Corrosion Protection of Steel Offshore Units and Installations

May 2006

Guidance Note
NI 423 DT R01 E
MARINE DIVISION

GENERAL CONDITIONS

ARTICLE 1

1.1. - BUREAU VERITAS is a society the purpose of whose Marine Division (the "Society") is the classification ("Classification") of any ship or vessel or structure of any type or part of it or system therein collectively hereinafter referred to as a "Unit" whether located at shore, river or sea bed or not, whether operated or located at sea or in inland waters or partly on land, including submarines, hovercrafts, drilling rigs, offshore installations of any type and of any purpose, their related and ancillary equipment, subsea or not, such as wet head and pipelines, mooring legs and mooring points or otherwise as decided by the Society.

The Society services:

- prepares and publishes Rules for classification, Guidance Notes and other documents ("Rules");
- issues Certificates, Attestations and Reports following its interventions ("Certificates");
- publishes Registers.

1.2. - The Society also participates in the application of National and International Regulations or Standards, in particular by delegation from different Governments. Those activities are hereafter collectively referred to as "Certification".

1.3. - The Society can also provide services related to Classification and Certification such as ship and company safety management certification; ship and port security certification, training activities; all activities and duties incidental thereto such as documentation on any supporting means, software, instrumentation, measurements, tests and trials on board.

1.4. - The interventions mentioned in 1.1., 1.2. and 1.3. are referred to as "Services". The party and/or its representative requesting the services is hereinafter referred to as the "Client". The Services are prepared and carried out on the assumption that the Clients are aware of the International Maritime and/or Offshore Industry (the "Industry") practices.

1.5. - The Society is neither and may not be considered as an Underwriter, Broker in ship's sale or chartering, Expert in Unit’s valuation, Consulting Engineer, Controller, Naval Architect, Manufacturer, Shipbuilder, Repair yard, Charterer or Shipyowner who are not relieved of any of their expressed or implied obligations by the interventions of the Society.

ARTICLE 2

2.1. - Classification is the appraiser given by the Society for its Client, at a certain date, following surveys by its Surveyors along the lines specified in Articles 3 and 4 hereafter on the level of compliance of a Unit to its Rules or part of them. This appraiser is represented by a class entered on the Certificates and periodically transcribed in the Society’s Register.

2.2. - Certification is carried out by the Society along the same lines as set out in Articles 3 and 4 hereafter and with reference to the applicable National and International Regulations or Standards.

2.3. - It is incumbent upon the Client to maintain the condition of the Unit after surveys, to prevent the Unit for surveys and to inform the Society of any delay of circumstances which may affect the given appraiser or cause to modify its scope.

2.4. - The Client is to give to the Society all access and information necessary for the performance of the requested Services.

ARTICLE 3

3.1. - The Rules, procedures and instructions of the Society take into account at the date of their preparation the state of currently available and proven technical knowledge of the Industry. They are not a code of construction neither a guide for maintenance or a safety handbook.

Committees consisting of personalities from the industry contribute to the development of those documents.

3.2. - The Society only is qualified to apply its Rules and to interpret them. Any reference to them has no effect unless it involves the Society’s intervention.

3.3. - The Services of the Society are carried out by professional Surveyors according to the Code of Ethics of the Members of the International Association of Classification Societies (IACS).

3.4. - The operations of the Society in providing its Services are exclusively conducted by way of professional inspections and do not in any circumstances involve monitoring or exhaustive verification.

ARTICLE 4

4.1. - The Society, acting by reference to its Rules:

- reviews the construction arrangements of the Units as shown on the documents presented by the Client;
- conducts surveys at the place of their construction;
- classes Units and enters their class in its Register;
- surveys periodically the Units in service to note that the requirements for the maintenance of class are met.

The Client is to inform the Society without delay of circumstances which may cause the date or the extent of the surveys to be changed.

ARTICLE 5

5.1. - The Society acts as a provider of services. This cannot be construed as an obligation bearing on the Society to obtain a result or as a warranty.

5.2. - The certificates issued by the Society pursuant to 5.1. here above are a statement on the level of compliance of the Unit to its Rules or to the documents of reference for the Services provided for.

In particular, the Society does not engage in any work relating to the design, building, production or repair checks, neither in the operation of the Units or in their trade, neither in any advisory services, and cannot be held liable on those accounts. Its certificates cannot be construed as an implied or express warranty of safety, fitness for the purpose, seaworthiness of the Unit or of its value for sale, insurance or chartering.

5.3. - The Society does not declare the acceptance or commissioning of a Unit, nor of its construction in conformity with its design, that being the exclusive responsibility of its owner or builder, respectively.

5.4. - The Services of the Society cannot create any obligation bearing on the Society or constitute any warranty of proper operation, beyond any representation set forth in the Rules, of any Unit, equipment or machinery, computer software of any sort or other comparable concepts that has been subject to any survey by the Society.

ARTICLE 6

6.1. - The Society accepts no responsibility for the use of information related to its Services which was not provided for the purpose by the Society or with its assistance.

6.2. - If the Services of the Society cause to the Client a damage which is proved to be the direct and reasonably foreseeable consequence of an error or omission of the Society, its liability towards the Client is limited to ten times the amount of fee paid for the Service having caused the damage, provided however that this limit shall be subject to a minimum of eight thousand (8,000) Euro, and to a maximum which is the greater of eight hundred thousand (800,000) Euro and one a half times the above mentioned fee.

The Society bears no liability for indirect or consequential loss such as e.g. loss of revenue, loss of profit, loss of production, loss relative to other contracts and indemnities for termination of other agreements.

6.3. - All claims are to be presented to the Society in writing within three months of the date when the Services were supplied or (if later) the date when the events which are relied on or were first known to the Client occurred. Any claim which is not so presented shall be deemed waived and absolutely barred.

ARTICLE 7

7.1. - Requests for Services are to be in writing.

7.2. - Either the Client or the Society can terminate as of right the requested Services after giving the other party thirty days' written notice, for convenience, and without prejudice to the provisions in Article 8 hereunder.

7.3. - The class granted to the concerned Units and the previously issued certificates remain valid until the date of effect of the notice received according to 7.2. hereabove subject to compliance with 2.3. hereabove and Article 8 hereunder.

ARTICLE 8

8.1. - The Services of the Society, whether completed or not, involve the payment of fee upon receipt of the invoice and the reimbursement of the expenses incurred.

8.2. - Overdue amounts are increased as of right by interest in accordance with the applicable legislation.

8.3. - The class of a Unit may be suspended in the event of non-payment of fee after a first unfaultful notification to pay.

ARTICLE 9

9.1. - The documents and data provided to or prepared by the Society for its Services, and the information available to the Society, are treated as confidential.

- Clients have access to the data they have provided to the Society and, during the period of classification of the Unit for them, to the classification file consisting of survey reports and certificates which have been prepared at any time by the Society for the classification of the Unit;
- copy of the documents made available for the classification of the Unit and of available survey reports can be handed over to another Classification Society Member of the International Association of Classification Societies (IACS) in case of the Unit’s transfer of class;
- the data relative to the evolution of the Register, to the class suspension and to the survey status of the Units are passed on to IACS according to the association working rules;
- the certificates, documents and information relative to the Units classed with the Society may be reviewed during IACS audits and are disclosed upon order of the concerned governmental or inter-governmental authorities or of a Court having jurisdiction.

The documents and data are subject to a file management plan.

ARTICLE 10

10.1. - Any delay or shortcoming in the performance of its Services by the Society arising from an event of force majeure foreseeable by or beyond the control of the Society shall be deemed not to be a breach of contract.

ARTICLE 11

11.1. - In case of diverging opinions during surveys between the Client and the Society’s surveyor, the Society may designate another of its surveyors at the request of the Client.

11.2. - Disagreements of a technical nature between the Client and the Society can be submitted by the Society to the advice of its Marine Advisory Committee.

ARTICLE 12

12.1. - Disputes over the Services carried out by delegation of Governments are assessed within the framework of the applicable agreements with the States, international Conventions and national rules.

12.2. - Disputes arising out of the payment of the Society’s invoices by the Client are submitted to the Court of Nanterre, France.

12.3. - Other disputes over the present General Conditions or over the Services of the Society are exclusively submitted to arbitration, by three arbitrators, in London according to the Arbitration Act 1996 or any statutory modification or re-enactment thereof. The contract between the Society and the Client shall be governed by English law.

ARTICLE 13

13.1. - These General Conditions constitute the sole contractual obligations binding together the Society and the Client, to the exclusion of all other representation, statements, terms, conditions whether expressed or implied. They may be varied in writing by mutual agreement.

13.2. - The invalidity of one or more stipulations of the present General Conditions does not affect the validity of the remaining provisions.

13.3. - The definitions herein take precedence over any definitions serving the same purpose which may appear in other documents issued by the Society.
Corrosion Protection of Steel Offshore Units and Installations

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SECTION 2  PROTECTION OF SUBMERGED ZONE
SECTION 3  PROTECTION OF SPLASH ZONE
SECTION 4  PROTECTION OF ATMOSPHERIC ZONE
SECTION 5  COATING SYSTEM
# NI 423

Corrosion Protection of Steel Offshore Units and Installations

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SECTION 1 GENERAL

1 Scope

1.1 Application

1.1.1 The present Guidance Note applies to mobile units, fixed platforms, underwater pipelines, underwater production facilities, buoys and anchoring systems attached to the sea bed. Chains, cables and anchors are excluded.

1.1.2 It provides guidelines for the prevention and control of corrosion on steel structures, appurtenances and equipment of units or installations operating in a marine environment.

1.2 Zones

1.2.1 Corrosive environments offshore are often categorized as marine atmosphere, splash zone, tidal zone, fully submerged zone and mud zone. However, within the present Guidance Note, only the three following zones are separately considered (see definition in [3]):

- the atmospheric zone
- the splash zone
- the submerged zone.

1.3 Reference documents

1.3.1 Recognised international standards

Reference is given to the following International Standards, which are assumed to be complied with, in addition to requirements of this Guidance Note:

- ISO 12473: 2002 - Specimen dimensions and procedures for shear testing resistance spot, seam and embossed projection welds.

