} = \frac{0.315\varrho}{\sqrt{A}} \qquad \ldots.5.7(3)$$

where

A = total exposed surface area, in square metres

5.7.8 Determination of anode output current At the end of the anode life, the anode dimensions will have decreased; this particularly applies to galvanic anodes. To ensure that adequate output is available at the end of anode life, it may be necessary to base the calculation of the anode output current on the reduced anode dimensions. For galvanic anodes it is common to allow for 90 percent radial consumption and 10 percent longitudinal consumption of the active material.

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

$$I = E/R \qquad \ldots.\ 5.7(4)$$

where

I = output current, in amperes

R = resistance of anode to electrolyte, as calculated using Equation 5.7(3), in ohms

E = anode driving voltage, in volts

For impressed current systems, the anode driving voltage (E_{ic}) is equal to the maximum operating voltage of the transformer/rectifier (E_{tr}), minus the voltage drop in the cables due to the passage of the current (E_{cable}), minus a back electromotive force of approximately 2 V between the polarized anode and the cathode, i.e.

$$E_{ic} = E_{tr} - E_{cable} - 2 \qquad \ldots.\ 5.7(5)$$

For galvanic anodes, the anode driving voltage (E_{ga}) is equal to the anode open-circuit potential (E_a), minus the polarized structure potential, (E_s), i.e.

$$E_{ga} = E_a - E_s \qquad \ldots.\ 5.7(6)$$

Typical open-circuit potentials of galvanic sacrificial anodes are given in Table 5.2.

TABLE 5.2
TYPICAL OPEN-CIRCUIT POTENTIALS OF GALVANIC ANODES

Anode type	Open circuit potential, E_a	
	Reference electrodes	
	$Cu/CuSO_4$	Ag/AgCl*
Aluminium	—	−1.10
Zinc	−1.1	−1.05
Magnesium		
—high potential	−1.7	—
—low potential	−1.5	—

* Applicable to seawater.

5.7.9 Galvanic anode mass requirement The mass of anode material required to provide protection current for a given period can be calculated using the following equation:

$$m = \frac{ZIt}{Du} \quad \text{. . . 5.7(7)}$$

where

m = mass of anode material, 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

D = 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.
(b) Zinc: 10.7.
(c) Aluminium: 3.

2 The anode current efficiency is the useful charge in ampere hours, which may be obtained from the metal in practice, compared with the theoretical value of the charge.
The anode efficiency is dependent on such factors as anode alloy composition, 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.
(c) Aluminium: 0.8 to 0.9.

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.

The mean current density requirements given in Table 5.1 should be used to calculate anode mass, which should then be compared with the anode numbers calculated for the initial and final current outputs, as detailed above. The largest calculated value should be selected.

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) The electrolyte resistivity.

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

(d) The extent of structure coating.

(e) The 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 should be located sufficiently remotely to ensure that potentials at adjacent primary structure surfaces do not become excessive.

In a homogeneous electrolyte, the relationship between potential and distance of an operating anode to the primary structure is given by the following equation:

$$d = \frac{I\rho}{2\pi V} \quad \text{. . . . 5.8(1)}$$

where

d = distance from anode to primary structure, in metres

I = current output of anode, in amperes

ρ = electrolyte resistivity, in ohm metres

V = potential (volts) at a distance d (metres) from the anode, relative to remote earth

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 inhomogeneous.

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 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 electrolyte resistivity is 0.25 Ω.m, the minimum spacing from the anode to the primary structure (for a maximum potential of 1 V) is calculated as follows:

$$d = \frac{10 \times 0.25}{2 \times \pi \times 1} \approx 0.4 \text{ m}$$

5.8.3 Positioning of anodes

5.8.3.1 *Positioning of galvanic anodes* Galvanic anodes may be attached to the structure by either the anode core insert or by a cable of appropriate size.

Anodes which are to be installed flush with the structure may be attached to the structure by any of the following methods:

(a) Welding of anode core metal to structure.

