BRITISH STANDARD

BS EN 12495:2000

Cathodic protection for fixed steel offshore structures

The European Standard EN 12495:2000 has the status of a British Standard

ICS 47.020.01; 77.060

National foreword

This British Standard is the official English language version of EN 12495:2000.

Reference should also be made to BS 7361, Code of practice for land and marine applications, which will eventually be withdrawn when all the CEN standards relating to cathodic protection currently being prepared, are published.

The UK participation in its preparation was entrusted to Technical Committee GEL/603, Cathodic protection, which has the responsibility to:

— aid enquirers to understand the text;

— present to the responsible European committee any enquiries on the interpretation, or proposals for change, and keep the UK interests informed;

— monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

Cross-references

The British Standards which implement international or European publications referred to in this document may be found in the BSI Standards Catalogue under the section entitled "International Standards Correspondence Index", or by using the "Find" facility of the BSI Standards Electronic Catalogue.

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Summary of pages

This document comprises a front cover, an inside front cover, the EN title page, pages 2 to 32, an inside back cover and a back cover.

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EUROPEAN STANDARD

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EN 12495

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English version

Cathodic protection for fixed steel offshore structures

Protection cathodique des structures en acier fixes en mer

Katodischer Korrosionsschutz von ortsfesten Offshore-Anlagen aus Stahl

This European Standard was approved by CEN on 3 December 1999.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Central Secretariat: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 12495:2000 E

Contents

Foreword

This European Standard has been prepared by Technical Committee CEN/TC 219, Cathodic protection, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by July 2000, and conflicting national standards shall be withdrawn at the latest by July 2000.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Annexes A, B, C, D, and E of this European Standard are informative.

Introduction

Cathodic protection, possibly together with protective coating or paint, is usually applied to protect the external surfaces of fixed steel offshore structures and appurtenances from corrosion due to sea water or marine sediments.

The general principles of cathodic protection are detailed in prEN 12473:1999.

The cathodic reaction ensures the protection from corrosion of the submerged areas of the structure and associated appurtenances which are exposed to the marine environment.

Cathodic protection involves the supply of sufficient direct current to the external surface of the structure in order to reduce the steel's electrolyte potential down to values where corrosion is insignificant.

1 Scope

This European Standard defines the means to be used to cathodically protect the submerged areas of fixed steel offshore structures and appurtenances.

1.1 Structural parts

This European Standard defines the requirements for the cathodic protection of fixed structures, including sub sea production and related protective structures whether connected or not to each other by pipelines and/or walkways.

It also covers the submerged areas of appurtenances attached to the structure, when these are electrically connected to the structure.

It does not cover the cathodic protection of floating structures such as ships, semi-submersible units, or elongated structures such as pipelines or cables.

This European Standard concerns only the cathodic protection of external surfaces, in contact with the sea water or with the sea bed. It covers the immersed or buried external surfaces of the jacket, conductor pipes, well casings, piles, J-tubes, production or utility risers, etc.

It does not cover the corrosion protection of the sections of the structure above the sea level, i.e. the splash zone and atmospheric zone.

This standard does not include the internal protection of any components such as jacket members, legs, conductor pipes; the protection of these is often performed using chemicals.

1.2 Materials

This European Standard covers the cathodic protection of bare or coated steels with a specified minimum yield strength (S.M.Y.S.) not exceeding 500 N/mm^2.

1.2.1 Overpolarization and high strength steels

If the potential of the structure becomes too negative the structure will become overpolarized and this can induce a penetration of hydrogen into the steel wall, resulting in embrittlement of the metal, and subsequently a possible detrimental effect, including propagation of cracks.

As a general indication the higher the tensile properties, the greater is the risk of hydrogen induced damage. However, material hardness and microstructure are also important.

These phenomena can occur on conventional steels used for offshore fixed structures (grade S355 as per EN 10025) at potentials more negative than −1,10 V vs. Ag/AgCl/sea water. Relevant tests should be performed for the use of cathodic protection outside these limits.

1.2.2 Galvanic coupling

Some parts of the structure can be made of metallic materials other than carbon manganese steel. The *cathodic protection system* should be designed to ensure that there is complete control over any galvanic corrosion arising from this coupling.

1.3 Environment

This European Standard is applicable for the whole submerged zone in any kind of sea water or sea bed.

For surfaces which are alternately immersed and exposed to the atmosphere, the cathodic protection is only effective when the immersion time is sufficiently long for the steel to become polarized. This is the case on about the lowest third part of the tidal zone. A different method of corrosion protection shall be therefore used for the protection of the wetted surface located above this level, i.e. by using a protective coating, cladding, sheathing or increasing the thickness of the structural material.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendement or revision. For undated references the latest edition of the publication referred to applies.

prEN 12473:1999, *General principles of cathodic protection in sea water.*

prEN 12496:1997, *Sacrificial anodes for cathodic protection in sea water.*

EN 10025, *Hot rolled products of non-alloy structural steels - Technical delivery conditions.*

3 Terms and definitions

For the purpose of this European Standard the terms and definitions in prEN 12473:1999 and the following apply.

3.1
atmospheric zone
zone located above the splash zone, i.e. above the level reached by the normal swell

3.2
buried zone
zone located under the mud line

3.3
conductor pipe
first installed casing of an offshore well

3.4
doubler plate
plate welded onto a member to locally reinforce it or to isolate it from further welding work

3.5
extended tidal zone
zone including the tidal zone, the splash zone and the transition zone

3.6
H.A.T.
level of the highest astronomical tide

3.7
immersed zone
zone located below the extended tidal zone and above the mud line

3.8
J-tube
curved tubular conduit designed and installed on a structure to support and guide one or more pipeline risers or cables

3.9
L.A.T.
level of the lowest astronomical tide

3.10
marine sediments
top layer of the sea bed composed of water saturated solid materials of various densities

3.11
M.T.L.
mean tide level (also known as M.S.L. or M.W.L.)

3.12
pile
deep foundation element supporting a fixed offshore structure

3.13
riser
vertical or near vertical portion of an offshore pipeline between the platform piping and the pipeline at or below the seabed, including a length of pipe of at least five pipe diameters beyond the bottom elbow, bend or fitting

3.14
salinity
amount of inorganic salts dissolved in the sea water. The standardized measurement is based on the determination of the electrical conductivity of the sea water. Salinity is expressed in grams per kilogram or in ppt

3.15
splash zone
height of the structure which is intermittently wet and dry due to the wave action just above the H.A.T

3.16
submerged zone
zone including the buried zone, the immersed zone and the transition zone

3.17
tidal zone
zone located between the L.A.T. and the H.A.T.