2 Miscellaneous definitions

2.1

2.1.1 The following definitions are considered throughout the present Guidance Note:

- acidity: presence of an excess of hydrogen ions over hydroxyl ions (see also "pH value")
- alkalinity: presence of an excess of hydroxyl ions over hydrogen ions (see also "pH value")
- anaerobic: lack of free oxygen. In the present Guidance Note, this term refers to the state of the electrolyte adjacent to the metal
- anchor pattern: roughness of a surface on which a coating is intended to be applied
- anode: electrode at which an oxidation process occurs;
- anode shield: synonym of "dielectric shield"
- anodic area: means the part of a metal surface which acts as an anode
- blistering (of paint film): formation of swellings on the surface of an unbroken paint film by moisture, gases, or the development of corrosion products between the metal and the paint film
- bond: piece of metal conductor, either rigid or flexible, usually made of copper, connecting two points on the same structure or on different ones, in order to prevent any appreciable change in the potential of one point with respect to the other
- coating breakdown factor (K): anticipated relative reduction in cathodic current density due to the application of an electrically insulating coating. K is a function of coating properties, operation parameters and time.
  - K=0: the coating is totally electrically insulating
  - K=1: the coating has no protective properties.
- calcareous deposit: layer mainly consisting of a mixture of calcium carbonate and magnesium hydroxide deposited on surfaces protected by a cathodic protection system in sea water due to the increased pH adjacent to the protected surface
- cathode: electrode of an electrolytic cell at which a reduction process occurs; it is usually the area which is not corroding
- cathodic area: part of a metal surface which acts as a cathode
- cathodic disbonding: failure of adhesion between a coating and a metallic surface which is directly attributable to the application of cathodic protection
- cathodic protection: technique to reduce the corrosion of the structure to insignificant rate by causing a direct current to flow from its electrolyte environment into the entire metal surface
- cell: complete electrolytic system including a cathode and an anode in electrical contact with an intervening electrolyte
- continuity bond: bond designed and installed specifically to provide electrical continuity. This bond may be permanent or temporary, e.g. during the course of a modification or repair (see also "bond")
• **copper/copper sulphate reference electrode**: reference electrode consisting of copper in a saturated copper sulphate solution; this electrode can become polluted by chlorides after a long term service in sea water

• **corrosion**: chemical or electrochemical reaction of a metal with its environment, resulting in its progressive degradation or destruction

• **corrosion product**: chemical compound or compounds produced by the reaction of a corroding metal with its environment

• **corrosion specialist**: person who, by reason of his education and/or experience is qualified to evaluate and solve problems related to the corrosion of materials. In the present Guidance Note, corrosion specialist refers to the one who is qualified in the control of corrosion in marine environments

• **current**: rate of flow of electrical charge carriers in the direction of net transport of positive charges (in a metallic conductor, this is the opposite direction of the electron flow), expressed in amperes (A) or milliamperes (mA)

• **current density**: current flowing to or from a unit area of an electrode surface

• **depolarisation**: removal of factors resisting the flow of a current in a cell

• **dielectric shield**: electrically non-conductive and alkali-resistant material such as organic coating, plastic sheet, or pipe, which is placed, in a cathodic protection system, between an anode and adjacent cathode to minimize the risk of hydrogen damage to the latter and to improve current distribution

• **doubler plate**: additional plate used to provide extra strength at a point of anode attachment to a structure

• **driving voltage** (sacrificial anodes system): difference between the structure/electrolyte potential and the anode/electrolyte potential

• **electrode**: conductor of the metallic class (including carbon) by means of which current passes to or from an electrolyte

• **electrolyte**: chemical substance or mixture, usually liquid, containing ions that migrate in an electric field

• **electro-negative**: applied to a metallic electrode, means that its potential is negative with respect to another metallic electrode in the system

• **electro-positive**: applied to a metallic electrode, means that its potential is positive with respect to another metallic electrode in the system

• **foreign structure**: any metallic structure which is not intended to be part of the concerned system

• **galvanic anode** (sacrificial anode): metal which, because of its relative position in the galvanic series corrodes and provides galvanic protection to metal or metals which are more noble in the series when coupled in an electrolyte. These anodes are the current source in sacrificial anodes cathodic protection systems

• **HAT**: highest astronomical tide, as obtained from site data

• **holiday**: discontinuity in a protective coating which exposes the metal surface to the environment

• **impressed current**: direct current supplied by a device employing a power source external to the electrode system of a cathodic protection system

• **interference current** (stray current): in its broadest sense, direct current flowing through paths other than the intended circuit. In the present Guidance Note, interference current means current discharged to the electrolyte from a structure which may be either not an intended part of circuit, or an intended part of circuit not adequately connected to the current source

• **IR drop**: voltage drop across a current carrying resistance (which can be the electrolyte) in accordance with Ohm’s law

• **"J" tube**: curved tubular conduit designed and installed on a structure to support and guide one or more pipeline risers or cables

• **LAT**: lowest astronomical tide, as obtained from site data

• **mill scale**: heavy oxide layer formed during manufacturing, hot fabrication or heat treatment of metals and alloys

• **mud line**: ocean floor at the concerned location; synonyms: sea floor, sea bed and sea bottom

• **mud zone**: zone lying under the mud line

• **MWL**: mean water level as obtained from site data

• **passivation**: phenomenon occurring when the surface of a metal or alloy susceptible to corrosion reaches a state where its electrochemical behaviour becomes less reactive and its corrosion rate is reduced. This is the result of the formation of a protective film

• **pH value**: scale used to indicate the concentration of hydrogen ions in an electrolyte

• **pitting**: localized form of corrosion whereby a number of cavities, never in the form of cracks, are formed in the surface

• **Pitting Resistance Equivalent Number (PREN)**: an empirical relationship to predict the pitting resistance of austenitic and duplex stainless steel. It is expressed as: PREN = %Cr + 3.3% (Mo + 0.5W) + 16 %N

• **polarization**: deviation from the open circuit potential of an electrode resulting from the passage of current

• **protected structure**: structure to which cathodic protection is applied

• **protection current**: current made to flow into a metallic structure from its electrolytic environment in order to effect cathodic protection of this structure

• **protection potential**: the less negative level to which the potential of a metallic structure, with respect to a reference electrode in an electrolytic environment, has to be depressed in order to effect cathodic protection of this structure

• **protective coating**: dielectric material adhering to or bonded to a structure to separate it from its environment in order to provide corrosion protection

• **reference electrode** (also called reference half-cell): reversible electrode the open circuit potential of which is constant under similar conditions of measurement. It is used for measuring the potentials of other electrodes
3.2.2 For floating unit, the waterballast tanks are to be considered as “submerged zone” in this Guidance Note.

3.3 Splash zone

3.3.1 The splash zone is the zone of the unit or installation which is alternatively in and out of water because of wind, wave, tide, and, for mobile units, unit’s motions. Surfaces which are wetted only during major storms are excluded from splash zone.

3.3.2 The exact location and vertical extent of the splash zone is generally determined at the design stage of unit or installation, as it depends upon environmental conditions corresponding to the site of installation of the fixed installation, or those expected to be met by the mobile unit, and used for its design.

3.3.3 The splash zone is usually considered as extending:
- from 3 m below LAT level to 5 m above HAT level for fixed platforms (these values varying from site to site)
- from 3 m below to 5 m above water line at draught corresponding to normal working condition for mobile units.

3.4 Atmospheric zone

3.4.1 The atmospheric zone is the zone of the unit or installation which extends upwards from the splash zone i.e. above the level reached by the normal swell, and exposed to sun, wind, spray and rain.

4 Corrosion protection systems

4.1 Submerged zone

4.1.1 Steel corrosion of the external areas of submerged zone is to be controlled by the installation of cathodic protection systems, i.e. sacrificial anodes system or impressed current system. In some cases, corrosion protection of the submerged zone can be provided by appropriate coating systems, supplemented by one of the above mentioned cathodic protection systems.

4.1.2 As concerned with steel corrosion on the internal areas of submerged zone:

a) Corrosion may be expected to be negligible on the internal surfaces of structures in compartments which are considered to be sealed and where no renewal of the electrolyte is possible

b) In compartments where presence and circulation or renewal of sea water is possible in normal conditions, as for example waterballasts in floating units, cathodic protection using sacrificial anodes combined with adequate coating systems is to be used.

c) In closed flooded compartments where bacteria may develop or where the electrolyte may be renewed, cathodic protection using sacrificial anodes combined with adequate coating systems is to be considered. Injection of chemicals (oxygen scavenger and bactericides) can be used in such compartment (i.e. permanent ballast) provided approval by Flag and Coastal State.
For b) and c), the possibility to provide thickness increments of steel should be also considered.

Note 1: Impressed current system is only permitted on external part of the structure. This system is not permitted for closed compartment such as waterballast tanks in floating units.

4.2 Splash zone

4.2.1 Steel corrosion in the splash zone is to be controlled by the following means:

- application of particular protective coating systems
- in addition for tubular structures:
  fitting of steel wear plates (doubler plates, often applied as welded wrap) or use of structural members with additional wall thickness for corrosion and erosion allowance.

Steel wear plates are to be sufficiently thick to compensate the anticipated corrosion and wear of the structure during the whole expected life of the unit or installation. They are generally coated or sheathed for additional corrosion protection.

- density current as defined in Sec 2, [3.2.2] is to be increased by 10% in the splash zone.

4.3 Atmospheric zone

4.3.1 Steel corrosion in the atmospheric zone should be controlled by the application of suitable protective coating systems.
SECTION 2  PROTECTION OF SUBMERGED ZONE

1 General

1.1

1.1.1 The purpose of using cathodic protection is to control the corrosion of metallic surfaces in contact with electrolytes.

2 Criteria for cathodic protection

2.1 Protection potential

2.1.1 Cathodic protection is effective if the reaction of oxidation of iron is not possible.

2.1.2 The purpose of [2.1.1] is achieved when the steel electrode potential is lowered below the protection potential of \( -800 \text{ mV} \) versus Ag/AgCl sea water reference electrode, which can be considered as a protection criterion. This value includes the IR drop across the steel/water interface but does not include the IR drop in sea water.

Under anaerobic conditions where micro-biologically assisted corrosion may occur, a potential of \( -900 \text{ mV} \) versus Ag/AgCl/sea water reference electrode is to be considered as the criterion.

Under particular conditions of pH, temperature or pressure, the potential criterion should be adjusted according to the thermodynamic laws.

2.1.3 In addition, negative limits for potential are to be settled by taking into account the hydrogen stress cracking susceptibility of steel and coating disbonding possibility, if any.

If the structure reaches too negative a potential, the cathodic protection may cause penetration of hydrogen, resulting in metal embrittlement, and subsequently inducing the propagation of cracks. The risk is significantly greater for high strength steels.

Steels with a specified minimum yield strength (\( R_y \)) not exceeding 500 N/mm², these phenomena can occur at potentials (V) lower than \(-1100 \text{ mV} \) versus Ag/AgCl/sea water reference electrode.

Anaerobic environments with presence of sulphate-reducing bacteria and sulphide increase the possibility of high strength steels to suffer from hydrogen stress cracking.

2.1.4 Tab 1 gives recommended limits for steel potential.

2.1.5 Use of cathodic protection outside these limits (\( R_y > 500 \text{ N/mm}^2 \) or/and \( V < -1100 \text{ mV} \)) is to be considered by the Society on a case by case basis.

Table 1 : Steel potential limits versus Ag/AgCl sea water

<table>
<thead>
<tr>
<th>Material</th>
<th>Upper limit (mV)</th>
<th>Lower limit for bare steel (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>aerated seawater</td>
<td>(-800)</td>
<td>(-1100)</td>
</tr>
<tr>
<td>non aerated seawater</td>
<td>(-900)</td>
<td>(-1100)</td>
</tr>
<tr>
<td>Austenitic stainless steel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PREN ( \geq 40 )</td>
<td>(-300)</td>
<td>(-1100)</td>
</tr>
<tr>
<td>PREN (&lt; 40 )</td>
<td>(-500)</td>
<td>(-1100)</td>
</tr>
<tr>
<td>Duplex stainless steel</td>
<td>(-500)</td>
<td></td>
</tr>
<tr>
<td>Martensitic stainless steel (13% Cr) steel</td>
<td>(-500)</td>
<td></td>
</tr>
</tbody>
</table>

(1) For stainless steels, the minimum negative potentials apply for aerobic and anaerobic conditions
(2) Depending on strength, specific metallurgical condition and stress level encountered in service, these alloys can be susceptible to hydrogen embrittlement and cracking. If a risk of hydrogen embrittlement exists, then potentials more negative than \(-800 \text{ mV} \) is to be avoided.

2.1.6 Other standard reference electrodes may be substituted to the Ag/AgCl/sea water reference electrode. Tab 2 lists these electrodes with their voltage equivalent to \(-800 \text{ mV} \) referred to Ag/AgCl/sea water reference electrode.

Table 2 : Steel potential upper limit versus other reference electrodes

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Potential (mV) equivalent to (-800 \text{ mV} ) vs Ag/AgCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated Cu( \text{CuSO}_4 ) (1)</td>
<td>(-850)</td>
</tr>
<tr>
<td>High purity zinc</td>
<td>+ 250</td>
</tr>
<tr>
<td>ASTM B418-80 type II</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>+ 250</td>
</tr>
<tr>
<td>MIL Spec A-18001 H</td>
<td></td>
</tr>
<tr>
<td>Saturated calomel</td>
<td>(-780)</td>
</tr>
</tbody>
</table>

(1) is to remind that the saturated Cu\( \text{CuSO}_4 \) is not stable for long term immersion service.