(b) The use of structure studs/nuts to attach the anode core.

(c) The use of half rings. For certain cylindrical structures, e.g. submarine pipelines and riser pipes, bracelet/collar shaped anodes may be attached by half rings. The bond to the structure is achieved by attaching suitable size cables using fusion welding, brazing or some similar process.

5.8.3.2 *Positioning of impressed current anodes* Anodes for impressed current systems may be installed singly or in groups from a single power source. They are generally immersed in an electrolyte, but certain anode types can be directly buried. Depending on the site layout, anodes are normally arranged for optimum uniform current distribution, and have the maximum possible spacing between anodes and between the anodes and the structure.

Anodes which are in close proximity to a coated steel structure should be provided with an adequate dielectric shield, designed so that the potential at the periphery of the shield does not exceed −1.15 V with reference to a silver/silver chloride electrode.

In the case of cantilever anodes, which generally are rod-shaped and project from the structure, obstruction of the active anode surface can be avoided by using an adequate shroud length to prevent build-up of a calcareous deposit on the structure surface.

5.9 ANODE MATERIALS AND APPLICATIONS 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 5.3.

5.10 POWER SUPPLY FOR IMPRESSED CURRENT SYSTEMS

5.10.1 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 (a.c.) power supply.

(b) Engine-driven generators.

(c) Alternative sources, e.g. solar, wind and gas.

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.

5.10.2 Equipment Regulatory authorities require that the equipment and wiring comply with AS 3000, AS 3100, AS 3108 and AS 3147 as appropriate.

NOTES:

1 Reduction of the a.c. ripple (smoothing) may be required for such special purposes as the suppression of electrical interference to telecommunication lines, data or signalling circuits and for safety of divers or other personnel likely to be working in close proximity to the anodes (see AS 3859).

2 Reduction of the a.c. ripple may also be required where using platinized titanium anodes.

3 Surge protection should be fitted to power sources as appropriate.

4 For the safety of divers or other personnel in close proximity to the anodes, the electrical peak field strength in the water should be kept below 3 volts per metre.

Where anode/cathode resistance varies, current control-voltage adjustment may either be manual or fully automatic.

It is prudent to provide the equipment with sufficient power capacity to provide a capability for coping with unknown factors such as changes in electrical resistivity.

NOTE: Facilities for current switching to allow for interference testing should be considered.

5.10.3 Calculation of voltage requirements The approximate d.c. voltage requirement can be calculated by multiplying the total loop resistance by the required current and adding the back e.m.f. The d.c. output voltage should not exceed 50 V d.c. for safety reasons (see Clause 5.2).

TABLE 5.3
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
Aluminium	Seawater	Up to 2		3.5	AS 2239
Magnesium	Waters and soils where a high current output is required	5 to 75		7	AS 2239
Impressed current nodes Platinized titanium/niobium	Seawater, seabed‡ or soils with coke-bed backfill	0.2 to 2	100 to 1000	1×10^{-5}	—
Silicon iron§	All waters, seabed and soils with coke-bed backfill	0.2 min	5 to 40	0.3 to 1	—
Magnetite	As for silicon iron (not used in mud)	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 wet down the backfill (see also Clause 5.11).

† 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 densities are exceeded or the environmental 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 seabed.

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

5.11 BACKFILL When land-based buried anodes are used they require either of the following types of backfill:

(a) *Electronic conduction backfill* Electronic conduction backfill is used with land-based 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 backfill include magnetite, calcined coke and graphite.

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

Care should be taken with electrolytic backfill 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.

5.12 SYSTEM DESIGN DOCUMENTATION Following the design of the cathodic protection system, it is necessary that suitable documentation be prepared to provide a permanent record which can be updated as necessary when construction is complete.

Documentation of the proposed system should be drawn up in the form of plans to acceptable engineering standards using appropriate signs and symbols.