3.18
transition zone
zone located below the L.A.T. and including the possible level inaccuracy of the platform installation and a depth with a usually higher oxygen content due to the normal swell

3.19
well casing
string of steel pipes lowered into oil, gas or water producing wells to shut off water or to prevent the caving in of loose ground

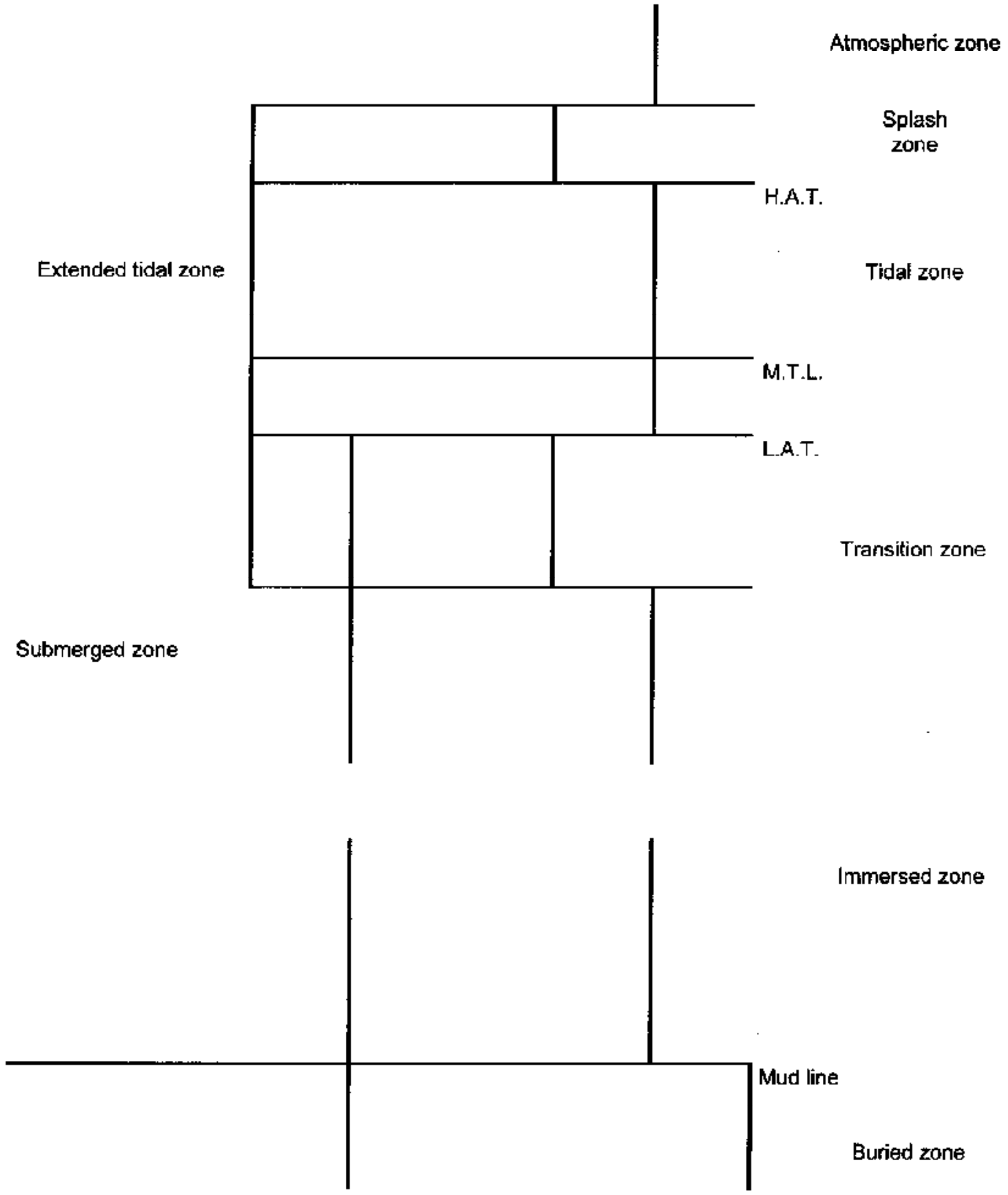


Figure 1 - Schematic representation of levels and zones in sea water environment

4 Design basis

4.1 Objectives

The major objective of a cathodic protection system is to deliver sufficient current to protect each part of the structure and appurtenances and distribute this current so that the steel to sea water potential of each part of the structure is within the limits given by the potential criteria (refer to 4.2).

Potentials should be as homogeneous as possible over the whole structure. This aim may only be approached by an adequate distribution of the anodes over the structure. This is difficult to achieve in some areas such as complex nodes or frames of conductor guides where little room can be allocated for the installation of anodes though large surfaces are to be protected. Therefore consideration should be given at the structure design stage:

- by avoiding complex configurations, i.e. tubular elements are preferred rather than T *or* H *profiles;*
- by reducing the number of ancillary surfaces;
- by limiting the ratio of steel surfaces over electrolyte volume in congested areas.

A protective coating may be used near anodes where their current output and proximity to the structure may lead to overpolarization (see 1.2.1).

The cathodic protection system should normally be designed for the lifetime of the structure.

In order to achieve an appropriate design of the cathodic protection system it should be carried out by a cathodic protection specialist.

4.2 Cathodic protection criteria

The cathodic protection criteria are detailed in prEN 12473:1999.

To achieve an adequate cathodic protection level, steel structures should have protective potentials as indicated in the following table.

Table 1 - Summary of potential versus silver/silver chloride/sea water reference electrode recommended for the cathodic protection of steel materials in sea water

Material	Minimum negative potential volt	Maximum negative potential volt
Carbon / low alloy steels		
aerobic environment	−0,80	−1,10
anaerobic environment	−0,90	−1,10
Stainless steel		
Austenitic steel		
- (PREN ≥ 40)	−0,30	no limit
- (PREN < 40)	−0,60 (see note 1)	no limit
Duplex	−0,60 (see note 1)	(see note 2)

NOTE 1 For most applications these potentials are adequate for the protection of crevices although higher potentials can be considered.

NOTE 2 Depending on metallurgical structure these alloys can be susceptible to cracking and high negative potentials must be avoided (see prEN 12473:1999).

4.3 Electrical current demand

In order to achieve the cathodic protection criteria on the whole structure it is necessary to consider the electrical current demand of each part of the structure.

The electrical current demand of each part of the structure is the product of its steel surface area multiplied by the electrical current density required.

The current density required is not the same for all parts of the structure as the environmental conditions are variable. Therefore, the following areas and parts should be considered, referring to zones as defined in clause 3:

- areas located in the tidal and transition zones (usually coated or cladded);
- areas located in the immersed zone;
- areas located in the buried zone;

- wells to be drilled; a current allowance per well shall be considered, depending on projected sizes, depth and cementing of the wells (see A.4 in annex A);

- *neighbouring* structures and pipelines in electrical contact with the fixed steel offshore structure to be protected.

The selection of design current densities may be based on experiences from similar structures in the same environment or from specific tests and measurements (typical values are given in annex A).

The electrical current density required for cathodic protection depends upon the kinetics of the electrochemical reactions and varies with parameters such as the electrode potential of the steel, the dissolved oxygen content of the sea water, the water flow rate, the temperature, and, possibly, the water depth. Furthermore, the build up of calcareous deposits and the settlement of marine growth modify the surface conditions for the cathodic reactions.