2.1.7 The silver-silver chloride reference electrode potential is affected by the temperature and the chloride concentration (i.e. the resistivity) of the sea water in which the electrode is immersed.
If the resistivity is known to differ appreciably from that of ordinary sea water (20 $\Omega$.cm), the electrode reading is to be corrected according to Fig 1.

For example, if brackish water of 100 $\Omega$.cm resistivity exists at contemplated site, the minimum protective potential to Ag/AgCl electrode is - 830 mV, corresponding to 850 mV to Cu/CuSO$_4$ electrode.

### 2.2 Potential drop

#### 2.2.1 A minimum negative (cathodic) voltage shift of 300 mV, measured between the surface of the unit or installation and a reference electrode immersed in the water, is to be produced by the application of protective current; this value includes the IR drop across the steel/water interface, but does not include the IR drop in sea water.

This protection criterion is mainly used for impressed current systems and is to be considered only if above protection potential cannot be reached.

### 3 Electrical current demand

#### 3.1 General

#### 3.1.1 The lowering of the steel structure potential within the voltage range given in Tab 1 should be achieved by delivering sufficient protection current to the structure, and distributing this over the whole surface to be protected. Therefore, protection current densities applied to all parts of the structure are to be considered.

#### 3.1.2 The following local environmental conditions affect the density of protection current which are to be used for the design of the cathodic protection system:

- sea water temperature
- sea water oxygen content
- sea water velocity
- sea water chemical composition
- sea water resistivity
- sea water pH (see Fig 2)
- water depth
- seabed composition
- possible biological activity in the seabed
- erosion conditions.

The selection of current density should be based upon available experience in similar environmental conditions.

Note 1: Some of the parameters are interdependent
3.2 Bare steel

3.2.1 The current density needed is not constant with time. For bare steel structures, the initial design current density is to be high enough to ensure an adequate polarization within a reasonable lapse of time, e.g. 1 or 2 months; then, the necessary current density may decrease due to the formation of calcareous deposits caused by the cathodic current. The repolarization design current density is to be high enough to give protection during storm periods and after major marine growth removal works which both induce a depolarization of the structure.

3.2.2 Tab 3 and Tab 4 provide guidance for selection of minimum design current densities for cathodic protection of bare steel.

3.3 Coated steel

3.3.1 The cathodic protection system may be combined with a suitable coating system (refer to [3.3.5]). The coating reduces the current demand and improves the current distribution.

The current demand of a coated surface increases with time as the coating deteriorates. In order to allow for possible mechanical deterioration and ageing, the following rates of deterioration may be considered:

- for fixed platforms with paint systems with minimum 2 layers of an ambient temperature cured paint (epoxy,...) with a dry film thickness ranging from 300 to 500 µm:
  - 2 % to 5 % of the surface of the coating due to installation
  - 1 % to 1.5 % per year after installation
- for pipelines, depending on the coating type (bituminous enamels, polyethylene, polypropylene, etc.) and possible weight coat:
  - 1 % to 5 % of the surface of the coating due to installation
  - 0.2 % to 0.4 % per year after installation
- for mobile units, 2 % to 5 % per year with an initial value of 2 %.

Note 1: For fixed platforms and pipelines, the whole projected life of the structure is to be considered.
For mobile units, the period between two dry dockings during which coating is renewed is to be considered.

3.3.2 The protection current density for coated steel is highly dependent on the quality of the coating materials, on the coating application and on installation and utilization conditions.

<table>
<thead>
<tr>
<th>Table 3 : Recommended minimum current densities for cathodic protection of bare steel of fixed structures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>North Sea (northern sector)</td>
</tr>
<tr>
<td>above 62° N</td>
</tr>
<tr>
<td>from 55° N to 62° N</td>
</tr>
<tr>
<td>North Sea (southern sector: West UK, West Ireland, Netherlands)</td>
</tr>
<tr>
<td>Arabian, Gulf, India, Australia, Brazil, West Africa</td>
</tr>
<tr>
<td>Gulf of Mexico, Indonesia, Mediterranean Sea, Adriatic Sea</td>
</tr>
<tr>
<td>Buried pipeline (bare)</td>
</tr>
</tbody>
</table>

- For the first 20 m below MWL, it is recommended to increase the above values by 10% (higher current velocity, higher oxygen content, more severe storm action)
- Higher current densities are to be used for steel temperatures above 25°C. The increase from values given in Table is to be 1 mA/m² per °C, the difference of temperatures to consider being the difference between actual steel surface temperature and 25°C
- The current density for the saline mud zone is to be identical to submerged zone.

<table>
<thead>
<tr>
<th>Table 4 : Recommended minimum current densities for cathodic protection of bare steel of mobile structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Situation</td>
</tr>
<tr>
<td>Immersed Low relative speed 0,5 &lt; v &lt; 1,5 m/s</td>
</tr>
<tr>
<td>Immersed Medium relative speed 1,5 &lt; v &lt; 3,0 m/s</td>
</tr>
<tr>
<td>Immersed High relative speed (v &gt; 3,0 \text{ m/s})</td>
</tr>
</tbody>
</table>
Tab 5 gives a general guidance for the selection of coating breakdown factor $K$, valid for fixed platforms and floating units intended not to be dry docked. This Tab 5 corresponds to thin film coating, i.e. with a thickness less than 1 mm.

### Table 5: Guidance on thin film coating breakdown (General)

<table>
<thead>
<tr>
<th>Lifetime (years)</th>
<th>$K$: Coating breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>10</td>
<td>0.05</td>
</tr>
<tr>
<td>20</td>
<td>0.05</td>
</tr>
<tr>
<td>30</td>
<td>0.05</td>
</tr>
<tr>
<td>40</td>
<td>0.05</td>
</tr>
<tr>
<td>50</td>
<td>0.05</td>
</tr>
</tbody>
</table>

#### 3.3.3 For risers and pipelines systems which are coated either with thick film coatings or special corrosion protective coatings and concrete weight coats, coating breakdowns for lifetimes up to 30 years may be considered equal to those given in Tab 7.

#### 3.3.4 For floating structures intended to be dry docked, the coating breakdown to be considered depends on the dry docking interval and of the kind of service of the floating unit. Guidance on values of coating breakdown is given in Tab 6 for a 5 years dry-docking interval.

### Table 6: Guidance on mobile unit coating breakdown

<table>
<thead>
<tr>
<th>Structures</th>
<th>$K$: Coating breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>Utility boats</td>
<td>0.05</td>
</tr>
</tbody>
</table>

#### 3.3.5 The cathodic polarization may have two detrimental effects on coatings, due to:
- alkalinity of the electrolyte close to the coating leading to cathodic disbonding which in some instances is due to saponification of sensitive coatings, such as oil-based and alkyd paints
- hydrogen evolution leading to loss of adhesion caused by mechanical action.

Coatings, therefore, should be chosen to be resistant to cathodic disbonding, chemically inert to the marine environment and to alkalis, as well as not likely to induce or promote the development of bacteria. A coating is to present a barrier to the transport of uncharged and charged species, to have a high electrical resistance to minimize the amount of current necessary to protect the steel.

### 3.4 Wells

#### 3.4.1 For wells of fixed platforms and subsea installations, the upper part of the wells achieves the potential of the structure to which they are connected. A complete protection of the external part of the casing may be obtained only if the decrease in potential along the casing is small enough to allow for a potential more negative than the protection criterion at the bottom of the well.

Good quality cementing of wells is essential to obtain efficient cathodic protection down to the bottom of the casing, as the potential level of the buried zone is set by the current demand of the structure. It is in no case possible to modify the potential level of the upper part.

#### 3.4.2 An allowance of 5 to 10 A per well should be considered for the buried part of wells of fixed platforms and subsea installations, depending on the size, depth and cementing quality of the well. The chosen value is to be documented.

#### 3.4.3 For fixed platforms, conductor pipes should be divided for calculation purposes into the same zones than the structure. For calculations, the maximum number of wells which may be installed in the guide frames is to be considered.

### 3.5 Current demand of the structure

#### 3.5.1 General

The current demand $I_c$ is to be obtained by multiplying the surface of steel $S$ to be protected by the specific current density of bare steel $i_c$ corrected by the coating breakdown factor $K$, where applicable, as per the following equation:

$$I_c = S_i K$$

#### Table 7: Guidance on pipeline and riser coating breakdown for 30 years

<table>
<thead>
<tr>
<th>Coating system</th>
<th>$K$: Coating breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
</tr>
<tr>
<td>3 layers system polyethylene or polypropylene or 1 layer fusion bonded epoxy + barrier coat both with concrete weight coat</td>
<td>0.01 to 0.02</td>
</tr>
<tr>
<td>Asphalt enamel with concrete weight coat</td>
<td>0.02 to 0.03</td>
</tr>
<tr>
<td>3 layers system polyethylene or polypropylene without concrete weight coat</td>
<td>0.02 to 0.03</td>
</tr>
<tr>
<td>Fusion bonded epoxy, liquid epoxy, or polyurethane without concrete weight coat</td>
<td>0.03 to 0.05</td>
</tr>
</tbody>
</table>

**Note 1:** The final considered values are to be given by the coating Manufacturer.
3.6 Cathodic protection systems

3.6.1 Two types of cathodic protection systems can be used, sacrificial anodes system and impressed current system. A combination of both systems (hybrid) is also possible and can bring a weight advantage for large capacity and long-life systems.

3.6.2 As the current density demand is normally not constant with time, the total current output capacity needs to be greater than the total (remaining) current demand at any time during the life of system.

3.6.3 The cathodic protection system is to be designed to minimize effects on associated or neighboring structures which may be induced by the operation of the system.

3.6.4 The cathodic protection system components should be located so that the possibility of disturbance or damage is minimized.

3.6.5 The sizing of cathodic protection systems is to be performed using Ohm’s law.

a) In the case of sacrificial anodes:

\[ I_a = \frac{\Delta V}{R_a} \]

where:

- \( I_a \) : Anode maximum output current, in A (see Note 1)
- \( \Delta V \) : Potential difference between operating anode and steel (driving potential), in V
- \( R_a \) : Circuit resistance, usually taken as the anodic resistance to earth, in \( \Omega \).

Note 1: With this equation, the anode maximum output current at the begin of lifetime \( I_{a_{\text{initial}}} \) and at the final lifetime \( I_{a_{\text{final}}} \) can be calculated from respectively the values of the circuit resistance \( R_{a_{\text{initial}}} \) and \( R_{a_{\text{final}}} \).

3.5.2 Areas

For designing a cathodic protection system, the following areas are to be considered:

- areas of the structure and appurtenances in sea water, defined:
  - for fixed platforms, as the whole immersed area, including the total height of the tidal zone, increased by 2.5 m to take into account the swells and the possible inaccuracy of the platform installation
  - for mobile units, as the maximum wetted surface
  - areas below the mud line, for fixed installations and bottom-supported units
  - casings of wells intended to be drilled, if any, although a fixed allowance is generally used, as indicated in [3.4.2]
  - uninsulated and unprotected neighboring foreign structures.

Where applicable, the current drainage by chains should be estimated.
### Table 8: Formulae for calculation of anodic resistance

<table>
<thead>
<tr>
<th>Anode Type</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long slender stand off anodes mounted at least with 0.3 m offset from structure surface and with ( L &gt; 4r ) (1)</td>
<td>( R_a = \frac{\rho}{2\pi L} \left[ \ln \left( \frac{4L}{r} \right) - 1 \right] )</td>
</tr>
<tr>
<td>Short slender stand off anodes mounted at least with 0.3 m offset from structure surface and with ( L &lt; 4r ) (1)</td>
<td>( R_a = \frac{\rho}{2\pi L} \left[ \ln \left( \frac{2L}{r} \right) \left( 1 + \frac{L}{2L} \right)^2 \right] - \frac{1}{2L} - \frac{1}{4} \left( \frac{L}{2L} \right)^2 )</td>
</tr>
<tr>
<td>Long flush mounted anodes</td>
<td>( R_a = \frac{\rho}{25} )</td>
</tr>
<tr>
<td>Flat plate anodes</td>
<td>( R_a = \frac{\rho}{25} )</td>
</tr>
<tr>
<td>Bracelet anodes and other shapes</td>
<td>( R_a = \frac{0.315 \rho}{4A} )</td>
</tr>
</tbody>
</table>

1 For anodes mounted with distance less than 0.3 m but minimum 0.15 m from structure surface, a correction factor equal to 1.3 may be applied in the formula of \( R_a \).