Appropriate documentation may include the following:

(a) A report of the proposed design and layout, including electrolyte resistivity and current drainage surveys, if applicable. The report should include design calculations, assumptions made in the design and an explanation of any departures 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) Structural details from which the wetted surface area can be calculated, including mud levels, rock level, penetration and tidal range.

(ii) The location of anodes and anode and cathode cable routes.

(iii) Details and location of the cathodic protection unit and the power supply.

(iv) The location of test points, individually identified.

(v) A list of owners of all structures that may affect, or be affected by, one or more proposed systems.

(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 ground-bed, if applicable.

(viii) The location of any reference electrodes and their types.

(ix) Installation instructions.

NOTE: Documentation may need to be updated in the light of changes which occur during construction (see Section 8).

(x) The location of insulating joints, and any insulation of structure sections in the protected area, or in other structures (see Clause 2.4).

(b) Documentation required by State and local government regulatory authorities, as appropriate.

(c) Details of any requests made to owners of neighbouring structures to seek their cooperation. Such requests may be required to comply with statutory requirements, if applicable.

NOTE: Advice on the control of interference currents on foreign structures is given in Clause 5.4 and Section 7.

(d) Advice to local government authorities.

(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 fixed immersed metallic structures.

Where required by regulatory authorities, it should be confirmed that the necessary approvals have been sought and obtained.

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. Departures from design specifications should be approved and permanently recorded for future reference.

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

It is necessary that precautions be taken in combustible atmospheres to prevent sparking due to potential differences between protected and unprotected structures (see AS 2430.1). Any insulated joints should be cross-bonded before being separated, and the cathodic protection system switched off.

Care should be exercised to ensure that cables and other components are protected from damage during installation. All cable connections need to provide reliable long-term low-resistance electrical contact.

As part of the general overall procedure of installation, insulating devices should satisfy the guidelines given in Clause 2.4, and the location of test points should comply with advice given in Clause 2.3.

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 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 integrity and continuity of connections.

(c) Anode-to-core continuity.

(d) Correct metal mass.

(e) Correct profile.

(f) Compliance of galvanic anodes with AS 2239.

The insulation of all impressed current anode cables should be inspected for the presence of nicks, cuts or other forms of damage which could cause premature failure.

6.2.3 Cables Cables should be inspected to ensure that they are 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.

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 the control pattern is suitable.

(d) Functional tests of any time switches installed.

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

(f) A temperature/load test.

(g) Output ripple, to specification.

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 damage to the joint insulation by heat transfer during the welding process. During welding the manufacturer’s recommendations on cooling rate should be followed.

6.3 INSTALLATION OF GALVANIC ANODE SYSTEMS The common methods of installation of galvanic anodes are as follows:

(a) By direct attachment to the structure before structure immersion.

(b) By direct attachment to the structure after structure immersion.

(c) By placing the anode on the sea-bed and connection to the structure by cable, either above or under water level.

(d) By suspension in the water from the structure via a cable or a rigid metal support, and connection of the cable to the structure above water.

In all cases, the anode should be in reliable long-term low-resistance metallic contact with the structure. This may be achieved by the use of fusion joints or bolted connections using corrosion resistant materials followed by effective insulation (encapsulation) of the joints.

Before anode immersion, it is necessary to remove any wrapping material. The anodes should not be painted and, where necessary, should be protected from accidental paint application.

6.4 INSTALLATION OF IMPRESSED CURRENT SYSTEMS

6.4.1 Anodes and cabling The common methods of installation of impressed current anodes are those recommended in Clause 6.3, Items (a) to (d). In the case of Items (a) and (b), however, the anode is isolated from the structure, and in all cases the electrical connection is to the positive terminal of the d.c. power source.

Because anodes are often brittle or have thin film electrodeposited coatings, care should be exercised to ensure that they are not damaged during handling. Certain anodes are specifically designed for suspension by their cable tails and may be lowered into position by the cable. Other anodes, generally of the direct immersion type, may need to be lowered into position by separate ropes, as their cable tails are designed for electrical purposes only and not for mechanical suspension. The installation drawings should be checked before commencement of anode installation.