For each particular set of environmental conditions and surface conditions of the steel (such as rusted, blast cleaned, coated with organic or metallic coating), the following electrical current densities shall be evaluated:

- initial electrical current density required to achieve the initial polarization of the structure, i.e. to achieve the lowering of the steel potential down to a value within the range recommended in Table 1;
- maintenance electrical current density required to maintain this polarization level on the structure;
- final or repolarization electrical current density required for a possible repolarization (i.e. for re-establishing the potential to the initial polarization level) of the structure after severe storms or cleaning operations.

As the initial polarization period preceding steady state or maintenance conditions is normally short compared to the design life, the time weighted electrical current density becomes very close to maintenance electrical current density.

A proper evaluation of the current densities required shall be carried out to optimize the cathodic protection system.

Interactions

A platform may be permanently or temporarily connected to other neighbouring structures. These structures should be fitted with their own cathodic protection system which shall be checked before electrically connecting them to the platform considered.

If temporary structures are not fitted with a cathodic protection system or if this is ineffective, the cathodic protection of the platform should be checked to ensure its efficiency during the connection period and the influence of this foreign structure should be evaluated.

4.4 Coatings

The cathodic protection system may be combined with suitable coating systems. The coating reduces the electrical current demand and improves the electrical current distribution on the structure due to its insulating properties.

This reduction of the electrical current demand may be in a ratio of 100 to 1 or even more. However, the current demand of coated steel will increase with time as the coating deteriorates.

An initial coating breakdown factor related mainly to mechanical damage occurring during the installation of the structure should be considered and a coating deterioration rate shall be thereafter evaluated in order to take into account the coating ageing and possible small mechanical damage occurring to the coating during the structure life.

These values are closely dependent on the actual installation conditions and operation conditions.

Guidelines for the values of coating breakdown factors are given in annex A.

The resultant electrical current density needed for the protection of coated steel is therefore equal to the product of the electrical current density for bare steel and the coating breakdown factor.

Due to possible interactions between the cathodic protection and the coating, all coatings to be used in combination with cathodic protection should be tested beforehand to establish that they have adequate resistance to cathodic disbondment.

4.5 Cathodic protection systems - anode dimensions

Cathodic protection can be achieved using:

- the galvanic anodes system;
- the impressed current system;
- a combination of both cathodic protection systems (hybrid systems).

When using hybrid systems the galvanic anodes should provide cathodic protection during float out, initial installation and subsequently during the impressed current system shutdowns.

Galvanic anodes should also be installed in areas where it may be difficult to achieve adequate level of polarization by the impressed current system due to shielding effects.

As the electrical current demand is not constant with time, the cathodic protection system shall be able to deliver the repolarization current density required for short periods throughout the life of the structure.

The number of anodes required in any particular zone of the structure will be determined by the cathodic protection current demand in that zone and the individual anode current output. The current output from each individual anode is calculated by Ohm's law:

$$I = \Delta V/R$$

where:

ΔV is the driving voltage between the anode potential and the protection potential of steel, in volts;

R is the circuit resistance, usually taken as the anode resistance, in ohms.

The anode resistance is a function of the resistivity of the anodic environment and of the geometry (form and dimensions) of the anode. The anode resistance may be calculated using one of the empirical formulae given in annex B.

If the anodes are grouped in arrays and close to each other, mutual interference between anodes should be considered when calculating the anodic resistance.

The cathodic protection system should be designed to minimize the risks of affecting associated pipelines or any other neighbouring structure.

All components of the cathodic protection system should be installed at locations where the probability of disturbance or damage is limited.

5 Design of galvanic anodes system

5.1 General

The galvanic anodes system provides protection of the steel structure by connecting it to a more electronegative alloy.

The dimensions, number and location of the anodes shall be determined so that the protection potential criteria are reached on the whole surface of the structure during the expected lifetime of the cathodic protection system (see 4.1).

This may be achieved using the method described in 5.2, which considers three design current densities.

Computerized numeric methods considering polarization curves may also be considered where applicable.

5.2 Design considerations

The three design electrical current densities as defined in 4.3 shall be considered:

- the (average) maintenance electrical current density shall be used to determine the weight of the anodes. This current density is required to maintain an adequate polarization level of the structure during its design life;
- the initial electrical current density shall be used to verify that the output current capacity of new anodes, i.e. their initial dimensions, is adequate to obtain a complete initial polarization of the structure within a few weeks;
- the repolarization electrical current density shall be used to verify that the output current capacity of the anodes when they are consumed to an extent commensurate with their utilization factor, i.e. their final usable dimensions (see B.2 in annex B), is adequate to repolarize the structure after severe storms or after marine growth cleaning operations.

A large variety of shapes and sizes can be used to deliver protective electrical current to the structure in order to optimize the electrical current distribution (see B.2 in annex B).

The performance of galvanic anodes in sea water depends critically upon the alloy composition, particularly when aluminium or zinc alloys are used (see prEN 12496:1997).

The electrochemical properties of the anodic material should be documented or determined by appropriate tests.

The information required includes:

- the driving voltage to polarized steel, i.e. the difference between closed circuit anode potential and the positive limit of the protection potential criterion;
- the practical electrical current capacity (ampere hour per kilogram) or consumption rate (kilogram per ampere per year);
- the susceptibility to passivation;
- the susceptibility to intergranular corrosion.

5.3 Galvanic anode materials

Galvanic anodes are manufactured from alloys of aluminium, magnesium and zinc.

The basic requirements for anode materials are defined in prEN 12496:1997.

The environmental impact of alloy metal components released into the electrolyte (sea water) should be taken into consideration.

5.3.1 Aluminium alloy anodes

Aluminium alloy anodes can be used in sea water or in marine sediments.

The behaviour of certain aluminium alloys may be adversely affected when covered with mud and particularly at low current output.

The alloys have a decreased electrochemical efficiency at elevated temperature and alloys may not even be suitable when operated at elevated temperatures.

The alloys may suffer intergranular corrosion even at low temperatures and certain alloys containing magnesium may age with loss of mechanical properties.

5.3.2 Magnesium alloy anodes

Magnesium alloy anodes have very negative potentials and can deliver high current outputs. They can provide an adequate level of cathodic protection with only a small number of anodes.

Their high negative potential may increase the risks of hydrogen embrittlement of the steel structure and of cathodic disbonding, and these risks should be assessed.

5.3.3 Zinc alloy anodes

Zinc alloy anodes can be used in sea water or in marine sediments.

Certain alloys may suffer intergranular corrosion particularly at elevated temperatures.

At elevated temperatures zinc alloys may undergo a reduction in driving potential and current capacity and should not be used at temperatures exceeding 50 °C unless supported by appropriate tests.

5.3.4 Factors determining the anode current output and operating life

The above anodic materials have different driving potentials when operating in a specified environment.

The anode electrical current output depends on the environment resistivity and on the anode shape and dimensions (refer to 4.5 and annex B).

The above anodic materials have also different specific consumption rates when operating in a specified environment.

