RECOMMENDED PRACTICE
DNV-RP-B101

CORROSION PROTECTION OF FLOATING PRODUCTION AND STORAGE UNITS

APRIL 2007

DET NORSKE VERITAS

FOREWORD

DET NORSKE VERITAS (DNV) is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancy services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions.

DNV Offshore Codes consist of a three level hierarchy of documents:

— *Offshore Service Specifications.* Provide principles and procedures of DNV classification, certification, verification and consultancy services.
— *Offshore Standards.* Provide technical provisions and acceptance criteria for general use by the offshore industry as well as the technical basis for DNV offshore services.
— *Recommended Practices.* Provide proven technology and sound engineering practice as well as guidance for the higher level Offshore Service Specifications and Offshore Standards.

DNV Offshore Codes are offered within the following areas:

A) Qualification, Quality and Safety Methodology

B) Materials Technology

C) Structures

D) Systems

E) Special Facilities

F) Pipelines and Risers

G) Asset Operation

H) Marine Operations

J) Wind Turbines

Amendments and Corrections

This document is valid until superseded by a new revision. Minor amendments and corrections will be published in a separate document normally updated twice per year (April and October).

For a complete listing of the changes, see the "Amendments and Corrections" document located at:
http://www.dnv.com/technologyservices/, "Offshore Rules & Standards", "Viewing Area".

The electronic web-versions of the DNV Offshore Codes will be regularly updated to include these amendments and corrections.

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Motives

Until now, the common corrosion protection requirements used on FPSOs are based on guidelines used for trading vessels (i.e. coating and cathodic protection). While traditional trading vessels will dock at regular intervals, an FPSO will be in continuous operation during its entire service life. Consequently, there is a need for guidelines covering corrosion protection for the next generation of stationary, floating vessel with a 10 year or longer service life.

Scope

This Recommended Practice (RP) is a new document, addressing cost effective corrosion control design for newbuilding FPSO specifically focusing on:

— identifying and quantifying the dominating factors related to corrosion control

— how to select a cost effective corrosion protection system based on a combination of corrosion margins, coating systems and cathodic protection

— fabrication inspection related to the desired corrosion protection system.

This RP also points out the importance of defining inspection, maintenance and repair (IMR) strategies for an extended service life of the FPSO, in fact having an IMR strategy is a prerequisite for achieving optimal life cycle costs for the corrosion protection.

The intent of the RP is to ensure that FPSO will attain a service life of 10 years or longer, avoiding curtailing this because the corrosion protection measures were based on that used for trading "tankers" and periodical drydocking.

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1. General

1.1 Introduction

1.1.1 It is a challenge to provide more than 10 years service life for the corrosion protection of an FPSO. While traditional trading vessels will dock regularly (every 5th year), the FPSO will be in continuous operation for its service life. The basic corrosion protection systems used for the FPSO are those used on the trading vessels (coating and cathodic protection). Consequently, for the FPSO the service life of the coating system and cathodic protection system have to be extended to more than 10 years, while the experience from the trading vessels are for the protection systems with about 5 years service life. The corrosion protection specifications used for trading vessels are not adequate for an FPSO. There is therefore a need to develop a specification for the corrosion protection of an FPSO with the service life of 10 years or longer. The present approach to the development of such a specification for an FPSO is to utilise the experiences from corrosion protection of fixed offshore platforms and the state-of-the art technology for marine corrosion protection.

1.1.2 The main objective of this RP is to achieve a long service life (10 years or longer) for the corrosion protection systems of FPSOs with minimal maintenance during service. The basic approach for the CP design is to use coating in combination with the cathodic protection. There are several advantages for a combination of CP with coatings:

— reduced total CP current demand (e.g. reduced weight of sacrificial anodes)
— even CP current distribution
— rapid polarisation to the protective potential.

    Guidance note:
    A possible negative synergism of the use of CP with coatings is accelerated coating breakdown due to cathodic disbonding. This concern is eliminated by the requirement of a pre-qualification of the coating products.

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1.2 Scope

1.2.1 The scope of this Recommended Practice (RP) concerns the corrosion protection of the hull of floating production and storage units with a service life of 10 years or longer. The corrosion protection measures covered by the RP are based on a combination with cathodic protection on a coated steel surface.

1.2.2 The RP covers protection of the steel hull structures against seawater and the marine atmosphere. Ballast tanks and other tanks exposed to seawater as well as oil cargo are known to be most susceptible to corrosion and are thus of prime concern. External areas such as decks and superstructure will also be susceptible to corrosion and other areas subjected to corrosion are also considered.

1.2.3 The aspects of Inspection, Maintenance and Repair are outside the scope of the present RP. However, in the case that corrosion protection is applied in a manner which does not comply with the requirements in the present RP (e.g. corrosion protection systems with a service life shorter than 10 years) this will lead to increased total life cycle costs of Inspection, Maintenance and Repair (IMR) tasks as compared to total life costs based on the present RP.

1.2.4 Detailed design of anode fastening devices for structural integrity is not included in the scope of this RP. Considerations related to safety and environmental hazards associated with galvanic anode manufacture and installation are also beyond its scope.

1.2.5 The requirements to manufacture of galvanic anodes are not addressed in this RP. For this item, reference is made to the more detailed recommendations in DNV-RP-B401.

1.2.6 The present document does not include any consideration of possible effect of CP on the fatigue life of the hull.

1.3 Application and use

1.3.1 This RP has two major objectives. It may be used as a guideline to owner's or their contractors' execution of conceptual or detailed coating and CP design, and to the specification of coating systems and galvanic anode manufacture and installation. It may also be used as an attachment to an inquiry or purchase order specification for such work. If purchaser has chosen to refer to this RP in a purchase document, then contractor shall consider all requirements in Section 5-6 of this document as mandatory, unless superseded by amendments and deviations in the specific contract. Referring to this document in a purchase document, reference shall also be made to the activities for which DNV-RP-B101 shall apply; i.e. Coating quality control in Section 5.11, CP design in Section 6.1-6.12, Anode installation in Section 6.13 or 6.14.

1.4 Document structure

1.4.1 The RP is divided into two main sections: "Specification for surface protective coatings for floating offshore structures" and "Cathodic protection of floating offshore structures". The recommendations provide specification for corrosion protection systems for a new building with a service life of 10 years or longer.

1.4.2 Tabulated data for coating are complied in Appendix A.

1.4.3 Tabulated data for CP design are complied in Appendix B.

1.5 Relation to other DNV documents

1.5.1 Cathodic protection design for CP of permanently installed offshore structures is covered in DNV-RP-B401.

2. References

2.1 ASTM (American Society for testing of materials)

ASTM D1212	Test methods for measurement of wet film thickness of organic coatings

2.2 DNV (Det Norske Veritas)

DNV-RP-B401	Cathodic protection design
Guidelines / RP No. 20	Corrosion protection of ships
DNV Rules for Classification of Ships.	Pt.3 Ch.1: Hull structural design of ships with length ≥100 m (Table D1)
	DNV notations for **COAT-1** and **COAT -2**

2.3 EN (European Standards)

EN- 3173	Cathodic protection of steel offshore floating structures (2001)
EN- 4628-3	Paints and varnishes- Evaluation of degradation of paint coatings- Designation of intensity, quantity and size of common defects Part 3: Designation of degree of rusting (1982)

2.4 ISO (International Organisation of Standardisation)

ISO 1461	Hot dipped galvanized coatings on fabricated iron and steel articles-Specifications and test methods" (1999)
ISO 8501-1	Preparation of steel substrate before application of paints and related products- Visual assessment of surface cleanliness-Part 1: Rust grades and preparation grades of uncoated steel substrate and of steel substrates after overall removal of previous coatings
ISO 8501-3	Preparation of steel substrates before application of paints and related products- visual assessment of surface cleanliness- Preparation grades of welds, cut edges and other areas with surface imperfections (2001)
ISO 8502-06	Preparation of steel surfaces before application of paints and related products-Test for assessment of surface cleanliness-Sampling of soluble impurities on surfaces to be painted- The Bresle method
ISO 8503-1	Preparation of steel substrate before application of paints and related products- Surface roughness and characteristics of blast-cleaned steel substrate- Part 2: Method for grading of surface profile of abrasive blast-cleaned steel- Comparator procedure
ISO 12944	Paint and varnishes-Corrosion protection of steel structures by protective paint systems
ISO-20340	Paints and varnishes- Performance requirements for protective paint systems for offshore and related structures (2003)

2.5 NACE International

"Surface preparation and cleaning of steel and other hard materials by high- and ultrahigh-pressure water jetting prior to recoating". Item No. 21076. Joint surface preparation standard NACE No. 5/SSPC-SP 12

2.6 NORSOK

M-501	Surface preparation and protective coating (2004) *Note: The coating qualification requirements for a given environmental service is now superseded by the requirements in ISO-20340*

2.7 Tanker structure co-operative forum

"Guidelines for ballast tank coating systems for surface preparation". Appendix 3. "Testing and qualification of ballast tank coatings" (1999).

3. Terminology and Definitions

3.1 Verbal forms

Owner	Party legally responsible for design, construction and operation of the structure.
Purchaser	Party (owner or main contractor) issuing inquiry or contract for the corrosion protection (CP design, anode manufacture or anode installation or coating supply or application work) or the nominated representative.
Contractor	Party to whom the work has been contracted.
Shall	Indicates a mandatory requirement.
Should	Indicates a preferred course of action.
May	Indicates a permissible course of action.
Agreed/ agreement	Refers to a written arrangement between *purchaser* and *contractor* (e.g. as stated in a contract).
Report and *notify*	Refers to an action by *contractor* in writing.
Accepted Acceptance	Refers to a confirmation by *purchaser* in writing.
Certificate Certified	Refers to the confirmation of specified properties issued by *contractor* or supplier of metallic materials according to EN 10204:3.1.B, ISO 10474:5.1-B or equivalent.
Purchase document(S)	Refers to an inquiry/tender or purchase/ contract specification, as relevant.

3.2 Definitions

Alkyd	Alkyds are synthetic resins of polyester type used as binders in paints or coatings. The name "alkyd" is derived from the parent chemicals alcohol + acid ester. Alkyd paints cure by air-drying and oxidation.
Anode	The corroding part of an electrochemical corrosion cell (or term for sacrificial anode or impressed current anode used in cathodic protection).
Anti-fouling paint	Paint for use on seawater submerged areas on hulls to prevent growth of living organisms, usually containing toxic agents (e.g. tin or other biocides).
Binder	The component in paint or coating binding its constituents together and fixed to the surface. Common binders are epoxy, chlorinated rubber, vinyl, and alkyd.
Cathode	The non-corroding or protected part of an electrochemical cell.
Cathodic protection	Protecting a metal surface from corrosion by making it a cathode in an electrochemical cell. Cathodic protection of a steel surface is obtained by installing sacrificial anodes or impressed current anodes. Protective current passes from the anode through the electrolyte (seawater) to the steel surface.
Coat	A continuous layer of a coating material resulting from a single application. Coating is often synonymous with painting, i.e. a protective film of thickness usually about 0.2 - 0.5 mm. Coatings or paints are usually sprayed on the metal surface.
Coating system (protective coating system)	The total sum of the coats of paints (or materials) which are applied to the substrate to provide corrosion protection.
Conductivity	The inverse of the Resistivity (ohm cm). In these guidelines: Conductivity, i.e. specific electrical conductance, of an electrolyte, usually seawater.
Corrosion	Chemical degradation of solid material by influence from its environment.