Cable supports should be corrosion resistant and located so that the cable insulation does not become abraded due to cable movement from wind or water forces. Cable routes should also avoid areas of likely damage from physical operations on the structure.

Cable joints should be completely waterproofed using an appropriate cable jointing compound. Waterproofing is particularly important on the positive side of an impressed current system to prevent localized rapid corrosion and subsequent failure of the cathodic protection system.

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, the encapsulation should include a minimum of 50 mm of the cable insulation each side of the repaired cable joint.

Anode to cable tail encapsulation for immersed anodes is generally fitted at the factory. Prior to installation the encapsulation should be carefully inspected for any handling damage during transit. Anodes which project from support pipes or require centring through insulating sleeves may require diver inspection after installation.

WARNING: WHERE UNDERWATER DIVING INSPECTION OR MAINTENANCE IS LIKELY, STRUCTURES SHOULD HAVE WARNING NOTICES DISPLAYED ADVISING OF THE DANGER OF ELECTRICAL GRADIENTS NEAR THE ANODES AND THE NEED TO SWITCH OFF THE SYSTEM PRIOR TO DIVING.

CAUTION: SIGNS SHOULD BE DISPLAYED INDICATING THE PRESENCE OF ANY IMMERSED CABLES OR ANODE SUPPORT ROPES WHICH ARE NOT PHYSICALLY PROTECTED.

6.4.2 Transformer/rectifier Requirements of relevant Standards and local authorities should be observed during the installation of a transformer/rectifier especially with regard to a.c. input, cabling and positioning.

After installation of a unit, it is important that the following be checked:

(a) The oil level is correct (if the unit is oil-cooled).

(b) The fuse ratings are correct.

(c) The a.c. input and the d.c. output cables are properly identified prior to connection to the electricity supply.

NOTE: When electricity is connected, correct polarity and loop resistance should be verified by energizing the unit.

6.5 INSTALLATION OF INSULATING FLANGES AND DEVICES All insulating flanges, or other insulating devices, 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 or damaged 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.

Insulating joints should be checked for insulation integrity, e.g. by the measurement of structure to electrolyte potential across the joint, with the reference electrode in the same location. Different potential readings usually indicate adequate insulation. If the potential readings are the same, the 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 insulated.

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.

Where a foreign structure is sited adjacent to a protected immersed structure, but not electrically bonded to it, interference can occur. Two common foreign structure types are as follows:

(a) A discrete movable structure, such as a moored ship.

(b) A buried or immersed pipeline or metal sheathed cable adjacent to the protected structure or its anode system.

Galvanic anodes used in immersed systems do not usually cause interference to other structures.

Interference problems are more probable with impressed current systems because of the electrolyte voltage gradients usually associated with the anodes.

7.2 REGULATORY REQUIREMENTS Most cathodic protection systems are installed in areas subject to the requirements of the responsible regulatory authorities. In some States it is required that formal approval be obtained prior to installation and operation 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 or appropriate regulatory authority.

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

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 will require reapproval by the relevant authority.

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 structure can be withdrawn until the 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 only with the fact that interference exists and with obtaining a resolution of the 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, for 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 7.3.3, to avoid interference currents.

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

As interference is evaluated by checking the change of potential of the foreign structure, it is common practice to install, temporarily, a cyclic interrupter which operates at 20 s on and 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.

7.3.3 Control of interference Mitigation of interference on a fixed buried or immersed foreign structure is generally achieved by either bonding the two structures, or by installing a separate cathodic system on the foreign structure to protect it in its own right.

Requirements for additional current to allow for bonding to fixed foreign structures should be considered in the design of the cathodic protection system.