Therefore, for a given electrical current output, the anode life will depend on the anodic material (consumption rate) and its weight.

The dimensions and number of anodes should be optimized in order to minimize the total weight of the galvanic anodes, and in order to provide a protective electrical current greater or equal to the protective electrical current required for the initial polarization and repolarization during the life of the structure.

The electrical current output is given by Ohm's law as explained in 4.5.

The net driving voltage between an anode made of a typical aluminium or zinc based alloy and a polarized structure at its minimum protection level (−0,80 V vs. Ag/AgCl/sea water) is only of 0,15 V to 0,30 V although the initial net driving voltage is much higher, in the range of 0,35 V to 0,50 V.

The anode life duration may be determined using the formulae given in annex B.

5.4 Location of anodes

5.4.1 Corrosion protection considerations

The galvanic anodes should be distributed over the steel surface in proportion to the local current demand in such a way as to obtain a uniform current distribution. Some particular situations may benefit from the use of computer modelling based on finite elements or boundary elements methods of analysis.

The galvanic anodes should be distributed in accordance with the calculated current demands.

Special consideration should be given to any area of complex geometry. Additional calculations to assess the galvanic anodes distribution may be necessary.

Node welds are of primary importance to the integrity of structures. They are also areas of complex geometry where the ratio of steel surface area to electrolyte volume may lead to poor current distribution (shadowed zones and shielding effects). Therefore the early polarization of nodes is also of primary importance. This implies that anodes should be located on the structure so that nodes will become polarized as soon as possible after the installation of the structure.

The adequacy of the current distribution can be improved using a greater number of galvanic anodes, which have a lower individual electrical current output.

5.4.2 Structural integrity considerations

Galvanic anodes should be attached by welding their insert to the structure in such a manner that stresses are minimized at the weld location.

Location and orientation of anodes should take into account the following:

- reduce wave/current impact;
- avoid damage from falling objects;
- reduce fabrication, transportation and launching induced problems.

5.5 Anodes' inserts and attachments design

5.5.1 General

The method of attachment of the anodes to the structure shall be governed by their type and application but low resistance electrical contact shall be maintained throughout the operating life of the anodes. The design of the attachments shall be in accordance with the design code for the structure. These requirements may affect the design of the anode insert.

The supports may be an extension of the insert of the anodes or an integral part and should be of weldable structural steel.

The galvanic anodes can be attached to the structure as follows:

- the anode supports can be welded directly on a thick walled component of the structure;
- doubler plates can be welded directly on a component of the structure, the anode supports being welded on the doubler plates possibly reinforced by means of gussets.

Gussets should be used either on highly stressed frame members or on fatigue sensitive components or areas.

The design of doubler plates and gussets should be supported by a strength calculation.

Doubler plates shall have rounded corners to avoid stress concentrations.

The welding of the anodes to the structure shall be performed in accordance with the design code for the structure and is outside the scope of this document. However, the welding of doubler plates and anode supports on load carrying components shall be performed by a qualified welder using a qualified welding procedure. These welds should be subject to non destructive testing examination, typically magnetic particle inspection or dye penetration.

5.5.2 Slender galvanic anodes with stand-off legs

The insert of the stand-off galvanic anodes should be preferably cylindrical in order to avoid gas entrapment during the alloy casting. However, other shapes of insert may be considered.

The dimensions of the insert and the supports are to be designed taking into account the weight of the anodic alloy and with the various environmental loading conditions as detailed in 5.5.4.

5.5.3 Flat plate galvanic anodes

The inserts of flat plate galvanic anodes should be made of flat or angle bars, the sizes of which should be based on the anode weights and dimensions.

These inserts generally protrude from the lateral faces of anodes in order to enable their welding to the structure.

This type of galvanic anode is used where space limitations or mounting considerations so dictate.

5.5.4 Structural considerations

The inserts and supports of the anodes shall have sufficient strength to sustain the following conditions:

- pre-service conditions including the structure fabrication, the transportation, the launching and the pile driving operations;

  - motions and accelerations of the structure on the transportation barge can be predicted from a motion simulation. The maximum calculated acceleration of the galvanic anodes can be determined from this simulation;
  - some galvanic anodes may overhang on the outer part of the structure, dip into the sea during the sea-transportation and therefore be subject to slamming forces;
  - the launching of the structure from the transportation barge may also induce slamming forces to the anodes as the structure enters into the water. This slamming is discussed in annex C;
  - anode attachments are also subject to fatigue due to pile driving operations or to wave loading;
- in-service conditions including fatigue from wave loading and extreme weather conditions.

6 Design of impressed current system

6.1 General

The impressed current system provides protection of the steel structure by connecting it to the negative terminal of a controllable power source, such as a transformer rectifier, which is normally used, and by connecting the positive terminal of this power source to a number of impressed current anodes.

The electrical current output delivered by the transformer rectifier is controlled during the expected lifetime of the cathodic protection system in order to obtain and maintain an adequate protection potential level on the whole steel surface of the structure.

The design calculations and specification shall provide detailed information on the following:

- design basis;
- calculations and design of equipment;
- general arrangement of the equipment;
- specification of equipment (such as transformer rectifier, anodes, connection cables and connection and protection devices, measurement electrodes);
- installation specifications and details;
- monitoring specification.

6.2 Design considerations

The impressed current system for fixed steel offshore structures usually includes a variable transformer rectifier and one or several anodes.

Manually adjustable rectifiers are generally selected because the current demand does not vary significantly with time.

Rectifiers with automatic potential control may be used in particular cases where the environment condition and the structure configuration induce large and frequent variations of the current demand.

Specific areas presenting particular situations may even require the consideration of a multi-zone control system in order to adapt and optimize the current distribution to the protection demands, the control of the protection of each zone being performed by a separate specific impressed current system.

The number and location of the anodes shall be determined in order to achieve, as far as is practical, an adequate protective potential level.

Individual impressed current anodes usually deliver higher electrical currents than galvanic anodes, therefore with impressed current anodes either dielectric shields or larger anode to structure separation should be used to prevent localized overpolarization and improve the electrical current distribution to the cathode.

The calculated total electrical current (I_{tc}) demand for the protection of a part or zone of the structure is given by the following relation:

$$I_{tc} = Sd$$

where:

- S is the total area of the part or zone considered, in square metres;
- d is the protective electrical current density which allows the adequate polarization of steel in the environment considered, in milliampere per square metre.

The electrical current density to be used for the design is the highest of the initial, steady state and final repolarization effective values. The initial values will be used for bare steel. For coated steel, the value to be used depends on the coating breakdown factor and shall be evaluated.

To compensate for a less efficient current distribution (small number of anodes), the impressed current cathodic protection system should be designed to be able to provide 1,25 to 1,5 times the calculated total current demand, which is the design total electrical current demand (I_t):

$$I_t = (1{,}25 \text{ to } 1{,}5) I_{tc}.$$

6.3 Equipment considerations

6.3.1 Direct current power source

The transformer rectifier or controllable DC generator should be able to deliver a current equal to or greater than 1,25 to 1,5 times the sum of calculated total electrical current demands for the zones or parts of the structure they are intended to protect.