**Note 1:**
- \( R_a \) : Anode resistance, in \( \Omega \)
- \( \rho \) : Electrolyte resistivity, in \( \Omega \cdot m \)
- \( L \) : Length of anode, in m
- \( r \) : Anode radius (for shapes other than cylindrical, \( r = \frac{P}{2\pi} \), where \( P \) is the cross section perimeter, in m)
- \( S \) : Arithmetic mean of anode length, height and width, in m
- \( A \) : Surface of the anode exposed area, in \( m^2 \).

### 3.6.6 Without information on local electrolyte resistance, the following values of \( \rho \) are to be considered:

- Sea bottom mud: \( \rho = 60 \) to \( 170 \) \( \Omega \cdot cm \)
- Cold sea water (< 10°C): \( \rho = 30 \) to \( 35 \) \( \Omega \cdot cm \)
- Warm sea water (> 25°C): \( \rho = 15 \) to \( 25 \) \( \Omega \cdot cm \)

### 4 Sacrificial anode systems

#### 4.1 General

4.1.1 Sacrificial anode systems consist in producing a direct current between the structure to be protected and sacrificial anodes which are generally welded to the structure.

The sacrificial anodes work by spontaneously corroding in an electrolyte, then protecting the structure they are connected to. The active surface of an anode is not to be painted or isolated from the electrolyte.

4.1.2 Sacrificial anodes are made of metallic alloys which are more electro-negative than steel. They are generally made of alloys based on aluminium, zinc or magnesium.

4.1.3 Dimensions, number and locations of anodes are to be determined so that the protection potential (refer to Tab 1) is reached on elementary surfaces of the structure, during the whole expected lifetime of the cathodic protection system. Therefore, the total mass of anodic material is to be such that, according to the output capacity of the anodic material, it can deliver the maintenance current demand for the whole design life of the structure. For mobile units, the period between two dry dockings with replacement of anodes could be considered.

Furthermore, the sizes, number and locations of anodes are to meet the protection current needed at the beginning of the life of the structure (initial polarisation) as well as at the end of their life - when consumed down to their utilisation factor - or for re-polarisation of the structure after heavy storm or marine growth removal.
4.2 Sacrificial material

4.2.1 Alloy anodes

The performance and therefore the suitability of a particular alloy for a specific application depends on the composition and characteristics of both the alloy and the electrolyte, the temperature of operation and the anode current density.

The characteristics of an anode alloy are obtained from the performance data which include:

- the current capacity in Ampere hour per kilogram (A.h/kg)
- the closed circuit potential of a working anode, measured against a standard reference electrode
- the susceptibility to passivation and/or to intergranular corrosion
- the anode surface morphology which affects its efficiency.

Tab 9 gives typical alloy compositions.

Some anode alloys may produce environmentally undesirable corrosion products. It is to be ascertain whether the contemplated alloy may be used under the intended conditions.

4.2.2 Tab 10 gives typical values of anode potential and current capacity in sea water for the most commonly used galvanic alloys.

4.2.3 Limitations

a) Al-Zn-In alloys containing magnesium may suffer age hardening and cracking.

b) Al-Zn-Sn alloys require heat treatment to achieve effective activation and may suffer intergranular corrosion and slow activation at low temperatures (i.e. 5°C).

c) Al-Zn-Hg alloys require particular care in manufacturing procedure in order to ensure a uniform distribution of mercury inside the alloy.

d) The efficiency of some aluminium alloys is adversely affected when covered with mud.

e) Magnesium alloys are only applicable where frequent replacement is practicable, they are not to be used in closed compartments where hydrogen evolution may present a safety hazard. They may be used for very short periods such as the initial polarisation.

f) At anode temperatures exceeding 50°C, zinc alloys may undergo a high reduction of their driving potential and current capacity and have been shown to suffer intergranular corrosion.

g) The current capacity of Al bas alloys anodes decreases with increasing anode surface temperatures (T> 25°C). This temperature should not exceed 80°C unless the performance is tested and documented.

h) Magnesium or magnesium alloy anodes are not permitted in oil cargo and tanks adjacent to cargo tanks.

i) Aluminium anodes are only permitted in cargo tanks and tanks adjacent to cargo tanks in locations where the potential energy does not exceed 28 kg.m (200 ft.lb). The height of the anodes is to be measured from the bottom of the tank to the centre of the anode, and its weight is to be taken as the weight of the anode as fitted, including the fitting devices and inserts. However, where aluminium anodes are located on horizontal surfaces such as bulkhead girders and stringers not less than 75 mm above the horizontal surface, the height of the anode may be measured from this surface. Aluminium anodes are not to be located under tank hatches or Butterworth openings (in order to avoid any metal parts falling on the fitted anodes), unless protected by adjacent structure.

4.3 Sizing of anodes

4.3.1 Dimensions and number of anodes are to be calculated in order to install the minimum mass of anode alloy and to ensure that the current delivered by these anodes is at least equal to the current demand for initial as well as for final or re-polarisation conditions.

Model testing and/or computer modelling based upon finite or boundary element calculations can be used, provided that the software and input data and parameters are adequately documented.

4.3.2 The number and the size of the anodes are estimated according to the equations defined in [4.3.3] and [4.3.4].

4.3.3 Mass of anode material is to be determined from one of the following formula:

If the actual consumption rate \( E \) is known:

\[
M = \frac{T E q I_{c\,\text{mean}}}{U}
\]

If the electrochemical efficiency \( \varepsilon \) is known:

\[
M = \frac{8760 T q L_{c\,\text{mean}}}{U \varepsilon}
\]

where:

- \( M \): Total mass of anode alloy, in kg
- \( T \): Design service lifetime, in years
- \( E \): Actual consumption rate of the anode alloy (i.e. including electrochemical efficiency of the anode material), in kg/A.yr
- \( I_{c\,\text{mean}} \): Mean current demand calculated from the mean current density, in A
- \( U \): Utilisation factor determined by the amount of anode material consumed when the remaining anode material cannot deliver the current needed
  - The following utilisation factors may be used:
    - long slender stand off anodes: 0,95
    - short slender stand off anodes: 0,90
    - long flush mounted anode: 0,85
    - bracelet anodes and others shapes: 0,80
  - It is recommended that the utilisation factor is not below those given values for predicting the performance of the anodes.
- \( \varepsilon \): Electrochemical efficiency of the anode material, in A.h/kg
- \( q \): Immersion factor.

Note 1: The Fig 3 gives an example of the evolution of the electrochemical efficiency of the Al-base anode in function of the temperature.
4.3.4 Number of anodes may be determined from the following formulae:

- at the beginning of the lifetime of the anodes:
  \[ n \geq \frac{n_{c_{\text{initial}}}}{I_{c_{\text{initial}}} q} \]

- at the final or re-polarisation time of the anodes:
  \[ n \geq \frac{n_{c_{\text{final}}}}{I_{c_{\text{final}}} q} \]

where:

- \( n \) : Number of anodes
- \( I_{c_{\text{initial}}} \) : Initial current demand, in A, defined in [3.5.1] with initial parameter
- \( I_{c_{\text{final}}} \) : Final or re-polarisation current demand, in A
- \( I_{a_{\text{initial}}} \) : Anode maximum output current at the beginning of lifetime, in A
- \( I_{a_{\text{final}}} \) : Anode maximum output current when the anode is consumed to its utilisation factor, in A.
4.3.5 The final condition of an anode is obtained when the anode has been consumed to its utilisation factor $U$, then the anode current $I_a$ is calculated by the following formula:

$$I_a = \frac{\Delta V}{R_a}$$

$R_a$ final is obtained by taking into account the formulae of the Tab 8 and replacing these values of $L$ and $r$ by $L_{\text{final}}$ and $r_{\text{final}}$ calculated as per below:

$$L_{\text{final}} = L_{\text{initial}} - 0.1UL_{\text{initial}}$$

$$r_{\text{final}} = \frac{m_{\text{final}}}{\pi d} + r_0^2$$

$$m_{\text{final}} = m_{\text{initial}} (1-U)$$

where:

- $R_a$ final : Final anode resistance when the anodes has been consumed to its utilisation factor, in $\Omega$
- $r$ final : Final anode radius, in m
- $m$ final : Final mass of the anode, in kg
- $L$ final : Final length of the anode, in m
- $r_0$ : Radius of anode core, in m
- $d$ : Anode density, in kg/m$^3$.

4.3.6 The anode manufacturers usually have standard size moulds available for specific line sizes. Although, the total mass of the anodes is given by the following equation:

$$M = nm_a$$

In practice $n$ and $m_a$ are selected using the following equation:

$$n \leq \frac{M}{m_a}$$

which is equivalent to:

$$TI_c \leq nt_a I_a$$

where:

- $n$ : Number of anodes to be installed on the specified section
- $m_a$ : Individual anode mass, in kg
- $t_a$ : Design service time of an anode in years.

4.3.7 Installation of additional anodes with smaller dimensions for the initial stage (for instance 2 or 3 years) to meet the initial high current demand may be more economical than to find a single anode shape which meets both criteria of [4.3.4].

4.4 Location of anodes

4.4.1 Anodes are to be distributed over the steel surface so that an even current distribution is achieved, which allows each elementary surface to reach the protection potential.

The anodes are to be distributed vertically and/or horizontally in accordance with the calculated current demand of each considered area.

4.4.2 Current distribution efficiency may be improved by using a greater number of anodes of lower individual output.

4.4.3 For structures including nodes, anodes should be located so that polarisation of node welds is ensured as rapidly as possible after installation or launching.

Polarisation of node welds is indeed of primary importance, as these nodes are critical for structural strength, and subject to fatigue effect.

Nodes are zones of large metal surface area and complex geometry, for which a greater care is necessary to avoid shielding (shadowed areas).

4.4.4 Particular attention should be given to uncoated areas with complex geometry. Separate calculations may be necessary to check the anodes distribution.

4.4.5 Where pipeline systems are located in the vicinity of other fixed installations, consideration is to be given to evaluate possible interference between pipeline systems and installations. Additional anodes are to be provided accordingly.

4.4.6 The efficiency of some aluminium alloys being adversely affected when covered with mud, it should be avoided to attach such anodes to structures located below the mud line. Zinc alloys are often preferred in this case.

4.4.7 If heavy anodes are used, they are to be attached to the structure so as to minimise stresses at the point of attachment.
4.4.8 For pipeline system, the spacing between anodes is to be determined once the number of anodes has been calculated. Anodes spacing exceeding 300m is to be justified by potential attenuation calculations or other mathematical modelling.

4.5 Fabrication of anodes

4.5.1 General

The efficiency of the cathodic protection system depends on the electrochemical characteristics of the sacrificial anode alloy.

The electrochemical properties of the alloy being highly dependent on the content and homogeneity of the alloy elements and on impurities, small deviations from specifications may result in significant reduction of protective properties and efficiency.

Therefore, the quality control system of the Manufacturer should be checked on the following:
- documentation on raw material (anode alloy and insert)
- production equipment and process
- testing during and after production
- identification of heat
- identification of anodes
- chemical analysis
- mass and dimensional tolerances
- surface aspect of anodes
- documentation on finished anodes.