Corrosion rate	The rate, usually in mm/year, at which the corrosion process proceeds. The corrosion rate is always to be calculated from metal loss on one surface, even when occurring on both sides of a steel plate, etc. (Corrosion rate is not to be confused with "steel thickness reduction rate".)	*Mechanical cleaning*	Power tool (not necessarily) cleaning, by means of grinding disc, wire brush, or similar.
Dew point	The temperature at which air is saturated with moisture.	*Marine environment*	In this context used in its widest sense, comprising basically sea water and marine atmosphere, including contaminants from cargoes, industry, harbours, wave and weather actions, and operational factors specific for each ship.
Electrochemical-cell	See electrolytic corrosion.		
Electrolytic corrosion	Corrosion occurring in an electrolyte, i.e. an electrically conductive liquid such as seawater. Anodes and cathodes formed on the steel surface, together with the electrolyte, constitute electrochemical cells.	*Paint*	Pigmented coating materials in liquid, paste or in powder form that, when applied to a substrate, forms an opaque film having protective, decorative or specific technical properties.
Epoxy	Common binder type in paints or coatings for marine use. Epoxies are normally of two component type, epoxy resin (A component) chemically cured with a hardener (B component, e.g. amine), resulting in a relatively hard film.	*Pigments*	Powders added to the coating in liquid condition to obtain colour. Pigments also influence the coating's viscosity, application and protective properties.
		Primer coating	First layer of a coating system applied in the shipyard (also called touch up primer, to differentiate from shop-primer).
Epoxy coal tar (coal tar epoxy)	Epoxy mixed with coal tar, constituting a part of the binder in paints or coatings for marine use. Chemical curing is accomplished by means of a hardener, as for pure epoxy. The tar component acts as pigment and influences the flexibility and water resistance of the cured coating film.	*Resin*	Material used as a binder constituent forming a non-crystalline film when dried or cured.
		Resistivity	Specific electrical resistance (ohm cm).
Film thickness	The thickness of a coating layer or a multi-layer coating system. Dry film thickness DFT is measured for cured coatings, in shipbuilding some times specified as average thickness. Minimum and maximum thickness can also be specified. Wet film thickness is usually controlled only during application by the coating applicator.	*Sa 1*	Light blast cleaning. Loose mill scale, rust and foreign matter shall be removed. The appearance shall correspond to the standard photos designated Sa 1. (This originally Swedish standard SIS 055900-1967 is adopted as ISO standard 8501-1. It is a pictorial surface preparation standard for painting steel surfaces. The pictures showing the surface appearance are not reproduced in this guideline. Grades Sa 1 - Sa 3 describe blast-cleaned surfaces.)
FPSO or FSO	The terms FPSO (floating production and storage offshore) and FSO (floating storage offshore) are used as synonyms for the term floating structure offshore in this guideline		
General corrosion	Relatively evenly distributed corrosion attacks on a steel surface.	*Sa 2*	Thorough blast cleaning. Almost all mill scale, rust and foreign matter shall be removed. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then be greyish in colour and correspond in appearance to standard photos designated Sa 2. (See parenthesis, Sa 1.)
Hard coating	Chemically cured coating normally used for new construction, or non-convertible air drying coating such as used for maintenance purposes, organic or inorganic (according to IMO (12)). The hard coating concept covers typical marine coatings such as those based on epoxy, coal tar epoxy, polyurethane, chlorinated rubber, vinyl, zinc epoxy, zinc silicate.	*Sa 2,5 (Sa 2 1/2)*	Very thorough blast cleaning. Mill scale, rust and foreign matter shall be removed to the extent that the only traces remaining are slight stains in the form of spots or stripes. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then correspond to standard photos designated Sa 2,5. (See parenthesis, Sa 1. It should be noted that Sa 2,5 is closer to Sa 3 than to Sa 2. Sa 2,5 corresponds to NACE grade No. 2 (near white) and SSPC grade SP 10 (near white).)
Inhibitor	Chemical having an inhibiting effect on corrosion, usually added to a closed liquid or gaseous system.		
Localised corrosion	An attack comprising various kinds of more or less concentrated or spot-wise corrosion attacks: Typically pitting, corrosion in way of welds, crevice corrosion, stress corrosion cracking, etc. Localised corrosion can proceed rapidly and can be dangerous, e.g. in case of loss of weld metal or penetration of a pressure vessel by pitting.	*Sa 3*	Blast cleaning to pure metal. Mill scale, rust and foreign matter shall be removed completely. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It shall then have a uniform metallic colour and correspond in appearance to standard photos designated Sa 3. (See parenthesis, Sa 1. Sa 3 corresponds to NACE grade No. 1 (white metal) and SSPC grade SP 5 (white).)

Shop-primer	Thin (approximately 15 - 25 microns) primer coating applied by steel manufacturer for temporary protection
Soft coat	Coating that remains soft so that it wears off when touched; often based on oils or sheep wool grease (Soft coatings are not recommended for use on floating offshore structures)
Semi hard coating	Coating which dries in such a way that it stays soft and flexible although hard enough to touch and walk upon.
St 2	Thorough scraping and wire brushing - machine brushing - grinding - etc. The treatment shall remove loose mill scale, rust and foreign matter. Finally, the surface is cleaned with a vacuum cleaner, clean, dry compressed air or a clean brush. It should have a faint metallic sheen. The appearance shall correspond to standard photos designated St 2. (This originally Swedish standard SIS 055900-1967 is adopted as ISO standard 8501-1. It is a pictorial surface preparation standard for painting steel surfaces. The pictures showing the surface appearance are not reproduced in this guideline. Grades St 2 - St 3 describe mechanically cleaned surfaces.)
St 3	Very thorough scraping and wire brushing - machine brushing - grinding - etc. Surface preparation as for St 2, but much more thoroughly. After removal of dust, the surface shall have a pronounced metallic sheen and correspond to standard photos designated St 3. (See parenthesis, St 2.)
Steel:	In these guidelines, if not a more precise definition is given; "steel" means carbon steel including hull structural steel.
Stripe coating	Application, normally by brush, of one or more coating layer on edges, welds or similar to build up adequate total dry film coating thickness at the actual locations.
Target useful life	Is the expected useful life/durability for the given coating system. The useful coating life is considered to be until 3 to 10% of the surface has rust or blisters. The useful target life is based on experience and the uncertainty in the specified useful target life may be +/- 3years.
Vinyl	Binder in paints or coatings based on dissolved or emulsified vinyl chloride or vinyl acetate polymers (Vinyl chloride: $CH_2 = CHCl$). Vinyl paints are of one-component, air drying type.
Zinc rich paint or coating or primer	Products containing usually > 85% of metallic zinc powder in the dry film. The binder usually is on epoxy or (inorganic) silicate basis.

4. Abbreviations and Symbols

4.1 Abbreviations

CP	Cathodic Protection
CRA	Corrosion Resistant Alloy
DC	Direct Current
DFT	Dry Film Thickness
NDFT	Nominal Dry Film Thickness
HAZ	Heat Affected Zone
HISC	Hydrogen Induced Stress Cracking
HV	Vickers's Hardness
NDT	Non-Destructive Testing
PQT	Production Qualification Test
ROV	Remotely Operated Vehicle
RP	Recommended Practice
SCE	Standard Calomel Electrode
SMYS	Specified Minimum Yield Strength
UNS	Unified Numbering System
YS	Yield Strength

4.2 Symbols for CP design parameters

A_c (m²)	surface area
a	constant in coating breakdown factor
b	constant in coating breakdown factor
C (Ah)	current charge associated with quality control testing of anode materials
c (m)	anode cross sectional periphery
C_a (Ah)	(individual) anode current capacity
$E_a^°$ (V)	design closed circuit anode potential
$E_c^°$ (V)	design protective potential
$\Delta E_c^°$ (V)	design driving voltage
E'_c (V)	global protection potential
E'_a (V)	(actual) anode closed circuit potential
$E^°$ (V)	design driving voltage
ε (Ah/kg)	anode electrochemical capacity
f_c	coating breakdown factor
f_{ci}	initial coating breakdown factor
f_{cm}	mean coating breakdown factor
f_{cf}	final coating breakdown factor
I_a(A)	(individual) anode current output
I_{ai} (A)	(individual) initial anode current output
I_{af} (A)	(individual) final anode current output
$I_{a\,tot}$ (A)	total anode current output
$I_{a\,tot\,i}$ (A)	total initial current output
$I_{a\,tot\,f}$ (A)	total final current output
I_c (A)	current demand
I_{ci} (A)	initial current demand
I_{cm} (A)	mean current demand
I_{cf} (A)	final current demand
i_c (A/m²)	design current density
i_{ci} (A/m²)	design initial current density
i_{cm} (A/m²)	design mean current density
i_{cf} (A/m²)	design final current density

L (m)   anode length

M_a (kg)   total net anode mass

m_a (kg)   net anode mass

m_{ai} (kg)   (individual) initial net anode mass

m_{af} (kg)   (individual) final net anode mass

N   number of anodes

r (m)   anode radius

R_a (ohm)   (individual) anode resistance

R_{ai} (ohm)   (individual) anode initial resistance

R_{af} (ohm)   (individual) anode final resistance

R_{atot} (ohm)   total anode resistance

S (m)   arithmetic mean of anode length and width

ρ (ohm·m)   seawater/sediment resistivity

t_f (years)   design life

u   anode utilisation factor

Δw (g)   weight loss associated with quality control testing of anode materials

5. Corrosion Protection of Floating Offshore Structures - with Coatings

5.1 General

5.1.1 This document presents the basis for achieving corrosion protection with the use of coatings with the aim to provide a 10 years or more service life for a floating offshore installation. The longevity of the applied coating system rely on that all tasks in process from surface preparation to the coating application is executed according to the given procedures. The requirements for adequate surface preparation are therefore a very important part of achieving the service life of 10 years or longer.

5.1.2 The selection of the coating systems and application procedures shall be made with due consideration to conditions during fabrication, installation and service of the FPSO.

5.1.3 The protection provided by coatings is to provide a barrier between the steel and the environment and thereby achieve the required protection of the steel. The service life of the applied coatings system must be optimised to the operation requirements of the floating offshore structure.

5.1.4 The property of a given coating product (paint) is also important for the performance. To ensure that the selected coating product has the necessary properties a qualification process is required as is specified in Section 5.11 in the present document.

5.1.5 Stringent requirements are needed to attain the 10 years or longer service life of the applied coating system. Two main factors which should be emphasised are:

— select and pre-qualify a coating product for service (e.g. by established standard)
— surface preparation and cleaning (e.g. limit the salt content on the steel surface to 30 mg NaCl /m^2).

Guidance note:
The NORSOK M-501 requires a 20 mg/m^2. The present guideline require a 30 mg/m^2, which is intermediate the NORSOK M-501 requirement and the requirement of 50 mg/m^2 as required by DNV for the coating of ships.

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5.2 Corrosion protection with coatings and the environmental impact

5.2.1 The environmental conditions for a floating offshore structure embrace conditions from tropical to arctic. This will imply temperature conditions from below freezing to tropical conditions at temperatures at around 30ºC. The humidity conditions may be expected to be close to 100% for all offshore areas for most temperatures. A high impact from sunlight (e.g. UV-light) can be expected at the tropical locations. The performance of the coating system for the given service needs to be established. To ensure that a coating product will have the ability to provide a 10 year or longer service life for the given service the selected product shall be qualified for the intended service.