The output voltage should take into account the resistance of the electric circuit (cables, anodes) and the back e.m.f. between the anode and the cathode. The back e.m.f. is the naturally occurring open circuit potential difference between the anode and the cathode in sea water.

The transformer rectifier should be able to deliver sufficient current to maintain the steel/sea water/reference electrode potential within the design range.

6.3.2 Anodes

Anodes used for impressed current systems can be of two main types: semi-consumable or inert anodes.

Inert anodes are preferred for high output currents.

The semi-consumable anodes are based on graphite, silicon-iron, magnetite, etc.

The inert anodes are made of platinum coated or clad titanium, niobium or tantalum with a thin layer of platinum applied to the substrate or of mixed metal oxide activated titanium. Platinum is applied in a thin layer on the various substrata.

See annex E for impressed current anode performance characteristics.

The installation system and attachment devices of anodes of impressed current systems are critical with respect to mechanical damage because few anodes are involved at relatively high output currents. The loss of an anode may significantly reduce the performance of the cathodic protection system.

Therefore, the installation system and attachment devices of anodes shall be designed in order to have a high level of resistance to mechanical damage.

The design shall include measures to minimize the risk of direct contact (short circuit of the cathodic protection system) between the anodes and the structure.

It should be confirmed that the anodes are capable of adequately distributing the design current that would be supplied by DC sources.

6.3.3 Dielectric shields

Materials selected shall be suitable for the intended service.

Liquid applied coatings, prefabricated plastic or elastomeric sheets can be used on the structure adjacent to the anodes, or incorporated into the anode assembly.

The electrochemical reactions occurring at the anode and cathode surfaces produce corrosive products and gases which may deteriorate the dielectric shield or induce its disbonding.

The design of the dielectric shield should take into account the possible deterioration and ageing characteristics of the materials.

6.3.4 Reference electrodes

Reference electrodes are used to measure the steel to electrolyte potential and may be used to control the output current of the cathodic protection system, see clause 7.

When reference electrodes are used to control the impressed current system, they should be installed at locations determined by calculations or experience to ensure the potential of the structure is maintained within the design set limits.

Precautions should be taken in order to avoid any direct electrical contact between the electrodes and the steel structure.

6.3.5 Cables, connections

All cables shall be adequately protected to avoid any mechanical damage. Steel conduits may be used for this purpose.

The electrical connection between the anode cable and the anode shall be watertight and mechanically secured.

The cable and connections insulation materials shall be resistant to the environmental conditions, chlorine, hydrocarbons and any other deleterious chemicals that may be present.

The cross -section of cables shall be determined in accordance with mechanical requirements, the current rating and the voltage drop for the cable length considered.

6.4 Location considerations

The electrodes and anodes location should:

- reduce wave/current impact on anode fixing devices;
- avoid damage from falling objects;
- reduce fabrication, transportation and launching induced problems;
- avoid damage from dragging objects.

Cables should be installed in conduits, the location and installation of which should comply with the above rules.

7 Design of monitoring systems

Permanently installed monitoring systems shall be used with impressed current systems and may be used with galvanic anode systems.

The portable equipment used for periodic surveys are not included in the monitoring system.

7.1 Objectives

The monitoring system of a cathodic protection system measures and may be used to control the operating parameters and the effectiveness of the cathodic protection system.

The cathodic protection is an active system, i.e. it is effective only when the galvanic anodes or the impressed current system are operating and provide adequate polarization of the steel to achieve the protection criteria stated.

Therefore, the steel potential should be measured during the life of the structure in order to verify the adequacy of the protection.

The measurement of the anode electrical current output gives additional information which may be used to verify that the installation is operating properly and gives an indication on the possible remaining life time of galvanic anodes (see 5.3.4).

7.2 Description

The monitoring system may include the following:

- permanent reference electrodes.
  The reference electrodes should be installed and secured on each immersed level of the structure, close to the steel surface, and at locations as mentioned in 7.3.2.
  These reference electrodes shall be electrically insulated from the structure and connected to the data transmission system;

- permanently monitored galvanic anodes.
  Monitored galvanic anodes should be taken from the batch of galvanic anodes intended to protect the structure and equipped as follows:

  - two insulating joints to be inserted between the galvanic anode supports and the structure. Therefore, the original supports may require to be cut for insertion of the insulating joints as these insulating joints cannot be fitted where there are gussets and their direct welding on the structure or on a doubler plate may cause problems in fixing the measurement equipment stipulated hereafter;

  - one calibrated shunt in order to short-circuit one of the above mentioned insulating joints. The shunt should be preferably installed inside the insulating joint. This shunt should be fitted with cables connected to the data transmission system. The shunt and insulating joint assembly should be preferably filled or surrounded with epoxy resin or an equivalent insulating compound;

  - one reference electrode may be installed as close as possible to the galvanic anode surface but in such a way to allow water circulation between the anode and the electrode. The reference electrode shall not become contaminated with the anode oxidation products. It shall be electrically insulated from the structure and connected to the data transmission system;

- conduit systems and cables.
  All cables connecting equipment shall be of an underwater type and should run through conduits.
  The conduits shall be sized and secured according to the number and sizes of the cables and according to the loading they are likely to encounter.
  They are generally screwed together and secured (preferably by welding) to the structure using steel supports.
  The design of the supports and the distance to be considered between consecutive supports should be determined according to the characteristics of the steel tube to be supported and according to conditions as detailed in 5.5.4;

- junction boxes.
  The junction boxes should be adequate for the number of underwater connecting cables. Each junction box shall be secured to the structure and the fitting should be able to withstand the environmental conditions. It shall be equipped with cable terminals to connect the cables from the monitored anodes and reference electrodes to the data transmission system;

- data transmission system(s) allowing transmission of signal without cables.
  The data transmission system may consist of multiple conductor cable(s) or acoustic transducer(s) or any other effective system(s) as required by the design of the monitoring system. Its installation and location shall allow an effective and reliable transmission of data. It shall be fitted with adequate protection devices to ensure its complete protection against the underwater environment (such as mechanical protection, corrosion protection, water ingress protection).
  The data transmission system shall be linked to the above mentioned equipment: monitored galvanic anodes, independent measurement electrodes and junction boxes, as applicable.

7.3 Potential measurements

7.3.1 Potential measurement method

The steel potential is measured using a high impedance voltmeter connected between the steel and a reference electrode. The reference electrode shall be located as close as possible to the steel surface to be measured.

If this measurement circuit remains permanently connected, care should be taken that it does not deliver current which will cause the reference electrode to become polarized and give false indications.

7.3.2 Location of the reference electrodes

The reference electrodes should be distributed in such a manner as to enable representative steel potentials to be measured.

In addition, permanent reference electrodes should be installed in locations such as:

- points located at the furthest distance from the anodes;
- structure nodes;
- shadowed areas which may appear where areas of complex geometry occur, or near appurtenances;
- areas with the highest mechanical stresses;
- areas where the effects of overpolarization can be suspected.