4.5.2 Insert and stand off legs

The anode insert, and stand off legs where applicable, should be made of a low carbon steel suitable for welding onto the parent structure.

The carbon equivalent of insert material is not to exceed 0.40 %, determined using the following formula:

\[ C_e = C + \frac{Mn}{6} \]

It should be abrasive blasted to a minimum grade Sa 2 1/2 (ISO Standard 8501-1) at the time of casting. Furthermore:

a) For stand off anodes, the insert should be cylindrical in order to avoid gas retention during the alloy casting. The dimension of the insert is in relationship with the anode alloy mass and with environmental conditions. Values given in Tab 11 are only indicative; a strength verification should be performed to check the adequacy of the fixations. The insert is to protrude from both extremities of the anodes and not from bottom face. The distance d between each end of anode alloy and the axis of the closest leg of the support should be as small as possible and, in all cases, is not to exceed values given Tab 12.

b) For flattened anodes, the inserts should be flat bars or corner shapes, the dimensions of which are to be adapted to the mass of the anode alloys. These inserts should protrude laterally in order to ensure mechanic fixation and electrical connection by welding.

c) The inserts are to be 100 % visually inspected prior to casting.

d) For zinc anodes, the steel insert may be hot dip galvanised or zinc electroplated.

<table>
<thead>
<tr>
<th>Mass M of anode alloy (kg)</th>
<th>Internal protection</th>
<th>External protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>M &lt; 50</td>
<td>round bar 1/2&quot; dia.</td>
<td>round bar 3/4&quot; dia.</td>
</tr>
<tr>
<td>50 ≤ M &lt; 75</td>
<td>round bar 3/4&quot; dia.</td>
<td>tube 2&quot; sch. 80</td>
</tr>
<tr>
<td>75 ≤ M &lt; 150</td>
<td>round bar 3/4&quot; dia.</td>
<td>tube 2 1/2&quot; sch. 80</td>
</tr>
<tr>
<td>150 ≤ M &lt; 200</td>
<td>tube 2&quot; sch. 80</td>
<td>tube 3&quot; sch. 80</td>
</tr>
<tr>
<td>200 ≤ M &lt; 350</td>
<td>tube 2&quot; sch. 80</td>
<td>tube 4&quot; sch. 80</td>
</tr>
<tr>
<td>350 ≤ M</td>
<td>tube 2&quot; sch. 80</td>
<td>tube 4&quot; sch. 80</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diameter of the insert</th>
<th>2&quot;</th>
<th>2 1/2&quot;</th>
<th>3&quot;</th>
<th>4&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum distance d (mm)</td>
<td>200</td>
<td>300</td>
<td>350</td>
<td>400</td>
</tr>
</tbody>
</table>
b) The anode is to be free from excessive shrinkage. The shrink sinks are limited to 10% of the anode thickness or 25% of the depth of the anode insert, or 10 mm, whichever is less. The depression is to be measured from the uppermost corner to the bottom of the depression. Overpouring to fill shrink sinks should be kept to a minimum. Pouring of molten alloy should be finished before the surface of the cast anode solidifies. The surface of the anode may be kept in a liquid state for a while by applying heat from gas burners, but once solidified, no remelting is to be performed, not even to fill shrinkage cavities.

c) The surface of the anode is to be free from coating, slag/dross inclusions, etc. An exception is coating which may be applied to the underside of anode for better performance. Such coating is recommended for flush mounted anodes.

d) Cold shuts or surface laps are not accepted for bracelets. They are not to exceed 10 mm in depth or extend over more than 150 mm in length for other shapes of anodes.

e) Anodes should be selected, prior to fabrication, to be cut for investigation upon internal defects. These anodes are to be cut transversely by single cuts at 25%, 50% and 75% of nominal length. Cut faces should be examined visually, without magnification, and the following should be checked:

- cut does not include more than 2% gas holes or non-metallic inclusions; in addition, the total area of these three cut surfaces does not include more than 1% gas holes or non-metallic inclusions
- for the insert position, in terms of nominal design position, lies within ±5% in anode width and length, and within ±10% in anode depth for stand-off type anodes or ±5 mm for bracelet and flush mounted type anodes.

4.5.4 Mass and dimension tolerances

A quantity of 10% of the anode delivery should be checked.

The following tolerances should be used:

a) For all types of anodes:

- gross mass:
  - ± 5% on individual anodes for anode masses less than 50 kg
  - ± 2% on individual anodes for anode masses equal to 50 kg and over
  - 0%, + 2% on total mass of anodes

b) For stand-off or flush mounted anodes:

- thickness, width or diameter:
  - ± 5% of anode nominal dimensions
- Length:
  - ± 2.5% of nominal length or ±25 mm, whichever is smaller
  - maximum deviation from straightness, for slender anodes: 2%.

c) For bracelet anodes:

- length:
  - ± 2.5% of nominal length or +25 mm whichever is smaller
- internal diameter:
  - 0, +4 mm for pipeline diameter < 300 mm
  - 0, +6 mm for pipeline diameter > 300 mm and < 600 mm
  - 0%, +1% for pipeline diameter ≥ 600 mm.

### Table 13: Maximum number of transverse cracks allowed for stand-off and flush mounted anode

<table>
<thead>
<tr>
<th>Maximum width of cracks (w), in mm</th>
<th>w &lt; 0.5 (hairline cracks)</th>
<th>0.5 ≤ w &lt; 1</th>
<th>1 ≤ w &lt; 3</th>
<th>w ≥ 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum depth of cracks d not applicable</td>
<td>measurement not necessary</td>
<td>d ≤ 0.1 t_c</td>
<td>d &gt; 0.1 t_c</td>
<td>any</td>
</tr>
<tr>
<td>Length of cracks l</td>
<td>any</td>
<td>l &lt; (3/4) φ_e</td>
<td>(3/4) φ_e ≤ l &lt; (3/2) φ_e</td>
<td>l ≥ (3/2) φ_e</td>
</tr>
<tr>
<td>Maximum number of cracks allowed per m of anode</td>
<td>any</td>
<td>10</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

**Note 1:**

- t_c: Thickness of anodic material covering the insert;
- φ_e: Equivalent diameter of the anode or thickness of the anode, whichever is less.
4.5.5 Chemical analysis
At least two analyses should be carried out per cast (beginning and end of casting), suitably identified with the correct heat number.

Samples may be taken from a finished anode if any doubt exists about the representativity of samples taken from the ladle.

The chemical analysis and temperature sensing and recording equipment should be suitably calibrated.

The supplier should provide analysis for showing the compliance with the specified composition limits of the alloy being produced. Additional samples may be taken and stored for future assessment of chemical composition.

For alloys where heat treatment is specified, details of the heat treatment history for furnace charge should be recorded.

4.5.6 Electrochemical properties
Checking of closed circuit potential and practical mass consumption (or current capacity) should be performed on:

- one sample for a delivery mass less than or equal to 10000 kg
- two samples for a delivery mass exceeding 10000 kg but not exceeding 20000 kg
- one additional sample for complementary 20000 kg mass for delivery masses exceeding 20000 kg.

The results should be checked to lie within the following ranges:

- closed circuit potential = specified value ± 25 mV
- mass consumption = specified value
  - 0, + 5 %, or current capacity not less than 95 % of the specified capacity

The test method is to be documented and approved.

4.5.7 Documentation and identification
The Manufacturer is to provide material certificates including the following information:

- certificate number and date of fabrication
- manufacturer name/mark
- designation of product (type of anode)
- anode serial number
- net mass of anode
- anode and core specification (alloy composition)
- charge/heat number with identification of anode serial numbers
- chemical composition of charge/heat
- anode nominal dimensions
- methods of analysis and of electrochemical testing
- electrochemical tests results.

Anodes are to be marked for identification including the Manufacturer’s mark and heat reference (cast/serial number), together with Inspector’s stamp.

Marking is to be made by cold stamping on the external part of the insert.

4.6 Installation of anodes
4.6.1 Anodes may be fixed using various methods. The method of fixation is to be chosen after evaluation of the design of the electrical connection, loads applied to the structure to which the anodes are attached and stresses to which the structure is submitted.

Gravity loads and drag forces caused by the sacrificial anodes system are to be minimised.

The anode supports and attachment devices and method are to be designed to withstand the following without damage:

- transportation condition
- structure launch
- vibrations induced by pile driving operations (if applicable)
- fatigue from wave and current loading
- extreme wave loading.

4.6.2 Electrical connections between anodes and steel surfaces should be normally made by manual welding. Brackets may be necessary.

Note 1: it should be noted that mechanical connections may not give reliable electrical connections for more than 5 years.

4.6.3 Doubler plates are to be provided in areas submitted to important pressures or high stresses.
They are to have rounded corners to avoid stress concentrations.

4.6.4 Welding operations are to be carried out by qualified welders using a qualified welding procedure.

4.6.5 Anodes are not to be located in areas subject to high stress concentrations.

In tanks classed as hazardous areas, anodes are not to be mounted higher above the tank bottom than a level producing a falling down potential energy of 28kgm. Magnesium anodes are not allowed in such tanks.

To minimise cavitation of propellers and thrusters on self-propelled units and units fitted with dynamic positioning or propulsion assistance devices, anodes should be located as shown in Fig 4, i.e. should not be installed between 0.3 D and 0.5 D from the propeller axis, D being the diameter of the propeller.

Adequate electrical connection should be ensured between the hull and the propeller shaft and between the hull and the rudder stock.

4.6.6 For mobile units, including floating storage units, anodes should be installed so that their supports are positioned in way of internal stiffening or local structural reinforcements.

4.6.7 Supports of anodes intended to be mounted on painted units or installations are to be painted.
5 Impressed current system

5.1 General

5.1.1 Impressed currents are not permitted in oil cargo tanks.

5.1.2 Impressed current systems are not allowed in water-ballast holds.

5.1.3 Impressed current system consists in producing direct current between:
- the structure to be protected, which is connected to the negative terminal of a d.c. power source such as a rectifier or a generator
- anodes which are connected to the positive terminal of this source.

5.1.4 The current delivered by the d.c. source is controlled during the expected lifetime of the cathodic protection system, in order to bring steel surfaces of the structure to a protection potential range within limits specified in Tab 1. Impressed current systems generally use manually adjustable rectifiers and one or several anodes because the current demand does not vary significantly.

Automatic rectifiers with control through potential are used where protection parameters change frequently and to a large extent, such as areas submerged with tides, or variable wetted surface of mobile units depending on their loading condition.

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

The current output of the rectifier, its distribution to anodes, the number and location of anodes should achieve an even distribution of the protection current according to the structure current demand.

5.1.5 To compensate for possible less efficient distribution, the cathodic protection system should be designed to provide 1.1 to 1.5 times the calculated total maximum current demand.

This total maximum current demand is the maximum value among initial, maintenance and re-polarisation current demands.

5.1.6 Due to higher anode current output than with sacrificial anodes system (smaller number of anodes), the impressed current anodes should be located as far as practicable from any steel surface to be protected.

A minimum distance of 1.5 m should be preferred. If such a distance is not practicable, a special dielectric shield is to be designed to prevent localised high current densities which may induce local over-polarisation with potentials out of the limits specified in Tab 1 and, consequently, induce hydrogen or chlorine evolution or interference phenomena with foreign structures.

5.1.7 As many precautions are necessary to ensure a good performance of impressed current systems, it is advisable not to use impressed current systems unless a cathodic protection specialist is controlling the system during installation, commissioning and periodical in-service inspection.

Impressed current systems are to be thoroughly inspected, particularly to detect possible insulation defects, prior to being energised.

5.2 Rectifier

5.2.1 The rectifier or controllable d.c. generator is to be able to deliver the protection current specified in [5.1] (1.1 to 1.5 times the maximum current demand).

Its nominal output voltage is to take into account the resistance of the electric circuit (cables, anodes, etc.).