With a discrete movable foreign structure, such as a ship berthed at a cathodically protected steel-piled wharf, bonding is usually avoided because of the following factors:

(a) A movable structure will usually have its own cathodic protection system.

(b) A movable structure is usually well coated; when bonded to a large fixed immersed structure system, excessively negative potentials may result on the movable structure, causing coating disbondment.

(c) A movable structure will normally only remain near the fixed immersed structure for a short period, i.e. during loading and unloading, and as a result the total interference effect is minimal.

(d) The making and breaking of temporary bond connections may result in the generation of sparks or arcs which can be hazardous at installations handling flammable materials.

SECTION 8 OPERATION AND MAINTENANCE OF CATHODIC PROTECTION SYSTEMS

8.1 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.

8.2 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.

Reference electrodes other than copper/copper sulfate and silver/silver chloride may be used provided that their relationship with these reference electrodes is either known or established prior to each series of measurements.

The structure potential is measured by connecting a high input-impedance voltmeter (at least 1 M.Ω) to the structure, usually at a test point, and placing a reference electrode, connected to the positive terminal of the voltmeter, as near as practicable to the immersed surface of the structure (see Figure 8.1).

Because accurate measurement of the structure potential requires the reference to be located at the surface of the structure, the reference electrode may be located by a diver, a remotely operated vehicle or be permanently installed at various areas of the structure (such as areas of complex geometry or where shielding can occur). Such readings can then be related to readings taken with a reference electrode placed adjacent to the side of the structure.

Care should be taken to ensure that the structure component to which the measuring voltmeter is connected is not carrying a substantial cathodic protection current. With impressed current systems, in particular, parts of the structure may be carrying a large current and hence may cause a significant voltage drop error in the measurement.