The optimum locations may not be acceptable due to structural constraints.

7.3.3 Types of reference electrode

The zinc/sea water electrode and the silver/silver chloride/sea water reference electrode are the most commonly used. the electrolyte being the surrounding sea water.

Reference electrodes are described in prEN 12473:1999.

7.3.4 Calibration of reference electrodes

Reference electrodes shall be calibrated, directly or indirectly at regular intervals by measuring their potential either directly or indirectly, against a saturated calomel reference electrode.

For installations where the reference electrodes cannot be dismantled from their permanent location, the portable reference electrode used for their calibration shall be placed in their close vicinity.

7.4 Measurement of the anode electrical current output

The measurement of the electrical current output of the monitored anodes should be carried out using an ammeter with a very low internal resistance.

7.4.1 Impressed current system

The electrical current delivered to each anode should be measured at the corresponding output terminal of the transformer rectifier or controllable DC generator or at the distribution box as applicable.

7.4.2 Galvanic anodes system

A visual inspection supplemented by the measurement of the dimensions of the galvanic anodes may be used to give an indication of current output.

A number of permanently monitored galvanic anodes or the use of ammeter probes, temporarily clamped around the supports of the galvanic anodes will give more reliable measurements of instantaneous current output.

The monitored galvanic anodes shall be manufactured to the same dimensions as the other galvanic anodes installed on the structure in order to be representative. Their supports shall be electrically insulated from the structure by means of insulating joints, one of which is short-circuited by a calibrated shunt in order to allow the measurement of the electrical current output, without any significant reduction of the driving voltage.

7.5 Transmission of data

The steel potential and shunt signal can be transmitted using either cables, acoustic transmission systems (direct or deferred transmission) or any other suitable means.

7.6 Control and monitoring of impressed current generators

The controllable DC generators deliver the impressed current to the anodes and should be equipped with the following control equipment:

- a voltmeter for the measurement of the DC output voltage;
- an ammeter for the measurement of the DC current output of each output circuit;
- protection devices against over-voltages and short circuits.

A meter, measuring the period of current output, may be installed for recording the operational periods of the controllable DC generator.

8 Installation of cathodic protection and monitoring systems

The cathodic protection and monitoring systems should be installed so that the design objectives are reached and kept during the lifetime of the cathodic protection system.

The installation of the materials and equipment should be carried out in accordance with the relevant drawings, specifications and procedures.

Installation work shall be in accordance with applicable codes, regulations and standards.

All materials should be inspected before installation to ensure that they are in accordance with the specifications and they have not been subject to damage or breakage.

The transformer rectifier cabinet (if any) shall be located and connected to comply with applicable regulations taking due account of hazardous areas classifications.

Depending on the type of system, the anodes may be installed on the seabed at remote locations or on the structure. Anodes installed on the seabed may be supported by concrete foundations and/or non-metallic buoyancy tanks in order to minimize their possible coverage with mud.

9 Commissioning and surveying of cathodic protection systems

9.1 Objectives

The objectives of the commissioning and the survey of the cathodic protection system are:

- to ensure that the cathodic protection system functions in accordance with the intentions of the design at structure installation;

- to establish if the cathodic protection system is continuing to perform in accordance with the design and that the structure remains satisfactorily protected from corrosion.

9.2 Galvanic anodes system

For galvanic anode systems a cathodic protection survey of the entire structure shall be performed within three months for bare steel structures or one year on coated structures from the installation of the structure.

The survey should include the measurement of the potential at selected locations.

The actual location and status of the anodes should be verified and recorded.

9.3 Impressed current system

For the commissioning of the impressed current cathodic protection system the following operations should be carried out, in the order indicated:

- check wiring to ensure correct polarity (negative terminal to structure);

- switching-on the transformer-rectifier(s) to supply direct current to the structure;

- monitoring of the structure's potentials with the monitoring system until the required potential values are reached.

A cathodic protection potential survey of the structure should be performed within one month of the commissioning of the cathodic protection system.

This survey should include the recording of the structure potential at selected locations. The actual location and status of anodes, cables, conduits, monitoring system should be verified and recorded.

10 Documentation

10.1 General

All information, data and results relating to the cathodic protection system should be recorded and in general should be included in the Operations Manual.

It should include all data pertinent to the design, manufacture, installation, commissioning, operation and maintenance and effectiveness of the cathodic protection system.

The documentation should reflect any changes from the design specification, such as the equipment location, or deviation in settling depth which might alter the protected areas.

Commissioning data should include results of surveys conducted after energizing each cathodic protection system in order to assess that it satisfies design criteria and operates effectively, including structure potential measurements to demonstrate that the protection is achieved.

10.2 Galvanic anodes system

The following data should be kept for reference and permanently updated, when applicable:

- design criteria including the design life, the environment characteristics (i.e. sea water salinity, resistivity), the protection criteria, the electrical current density requirements (initial, maintenance and final or repolarization values), the assumed values of the anode current output at these various periods, and the anode theoretical efficiency and driving potential;

- the number of galvanic anodes, their dimensions, weight, specification, chemical composition, practical consumption rate (as measured during laboratory tests), utilization factor, as well as the manufacturer/supplier's references and documentation;

- the location of each and every galvanic anode as checked during construction or after positioning, all discrepancies with the design location being highlighted (these locations can be conveniently recorded on a specific drawing of the structure), the method of attachment, the date of installation; these data should be updated during the life of the structure;

- the description, specification and position of any electrical current or potential control or monitoring device, including type of reference electrode, measuring equipment, and connecting cables;

- the commissioning results including the potential survey data;

- the results of periodic maintenance inspection survey data including current and protection potential measurements with type of reference electrode, equipment and the measuring technique in order to follow the changes of the cathodic protection potential status of the structure.

10.3 Impressed current system

The following data should be kept for reference and permanently updated, if applicable:

- the design criteria including the design life, the environmental characteristics (i.e. sea water salinity, resistivity), the protection criteria, the current density requirements (initial, maintenance and final or repolarization values), the design values for the anode current output;

- the number of anodes, their dimensions, specification, description of anodic equipment and connection, effective output current densities and allowable voltage, as well as the manufacturer/supplier's data and documentation;

- the description and specification for the anode attachments, the composition, location and dimensions of any dielectric shield (when applicable), as well as the specification, characteristics and attachment method of the connecting cables, junction box(es) and intermediate box (if any);

- the location of each and every anode as checked during construction or after positioning, all discrepancies with design location being highlighted (these locations can be conveniently recorded on a specific drawing of the structure), the date of installation (date of setting of the structure offshore if installed during the construction); these data should be updated during the life of the structure;

- the location, detailed specification, drawings, and output characteristics of each controllable DC power source (transformer rectifier) with the manufacturer's test reports;

- the description, specification and position of any protection potential control or monitoring device, including type of measurement electrode, measuring equipment and connecting cables;

- the commissioning results including potential survey data, electrical current and voltage output values of each controllable DC power source and any adjustment made;

- the results of surveys performed during periodic inspection including potential values, DC output values, maintenance data on rectifiers and downtime periods in order to follow the changes of the protection potential.