This output voltage is to be in accordance with the anodic material used (maximum operating voltage). For automatic potential controlled system, the rectifier should deliver a constant or variable current when one of the control reference electrode gives a potential value less negative than the upper threshold (refer to Tab 1). It is to be, however, able to deliver no current if control reference electrodes give potential values more negative than the lower threshold (refer to Tab 1).

In case of an electrode breakdown, the system is to automatically disregard this electrode for current delivery calculations.

5.3 Anodes

5.3.1 Semi-consumable anodes made of graphite, silicon-iron alloy, etc., may be used but inert anodes should be preferred for high output currents: platinized or mixed oxides activated titanium, platinized niobium or even platinized tantalum.

The platinum is applied in a thin layer.

5.3.2 The output current densities used for impressed current anodes are ranging from 500 to 3000 A/m² but are generally sized using 500 A/m². For these current densities, the
consumption of platinum is ranging from 4 to 12 $10^{-6}$ kg/A.yr (0.6 to 6 $10^{-6}$ kg/A.yr for 600 A/m² for mixed metal oxides activated titanium).

As high voltage highly deteriorates the anode, the anode/sea water voltage is to be limited to the following values:

- platinized titanium: 8 V
- platinized niobium: 50 V
- mixed metal oxides activated titanium: 8 V

For platinized tantalum, the limit may reach values greater than 100 V.

5.3.3 These anodes, their connection devices and supporting systems should be designed with an adequate mechanical resistance in order to withstand the structure transportation, structure launch, pile driving vibration (if applicable), fatigue from wave/current loading, extreme wave loading, etc.

The susceptibility to mechanical damages is very critical because only a few number of anodes are generally installed for reasonably high output currents; the loss of one anode may therefore seriously reduce the performance of the system.

5.3.4 Necessary measures should be taken in order to maintain a good insulation between the anodes and the structure.

5.3.5 The number, sizes and location of anodes are to be determined in order to deliver the current distributed by the rectifier to which the anodes are connected.

Computer modelling based upon finite or boundary element calculations can be used, provided that the software and input data and parameters are adequately documented.

The structure may be split into areas corresponding each one to the zone of influence of a single anode. Anode is to be sized to deliver the maximum current demand of its associated area including an overlapping with neighbouring areas.

Anodes may be installed either distributed in view of their protected surface or, for fixed installations and storage units, at a remote location on the sea bottom. In this last case, the supporting system is to be designed to avoid the possibility of anodes becoming covered with mud.

5.3.6 Inspection during installation is to be carefully performed to ascertain that equipment sizing and material are in accordance with the specifications.

5.3.7 Provisions for anode replacement are to be considered.

5.4 Dielectric shields

5.4.1 For anodes intended to be located at less than 1.5 m from the structure (this distance is to be adjusted according to the anode output current), the installation of dielectric shields is necessary.

5.4.2 Dielectric shields may consist of thick yard applied coatings, prefabricated plastic or elastomeric sheets, etc. The material is to be selected considering the intended service: it is to be resistant to chlorine, hydrocarbons, other various chemicals, anode and cathode corrosive products and gases as well as to disbonding.

5.4.3 The anticipated life time and deterioration rate of the dielectric shields should be considered.

5.4.4 The shield is to be large enough for the output current considered.

5.5 Reference electrodes

5.5.1 Reference electrodes are used for periodical structure/sea water potential measurement at selected locations and possibly for the control of the output current of the rectifier.

5.5.2 These electrodes are to be carefully insulated from the structure.

5.5.3 The reference electrodes are to be installed in the vicinity of nodes, highly stressed areas, possible shadowed areas, areas where overpolarisation or underpolarisation may be suspected. Zinc/sea water and silver/silver chloride/sea water are the most widely used reference electrodes. They are to be calibrated at regular intervals versus a saturated calomel reference electrode.

5.5.4 The validity of their measurements should be regularly verified as wrong values may disturb the performance of the impressed current system if automatic potential control unit is used, or, otherwise, give a false estimation of the system efficiency.

5.6 Cables

5.6.1 Cables and connection insulation materials are to be resistant to the aggressive environment as already stipulated for dielectric shields in [5.4].

5.6.2 Cables are to be adequately protected to avoid any risk of mechanical damage, as deterioration of their insulations will deeply reduce the performance of the impressed current system; tubular steel conductors may be used for this purpose.

5.6.3 Electrical connections between cables are to be avoided for underwater installation.

5.6.4 Electrical connection between anode lead cable and anode body is to be watertight and mechanically secured and protected.

5.6.5 Sections of cable are to be determined according to the drop voltage considered for the cable length.

5.6.6 Dedicated cables are to be used for potential measurements. These cables are to be screened to avoid any interference.
6 Monitoring system

6.1 Design of monitoring system

6.1.1 Monitoring systems may be dispensed with for sacrificial anodes but they are essential for impressed current systems.

6.1.2 They are to be of high reliability as they are to allow a permanent control of the status of the cathodic protection system and even monitor the output characteristics of d.c. power sources of impressed current systems in order to maintain the protection level of the structure.

6.2 Potential measurement

6.2.1 The potential of steel is to be measured using a high impedance voltmeter connected to at least two independently checked permanent reference electrodes (one Ag/AgCl and one pure Zn) (refer to [5.5]).

6.2.2 Care is to be taken that this voltmeter does not permanently deliver current into this reference electrode which may become polarised and give false indications.

6.3 Anode current output

6.3.1 The measurement of the current output of impressed current anodes is to be done either at the output terminal of the d.c. power source or of a distribution box, as applicable.

6.4 Impressed current power source control

6.4.1 The d.c. power source delivers the protective current to the anodes and is to be equipped with the following control equipment:

- a voltmeter for the measurement of the d.c. output voltage
- an ammeter for the measurement of the d.c. output intensity, possibly connected to a switch allowing the measurement of the electrical current output of anode
- protection devices against over-voltages and short circuits.

An hour meter may be installed for recording the operational periods of the d.c. power source.

7 Cathodic protection records and surveys

7.1 Records

7.1.1 General

Information, data and results related to the cathodic protection system are to be included in the Operation Manual, with all data pertinent to the design, manufacture, installation, commissioning, operation and maintenance recommendations and efficiency of the cathodic protection system.

The as-built documentation is to reflect any change from design specifications, may it be modifications of equipment location, deviation in setting depth liable to alter protected areas, etc.

Commissioning data are to include results of surveys carried out after energising cathodic protection system in order to assess that it satisfies design criteria and operates effectively, including structure potential measurements to demonstrate that protection is achieved.

7.1.2 Sacrificial anodes systems

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

- design criteria including the design life, the design environment characteristics (i.e. sea water temperature, resistivity, etc.), the protection criteria, the electrical current density requirements (initial, maintenance and repolarisation values), the assumed values of anodes current output during these various periods, and the anodes theoretical efficiency and driving potential
- the number of sacrificial anodes, their geometries, weights, chemical composition, specification, effective consumption rate (as measured during laboratory tests), utilisation factor, as well as Manufacturer/Supplier references and documentation
- the location after installation of anodes, any discrepancy from design location being highlighted (these locations may be conveniently recorded on a specific drawing of the structure), the method of attachment, the date of installation (date of installation of the platform, or launching of the unit, if anodes are installed during construction); these data are to be updated during the life of the unit or installation
- 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 potential survey data and where possible the anode current output
- the results of periodic survey measurements, including electrical current and protection potential, with type of reference electrode, equipment and measuring technique in order to follow the changes of the protection potential status of the structure.

7.1.3 Impressed current systems

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

- the design criteria including the design life, the environment characteristics (i.e. sea water temperature, resistivity, etc.), the protection criteria considered, the current density requirements in initial, maintenance and repolarisation periods, the assumed anode current output
- the number of anodes, their geometries, sizes, description of anodic equipment and connections, specification, effective output current densities and allowable voltage, etc., as well as the Manufacturer/Supplier data and documentation
• the description and specification of the anode fixation device, the composition and location of any dielectric shield (where applicable), as well as the specification, characteristics and attachment method of the connecting cables and junction boxes (if any)
• the location of anodes, as checked during construction, any discrepancy from design location being highlighted (these locations may be conveniently recorded on a specific drawing of the structure), the date of installation (date of installation of the platform, or launching of the unit, if anodes are installed during construction); these data are to be updated during the life of the unit or installation
• the location, detailed specification, drawings, and output characteristics of d.c. power source (transformer-rectifier) with its factory test reports
• the location, description and specification of any protection potential control or monitoring device, including type of reference electrode, measuring equipment and connecting cables
• the commissioning results including potential survey data, electrical current and voltage output values of d.c. power source and any adjustment performed
• the data obtained during periodic in-service inspection, including protection potential values, d.c. output values, maintenance data on d.c. sources and downtime periods in order to follow the changes of the protection potential status of the structure.

7.2 Surveys

7.2.1 General
The assessment of the efficiency of the cathodic protection system is to be performed by measuring the steel to sea water potential and inspecting the cathodic protection equipment.

Measurements and inspections are necessary for:
• checking that protection has been achieved according to applicable criteria and that part of the cathodic protection system is operating properly
• detecting performance changes of the cathodic protection system because of working conditions variations with time.

It is to be noted that changes in the cathodic protection system to maintain protection are necessary to meet changes with time of conditions which affect protection.

7.2.2 Performance of potential surveys
The choice of locations where structure to sea water potential are to be measured is of primary importance in order to evaluate the working conditions of the cathodic protection system.

Potential measurements are to be carried out with the reference electrode as close as possible to the steel surface in order to minimise IR drop through sea water. Selected locations for measurements are to be as far as possible from any anode. A particular attention is to be paid to areas with a complex geometry, which may be shadowed areas for the cathodic protection currents.

Additional potential measurements are to be carried out on at least 2% of the sacrificial anodes of the structure.

On structures protected by impressed current systems, measurements are also to be carried out in areas close to anodes where over-polarisation is liable to occur. In order to avoid errors due to IR drop through sea water and not to impair diver safety, it may be necessary to measure off-potentials. Any measurement is to be performed immediately after the system has been switched off.

7.2.3 Periodicity of potential surveys
Conditions may exist, such as after severe storms, where experience in operation indicates that it is necessary to perform surveys and inspections more frequently than recommended below.

An initial potential survey is to be carried out by the operator after the cathodic protection system is put into operation in order to ensure that it satisfies applicable criteria and operates effectively. This survey is to include enough potential measurements to demonstrate that protection has been achieved.

This survey is to be carried out within:
• three months on bare steel structures with sacrificial anodes system
• one year on coated structures with sacrificial anodes system
• one month for impressed current system.

A close follow-up of some selected points can also be performed during the period between installation and initial survey, in order to detect any early failure of the system.

An annual potential survey is to follow the initial survey to ascertain the continuity of cathodic protection.

7.2.4 Extent of potential surveys
The extent of periodic surveys mentioned in [7.2.3] should mainly be determined from results of previous surveys; they are however to cover major parts of the installation, and feature a significant overlap with previous surveys.

Emphasis are to be given to areas with complex geometry and partly closed compartments.

Priority is to be given to parts of primary importance for structural safety, highly stressed areas, and areas where steel with yield strength above 500 MPa is used.

For structures equipped with a fixed monitoring system (reference electrodes), extent of in-service surveys may be somewhat limited, and their frequency decreased as compared with those applicable to structures without such a system.

Note 1: current densities or field gradients may be used as alternative assessment of the effectiveness of the cathodic protection system.

7.2.5 Verification of equipment
The test equipment used to perform readings is to be maintained in good operating condition and annually checked for accuracy by the operator. Reference electrodes should be more frequently checked, (i.e. before and after any dive or set of readings) for possible inaccuracy due to contamination, had electrical connections, or deterioration of wire insulations where applicable, or polarisation of electrode.
Furthermore, d.c. sources are to be checked at intervals not exceeding one month. Evidence of proper functioning is to be obtained by recording the values of current output, power consumption, or satisfactory structure/sea water potentials.