5.2.2 The given allocation will be important for the performance e.g. for external hull surface above the waterline, the coating must have resistance to UV, while a submerged coating must be compatible with cathodic protection. These aspects must be considered in relation to a qualification process.

5.2.3 The performance of the coating system needs to be established. To ensure that a coating product will have the ability to provide a 10 year or longer service life a qualification shall be done based on one of the two:

— documentation of the given coating product from previous experience
— performing a pre-qualification testing program.

5.2.4 In the case that coating qualification is to be based on a pre-qualification testing program the following standards are recommended:

— ISO 20340(2003)" Paints and varnishes - Performance requirements for protective paint systems for offshore and related structures"
— Tanker Structure Co-operative Forum. "Guidelines for ballast tank coating systems and surface preparation" (Appendix 3 -Testing and classification of ballast tank coatings).

Guidance note:
International standard for pre-qualification testing of coatings for use offshore incorporate the "worst case" situations. The impact due to low and high temperatures as well as cyclic variations also reflecting coating ageing is including in ISO 20340. The present document therefore require the pre-qualification of coatings by the procedure" given in the Annex A of ISO 20340 ("Performance requirements for protective paint systems for offshore and related structures"). The required qualification for ballast tank coatings is the testing scheme according to the Tanker Structure Co-operative Forum "Guidelines for ballast tank coating". The application of these rigorous prequalification requirements for the selection of coating products based on international standards form the basis for an adequate coating performance. The pre-qualification is considered to cover impact for the global offshore environment.

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5.2.5 Note that the DNV class notations can provide assistance for effective corrosion protection.

Guidance note:
The DNV class notations **COAT-1** and **COAT-2** define coating systems and in which category spaces they are to be applied. The coating systems describe the type of paint, number of coats and level of surface preparation and cleaning before paint application. The coating systems are developed during discussions with shipyards, ship owner and paint manufacturer, and reflect good practice of high quality corrosion prevention technology.

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5.3 Unpainted surfaces

5.3.1 The following items shall not be coated unless otherwise specified:

— aluminium, titanium, un-insulated stainless steel, chrome plated, nickel plated or plastics
— jacketing materials on insulated surfaces.

Guidance note:
In case that stainless steel is connected to carbon steel in a topside application, the stainless steel should be coated about 50 mm beyond the weld zone onto the stainless steel.

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5.4 Coating materials

5.4.1 The selected coating materials shall be suitable for the intended use and shall be selected and qualified after an evaluation of all relevant aspects such as:

— corrosion protection properties
— requirements to health, safety and environment
— properties related to application conditions and equipment.

5.4.2 Contractor shall submit the list of the selected coating products, with the qualification documentation, to the owner for approval.

5.4.3 All coating materials and solvents shall be delivered in the Manufactures original containers with labels and include the relevant instructions and technical datasheet. Each product shall have a batch number showing year and month of manufacture. The shelf life shall be included in the technical data sheet.

Guidance note:
The aspects of health, safety and the environment are not covered by the present document.

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5.5 Type of paints

5.5.1 There are a range of generic paints which may be suitable for marine application. Typically the following generic paint types are in use by the marine industry. (E.g. exposed to seawater or marine conditions or may also be suitable for other corrosive conditions):

— epoxy paints (e.g. pure or modified, also with tar)
— polyurethane (PU) paint (also with tar)
— vinyl paints
— zinc rich paints
— epoxy glass flake (abrasion resistant)
— polyester glass flake
— polysiloxan
— semi hard coatings (only for maintenance purposes).

Guidance note:
The terms paint, coat and coating system are defined in Section 3.2.

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5.5.2 Epoxy generic type products represent a wide range of coatings which are suitable for both new building and for maintenance application. Tar products may be prohibited to local Health Safety and Environmental legislation restrictions.

Guidance note:
The newer polysiloxan products may offer the advantage of needing fewer coats, but as a new paint there is less experience available on long term performance in service.

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5.5.3 The owner will specify a need for the use of an antifouling for the underwater part of the hull or for given parts/sections of the underwater hull.

An antifouling coating is primarily used to reduce the skin friction of the hull and thereby reduce the use of bunker fuel. For an FPSO which is moored the application of an antifouling coating on the submerged part of the hull will reduce the formation of macro fouling for a period of around 3 to 7 years. The benefit of reduced macro fouling on the hull will be better inspecting ability for the hull. In this context the owner should consider the need to inspect the whole external hull or whether only certain critical areas shall be inspected. In the latter case, it would be sufficient to apply the antifouling on specific areas. The friction effect and its effect on the anchoring system should also be considered.

Guidance note:
In the case that a heavy fouling occurs on a bare steel surface a reduced general corrosion can be expected. However, local corrosion due to sulphate reducing bacteria may occur.

In the case when a close survey is needed for the submerged hull the alternative approach to making the hull surface free of fouling/macro fouling is to apply water jetting /hydro jetting prior to inspection.

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5.6 Surface with shop primed steel

5.6.1 Shop primed steel may be used as an integral part of the coating system. The plates are automatically cleaned by shot blasting and the shop-primer applied immediately afterwards in the same plant. The cleanliness standard for application of shop-primer should be near white metal or equivalent, i.e. Sa 2.5 according to ISO 8501-1.

Guidance note:
It needs to be ensured that shop primers are not used on a tank – coat, polyester, –glass flake systems or other coatings for dedicated service.

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5.6.2 Compatibility with the coating system shall be ensured by a pre-qualification testing program or by agreement with the coating manufacturer for the applied coating product.

Guidance note:
The best shop-primers from a corrosion protection point of view are those containing zinc, preferably inorganic silicate based. The compatibility of a given coating system on a shop-primed surface shall be established in a pre-qualification.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.6.3 Sweep blasting of the whole or parts of shop-primed surfaces may be relevant, dependent on their condition, type of shop-primer and coating system to be applied. When relevant, cleaning should be carried out before application of the first coating layer (primer coat applied in the yard) to shop-primed surfaces.

5.6.4 Any salt contamination, oil, grease, dust, weld smoke, metallic or other particles shall be removed, e.g. with solvent cleaning, or washing with fresh water containing detergent followed by rinsing with fresh water and drying. Such degreasing, washing and drying of shop-primed surfaces shall, if required, be carried out before final blast cleaning operations. Periodic checking of abrasive for harmful contaminants shall be specified in the coating procedure.

5.6.5 Ultra high pressure water jetting (above approximately 1 700 bar) with equipment free from back thrust and combined with chloride control may be an alternative for cleaning of shop primed surfaces.

5.7 Metal coating

5.7.1 Hot dipped galvanising shall be in accordance with ISO
1461. Minimum thickness for structural items and outfitting
steel shall be 125 μm. Structural items shall be blast cleaned
before hot-dipped galvanising. When coating is considered to
be required for the galvanised item an epoxy system may be
used as a topcoat.

5.8 Thermally sprayed coatings

5.8.1 Thermally sprayed aluminium coating may be applied in
local areas (or for items) which are exposed to seawater, but
the area may not be easily accessible for inspection or mainte-
nance during as service life of 10 years or longer.

5.8.2 The materials for metal spraying shall be accordance
with the following standards:

— aluminium: Type 99.5 to DIN 8566-2 or equivalent
— aluminium alloy: Aluminium alloy with 5% Mg to DIN
  8566 -2-AlMg5 or equivalent.

5.8.3 All the coating materials shall be supplied with product
data sheets and quality control certificates, and be marked with
the coating manufacturer's name, manufacturing standard,
metal composition, weight and manufacturing date.

5.8.4 A sealer may be applied on the thermally sprayed coat-
ing. The objective of the sealer is to fill the porosity of the ther-
mally sprayed coating. The sealer should be applied to the
absorption is complete. There should be no measurable overlay
of the sealer on the metallic coating after the application.

5.9 Surface preparation

5.9.1 The preparation of steel surfaces is of greatest importance
for the durability of a coating. It may be more important than the
selection of coating type. Use of a high quality and technically
sophisticated coating is useless if the steel surface preparation is
neglected. Consequently, the good performance of the coating
depends on adequate surface preparation. Early coating failures
are often caused by inadequate surface preparation.

5.9.2 All steel imperfections should be treated to Preparation
Grade P3 according to ISO 8501-3 "Preparation of steel sub-
strates before application of paints and related products-Visual
assessment of surface and cleanliness-Part 3: Preparation
grades of welds, cut edges and other areas with surface imper-
fections". For rounding of edges the Preparation Grade 3 cor-
responds to a 2 mm rounded edge (Figure 5-1). All edges,
including cut-outs, rat holes, welds and edges from gas/plasma
cutting etc. should be included in the above treatment.
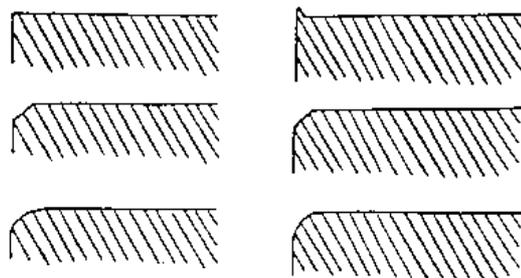
Figure 5-1
Edges on steel plates, enlarged, cross section.
Upper case: Sharp.
Middle case: Broken, after one pass of grinding tool.
Lower case: Rounded after blast cleaning.

5.9.3 Stripe coating shall be used for each coat on all edges,
fillets, welds and areas where spraying may not be effective.
Stripe coating shall always be done by a brush.

5.9.4 After any required re-grinding or breaking of edges the
inspector shall accept the surface for final blast cleaning and
coating.

5.9.5 Final blast cleaning should be carried out only when the
air and steel temperatures and air humidity is under control, i.e:

— the air humidity shall not be above 85%
— the steel temperature shall be 3ºC or more above the dew
  point.
— the above, dry conditions shall be maintained, so that no
  trace of moisture condensation on the steel occurs before
  the primer coating is applied.

5.9.6 Dry conditions are obtainable in tanks and closed com-
partments by means of heating and ventilation. On sections or
blocks of the FPSO new building, dry conditions are obtaina-
ble in heated and ventilated buildings or tents.

5.9.7 The cleanliness of blast cleaned surfaces should be Sa 2.5 according to ISO 8501-1.

> **Guidance note:**
> Several methods of surface preparation exist. However, for new-buildings a grit blasting shall be utilised. The cleanliness of the blast cleaned surface shall be as referred to for each coating system according with ISO-8501-1. Visual, pictorial standards for surface cleanliness are usually sufficient:
>
> - ISO 8501-1, with grades Sa 3 and Sa 2,5
>
> The grades Sa 3 and 2.5 approximately correspond to, respectively:
>
> - BS 4232, grades First Quality and Second Quality
> - NACE, grades No. 1 (white metal) and No. 2 (near-white)
> - SSPC, grades SP 5 (white) and SP 10 (near-white).
>
> ISO 12944 is a relatively new standard, 1st edition 1998, comprising Paints and Varnishes for corrosion protection in general, consisting of 8 parts. The part no. 4 concerns steel surface preparation. National and EN standards are issued with the same number and same content.
>
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5.9.8 Blasting abrasives and dust shall be completely removed after finished blasting operations, e.g. by means of vacuum cleaning, compressed air and/or brushes.

5.9.9 Surface roughness profile after blast cleaning can be checked with a surface profile gauge to as grade medium G (50 μm -85 μm, R_{y5}) be according to ISO 8503.