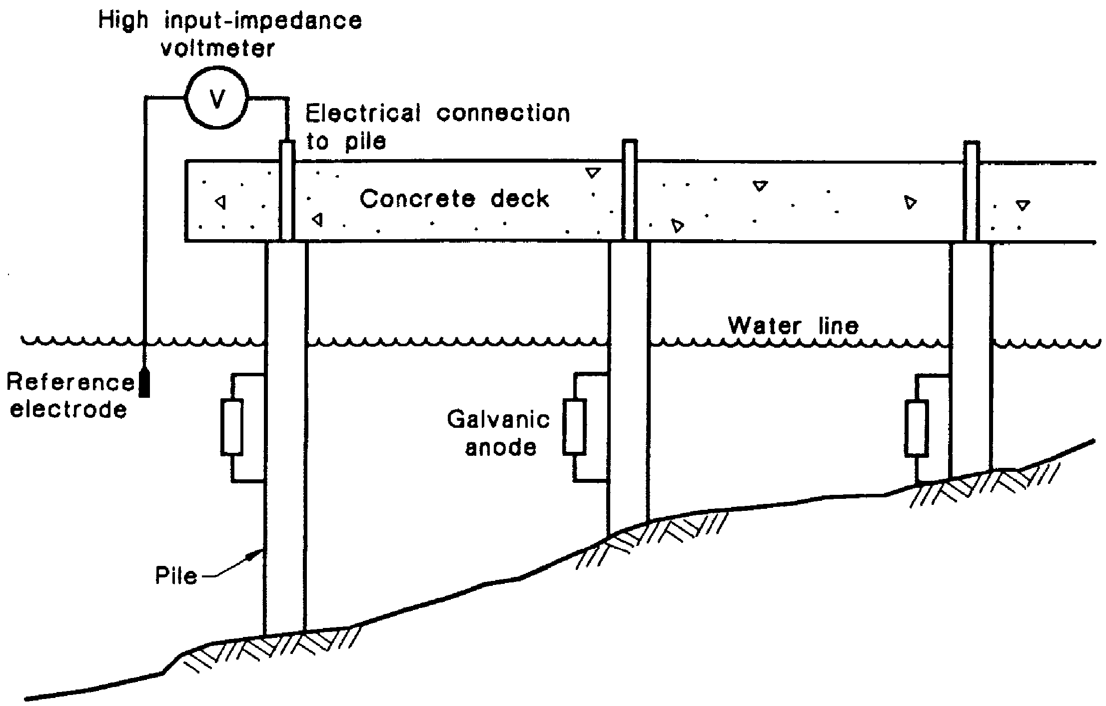

FIGURE 8.1 MEASUREMENT OF STRUCTURE POTENTIAL

8.3 COMMISSIONING SURVEY The commissioning survey shall include the following tests and measurements, where applicable, to ensure that the structure is protected in accordance with the design criteria, and that all equipment is correctly installed and functioning correctly:

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

NOTES:

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

2 Systems requiring large currents may need to be briefly de-energized to permit potential measurement free of voltage drop error (see Clause 4.6).

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

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

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

(i) All insulating devices.

(ii) The continuity of bonds.

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

(e) A check that the anode current distribution is as desired.

(f) For impressed current systems, the measurement of back e.m.f. and loop resistance.

(g) The current required to provide protection.

(h) The voltage output of the impressed current system.

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

The survey should also identify the following:

(i) The variation in output current and structure potential with time. The rectifier output voltage may also be recorded.

(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.

8.4 CATHODIC PROTECTION POTENTIAL SURVEYS Periodic potential surveys are necessary to ensure that the cathodic protection system continues to protect the structure from corrosion.

Cathodic protection potential surveys should be carried out at time intervals determined from a consideration of the system parameters, including the nature of the structure, its environment and the type of cathodic protection system. For critical structures employing complex protective systems this may be at three monthly intervals, however simple structures in stable environments may require surveys as infrequently as every five years. The frequency at which it is necessary to recheck any system depends ultimately upon the nature and history of the structure and similar structures in the same locality.

NOTE: Some structures may be subject to regulations which define the frequency at which surveys are to be conducted.

8.5 EQUIPMENT MAINTENANCE CHECKS

8.5.1 For impressed current systems Equipment checks for impressed current systems should be carried out at regular intervals not exceeding two months.

Functional checks on equipment should be carried out to determine changes in the rectifier current output and voltage.

Electrical equipment, including rectifiers, transformers and switchgear, should be kept clean to ensure adequate cooling and electrical insulation. More comprehensive electrical maintenance checks may be needed on an annual basis.

8.5.2 For galvanic anode installations For galvanic anode installations, the frequency and extent of inspection will depend upon a variety of considerations, e.g. additions and alterations to the structure, and coating conditions.

8.6 STRUCTURE INSPECTIONS Where the structure is exposed, 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.

8.7 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 5.12.

  (ii) Results of periodic survey checks (see Clause 8.4).

  (iii) Results of equipment checks (see Clause 8.5).

  (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 regulatory 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 nature and extent of repairs carried out.

  (iv) Condition of coating at failure points and remedial action taken.

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

A2 GENERAL COMPONENTS OF CATHODIC PROTECTION INSTALLATIONS The general components of a cathodic protection system for an immersed structure, employing galvanic anodes as the current source, are shown schematically in Figure A1.

The general components of an impressed current cathodic protection system for an immersed structure are shown schematically in Figure A2. This system employs a d.c. source with relatively permanent anodes.

In either 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 soil or water for as long as sufficient current flow is maintained.

A3 FACTORS AFFECTING THE CORROSION OF 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 metal include the following:

(a) *The environment surrounding the structure* The characteristics of the environment surrounding the structure are affected by the following properties:
   (i) Resistivity.
   (ii) pH value.
   (iii) Concentration of dissolved salts.
   (iv) Presence of sulfate-reducing bacteria, and their state of activity.
   (v) Degree of aeration.

(b) *Abnormal environmental factors* Abnormal environmental factors may include:
   (i) Presence of mineral ores which are cathodic to steel.
   (ii) Presence of ash, cinders or other corrosion-inducing substances.
   (iii) Presence of effluents.
   (iv) Presence of aqueous growths.