Impressed current protection d.c. source equipment is to be thoroughly inspected on a quarterly basis as part of a preventive maintenance program in order to minimise the risk of in-service failure of any component. Inspection may include a check for electrical short-circuits, satisfactory ground and header cable connections, ammeter and voltmeter accuracy, rectifier efficiency, and overall circuit resistance.

7.2.6 Corrective measures
Corrective measures are to be taken as soon as possible where periodic surveys and inspections indicate that protection is no longer adequate. These measures may include:

- repairing, replacing, or adjusting components of cathodic protection system
- providing supplementary cathodic protection equipment where additional protection is necessary
- repairing defective insulating devices or continuity bonds
- removal of metallic debris.

8 Safety and cathodic protection

8.1 General

8.1.1 The present article deals only with safety hazards due to cathodic protection systems to which diving personnel are exposed during their underwater operations.

8.1.2 Sacrificial anode and impressed current systems are to be considered in association with the following main dangers: physical obstruction, electric shock, and evolution of dangerous gases.

8.1.3 The cathodic protection systems are to comply with safety standards and regulations related to electrical equipment applicable to the unit or installation considered. These requirements, covering safety aspects related to above water equipment (step-down transformer rectifiers, cables, connectors, etc.), are not recalled within the present Subsection.

8.1.4 The specific safety aspect of diving operations is covered by statutory regulations and is not recalled within the present Guidance Note.

8.2 Sacrificial anodes systems

8.2.1 The main danger of sacrificial anodes for divers consists in the risk of having their umbilicals or life lines entangled or damaged by the anodes or the marine growth covering them.

8.2.2 Sharp assemblies and sacrificial anodes with stand-off supports protruding directly below their body are to be avoided.

8.2.3 Therefore the following anode shapes and assemblies should be preferred:

- slender sacrificial anodes with J-shaped cylindrical stand-off supports, i.e. where the insert protrudes at anode extremities
- flat plate sacrificial anodes.

8.2.4 In particular situations where anodes are installed in enclosed areas, where an accumulation of gases is liable to occur, an explosion hazard may arise (refer to [8.3.4]).

8.3 Impressed current systems

8.3.1 General

The main danger of an impressed current system for divers are the risks of having their umbilicals entangled, electric shock and gas evolution in particular configurations.

8.3.2 Physical obstruction

The divers umbilical or life line may become entangled around or damaged by the supporting systems of the impressed current anodes, the anodic cables or the junction boxes.

Therefore these support and anode shapes are to be designed so as to avoid any sharp or protruding assembly or extremity.

8.3.3 Electrical shock

The divers may suffer electric shock in case of faulty electric equipment or direct contact with anodes.

The electric equipment is to comply with applicable safety standards, codes and regulations.

Unless the step-down transformer is of a double-insulated isolating type, it is to be fitted with protective devices operating in the event of a fault between the a.c. input of the transformer and the d.c. output of the rectifier.

The following recommendations are to be considered:

- for divers who are not involved in or are not aware of cathodic protection (such as for marine growth cleaning), it is recommended to switch off the impressed current system during diving operations
- for divers involved in the inspection of cathodic protection systems, a safe distance of 1 to 2 m is 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 d.c. supply of anodes is to be switched off.

The requirements as given for the additional class notation INWATERSURVEY are to be employed to avoid electric shock. The requirements for the assignment of this notation are given in Pt E, Chap 10, Sec 3 of the "Rules for the Classification of Steel Ship".

8.3.4 Hydrogen evolution

With impressed current systems, and sometimes with sacrificial anodes, polarisation of the structure may cause significant evolution of hydrogen on the protected structure. In enclosed spaces where hydrogen can collect, an explosion hazard may arise.
To avoid this hazard:

- the structure is to be provided with an adequate venting to prevent hydrogen build up
- the structure to sea water potential is to be kept within values less negative than the threshold value at which hydrogen evolution becomes significant
- a minimum distance is to be kept between the structure and impressed current anodes
- an even distribution of impressed current anodes is to be preferred, unless anodes are installed on the seabed at a sufficiently great distance from the structure and its appurtenances
- magnesium anodes are not to be installed in enclosed spaces.

It is also reminded that too negative potentials may cause absorption of hydrogen in steels, resulting in embrittlement of steels having high mechanical characteristics and in propagation of fatigue cracks, thus endangering the structural integrity of the unit or installation.

8.3.5 Chlorine evolution

With impressed current systems, anodic reactions in sea water result in the formation of chlorine.

As hydroxyl ions are produced on the cathode, the chlorine forms hypochloric acid and hypochlorite ions dissolved in sea water.

In particular circumstances, such as in areas where sea water becomes stagnant, the chlorine may evolve as a gas and present a hazard to personnel and material.

To avoid this hazard, designs are to prevent the build up of gas.
SECTION 3 Protection of Splash Zone

1 Protection of splash zone

1.1 General

1.1.1 As mentioned in Sec 1, [4.2], protection in the splash zone should be performed by means of protective coatings and steel thickness increments on floating units. Wear plates or sheathing may be accepted on a case by case evaluation.

1.2 Extent

1.2.1 Unless the setting depth of the structure can be assessed, consideration should be given for fixed installations to additional protection beyond the splash zone to provide a margin of safety.

1.3 Thickness increments and steel wear plates

1.3.1 Thickness increments should compensate for the anticipated corrosion and wear of the structure during its life.

1.3.2 Attention is to be paid to the welding of the wear plates to the structures. Welding plan to be submitted for review size of wear plates to be limited as much as possible.

1.4 Sheathing

1.4.1 Attention is to be paid to the risk of galvanic corrosion if sheathing plates are different to hull structure. Sheathing should be attached to the structure in such a way that the free space between the structure and the sheathing is sealed.

1.5 Coatings

1.5.1 The splash zone is to be protected against corrosion by means of coatings. For coating system, refer to Sec 5.
SECTION 4 PROTECTION OF ATMOSPHERIC ZONE

1 Protection of atmospheric zone

1.1 General

1.1.1 The atmospheric zone of structures is to be protected against corrosion by means of coatings. For the coating system, refer to Sec 5.
SECTION 5 COATING SYSTEM

1 General

1.1 Introduction

1.1.1 The coating choice should take into account facilities on construction yard, environmental and operating conditions of the unit or installation, and the possible on-site repairs.

Some coatings may be reinforced with impregnated fiberglass wrapping or silica glass flake.

The final coating system is to be approved by the paint manufacturer or independent coating expert.

These coatings may be vulcanized chloroprene, high-build organic coatings, or even conventional heavy-duty coatings, etc.

These coating systems should withstand continuous or intermittent immersion in water or sea water without loss of adhesion, blistering, cracking, swelling or softening.

They should be resistant to weather (sun, rain, temperature, etc.) without loss of thickness or film continuity, embrittlement, necking or cracking.

Coating systems should also be resistant to shock, abrasion, attacks by chemical products found on the unit or installation or in the surrounding environment. They should also present insulation qualities versus ionic transport (more than $10^8 \, \Omega \cdot \text{cm}^2$ is recommended).

1.2 Protection of splash zone

1.2.1 The splash zone is in and out of the water as mentioned in Sec 1, [3.3]. Therefore, the coating systems are also to be resistant to cathodic disbonding for the considered potential range.

1.3 Protection of atmospheric zone

1.3.1 The atmospheric zone of structures as mentioned in Sec 1, [3.4] is to be protected against corrosion by means of paints and/or coatings.

2 Surface preparation

2.1 General

2.1.1 The purposes of surface preparation for steel in the atmospheric zone are to provide the necessary degree of cleanliness and the specified anchor pattern needed for the adhesion to the designed coating system.

2.1.2 Surfaces contaminants (oil, soil, dust,...) are to be removed including substrate related surface contaminants (millscale and red rust). Slivers, laminations, and underlying mill scale exposed before or during operations are to be removed, leaving the surface smooth. Weld flux and splatter are to be removed from weld areas.

2.1.3 The completed structure is to be inspected to locate damaged or improperly primed areas prior to top-coating. On damaged areas and weld areas, spot blasting and priming are to be performed prior to completing the coating system.

2.1.4 If performed in the open air, surface preparation should be completed as far as the surface is visible, early enough to allow priming prior to the development of any surface rusting. If blasting is done at night, the surfaces should be re-blasted the following day, prior to priming.

No surface preparation (apart from wet blasting) or priming should be undertaken unless the surface and ambient temperature are $3^\circ \text{C}$ or more above the dew point or when the ambient relative humidity exceeds $85 \%$.

2.1.5 If properly carried out, wet blasting may adequately prepare surfaces and reduce the dust problem. If this type of cleaning is used, the coating systems are to be compatible with the inhibitor and chemicals added in the water systems. A steel surface is not to be conventionally coated while it is damp or wet.

Solvent or detergent degreasing should be done with extreme caution (it is difficult to obtain proper cleanliness to ensure adhesion of top-coats with these methods).

Hand cleaning should in general be avoided. It may be used for small areas where other methods cannot be used.

2.2 Surface preparation types

2.2.1 The surface preparation is to be determined in accordance with the coating selected. Reference is made in the present article to ISO 8501, 8503 and 4628 Standards as follow:

- cleanliness : ISO 8501 part 1 to part 3
- roughness : ISO 8503 part 1 to part 4
- contaminants : ISO 8502 part 1 to part 10 and ISO 4628 part 1 to part 6
- methods : ISO 8504 part 1 to part 3.

2.2.2 Surface designation Sa 3

For corrosive conditions and particularly for areas presenting a difficult access for in-service inspection and maintenance, surfaces should be blasted to white metal finish, defined as a surface with a grey-white (uniform metallic) color, slightly roughened to form a suitable anchor pattern for coatings. This surface should be free of oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, or any other foreign matter.
2.2.3 Surface designation Sa 2 1/2
For corrosive conditions where Sa 3 cannot be reached, surfaces should be blasted to near-white metal finish, defined as a surface from which oil, grease, dirt, mill scale, rust, corrosion products, oxides, paint, or other foreign matter have been removed except for light shadows, streaks, or slight discolorations (of oxide bonded with metal). At least 95% of the surface to be treated has the appearance of Sa 3, and the remainder of that area is limited to slight discolorations.

2.2.4 Surface designation Sa 2
For less corrosive atmospheric conditions which are less influenced by the marine environment and for repairs, surface may be blasted to commercial metal finish, defined as a surface from which oil, grease, dirt, rust scale, and foreign matter have been completely removed while rust, mill scale, and old paint have been removed except for slight shadows, streaks, or discolorations caused by rust stain or mill scale oxide binder.

At least two-thirds of the surface area should be free of visible residues, and the remainder should be limited to light discoloration, slight staining, or light residues mentioned above. If the surface is pitted, slight residues of rust or paint are found in the bottom of pits.

3 Criteria for coating selection

3.1 Coating tests

3.1.1 Accelerated tests for coating selection include:
- salt spray testing (4000 h) in accordance with ASTM Standard B 117
- testing with a weather-o-meter (2000 hours) in accordance with ASTM Standard G 23-81 or ASTM Standard G 53-77
- humidity cabinet testing (4000 hours) in accordance with ASTM Standard 2247-68.

Some operators carry out combinations of the above tests on a rotating basis, such as 1000 hours in salt spray, 1000 hours in a weather-o-meter, followed by an additional 1000 h test in salt spray, and a final 1000 h in a weather-o-meter.

3.1.2 Other coating properties that may be determined from laboratory tests and which may aid in evaluating materials are:
- adhesion test, or tape test, according to ASTM D 3359-78
- flexibility test, or elongation test, according to ASTM D 522-60
- chalking test, according to ASTM D 659-80
- hiding power test, according to ASTM D 344-39
- levelling test, according to ASTM D 2801-69
- hardness test, according to ASTM D 3363-74
- impact test, by sand method, according to ASTM D 968-81
  - cathodic disbonding test, according to ASTM G 8-82
  - (for pipelines) and/or BS 3900.