> **Guidance note:**
> R_{y5} is the mean maximum peak-to-valley height (by stylus). The mean arithmetic mean of the maximum mean peak-to-valley heights, R_y of five adjoining single sample lengths.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.9.10 The surface to be coated shall be clean, dry, free from oil/grease and have the specified roughness and cleanliness until the first coat is applied. Dust and blast abrasives shall be removed from the surface after blast cleaning such that particle quantity and particle size do not exceed rating 2 of ISO 8502-3.

5.9.11 The maximum content of soluble impurities on the surface shall not have a conductivity exceeding a salt content which corresponds to measured conductivity of 30 mg/m^2 of NaCl according to sampling using ISO 8502-06 with distilled water and conductivity measured in accordance with ISO 8502-9.

5.9.12 Mechanically cleaned steel (wire brushing and similar) is not adequate, but may be accepted in new-building on block joints and on a minimum of spots of damaged coating.

5.9.13 An agreement between the owner and the yard (contractor) shall be made and any accepted use of mechanical cleaning should be included in the yards procedure.

5.10 Painting schedule

5.10.1 The basic coating system requirements for the external hull and the ballast tanks are summarised in Table A-1.

> **Guidance note:**
> The coating to be used for the submerged external hull and the ballast tanks used must be compatible with CP. Compatibility of a coating with CP is established by a pre-qualification testing of the coating product. This also includes the presence of a shop-primer.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.10.2 The painting schedule for the external hull and for the ballast tanks are given in Tables A-2 and A-3. For other areas the painting schedule are as given in Table A-4.

> **Guidance note:**
> The painting schedules given in Tables A-2 to A-4 are considered to embrace the relevant locations and structural members affected by a global service when the coatings are pre-qualified according to Section 5.2.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.11 Coating quality control tests for coatings

5.11.1 For the application of coatings and for the subsequent documentation of the applied coatings there are several inspection techniques which should be applied:

— coating quality control during application: WFT
— coating control after application: DFT
— coating control after application: Coating adhesion
— coating control after application: Holiday detection or spark testing.

> **Guidance note:**
> An agreement shall be made between the owner and the yard (contractor) concerning the requirements for documentation of the coating application.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.11.2 Wet film thickness (WFT) is usually measured only by the coating applicator. Rollers and comb type of equipment are in use. The dry film thickness DFT can be estimated from the WFT:

$$DFT = \frac{WFT \cdot volume\,\%\,solids}{100} \qquad (1)$$

5.11.3 After the coating application the dry film thickness (DFT) shall be documented.

The minimum dry film thickness DFT should be stated for each coating layer and for the full coating system. If it is considered more practical to specify the average DFT, it should be increased so that it will comply with a stated minimum DFT.

> **Guidance note:**
> Electromagnetic and magnetic type instruments are used for coatings on steel. Eddy current based instruments may be used on non-magnetic substrates. Due consideration to surface profile should be taken when calibrating DFT measuring equipment.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.11.4 The total nominal dry film thickness NDTF is stated in this document. However, the average DFT is also used in shipbuilding. In case the average thickness is used, it should be specified sufficiently high to obtain the NDFT-value.

5.11.5 The NDFT shall follow the "90/5 rule" for the coating system: The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 5% of the measurements may have measurements between 100% and 90% of the NDFT, but the measured DFT shall always be larger than 90% of specified NDFT.

> **Guidance note:**
> For some coating types, it may be important that a maximum thickness is not exceeded.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

5.11.6 Proper coating adhesion (bonding) to the steel surface and between individual coats is most important for the quality and durability of the coating. Inadequate adhesion results in a mechanically weakened coating layer which may soon be lifted, blistered or peeled off by moving water, weathering actions, impacts or traffic.

5.11.7 Proper adhesion is obtained by following the above guidelines for surface preparation and coating application.

5.11.8 Criteria for minimum acceptable adhesion may be specified, referring to either a cross cut test or pull-off test. Adhesion testing is, however, destructive and is normally used only in cases of complaint, not as a routine test.

Adhesion (bonding) may be tested by the pull-off method, cross cutting or tape test, manual peel testing, etc.

— standards for cross cut test, e.g.: ISO 2409
— standards for pull-off test: ISO 4624.

5.11.9 Holiday detection, or spark testing, or continuity testing, is not commonly used on paint coatings but can be essential for linings for chemicals, pipe coating, and other critical coating or lining applications. The equipment must be calibrated strictly according to the manufacturer's instructions and duly considering the coating or lining type and thickness. Low voltage equipment only is relevant for paint coatings.

5.12 Repair procedure for coated items

5.12.1 The contractor shall develop a procedure with repair of damaged coating. This procedure shall contain quantitative requirements for repair of a given area of damaged coating and acceptance criteria for the repair work. This procedure shall be developed by the contractor for the approval of the owner.

5.13 Handling and shipping of coated items

5.13.1 Coated items shall be carefully handled to avoid damage to coated surfaces. No handling shall be performed before the coating system is cured to an acceptable level.

5.14 Documentation

5.14.1 The final coating specification shall be based on the present document and the specific detailed agreement between the owner and the contractor. This should also include coating inspectors' duties and reporting. The developed specification should describe:

— which coating systems (types of coating, thicknesses and number of coats) to be applied and where
— coating manufacturers accepted for delivery
— general requirements to yard's coating facilities
— requirements to coating application procedures
— equipment for control of air humidity, temperatures, ventilation
— coating applicator's duties and application equipment
— steel surface treatment
— coating application and curing
— requirements to repair procedures for damages
— test methods, equipment and acceptance criteria.

The yard shall establish a procedure for the execution of the coating work (including surface preparation). This procedure should include the following testing requirements for surface preparation and for coating application.

6. Corrosion Protection of Floating Offshore Structures - with Cathodic Protection

6.1 General

6.1.1 This section present the basic technical requirements for the CP design for the underwater hull, ballast tanks and void spaces which contain seawater for a service life of 10 years or longer. The CP design in this document is based on the combination of CP with coatings. This approach is utilised as it provides a viable technical solution for a CP design with a long service life, providing a design with the lowest required anode current output. A low anode current requirement is a benefit in relation to the design and installation of the anode system. This approach requires that all main items and appurtenances which will be part of the CP system are coated.

> **Guidance note:**
> An approach with CP based on bare steel for major surface areas is not considered to be a cost optimal design solution for a 10 years or longer service for a floating structure (FPSO) permanent deployment at sea. The CP current and the consequential sacrificial anode weight (SACP-system) for a 10 years or longer design life would be expected to be excessively high and prohibitive for the FPSO. For a CP system with an ICCP –system a very high anode current output would be required for a hull with a bare steel surface. A consequence for such a CP –system would be the requirement of a very high number of ICCP- anodes. A high number of ICCP- anodes mounted on the hull could be prohibitive in relation to the construction of the hull both in respect to practicality of anodes and cable installation.
>
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6.1.2 'Cathodic protection' (CP) can be defined as e.g. "electrochemical protection by decreasing the corrosion potential to a level a which the corrosion rate of the metal is significantly reduced" (ISO 8044) or "a technique to reduce corrosion of a metal surface by making that surface the cathode of an electrochemical cell" (NACE RP0176). The process of suppressing the corrosion potential to a more negative potential is referred to as 'cathodic protection'.

6.1.3 Cathodic protection is primarily intended for metal surfaces permanently exposed to seawater or marine sediments. Still, CP is often fully effective in preventing any severe corrosion in a tidal zone and has a corrosion reducing effect on surfaces intermittently wetted by seawater.

6.1.4 The basic approach for the CP design of floating offshore structures is to combine CP with the coating system III defined in DNV-RP-B401 for the underwater hull and for the ballast tanks. Bare steel surface areas should only constitute a minor part of the CP current demand for the system.

> **Guidance note:**
> The surface area of the bare steel should be less than about 1% of the total surface area to be protected by CP.
>
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6.1.5 The coating to be used for the submerged external hull and the ballast tanks used must be compatible with CP. Compatibility of a coating with CP is establish by a pre-qualification testing of the coating product.

> **Guidance note:**
> The requirement for pre-qualification of the coating system is given in Section 5.
>
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6.1.6 Interactions of the CP system for the FPSO to other installation (e.g. risers, mooring systems or pipelines) are to be considered to be part of the CP design.

6.1.7 The CP design calculation and design procedure, including the coating breakdown factors are based on the DNV-RP-B401 (2005) "Cathodic protection design". The relevant coating breakdown of the required coating system is included in the present document.

6.1.8 CP of a floating structure may be achieved by either a sacrificial anode cathodic protection (SACP) system or by an impressed current cathodic protection (ICCP) system. Section 6.5 describes the advantage and disadvantages of the two systems. Section 6.2-6.4 and Section 6.6-6.8 are relevant for both types of cathodic protection system. Section 6.9-6.13 are relevant only for SACP system, while Section 6.14 are only rele-

vant for ICCP system.

6.1.9 In this document, "current density", i_c refers to cathodic protection current per unit surface area (in A/m^2). The "initial" and "final" design current densities, i_{ci} (initial) and i_{cf} (final) respectively, give a measure of the anticipated cathodic current density demand to achieve cathodic protection of a bare metal surface within a reasonably short period of time. They are used to calculate the initial and final current demands which determine the number and sizing of anodes. The effect of any coating on current demand is taken into account by application of a "coating breakdown factor", f_c.

> **Guidance note:**
> As the CP design is to be based on a coated structure, the initial current demand will be very low and will not be a critical dimensioning value for the CP design according to this guideline.
>
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6.1.10 The initial and final current densities are used to calculate the required number of anodes of a specific type (6.9) to achieve a sufficient polarizing capacity by use of Ohm's law and assuming that:

1) The anode potential is in accordance with the design closed circuit potential (Appendix B, Table B-13), and

2) The potential of the protection object (i.e cathode) is at the design protective potential for the C-steel and low-allow steel, i.e. - 0.80 V (Appendix B, Table B-1).

> **Guidance note:**
> It follows from the above relationship that the anode current and hence the cathodic current density decreases linearly when the cathode is polarised towards the closed circuit anode potential, reducing the driving voltage for the galvanic cell. According to 6.10.4, the total CP current for a CP unit, I_{tot} (A), becomes:
>
> $$I_{tot} = \frac{(E'_c - E'_a)}{R_{a\,tot}} \qquad (2)$$
>
> Where $R_{a\,tot}$ (ohm) is the total anode resistance, E'_c (V) is the global protection potential and E'_a (V) is the actual anode (closed circuit) potential.
>
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6.2 Protection criteria

6.2.1 The protection criteria for CP are given in Table B-1. To achieve adequate cathodic protection, the steel structure should have potentials as indicated in Table B-1.The criterion of cathodic protection is that the potential of the protected surfaces shall be -0.80 V or more negative values measured with a silver/silver chloride (Ag/AgCl) reference electrode, or equivalent potential with other reference cells.

6.3 Detrimental effect of cathodic protection

6.3.1 Cathodic protection (CP) may induce hydrogen stress cracking (HISC) in extra high strength steels with specified minimum yield strength > 550 MPa. The applied protection potentials shall be in accordance with Table B-1 to avoid any detrimental effects due to hydrogen generated by the CP.