(c) *Climatic and intermittent wetting factors* Factors which are affected by climate and cause intermittent wetting include:
   (i) Rainfall.
   (ii) Temperature.
   (iii) Velocity of water, e.g. for wharf piles.
   (iv) Tidal fluctuations.

(d) *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.

(e) *Other factors* Other factors which affect corrosion rate of a metal or metallic structure include the following:
   (i) Deterioration of any protective coating.
   (ii) Dissimilar metals in contact.
   (iii) Abrasion.
   (iv) Erosion.
   (v) Structure design.

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 across 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.

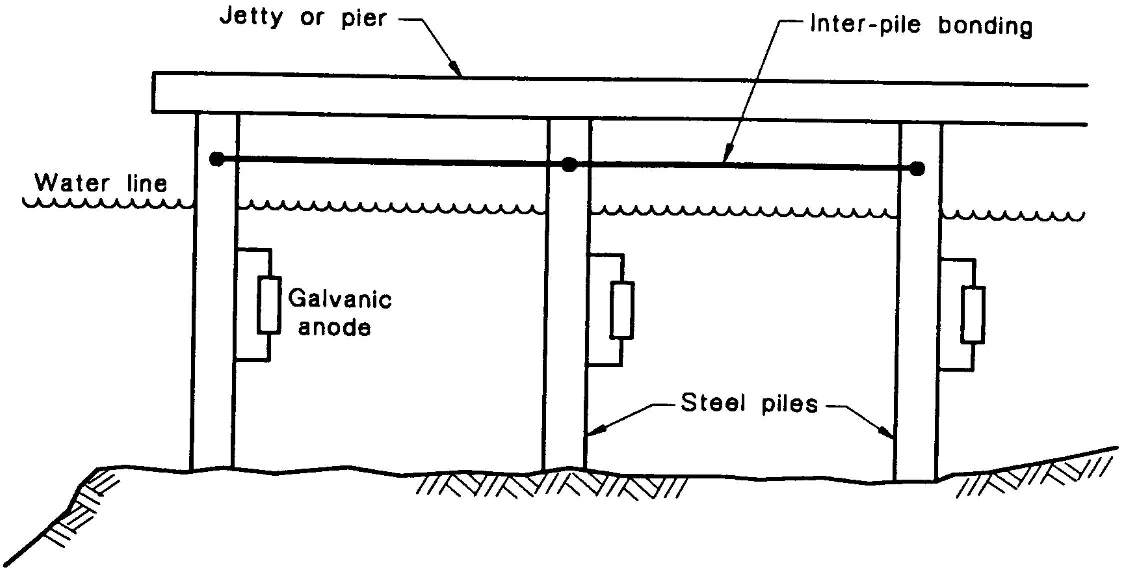

FIGURE A1 CATHODIC PROTECTION OF AN IMMERSED STRUCTURE WITH GALVANIC ANODES (SCHEMATIC)