3.1.3 Tests from other organizations may be used in place of ASTM ones listed above.

3.2 Coating selection

3.2.1 The following points should be considered for coating selection:
a) Consideration is to be given to primer coatings capable to protect the steel for extended construction periods and to withstand abrasion associated with handling and fabrication with a minimum of damage.
b) Preference should be given to coating systems that may be applied and maintained with conventional and readily available application equipment.
c) For structures placed in, or liable to operate in cold areas, where coatings are exposed to low temperatures, preference should be given to coatings that allow repairs with solvent deposited coatings and which do not involve use of catalysts.
d) For deck areas, which are exposed to weathering and may be also exposed to abrasion associated with drilling or other operations, spills of drilling fluids, formation fluids, diesel fuels, lubricants, and well completion compound, consideration should be given to coatings with high impact resistance and resistance to spills of solvent and corrosion chemicals, i.e. to chemically cured materials.
e) Offshore coatings being usually exposed to high-intensity ultraviolet light, consideration should be given to materials that resist heavy chalking and color change.
f) Systems where top-coating is associated with physical drying (solvent-deposited coatings) are generally more easily repaired than those using a chemical drying process.
g) Inorganic zinc primers having no adhesion to other coatings, they should not be chosen for offshore repair of coating systems where spot-blasting is used.

Typical coating systems are given in Tab 1.

3.2.2 The coatings is to be comply with the following international standards:
- ISO 20340:2003 - Performance requirements for protective paint systems for offshore and related structures

4 Coatings

4.1 Coating systems

4.1.1 A paint system is formed by one or more coats of paint, each of which is applied at a specified film thickness. This sequence of coats, called paint system, provides corrosion control by means of one or more of the following mechanisms:
- barrier protection (namely providing an insulating barrier between electrolyte and metal)
- chemical inhibition of corrosion reaction
- cathodic protection when a coat of zinc rich primer, acting as sacrificial anode, is applied.
### 4.1.2 Paint system

Paint system is the logical and organic sequence of successive coats. It can be represented in a schematic generic form as: Primer - Undercoats - Finishing

- **Primer** is the first coat of the paint system. It must be applied after a proper surface preparation, before which its quality could decay. Primer has to be overcoated according to the overcoating time and instructions recommended by the paint manufacturer.

- **Undercoats** are used to connect the primer with the finishing coat and to increase the total thickness of the system, as requested by the material to be protected and the location (e.g. bottom, topside etc.).

- **Finishing** provides specific characteristics to the area where it is applied: aesthetic appearance for topside and other exposed areas, anti-fouling protection for the underwater etc.

### 4.1.3 On ballast tanks in order to optimize corrosion prevention, the same paint is generally applied in more coats, providing more properties at the same time.

### 4.1.4 The final coating system is to be approved by the paint manufacturer or independent coating expert.

### 4.1.5 In any case, the paint is to be applied in accordance with associated product data sheets.

#### 4.2 Primer

##### 4.2.1 General

Primers protect the steel, provide a surface compatible with both the steel and top-coats, and promote adhesion of the top-coats. Primers used include wash primers, zinc-rich primers and organic inhibitive primers.

Primers are to comply with local regulations with respect to toxicity.

The primers can be classed in two different categories:
- thermoplastics : vinyl paint, bitumen, emulsion...
- thermosetting : epoxy, polyurethane, zinc rich, shop primer...

##### 4.2.2 Wash primers

Wash primers are conversion coatings consisting of a vinyl butyric resin solvent solution, pigmented with zinc or strontium chromate.

Prior to application, these coatings are mixed with a second component consisting of a solution of alcohol and phosphoric acid.

They are applied as very thin films. On contact with the surface of steel, they generate a passive iron phosphate layer. For maximum efficiency and to prevent rust breakthrough, wash primers are to be quickly over-coated.

##### 4.2.3 Zinc-rich primers

Zinc-rich primers are organic or inorganic coatings with a high loading of zinc dust; on contact with moisture, the zinc coatings tend to protect the substrate by galvanic action.
Since zinc reacts with both acids and strong alkalis, zinc-rich primers should be top-coated with chemically resistant coatings when used offshore, because of possible exposure to alkaline drilling muds and acidic well completion fluids.

Zinc-rich primers are pre-construction primers because of their abrasion and impact resistance and ability to protect the steel during long construction phases.

Care should be taken in ascertaining that the surface is clean prior to the application of additional coating. Light blasting or fresh water washing may be necessary to remove contaminants.

As inorganic zinc primers are porous, an intermediate tie-coat is to be applied before the top-coat.

4.2.4 Organic inhibitive primers

Organic inhibitive primers may be solvent deposited or thermoplastic, which cure or dry upon loss of solvent, or chemically cured coatings, which need mixing of a second component for curing. These coatings include special pigmentation, e.g. red lead, strontium chromate, basic lead, silica chromate, etc., which react when in contact with moisture, thus protecting the base metal from corrosion.

4.3 Undercoats and finishings

4.3.1 General

Primers used for offshore structures are to be over-coated with intermediate and/or finish coats. These barrier coatings retard intrusions of water, oxygen, and active chemical ions.

Undercoats may also provide added impact resistance and solvent resistance, as well as a smooth, non porous surface. The finishing coat, commonly of the same generic type as the intermediate, may be selected in a specific color to provide organizational color identification.

4.3.2 Chemically cured coatings

Chemically cured coatings are usually epoxies, polyesters, or some polyurethanes; they are cured by mixing with a second component commonly called a "catalyst" or converter.

These coatings, which are typically applied in films exceeding 100 µm thickness per coat, should have chemical-resistant properties.

Since these materials continue to cure during exposure, they become increasingly hard, brittle, and solvent resistant with age. Therefore, sweep blasting should be carried out prior to re-coating, in order to achieve good mechanical bonding.

With the exception of polyurethane, these coatings tend to chalk on exposure to ultra-violet light. These materials are temperature and humidity sensitive during curing and need adequate conditions to dependably cross-link and develop into chemically resistant films.

4.3.3 Solvent deposited or thermoplastic type coatings

Solvent deposited or thermoplastic type coatings include vinyl acrylics, vinyls or chlorinated rubbers. These coatings dry by the evaporation of solvents, which distinguishes them from epoxies, polysteres, and other chemically cured coatings, since the change from a liquid to a solid state is not accompanied by any chemical change.

This mode of drying allows coating application at relative humidities up to 90 % and temperatures as low as 0°C. These coating films generally exhibit resistance to environmental conditions. These solvent-soluble films simplify over-coating by providing solvent bonding between a refresher and a previous coat.

These coating materials are limited temperature resistance and reduced chemical and solvent resistance and a low solids-by-volume content. Because of this low solids-by-volume content, additional coats may be necessary to achieve the specified thickness. Technology indicated products with improved solids-by-volume capabilities and allowing thicker films, which may reduce the number of necessary coats.

4.4 Antifouling paints

4.4.1 General

Fouling settlement generally occurs when a ship is stationary. However, certain marine organisms (e.g. goose barnacles) may settle and grow when units are sailing. Fouling is the growth and settlement of marine organisms (plants, animals) on man-made structure.

Fouling can be removed by mechanical cleaning or can be avoided by application of paint with bio-active compounds (antifouling paint) or surface energy paint (fouling release coating).

"Antifouling systems" are defined as "a coating, paint, surface treatment, surface or device that is used on a ship to control or prevent attachment of unwanted organisms". The antifouling paints are used for coating on the submerged zone.

4.4.2 Classification of anti-fouling paint

Antifouling paints are to be TBT free. The following types are available:

- conventional antifouling: they are based on modified wood resin and mainly pigmented with copper oxide. Other organic toxins are sometimes incorporated as well. This type of antifouling usually has a high pigment volume concentration resulting in direct contact between the toxins and seawater. Due to the relatively high toxin release rate these types of anti-foulings are generally exhausted and/or clogged after 8-12 months. This means that increase of specified film thickness does not result in a longer service life.

- high performance or long life anti-foulings (18-24 months): they are high build coatings based on insoluble and semi-soluble binders in which copper oxide and other organic toxins are finely dispersed. On contact with seawater the toxins leach out from the paint film into the laminar layer around a hull by means of a diffusion process. However, the relation between leaching rate of the toxins in the antifouling coating and the service lifetime is not linear.
• self polishing organotin copolymer anti-fouling (up to 3 years): they are high build coatings based on a toxic binder pigmented with finely dispersed boosting biocides. The principle of the copolymer antifouling is that one component of the toxins (TBT) is chemically linked to the binder. Hydrolysis of the hydrophobic organotin copolymer, when immersed in seawater, results in a release of toxins at a controlled rate and in an effective dose. The residual binder becomes hydrophilic and the surface material is gradually polished off resulting in a continuous exposure of fresh toxic layers, even under static conditions. The speed of this process is called the polishing rate and depends on the composition of the specific organotin copolymer

• Tin-free self polishing anti-foulings are based on a physically drying binders (2-5 years). The active ingredients (“biocide”, “toxicants”) in the tin-free antifouling are most often a mixture of cuprous oxide and additional organic biocides which are ready degradable in the marine environment

• Fouling release coatings: Fouling release is fouling control technology which, unlike traditional anti-foulings, does not contain any toxic biocides. Fouling release coatings provide a physical barrier as opposed to the chemical barrier of anti fouling coatings

Fouling release coatings are generally silicone based and provide a smooth, low friction, hydrophobic surface, onto which fouling organism have difficulty settling and adhering.

4.4.3 Regulations

IMO has banned the application of tin based anti-fouling from 1ST January 2008. From the same date, no ship irrespective of their flag can enter an European Union port with active tin based antifouling. Consequently, the Flag Authorities and Coastal State are to confirm the detailed requirements applicable to the antifouling system.

5 Coating application

5.1 General

5.1.1 The application and repair procedures are to be set up in accordance with the recommendations of the coating Manufacturer, giving particular consideration to the required environmental conditions.

5.1.2 Unless otherwise accepted by the coating Manufacturer, coating application is not to be performed when the surface temperature is less than 3°C above dew point or when the atmosphere relative humidity exceeds 85%.

5.1.3 Painting in high winds, extreme temperature conditions, approximately below 5°C and above 35°C (or on hot steel surfaces due to exposure to sunshine) should be avoided.

5.1.4 The coating applicator has to fill a record. This recording book is to be available on board.

5.1.5 Long-life protective coatings are to be specified for fixed installations and storage units not intended to be periodically dry docked. Proper use of these materials makes necessary a stringent surface preparation and a skilled craftsmanship for coating application and inspection. This may be achieved only through the issuing and following of detailed and complete job specifications.

5.1.6 Proper application of a coating also implies that personnel health and safety is considered and in compliance with laws and instructions in force at the given locations.

5.2 First layer

5.2.1 The first layer of paint should be applied in the shortest possible time after surface preparation (less than 12 hours), otherwise preparation is to be carried out again. The same recommendation applies to the application of following coats subject to the required drying time.

5.3 Critical areas

5.3.1 Due care should be exercised to achieve the required protection in critical areas:

a) Adequate surface wetting must be ensured when spraying, particularly where dust may be present; roller or brush application may be necessary for coatings with critical wetting characteristics.

b) Precaution should be taken to build up the required thickness in way of edges and corners of stiffeners, around openings, on flanges, etc.

c) Welded areas should be given special attention, particularly to hand welds and to the removal of testing products prior to the application of coatings.

d) Overlapping passes should be adequate to ensure the even coating of cylindrical members, particularly when the application is performed by spraying.

5.4 Quality control

5.4.1 Adequate quality control is to be implemented in accordance with the recommendations of the coating Manufacturer. Particular attention should be directed to the measurements of dry film thickness, repaired areas, unscheduled welding or cutting operations, etc.