> **Guidance note:**
> The potential requirement is specified to avoid susceptibility to hydrogen induced damage. The hydrogen charging of the steel can reduce the fatigue resistance of the highly stressed steel. The potential limit is also applicable in relation to avoiding cathodic disbonding of the coating. Consequently, the protection potential requirement in Table B-1 represents an important basis for ensuring the integrity of the hull.
>
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6.4 Design approach

6.4.1 The CP design approach is intended to provide a protection based on a minimum requirement for maintenance and/or retrofitting of anodes during the service life.

> **Guidance note:**
> The CP design may include a retrofitting. In such a case the plans for implementation of the retrofitting should be documented as part of the design. This should also document that a retrofitting is a cost effective approach to the design of the CP- system.
>
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6.4.2 For the underwater hull the CP may be achieved by either a sacrificial anode cathodic protection (SACP) system or by an impressed current cathodic protection (ICCP) system. While for the ballast tanks and other tanks with seawater, only a SACP system shall be applied. The reason for this is the fact that the impressed current system may generate excessive hydrogen gas which may be hazardous.

> **Guidance note:**
> The advantages and disadvantages with SACP and ICCP systems are discussed in Section 6.5.
>
> Present experience indicate that for a 20 years or longer service the SACP system is considered to be the most effective alternative for the underwater hull. Hybrid systems may be required. A SACP system for protection prior to the commissioning of an ICCP- system and/or additional sacrificial anodes to dedicated items (e.g. for sea-chests) may be required.
>
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6.4.3 The ballast tanks and other tanks with seawater will be subjected to inspection during the 10 years or longer service life. Consequently, depending on the owners inspection, maintenance and repair (IMR) strategy these tanks may be available for easy and cost effective retrofitting of sacrificial anodes.

6.4.4 For large protection objects such as a FPSO, the detailed design of a CP system is normally preceded by a conceptual design activity. The decision to use SACP or ICCP-system for the external hull should be taken at this conceptual stage. The possible damage to the anodes during installation, operation as well as an evaluation of alternatives for retrofitting of anodes should be evaluated as part of the conceptual design. The following information and any optional requirements (intended as a check-list) shall be provided by the owner or party issuing a contract for the CP design:

Information:

— identify the anode system to be selected (e.g. sacrificial anodes or impressed current anodes)
— conceptual CP design report
— design life of CP system to be installed
— relevant environmental information from the project design basis to establish the climatic region and other parameters; e.g. temperature and salinity
— structural drawings and information of coating systems as required for calculation of surface areas to be protected, including components which may exert temporary or permanent current drain
— identification of any interfaces to electrically connected components/systems with self-sufficient CP systems, e.g. risers or mooring systems
— requirements to documentation and verification, including schedule for supply.

> **Guidance note:**
> To ensure an effective CP design it is necessary that all the above information is made available. The information should be included in the final CP design report.
>
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6.4.5 Owners of floating offshore structures may specify a less, or in certain cases a more conservative design data, based on their own experience or other special considerations. Contractor (i.e. other than owner) may further propose use of alternative design data; however, any such data shall then be approved by owner.

6.5 Cathodic protection systems for the underwater hull – SACP versus ICCP

6.5.1 Selection of the cathodic protection system for the underwater hull is a choice between the following systems:

— sacrificial anode system (SACP)
— impressed current system (ICCP)
— a combination of both systems (hybrid system).

> **Guidance note:**
> Prior to the commissioning of an ICCP –system the underwater hull will need an intermediate CP system (e.g. for a period of about 6 months or longer during fitting of the FPSO). This will require a SACP – system to be fitted and be effective for this duration.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.5.2 The selection of CP -system needs to be considered in relation to a range of advantages and/or limitations of the system in respect to installation, operation and maintenance.

The advantages of an SACP-system are as follows:

— high reliability
— low maintenance
— no risk of hydrogen damage (HISC)
— no risk of damage to coating due to overprotection
— no electrical isolation issues.

The advantages of an ICCP- system are as follows:

— ease of installation
— less transport issue
— flexible life.

> **Guidance note:**
> The aspect of susceptibility to HISC is given in the DNV-RP-B401.The coatings to be used are to be pre-qualified as described in Section 5.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.5.3 In selecting the SACP or ICCP the following needs careful considered in order to provide a cathodic protection system which will provide a required 10 years or longer service life:

SACP –system matters to be considered:

— available space for anode installation
— attachment of anodes to the hull
— need of doubler plate for anode attachment
— total weight
— individual anode weight
— anode damage during construction (e.g. damage by fenders during installation/fitting work of the FPSO).

ICCP-matters to be considered:

— number of ICCP-anodes to provide the required current demand at the end of the service life
— size of anode shields to avoid too negative potentials at the edge of the shield
— anode service life and installation matters for anode retro-fits at hull penetration locations

— service life of the dielectric shields and plans for the retro-fitting of shields
— low (negative) potentials due to high current output from ICCP-anodes and possible risk of hydrogen embrittlement and/or coating damage
— need for electrical isolation of hull from risers or other field structures
— subsea diver work may require power off
— need for a protection of the ICCP-anode cables from any mechanical damage in service (e.g. use conduits for all cables from the anodes to the rectifier unit).

> **Guidance note:**
> The sacrificial anodes are to be installed in a manner which will achieve an adequate current distribution over the hull while not locating anodes in such a manner that they interfere with construction activities in the yard (e.g. often anodes can not be located at the bottom of the hull as it rests on the floor of the dry-dock in the fabrication yard).
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.5.4 Computer modelling of the CP system should be considered for a verification of the ICCP- design. This modelling can establish confidence in the planned anode design configuration and the expected service performance.

> **Guidance note:**
> The ICCP- system for a floating structure with a 10 years or longer service life need to provide a much higher current output towards the end of the service life than similar ICCP –systems on trading vessels. In order to avoid overprotection from the ICCP-anodes the anode shields may have to be much larger on a floating structure as compared to a trading tanker. The size of the anode shields will be restricted by the dimensions of the size of a hull construction block. Alternatively, the number of ICCP-anodes may have to be increased to a significant number to attain the needed total current output while avoiding overprotection at any individual anode shield edge.
>
> ---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.6 Electrical continuity and current drain

6.6.1 For anodes attached to the protection object by other means than welding, and for components of a CP unit without a reliable electrical connection, electrical continuity shall be ensured by a stranded cable (typically copper). Besides welded connections, full electrical continuity may be assumed for cold forged connections, metallic seals and threaded connections (i.e. across the mated threads) without coating.

If the CP design includes use of cables for electrical continuity, requirements to verification of electrical continuity shall be specified in the CP design report. It is recommended that the product of the connection resistance and the current demand (or current output for a non-welded anode) does not exceed 10% of the design driving voltage. In no case shall the resistance across a continuity cable exceed 0.1 ohm.

6.6.2 A floating structure may be connected to other structures. In the case of an electrical connection between the structures the current drain must be established and possible detrimental effects on the operation of the CP system needs to be evaluated.

> **Guidance note:**
> For two structures which are electrically connected, each structure should have its own dedicated CP system. However, measures should be done to ensure that there are no detrimental effects by a stray current between the structures.
>
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6.6.3 Stray current (especially DC Current) can result in extensive corrosion ("stray current corrosion"). It is therefore important that all electrical equipment on the FPSO is installed in a manner which can avoid stray current in the hull. In the case of the installation of an ICCP system for the underwater hull it is important that all electrical wiring and connections are checked to avoid stray currents.

> **Guidance note:**
>
> A potential monitoring of the underwater hull early in the service life of the FPSO can also be done to ensure that stray current corrosion is not occurring on the hull. If the measured potentials show relatively constant values in the range -900 to -1 000 mV (reference electrode Ag/AgCl) it shows that no stray current corrosion is occurring. A measured local peak in the potential (e.g. a measured potential at a location of the hull which is more positive than about -800 mV would indicate a possible stray current corrosion situation on the hull. Note that the measurement of a potential more positive than -800 mV shall under any circumstance result in further action (See Table B-18).
>
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6.6.4 All items which are planned to be electrically connected to the CP system shall be considered in the CP current drain calculations. The components or structures which may have to be included in relation to CP current drain can, but may not be limited to the following:

— connectors/risers
— mooring systems
— structural appurtenances
— specific zones (e.g. turret/conduits).

> **Guidance note:**
>
> Current drain calculations shall also include the electrically connected components which are fully resistant to corrosion (e.g. items made of corrosion resistant alloys).
>
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6.7 Surface area calculation

6.7.1 In the design of CP systems for large and/or complex objects, it is always convenient to divide the protection object into units to be protected. The division into units may be based on e.g. depth zones or physical interfaces of the protection object such as retrievable units within a subsea production system.

> **Guidance note:**
>
> This division is considered useful for the CP design; even though this does not imply that a zone is electrically isolated from its neighbouring zone.
>
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6.7.2 For each CP unit, surface areas to receive CP shall be calculated separately for surfaces with and without a coating system. The main surface area shall be coated (coating system III according to DNV-RP-B401) and only a very minor area shall be as bare steel. Surface areas affected by other parameters (e.g. high surface temperature) needs special consideration with respect to the influence on the CP current demand.

> **Guidance note:**
>
> For major surface areas, an accuracy of -5/+10% is adequate. For smaller components, the required accuracy may be lower depending on whether or not a coating will be applied to such items and to the major surfaces.
>
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6.7.3 Surface area calculations for each unit shall be documented in the CP design report. Reference shall be made to drawings, including revision numbers.

6.8 Calculation of mean current demand for cathodic protection

6.8.1 For the underwater hull the CP current demand design calculation shall include the a calculation of the mean current demand required to maintain cathodic protection throughout the design period, I_{cm}, and the final current demand, I_{cf}, to establish polarisation at the end of the service life.

> **Guidance note:**
>
> For the underwater hull retrofitting of anodes will be complex and very costly. Consequently, for the underwater hull, the CP current demand calculations shall include both the mean current demand (I_{cm}) and the final current demand calculations (I_{cf}). This will ensure a robustness of the CP design and thereby reduce the risk of a need for any retrofitting of anodes on the underwater hull.
>
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6.8.2 The ballast tanks and the internal tanks will be accessible for inspection and maintenance. During the service life of the FPSO maintenance task may be executed, depending on the IMR- strategy. Such maintenance may also include retrofitting of anodes and/or spot maintenance of coatings in the tanks. Subsequently for ballast tanks the CP current demand calculations shall be based on utilising one of the two design alternatives:

— CP current demand design calculation shall be limited to a calculation of the mean current demand (I_{cm})
— CP current demand design calculation shall include the calculation of the mean current demand (I_{cm}) and the final current demand (I_{cf}).

> **Guidance note:**
>
> For an FPSO which has established an IMR-strategy which may include retrofitting of anodes in the ballast tanks alternative (1) may be chosen (E.g. any need for a retrofitting of anodes would occur late in the second half of the service life of the FPSO). The alternative (2) represents the most robust approach to a CP design in ballast tanks. Consequently, to minimise IMR- tasks and avoid any maintenance work related to retrofitting of anodes in ballast tanks the alternative (2) should be chosen.
>
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6.8.3 The current demand calculations form the basis for designing and providing adequate anode current output to fulfil the requirements as given in Table 6-1.

Table 6-1 Required: CP anode current output calculations for FPSOs

Calculated CP current demand requirement	Required anode current output calculation, I_a	
	Underwater hull	Ballast tanks and other seawater tanks and void spaces with seawater
Mean current demand	$I_{a\ tot} \geq I_{cm}$	$I_{a\ tot} \geq I_{cm}$
Final current demand	$I_{a\ tot\ f} \geq I_{cf}$	*Alternative (1): Not required **Alternative (2): $I_{a\ tot\ f} \geq I_{cf}$

*   Alternative (1): The FPSO IMR-plan include a strategy for anode retrofitting in ballast tanks and other tanks and void spaces with seawater during the service life.