11 Safety and cathodic protection

11.1 Objectives

The cathodic protection system shall comply with all safety standards and regulations related to electrical equipment that may apply to fixed steel offshore installations.

This clause deals with safety hazards due to cathodic protection systems and related to diving personnel during their underwater operations.

Safety aspects of diving operations are outside the scope of this document. Reference should be made to appropriate statutory regulations (see annex D).

The galvanic anodes system and the impressed current system will be considered, in association with the following main dangers: physical obstruction, electric shock, and evolution of dangerous gases.

11.2 Physical obstructions

The major risk from anodes is the entanglement of the divers' umbilical or lifeline around the anodes or the anode supports, and the mechanical damage to the equipment due to chafing. Thus the following galvanic anode and anode assembly characteristics are recommended:

- slender galvanic anodes with J-shaped cylindrical stand off supports, protruding from anode extremities;
- flat plate galvanic anodes;
- bracelet galvanic anodes.

Similarly, anode cable conduits, junction boxes, etc., should be designed to exclude any sharp edges or corners or protruding extremities.

For particular situations where anodes are installed in areas where gas can collect, explosion hazard can arise (refer to 11.4).

11.3 Electric shock

In the event that the impressed current cathodic protection system equipment is defective, or the diver inadvertently makes direct contact with the active anode element, he may suffer an electric shock.

During diving operations not directly related to the cathodic protection system, and any diving inspection carried out close to impressed current anodes, the DC supply of anodes shall be switched off. However, diving cathodic protection inspection may be performed, with the impressed current system in operation, providing all relevant safety regulations and precautions are applied (see annex D).

11.4 Gas evolution

11.4.1 Hydrogen evolution

Polarization of the structure to a potential more negative than −0.8 V against Ag/AgCl/sea water reference electrode can result in the evolution of hydrogen gas at the steel surface. If the gas is allowed to collect in confined air spaces, such as cofferdams which are only part full of sea water, it may present a risk of explosion.

To avoid this hazard, the following measures should be taken:

- all designs to include an adequate venting to prevent the build up of hydrogen;
- the structure to electrolyte potential to be kept at values less negative than the threshold value at which hydrogen evolution is not significant. This can be achieved by ensuring that a minimum distance should be kept between the structure and impressed current anodes;
- magnesium alloy anodes should not be installed in areas where hydrogen build up may occur.

11.4.2 Chlorine evolution

Electrochemical reactions at the surfaces of impressed current anodes in sea water invariably result in the evolution of chlorine gas which is highly toxic and corrosive. If this is allowed to collect in confined air spaces above the water line, it may present a hazard to personnel and materials.

To avoid this hazard, all designs shall prevent the build up of gas.

Annex A
(informative)

Guidance on current requirement for cathodic protection of fixed steel offshore structures

In the absence of any other documented experience, the following values may be considered.

A.1 Design current densities for the protection of bare steel in immersed zone

Table A.1 - Design current densities in immersed zone

Geographic areas	Current density (mA/m^2)		
	Initial value	**Maintenance value**	**Repolarization value**
above 62 °N	220	100	130
North Sea (northern sector) 55 °N to 62 °N	180	90	120
North Sea (southern sector) below 55 °N West UK - West Ireland – Netherlands	150	90	100
Arabian Gulf, India, Australia, Brazil, West Africa	130	70	90
Mediterranean Sea, Adriatic Sea Gulf of Mexico, Indonesia	110	60	80

A.2 Design current densities for the protection of bare steel in extended tidal zone

The current densities given in Table A.1 should be increased by 20 %.

A.3 Design current densities for the protection of bare steel in marine sediments (ambient temperature)

Table A.2 - Design current densities in marine sediments

Current density (mA/m^2)		
Initial value	**Maintenance value**	**Repolarization value**
25	20	20

A.4 Current drained by wells: 5 A to 6 A per well

The complete protection of the external surface of the casing may be obtained only if the potential drop along the casing is small enough to obtain a value of the potential at the bottom of the well more negative than the cathodic protection criterion. The level of cathodic protection at the bottom of the casing is closely dependent on the quality of the cementing of the casing; a good cementing will reduce the current drained by the well and improve the cathodic protection of the casing.

A.5 Values of coating breakdown of usual paint system for the design of cathodic protection systems

Initial coating breakdown factor:	1 % to 2 % for submerged zone
	2 % to 5 % for extended tidal zone
Annual depletion rate:	1 % to 1,5 % per year

NOTE Usual paint systems include a minimum of 2 layers of an ambient temperature cured paint (coal tar epoxy, epoxy, ...) with dry film thickness ranging from 300 μm to 500 μm.

Annex B
(informative)

Anode resistance and life duration formulae

B.1 Anode resistance formulae

Slender galvanic anodes mounted at least 0,3 m offset from structure steel surface

if $L \geq 4r$

$$R_a = \frac{\rho}{2\pi L}\left(\ln\left(\frac{4L}{r}\right) - 1\right)$$

if $L < 4r$

$$R_a = \frac{\rho}{2\pi L}\left(\ln\left(\frac{2L}{r}\right)\left(1 + \sqrt{1 + \left(\frac{r}{2L}\right)^2}\right)\right) + \frac{r}{2L} - \sqrt{1 + \frac{r}{2L}}$$

Flat plate galvanic anodes

$$R_a = \frac{\rho}{2S}$$

Other shapes and bracelet anodes

$$R_a = \frac{0{,}315\rho}{\sqrt{A}}$$

where:

ρ is the environment resistivity, in ohms metres,

L is the length of the anode, in metres,

r is the radius of the anode (for other shapes than cylindrical, $r = (C/2)\pi$, where C = cross-section periphery), in metres,

S is the arithmetic mean of anode length and width, in metres,

A is the exposed surface area of anode, in square metres.

Without any information on the resistivity of the environment, the values obtained from Figure B.1 may be used.

For the sea bed the resistivity may vary from 0,70 Ωm for very soft clay to 1,70 Ωm for sand.