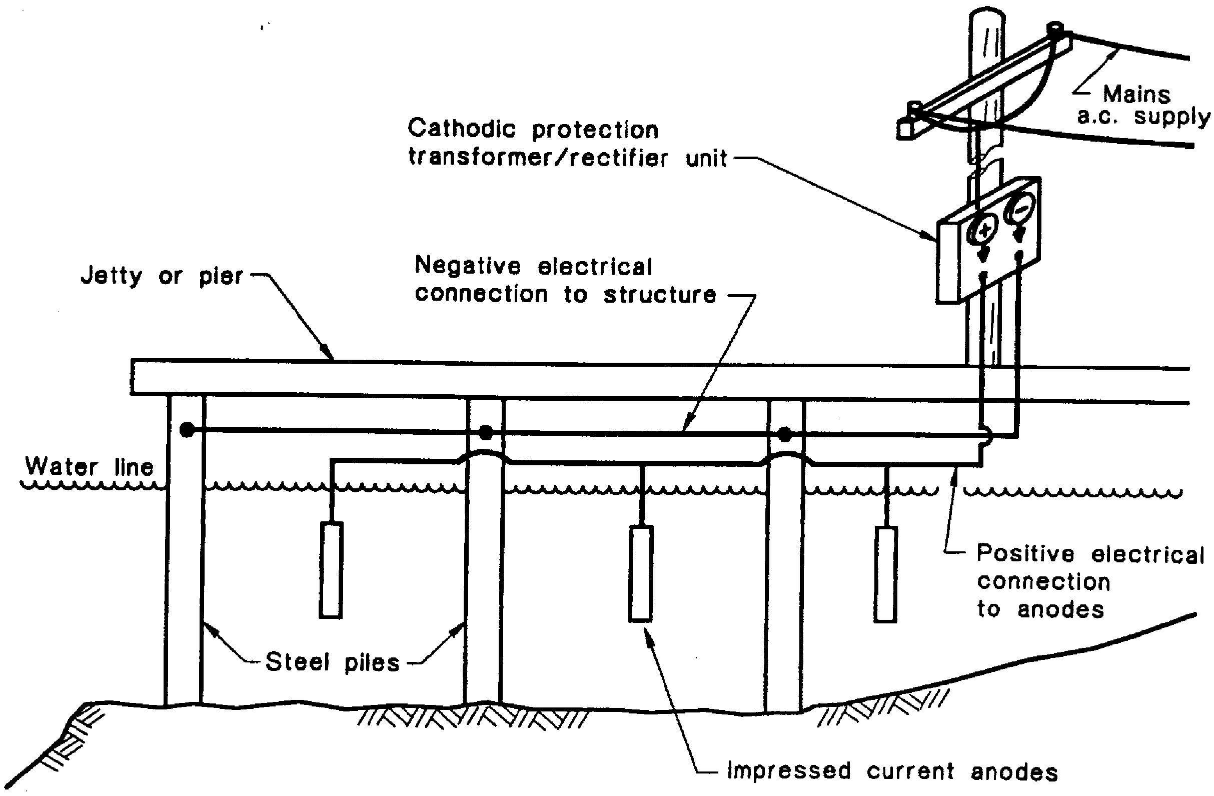

FIGURE A2 CATHODIC PROTECTION OF AN IMMERSED STRUCTURE WITH IMPRESSED CURRENT (SCHEMATIC)

APPENDIX B

CONTROL OF INTERFERENCE CURRENTS — LIST OF ELECTROLYSIS COMMITTEES

(Informative)

State	State electrolysis committee
A.C.T.	A.C.T. Electrolysis Committee C/- ACTEW PO Box 366 CANBERRA CITY A.C.T. 2601
N.S.W.	New South Wales Electrolysis Committee Sydney Electrolysis Technical Committee Newcastle Electrolysis Technical Committee (All) C/- N.S.W. Office of Energy PO Box 536 ST LEONARDS N.S.W. 2065
N.T.	The Managing Director The Power and Water Authority PO Box 1921 DARWIN N.T. 5794
Qld	Queensland Electrolysis Committee C/- Queensland Electricity Commission 61 Mary St BRISBANE QLD (GPO Box 10 BRISBANE QLD 4001)
S.A.	South Australian Electrolysis Committee C/- PO Box 206 KILKENNY S.A. 5009
Tas.	The Chief Electrical Inspector The Hydro-Electric Commission 4-16 Elizabeth St HOBART TAS. 7000
Vic.	Victorian Electrolysis Committee Electrolysis Technical Subcommittee (both) C/- State Electricity Commission of Victoria GPO Box 2765Y MELBOURNE VIC. 3001
W.A.	None at present, refer to: State Energy Commission of Western Australia 365 Wellington St PERTH W.A. (GPO Box L921 PERTH W.A. 6001)