**   Alternative (2): The FPSO IMR-strategy do not include plans to retrofit anodes (E.g. The IMR- strategy is to minimise all tasks related to maintenance of tanks during the service life.)

Guidance note:
The owner shall decide if the CP design for the ballast tanks is to be based on the alternative (1) or (2) as given in Table 6-1.

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6.8.4 The cathodic current demand shall include calculations (for each CP object unit) of the current demand according to:

$$I_c = A_c \cdot i_c \cdot f_c \qquad (3)$$

Equation (3) applies to both initial, mean and final current demand calculations.

6.8.5 The specifications for CP current demand requirements for the underwater hull will depend on the given climatic regions or the specific conditions at the given geographical location for the FPSO.

The environmental conditions determine the corrosion protection requirements for the cathodic protection. The approach is to define the environmental impact based on climatic regions. The definition of a climatic region is based on the seawater temperature of the surface water according to the following division:

— tropical region (temp. > 20ºC)
— sub-tropical region. (temp. > 12ºC, but ≤ 20ºC)
— temperate region (temp. > 7ºC, but ≤ 12ºC)
— arctic region (temp. ≤ 7ºC).

The CP current density values for bare steel for the underwater hull of an FPSO in the various climatic zones are given in Table B-2.

Guidance note:
The climatic regions influence the CP current demand for bare steel. The current density values for the bare steel are based on the climatic regions given in the DNV-RP-B401 (2005) for depth zone 0-30 m (for an FPSO the draft will always be within the depth zone of 0-30 m). Riser and mooring systems can be in much deeper waters than 30 m. The temperature in the deeper waters will generally always be much less than the upper 30 m.

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6.8.6 The CP current demand calculations for ballast tanks and other tanks with seawater shall be based on the design current density values given in Table B-12.

The Table B-12 also include the option to select a "High design current density". Some areas in ballast tanks and other seawater tanks are especially liable to suffer corrosion and a higher design current density should be used in these areas. The "High-design current density" is the CP design current density for the coated steel multiplied by a factor of 1.2.

"High design current density" shall be used in ballast tanks and other seawater tanks and void spaces with seawater under the following conditions:

— bulkheads in seawater tanks in contact with cargo tanks with hot oil
— upper wing tanks
— conditions in the tanks that are considered to be especially detrimental to the coating system
— for tanks and void spaces which will have very limited access for inspection during the service life of the FPSO.

Guidance note:
The environmental conditions inside the ballast tanks and other tanks filled with seawater are not primarily dependent on the given geographical location for the FPSO. The requirement in Table B-3 is based on experience on general design current densities for uncoated clean tanks.

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6.8.7 The approach to a cathodic protection design for a floating structure shall be to utilise a combination with a coating system. The recommended coating system is termed the Coating System III as given in Table B-5. The coating breakdown will be a function of the coating properties, operational conditions and time. The coating breakdown for the given coating system (assume a linear breakdown as a function of time) is primarily a time effect. As the coating breakdown increase with time, the coating breakdown factor (f_c) will increase with time (Table B-5). The CP current demand value (I_c) for the coated surface will increase as the breakdown factor for the coating (f_c) increase with time. For the initial new coating the factor f_c will be close to 0, while as the coating breakdown increase with time the breakdown factor will approach 1. The CP design calculations shall be based on the coating breakdown factors given in Table B-5.

Guidance note:
The basic approach to CP design is to use a combination with coatings. The surface area of bare steel and consequently the current demand for the areas with bare steel should only constitute a very minor part of the CP current demand for the floating structure (The bare surface area should be less than about 1% of the total area to be protected).

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6.8.8 The CP current demands for a coated underwater hull of a FPSO structure for the various climatic zones for a design with a service life of 10 to 40 years are given in Tables B-6 to B-11. These current density values are applicable for the underwater hull in the respective climatic zone. The values for the coating breakdown are based on the breakdown factors for the Coating System III in the DNV-RP-B401.

Guidance note:
The initial current demand will not be critical for a CP design which is based on a fully coated structure. The initial current demand does not need to be part of the CP design, but for future reference the calculated initial current demand should be included in a CP design report.

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6.8.9 For the ballast tanks and other tanks and void spaces with seawater the CP current demand shall be based on the current density values given in the Table B-12.

Guidance note:
The basic CP design for the ballast tanks is based on the combination with a coating. The considerations for CP current demand in the ballast tanks needs to be done based on the given impact factors. The CP current demand for the ballast tanks or other tanks with seawater can be influenced by a range of factors which may increase the CP current requirements (e.g. temperature, sloshing quality of the ballast water, complex tank geometry). The CP current demand calculations for the ballast tanks shall be based on selecting one of two design alternatives as presented in Table 6-1. The applicable CP current demand values are provided in Table B-12.

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6.9 CP design with sacrificial anodes - Calculation of total anode net mass to meet current demand

6.9.1 The anode mass to provide protection over the service life shall be calculated to satisfy the anode current output requirements given in Table 6-1 in the following manner:

The total net anode mass, M_a (kg), required to maintain cathodic protection throughout the design life, t_f (yrs), is to be calculated from I_{cm} (A) for each unit of the protection object (including any current drain):

$$M_a = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \qquad (4)$$

In Equation (4) the number 8760 refers to hours per year. The value for ε (anode electrochemical capacity, Ah/kg) and u (anode utilisation factor) are to be selected based on the values given respectively in Table B-13 and Table B-14.

6.10 CP design with sacrificial anodes - Calculation of total anode current output to meet current demand

6.10.1 From the anode type selected the number of anodes, (N), anode dimensions and anode net mass, m_a (kg), shall be defined to meet the requirements for:

— final current output, I_{cf} (A)
— individual anode current capacity C_a (Ah).

which relate to the CP current demand, I_{cf} (A), of the protection object.

6.10.2 For the underwater hull the anode output calculations shall establish that the anode current output (I_a) is equal to or higher than the mean (I_{cm}) and also that final anode current output (I_a) is equal to or larger than the final current demand (I_{cf}).

Guidance note:

For the submerged hull retrofitting of anodes can not easily be achieved and can be expected to be very costly. It is therefore necessary to ensure a CP design which can provide an effective service life with minimal requirements for maintenance/retrofitting. The CP design calculations therefore include requirements for anode outputs both for the mean and final current outputs.

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6.10.3 For ballast tanks and other seawater tanks the anode output calculations shall be done by one of the two alternatives (Table 6-1):

1) To establish that the anode current output (I_a) is equal or larger than the mean current demand (I_{cm})

2) To establish that the anode current output (I_a) is equal or larger than the mean current demand (I_{cm}) and also that the final anode current output (I_{af}) is equal or higher than the final current demand (I_{cf}).

Guidance note:

The two alternatives for the CP anode current output requirement calculations for ballast tanks and other seawater tanks and void spaces with seawater are described in Table 6-1

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6.10.4 The individual anode current output, I_a (A), required to meet the current demand, I_c (A), is calculated from Ohm's law:

$$I_c = N \cdot I_a = \frac{N(E_c^{\,o} - E_a^{\,o})}{R_a} = \frac{N \cdot \Delta E^o}{R_a} \qquad (5)$$

where E_a^o (V) is the design closed circuit potential of the anode material as given in Table B-13 and R_a (ohm) is the anode resistance which Table B-16. The final current output, I_{af}, is to be calculated using the final anode resistance, R_{af}. $E_c^{\,o}$ (V) is the design protective potential according to Table B-1. The E^o (V) is the design driving voltage.

6.10.5 The individual anode current capacity, C_a (A·h), is given by:

$$C_a = m_a \cdot \varepsilon \cdot u \qquad (6)$$

where m_a (kg) is the net mass per anode. The total current capacity for a CP unit with N anodes thus becomes N C_a (A·h).

6.10.6 Calculations shall be carried out to demonstrate that the following requirements are met:

$$N \cdot C_a \geq I_{cm} \cdot t_f \cdot 8760 \qquad (7)$$

$$I_{a\,tot\,f} = N \cdot i_{cf} \geq I_{cf} \qquad (8)$$

I_{cm} and I_{cf} in equations (7) and (8) are the total mean and final current demands of a CP unit, including any current drain. 8760 is the number of hours per year.

6.10.7 If the above criteria cannot be fulfilled for the anode dimensions and net mass initially selected, another anode size shall be selected and the calculations repeated until the criteria for equations (7) and (8) are fulfilled.

6.11 Calculation of anode resistance

6.11.1 The anode resistance, R_a (ohm), to be used in equation (5) shall be based on the applicable formulas as given in the Table B-16, using the actual anode dimensions and the specific resistivity of the surrounding environment. The specific resistivity of the surrounding environment shall be selected according to the salinity and temperature for the seawater at the given location as given in Figure B-1.

For ballast tank water a default value of 25 ohm cm may be used for the seawater resistivity if actual measurements are available.

6.11.2 The final anode resistance, R_{af} (ohm), is calculated based on the expected dimensions when the anode has been consumed to its utilisation factor, u, using the resistance formulas given in Table B-16.

6.11.3 To calculate the initial anode resistance, Rai (ohm), the initial anode dimensions are inserted in the relevant anode resistance formulas in Table B-16. The final anode resistance, Raf (ohm) is calculated based on the expected dimensions when the anode has been consumed to its utilisation factor, u, as explained below.

6.11.4 When the anode has been consumed to its utilisation factor, u, at the end of the design life, t_f (years), the remaining net anode mass, m_{af} (kg), is given by:

$$m_{af} = m_{ai} \cdot (1 - u) \qquad (9)$$

The final volume of the anode to be used for calculation of R_{af} can be calculated from the remaining net anode mass, m_{af} (kg), specific density of anode material and the volume of insert materials. When details of anode inserts are not available, their volume should either be neglected or estimated to give a conservative approach.

6.11.5 The detailed anode design shall ensure that the utilisation factor assumed during calculations of required anode net mass according to equation (4) is met. Hence, it shall be ensured that the anode inserts are still likely to support the remaining anode material when the anode has been consumed to its design utilisation factor. Unless otherwise agreed, anode cores of stand-off type anodes shall protrude through the end faces.

6.11.6 For long and short slender stand-off anodes consumed to their utilisation factor, a length reduction of 10% shall be assumed. Furthermore, assuming that the final anode shape is cylindrical, the final radius shall be calculated based on this length reduction and the final anode mass/volume as given in relation to equation (9).

6.11.7 For long and flush mounted anodes, the final shape shall be assumed to be a semi-cylinder and the final length and radius shall be calculated as above.

6.11.8 For short flush-mounted anodes, bracelet anodes and other shapes mounted flush with the protection object, the final exposed area shall be assumed to be equivalent to the initial area facing the surface to be protected.

6.12 Sacrificial anodes: distribution of anodes

6.12.1 The calculated number of anodes, N, for a CP unit shall be distributed to provide a uniform current distribution, taking into account the current demand of individual members due to different surface areas. The location of all individual anodes shall be shown on drawings.

> **Guidance note:**
> For stand-off type anodes, the minimum distance from anode to protection object shall be minimum 300 mm. However, the use of stand-off anodes may not be applicable for the FPSO due to installation restrictions during construction and/or possible implications of drag force effects created by such anodes.
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6.12.2 Anodes shall be located with sufficient spacing between each other to avoid interaction effects that reduce the useful current output. As far as practical, anodes shall be located so that those of its surfaces intended for current output are not in close proximity to structural members, reducing the current output.