B.2 Galvanic anodes life duration

The galvanic anode lifetime (L) may be determined using the following formula:

$$L = \frac{Wu}{EI_m}$$

where:

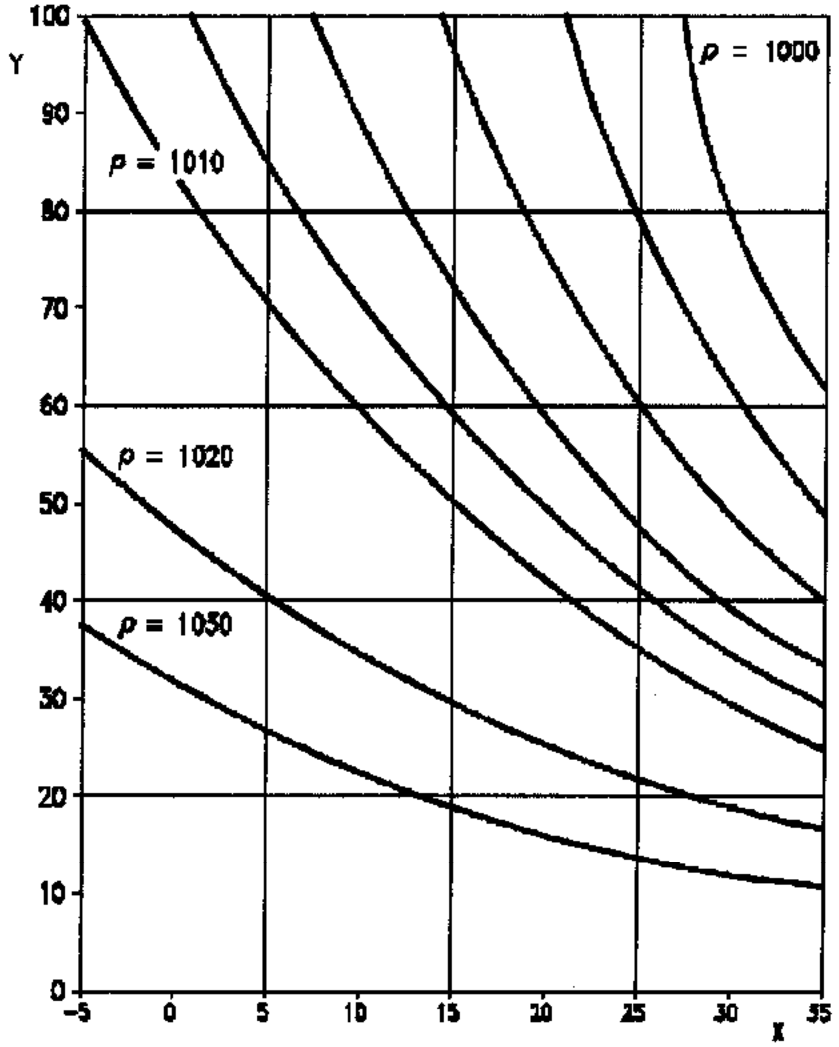
L is the effective lifetime of the anode, in years,

W is the net mass of the anodes, in kilograms,

u is the utilisation factor. It is determined by the proportion of anodic material that may be consumed before the anode ceases to provide the required current output. The shape of the anode will affect the utilization factor which may be in the range of 0,70 to 0,95,

E is the consumption rate of the anodic material in the environment considered, in kilograms per ampere per year,

I_m is the (average) maintenance current output during the lifetime, in amperes.



Key:

x Temperature in °C
y Resistivity in ohms centimetres
ρ Density of sea water in grams per cubic centimetre

Figure B.1 - Sea water resistivity vs. temperature vs. density (grams per litre)

Annex C
(informative)

Recommendations for anode installation

C.1 Slamming force

The static slamming force F_S per unit of length can be evaluated by Morison's formula:

$$F_s = \frac{1}{2}\rho C_s D U^2$$

where:

C_S is the slam coefficient;

ρ is the volumic mass of water, in kilograms per cubic metre;

D is the diameter of the anode support/insert, in metres;

U is the velocity component predicted by motion analysis for launch, normal to the anode support/insert surface, in metres per second.

NOTE The theoretical value of the slam coefficient C_S is π for cylindrical anodes. It is higher for trapezoidal section anodes and depends on cross-section shape.

The forces sustained during fabrication and transportation are generally much less than this slamming force due to launching.

C.2 Fatigue failure of anode supports

The following steps can be used to assess the probability of fatigue failure of the support of anodes during the pile driving operations:

- assess the maximum acceleration of the pile sleeve for each hammer blow;
- assess the effective mass (anodic material mass plus insert and support added mass) of the anodes;
- compute the maximum bending stress in the insert and the supports of the anode;
- compute the natural frequency of the anodes;
- assess the stress response of the anode by assuming half-sine wave input and a suitable level of damping;
- assess the fatigue class (S-N curve);
- compute the fatigue damage for the sequence of stress ranges experienced from one blow;
- multiply by the number of blows expected to drive a pile, this number being predicted from the pile driveability studies.

Annex D
(informative)

Safety precautions for impressed current system

Any applicable statutory regulation shall apply.

The following general information shall be considered.

Unless the step-down transformer is a double-insulated isolating type transformer, it should be fitted with protective devices which operate in the event of a fault between the AC input of the transformer and the DC output of the rectifier.

Some typical electrical characteristics for impressed current anodes are given in annex E.

Based on the maximum current delivered by an anode, the resulting voltage gradient in the surrounding water can be calculated using the conductivity of the sea water, which can in turn be used to estimate the current likely in the diver's body, assuming the worst case.

IEC/TR2 60479-1, IEC/TR 60479-2, IEC/TR 60479-3 (see bibliography) curves give the relationship between shock duration and allowable current passing through the body.

Considering the worst case of a safe body current of 40 mA as acceptable, the maximum safe voltage gradient without DC trip device will be 30 V maximum corresponding to a nominal voltage of 24 V.

This value is applicable for divers who may approach impressed current anodes and are normally wearing a complete rubber suit including rubber gloves.

In this case, the body resistance is considered to be of 750 Ω if the voltage remains inferior to 50 V (500 Ω for higher voltages).

Values of the safe distance from diver to anode in water, i.e. with drop voltage inferior to 30 V, depend on the ratio of delivered current (I_a) to the safe body current (I_b).

For divers who are not involved in or not aware of cathodic protection (such as for marine growth cleaning), it is recommended that the impressed current system is switched off during diving.

For divers involved in cathodic protection inspection, a safe distance to be kept between divers and impressed current anodes which are in operation.

For the performance of close visual inspection of impressed current anodes, the DC supply of anodes should be switched off.

Annex E
(informative)

Typical electrochemical characteristics for commonly used impressed current anodes

Anode materials	Consumption rate (g/Ay)	Maximum current density (A/m^2)	Maximum voltage (V)
Platinized titanium	0,004 to 0,001 2[a)]	500 to 3 000	8[b)]
Platinized niobium	0,004 to 0,001 2[a)]	500 to 3 000	50
Platinized tantalum	0,004 to 0,001 2[a)]	500 to 3 000	100
Mixed metal oxide	0,000 6 to 0,006	400 to 1 000	8[b)]
Lead silver[c)]	25 to 100	250 to 300	24
Chromium silicon iron	250 to 500	10 to 30	50

[a)] The life of the platinum film may be affected by the electrolyte resistivity, the consumption rate increasing with resistivity. The life of the platinum film can also be affected by the magnitude and frequency of the ripple present in the DC supply. Ripples frequencies less than 100 Hz should be avoided.

[b)] In sea water, the oxide film on titanium may break down if the voltage at the anode exceeds 8 V vs Ag/AgCl/sea water. Higher voltages may be used with fully platinized anodes or in less saline environments.

[c)] PbO_2 film formation may be enhanced by the use of Platinum pins in the lead silver alloy.

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