> **Guidance note:**
> Anode location should be considered in relation to hull construction, launching and work related to topside fitting to avoid damage to the anodes(e.g. fenders with contact with the hull during topside fitting can seriously damage stand off anodes). Consequently, early liaison with other engineering disciplines, as well as with fabrication and installation contractors is advised.
>
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6.12.3 For ballast tanks sacrificial anodes should be distributed over the surface area of the tank which will be submerged. To avoid pitting corrosion on the bottom of the tanks anodes should here be placed as close as possible to the bottom plating.

> **Guidance note:**
> The anodes should be installed to provide an even CP current distribution. For a coated surface, this may be achieved by an even distribution of anodes as a main approach. However, for areas which are assumed to be critical or for areas of a tank with an assumed higher CP current requirement a higher number of anodes should be installed. The area to which an individual anode provides protection is often termed its "throwing power". For a coated surface the extent of the anode "throwing power" is significantly higher than for the similar anode on a bare steel surface. An anode may, as a first approximation, be assumed to provide protection to a surface which it can "see". An anode mounted on an edge may therefore provide protection over a larger area (e.g. have a "high throwing power"), while an anode mounted in a corner is expected to have a "limited throwing power".
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6.12.4 Aluminium alloy anodes in ballast tanks are to be so located in the tanks that a kinetic energy of ≤ 275 J is developed in case of their loosening and falling down which is equivalent to:

$$H \leq 28/W \qquad (10)$$

where H (m) is the height above tank bottom, deck or stringer, W (kg) is the anode gross mass.

> **Guidance note:**
> This implies that e.g. a 10 kg aluminium anode should not be more than 2.8 m above the tank bottom.
>
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6.13 Installation of anodes - sacrificial anodes

6.13.1 For anodes that may become subject to significant forces during installation and operation, the design of anode fastening devices shall be addressed in the design report. Doubler and/or gusset plates may be required for large anodes.

6.13.2 With the exception of stand-off type anodes, a marine grade paint coating (min. 100 μm DFT) shall be specified for anode surfaces facing the protection object.

6.13.3 Anode alloy materials based on aluminium or zinc are acceptable. Magnesium based alloys are not acceptable.

6.13.4 The tanks' size, shape and areas to be protected should be presented accurately in the CP design. Areas coated, respectively uncoated appurtenances should be specified. The ballasting routines, including the percentage of the total time the tanks will likely be filled with ballast water, the probable duration of ballasted periods, and quality of ballast water should be considered (e.g. for tanks that will stay empty less than approximately 50% of the time).

6.13.5 Cathodic protection systems are without effect when the tanks are empty, and it will take some time (1/2 day or more) to obtain full effect (polarisation) of submerged steel surfaces after filling with sea water. In the ullage space or under deck area on top of tanks sacrificial anodes will not be effective unless the tank is completely filled.

> **Guidance note:**
> For cathodic protection current output calculations a resistivity value (ρ) of 25 ohm cm can be used for sea water in ballast tanks if a measured value is not available. The resistivity value (ρ) can be established from information on the seawater salinity (Salinity: 30 to 40‰) and the temperature as given in the Figure B-1.
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6.13.6 Ballast tanks adjacent to tanks for liquid cargo with flash point < 60ºC are considered as gas dangerous areas according to the DNV Rules for Classification of Ships.

6.13.7 There is no requirement for a permanent monitoring system of a sacrificial anode system. Manual monitoring of the effectiveness of the system may be done by visual inspection of the anodes and/or by measurement of the protection potential.

Measurement of protection potentials are done by readings using a portable reference electrode. Based on the measured potential value the required action should be according to Table B-18.

6.14 Underwater hull: CP with an impressed current system

6.14.1 Impressed current (ICCP) systems may be used on the underwater hull.

> **Guidance note:**
> ICCP- systems shall not be used in ballast tanks due to development of hydrogen, which can result in an explosion hazard.
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6.14.2 The impressed current anodes are generally made of titanium, niobium or tantalum with a thin layer of platinum or with a thin layer of a mixed oxide. This inert material allows a discharge of a high electrical current. Typical data on some ICCP anode materials are listed in Table B-15.

6.14.3 —The impressed current provide the protection current (DC: direct current) to the steel structure by an adjustable DC power source. The current is delivered by connecting the structure to the negative terminal of the power source and the positive terminal to the anodes. The supplied cur-

rent is to be controlled during the service life. The suitable current output can then be obtained to achieve an adequate protection level over the whole surface of the structure.

6.14.4 Permanently installed reference electrodes are installed to measure the protection potential and thereby control the electrical current supplied to the CP system.

> **Guidance note:**
> The document EN 13173 "Cathodic protection of steel offshore floating structures" provide detailed requirements for the application of an ICCP system.
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6.14.5 The design and specification for the system should include the following:

— CP design basis (given in the present document)
— specification of equipment (e.g. DC- power source, anodes, connection cables, terminations and protection devices, reference electrodes)
— size of equipment
— general arrangement of equipment
— installation specifications of equipment
— monitoring system specification.

6.14.6 The impressed current system design and installation, including anode alloy type, design, location and distribution, reference electrodes, rectifiers, cabling, hull penetrations, cofferdams, monitoring units, anode shields etc. should be delivered by a recognised specialist company with good references.

6.14.7 The impressed current system should be designed to provide protection for a defined CP objective. Specific objects or areas may require a dedicated system in order to optimise the protection current. The total maximum current output should be the sum of the current for each dedicated system (Σ I a) and satisfy the current demand values given in Table B-1 for the mean and final current output.

6.14.8 To ensure adequate current distribution an efficiency factor of 1.25 to 1.5 should be introduced in the design of the maximum required anode current output ($I_{a\,tot\,max}$):

$$I_{a\,tot\,max} = (1.25\ to\ 1.5) \cdot \Sigma\,I_a \qquad (11)$$

6.14.9 Impressed current systems for a floating structure shall include one or more variable power sources, and with several anodes and normally a number of reference anodes. The power source (DC, direct current) will normally be equipped with an automatic potential power control which can be used to control the current output.

> **Guidance note:**
> A computer modelling based on finite element or boundary element methods to verify an adequate current distribution for the impressed current system may be executed. This will provide confidence in the global performance of the system and of the location of the individual anodes.
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6.14.10 The power source shall be able to deliver the total maximum current required ($I_{a\,tot\,max}$).

6.14.11 The output voltage shall take into account the resistance in the electrical circuit (e.g. cables and anodes) and the maximum recommended operating voltage of the anodes.

6.14.12 The DC power source shall be able to deliver sufficient current to provide the adequate protection potential of the cathode. For an automatic controlled DC power source the potential control shall be able to deliver a current when the control unit reads a potential more positive than the set potential limit. Sim-

ilarly the DC power source shall deliver no current when the control unit reads a potential more negative than the set potential limit. There shall be a device or control unit which limit the current output from each anode to a preset value.

6.14.13 The anodes used for an impressed current system on the underwater hull are to be of the inert type (Table B-15). Generally the current outputs for the inert anodes vary from about 400 to 3 000 A/m^2.

6.14.14 The selected anodes shall be suitable for the service life of the structure or should be planned to be replaced. The anode assemblies should be designed to have a high resistance to mechanical damage. Precautions shall be taken to avoid short circuit of the anode to the structure and water leakage at the anode penetration. A hull penetration with cofferdam and sealing arrangement are normally used for the mounting of the anode. The number, size and location of the anodes shall be determined to be adequate for delivering the required current from the DC current source.

> **Guidance note:**
> Numerical methods may be used to calculate and verify an adequate current distribution for the underwater hull based on the selected locations of the anodes.
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6.14.15 The dielectric shield shall be suitable for the intended service and be resistant to cathodic disbonding and to the alkaline and possible chlorine produced during operation of the anodes.

6.14.16 The design of the shield should include possible ageing of the material. The need for reinstallation or upgrading of shield and/or anode should be evaluated.

6.14.17 A dielectric shield shall be fitted around each anode to prevent local overprotection and improve the current distribution on the object. Calculations shall be done to document that potential at the edge of the steel is in compliance with the protection potentials given in Table B-1. Such calculations may be done by the equations given in Table B-17 or by other established equations (e.g. for the relevant shield geometry and anode output currents.)

6.14.18 Reference electrodes are essential for the control of an ICCP system. Reference electrodes are used to measure the potential of the structure (steel). This potential value is used to control the electric current delivered to the CP- system. The reference electrodes can be of various types:

— zinc (robust but less accurate than a silver/silver chloride electrode)
— silver/silver chloride/seawater (accurate but less robust than zinc and with a shorter service life).

6.14.19 Precautions shall be taken to avoid damaging the reference electrode.

> **Guidance note:**
> The reference electrodes shall be mounted in such a manner that they can not be damaged in service. This can be achieved by either a robust construction of the reference electrode and/or fitting the reference electrode in cofferdams.
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6.14.20 The location of a reference electrode may have two essential applications for an ICCP system:

— to control the average protection potential for the given CP-object
— to measure potentials which may be outside the set limit potential limits for the area/object.

Guidance note:
A computer modelling may provide input to critical areas for the potential at a given CP design and anode locations. (E.g. to monitor a possible overprotection a reference electrode may be located close to the edge of the anode shield).

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6.14.21 The reference electrodes shall be regularly checked (e.g. calibrated at regular intervals).

Guidance note:
This can be done by measuring against portable reference electrodes in service. Alternatively the installed reference electrodes can be as dual electrodes, which can be automatically checked during service.

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6.14.22 All cables shall be fitted with adequate external protection to avoid mechanical damage during installation or service conditions. The cable as well as all electrical connections and connections to the anode lead cable shall be watertight and resistant to the environmental and operating conditions.

6.14.23 The cross section of the cables shall consider possible voltage drops for the length of the cable. The specified maximum current rating of the cable should not be exceeded.

6.14.24 Dedicated cables should be used for potential measurements. Such cables should be suitable screened/sheathed to avoid interference.

6.14.25 An impressed current system shall be installed with a permanent CP monitoring system. Fixed monitoring is not essential for a sacrificial anode system. For an impressed anode system a fixed monitoring system shall be installed.

6.14.26 The monitoring of the impressed system should include:

— potentials (by fixed reference electrodes on the hull)
— anode current output (measure current output from anodes will be part of the impressed current control system).

6.14.27 In order to avoid inaccurate potential measurements it is advised to use dual reference electrodes.

6.14.28 The basic requirement of the monitoring system is to provide protection potential values for various parts of the underwater hull based on permanent reference electrodes. The location of the reference electrodes shall consider both (1) areas with average potentials and (2) areas with possible overprotection and under protection.

Guidance note:
It is advised that the potential monitoring system should be interfaced with a data acquisition system to provide real –time data. The measured potential and the required action should be in accordance with the criteria given in Table B-18.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.14.29 The electrical current delivered to each anode shall be measured at the corresponding output terminal of the direct current power source or at the distribution box.

Guidance note:
A system for automatic logging of the current output should be considered.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

6.14.30 During the fitting and installation period electrical current supply may not be available on the FPSO. Consequently, the impressed current system can not be activated before the current generators on the structure are functional. As the ICCP-system will not be active for the initial period during fitting and installation work, the hull will have to be protected by a sacrificial system for an intermediate period.

Guidance note:
If the underwater hull is to be designed with an ICCP system as the main CP system, the actual system may have to be designed as a SACP-ICCP-hybrid system to incorporate the intermediate period with no active ICCP. An intermediate SACP–system can be based on hanging the anodes along the hull side. (E.g. for areas like sea- chests dedicated sacrificial anodes may be considered even with an ICCP- system).

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

APPENDIX A
COATING TABLES

Table A-1 Summary of the requirements: Coating system for external hull and ballast tanks	
Coating System [1]	Epoxy (e.g., pure epoxy or modified epoxy) based Other recognised hard coating which is pre-qualified [2]
Coats and Thickness	2 to 3 coats [3] Total nominal dry film thickness (NDFT) 300-400 microns[4]
Primary surface preparation	Zinc containing, silicate based pre-fabrication primer on surface blast cleaned to minimum Sa 2,5 with surface roughness: ISO 8503 grade medium G(50 to 85 μm R)
Secondary surface preparation	Sharp edges to be removed Damaged shop primer blast cleaned to ISO 8501 Sa 2,5, including welds and burns. Intact shop primer to be sweep blasted. (Intact and sufficiently cleaned shop primer may be kept as the first coat in the paint system if recommended by the paint producer and accepted by the owner.) Mechanical cleaning to St 3 acceptable on block joints and damages to the applied coating system
Clean conditions	Any visible salt contamination, oil, grease, dust, weld smoke or dirt on shop primed or other surface to be coated, to be removed by cleaning The chloride content on surfaces to be coated shall be less than 30 mg/m^2 (as NaCl) according to Bresle conductimetric method, or an equally recognised method
Thermal and hygrometric conditions	Air humidity $\leq$ 85% and steel temperature $\pm$ 3°C above the dew point during blast cleaning and coating application operations

Comments to coating system

[1] Light coloured coatings are recommended. Tar containing coatings are dark. If coal tar epoxy is used the epoxy to tar ratio shall not be less than 60 to 40.

[2] The selection of a recognised coating may depend on the type of compartment and it's function.

[3] One stripe coat to be applied prior to or after each full coat on edges, welds and in areas where spraying may not be fully effective. Stripe coating shall always be applied by brush.

[4] Nominal dry film thickness shall follow the "90/5 rule" defined as follows:
- The average DFT based on measurements shall always be equal to or larger than the NDFT. Up to 5% of the area (measured points) may have a thickness between 100% and 90% of the NDFT, but the measured dry film thickness shall always be larger than 90% of the NDFT.
- The measured DFT shall not exceed the maximum dry film thickness defined by the paint manufacturer or as specified by the owner.

[5] Only applicable for a reasonable amount of damages. Otherwise the basic surface preparation to be re-applied.

Table A-2 External hull: Alternative coating systems

Allocation	Coating type	Total average DFT microns	Number of coats
External hull, under water including boot-top area up to ballasted water line[1]	Abrasion resistant Epoxy or Aluminium pigmented Epoxy or other Epoxy anticorrosive + Anti-fouling paint[1]	300 - 450 250 - 350	2 - 3 2 - 3
	Epoxy anticorrosive Aluminium pigmented Vinyl Anti-fouling paint[1]	200 - 300 100 250 - 350	1 - 2 1 2 - 3
External hull, Adjacent to waterline in a zone of about +/- 2 m	Epoxy or Polyester based glass flake or glass fibre reinforced[2]	600 - 1500	1 - 2
	Abrasion resistant Epoxy or Aluminium pigmented Epoxy or other Epoxy anticorrosive	300 - 350	2 - 3
External hull, above ballasted water, and deck, deckhouse, superstructure	Zinc Ethyl Silicate or Zinc Epoxy Epoxy Polyurethane, Acryl polyurethane or Polysiloxan topcoat	50 200 - 300 50 - 100	1 1 - 2 1
	Zinc Ethyl Silicate or Zinc Epoxy Polysiloxan[3]	50 200 - 300	1 2
	Epoxy Polyurethane, Acryl polyurethane or Polysiloxan topcoat	250 - 300 50 - 100	2 1

Note:

[1] The benefit of applying an antifouling needs to be evaluated.

[2] To provide a flexible heavy duty coating with resistant to some mechanical impact on the hull in a zone around the water line may be considered e.g. glass flake reinforced epoxy 500 microns DFT.

[3] Polysiloxan may be applied in thicker coats. Consequently, a higher film thickness may be achieved with a reduced number of coats.

Table A-3 Basic coating system: Ballast tanks and internal voids

Allocation	Coating type	Total average DFT microns	Number of coats
Ballast tanks and voids exposed to seawater	Epoxy based (pure epoxy or modified epoxy) or other recognized hard coating	300 - 400	2 - 3

Table A-4 Basic coating system: Oil tanks and miscellaneous areas

Allocation	Surface preparation	Coating type	Nominal DFT microns	Number of coats minimum
Oil cargo tanks	Sa 2.5	Epoxy based or other qualified hard coating	300 - 400	2 - 3
Fresh water tanks	Sa 2.5	Epoxy	200	2
Product tanks	Sa 3	Epoxy	300 - 350	2 - 3
		Phenolic Epoxy	300 - 350	2 - 3
		Zinc silicate	75 - 100	1
Accommodation and Engine rooms	Sa 2 - St 3	Alkyd, etc.	100 - 150	2
Underneath thermal insulation on tank top or inner bottom plate	Sa 2.5	Epoxy	300	2
Void spaces (except dry, sealed-off compartments)	Sa 2.5 - St 3	Epoxy based	200 - 300	2
Exposed decks[1]	Sa 2.5	Epoxy based with topcoat	300 - 350	2 - 3
Areas with restricted access for visual inspection and areas with restricted space for fitting of anodes or areas suffering from both corrosion impact and wear	Sa 2.5	Thermally sprayed aluminium (99.5 Al or Al5Mg9	200	[2]
[1] In walkways, escape routes a non skid epoxy should be used (particles in non skid areas should be 1 -5 mm).				
[2] See NORSOK M-501 coating system No. 2.				

APPENDIX B
CP DESIGN

B.1 Tables

Table B-1 Potential criteria for the protection of carbon/low alloy steel and stainless steels in seawater

Material		Minimum negative protective potential Silver /silver chloride/SW reference electrode, V	Maximum negative protective potential Silver/ silver chloride/SW reference electrode, V
Carbon steel/ low alloy steels	Aerobic SW environment	-0.80	-1.10
	Anaerobic SW environment	-0.90	-1.10
Stainless steel Austenitic steel	PREN ≥ 40	-0.30	
	PREN < 40	-0.60	No limit
	Duplex	-0.60	No limit[1]

Note:

[1] Consideration of susceptibility to HISC at high negative potential may be needed, including a need to establish specify a limit to the negative potential value

Table B-2 Design current density requirements for bare steel on the underwater hull

Climatic region	CP current density (For depths 0 to 30 m) A/m^2			Comment
	Initial	Mean	Final	
Tropical	0.150	0.070	0.100	West Africa
Subtropical	0.170	0.080	0.110	
Temperate	0.200	0.100	0.130	North Sea
Arctic	0.250	0.120	0.170	

Table B-3 Design current density requirements for bare steel on ballast tanks and other tanks filled with seawater

Location	Mean current density (A/m^2)	Final current density (A/m^2)
Tank General	0.100	0.120
"High-design current density" [1]	0.125	0.150

[1] "High-design current density" is used in areas of the tank that are considered especially vulnerable to corrosion.

Table B-4 CP and coatings for 20 year service life: Coating system to be used in combination with CP

Coatings and expected service life	Basic requirements	Comments
Coating system [2]	Epoxy based[1]: Minimum 2 coats Total dry film thickness, NDFT: 300 - 400 μm	The detailed requirements for the coating system is given in Table A-2

Other generic coatings may be used (Coating products are to be pre-qualified).
The coating system is based on coating system III in DNV-RP-B401.

Table B-5 CP with coatings: Coating breakdown factors (fc) for Coating systems III
According to DNV-RP-B401 (Ref /4/)

Design period, Years	Coating system III		
	Initial f_{ci}	Mean f_{cm}	Final f_{cf}
10	0.02	0.08	0.14
15	0.02	0.11	0.20
20	0.02	0.14	0.26
25	0.02	0.17	0.32
30	0.02	0.20	0.38
40	0.02	0.26	0.50

Table B-6 CP with coatings: Current density for 10 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.08$ A/m^2	Final current density; $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.14$ A/m^2
Tropical	0.003	0.006	0.014
Subtropical	0.003	0.006	0.015
Temperate	0.004	0.008	0.018
Arctic	0.005	0.010	0.024

Table B-7 CP with coatings: Current density for 15 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.11$ A/m^2	Final current density; $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.20$ A/m^2
Tropical	0.003	0.008	0.020
Subtropical	0.003	0.009	0.022
Temperate	0.004	0.011	0.026
Arctic	0.005	0.013	0.034

Table B-8 CP with coatings: Current density for 20 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.14$ A/m^2	Final current density; $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.26$ A/m^2
Tropical	0.003	0.010	0.026
Subtropical	0.003	0.011	0.029
Temperate	0.004	0.014	0.034
Arctic	0.005	0.017	0.044

Table B-9 CP with coatings: Current density for 25 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.17$ A/m^2	Final current density: $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.32$ A/m^2
Tropical	0.003	0.012	0.032
Subtropical	0.003	0.014	0.035
Temperate	0.004	0.017	0.042
Arctic	0.005	0.020	0.054

Table B-10 CP with coatings: Current density for 30 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.2$ A/m^2	Final current density: $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.38$ A/m^2
Tropical	0.003	0.014	0.038
Subtropical	0.003	0.016	0.042
Temperate	0.004	0.020	0.049
Arctic	0.005	0.024	0.065

Table B-11 CP with coatings: Current density for 40 years design life (Coating system III)			
Climatic region	Initial current density; $i_{ci} \cdot f_{ci}$ $f_{ci} = 0.02$ A/m^2	Mean current density; $i_{cm} \cdot f_{cm}$ $f_{cm} = 0.26$ A/m^2	Final current density: $i_{cf} \cdot f_{cf}$ $f_{cf} = 0.50$ A/m^2
Tropical	0.003	0.018	0.050
Subtropical	0.003	0.021	0.055
Temperate	0.004	0.026	0.065
Arctic	0.005	0.031	0.085

Table B-12 CP current density requirements for ballast tanks and tanks and internal voids with seawater (coating system III)

Design years	$i_{cm} \cdot f_{c,m}$ (A/m²)	$i_{cm}' \cdot f_{c,m}$ (High) (A/m²)	$i_{c,f} \cdot f_{c,f}$ (A/m²)	$i_{c,f}' \cdot f_{c,f}$ (High) (A/m²)
10	0.008	0.010	0.017	0.020
15	0.011	0.013	0.024	0.029
20	0.014	0.017	0.031	0.037
25	0.017	0.020	0.038	0.046
30	0.020	0.024	0.046	0.055
40	0.026	0.031	0.060	0.072

The selection of a CP design current density for current demand calculations as a "High-design current density" alternative should be based on evaluations as given in 6.8.6.

Table B-13 Recommended design electrochemical capacity and design closed potentials for sacrificial anodes (Al- and Zn-anodes)

Anode and environment	Anode electrochemical capacity, ε Ah/kg	Closed circuit potential, V
Al based anodes in sea water	2 000	-1.05
Al based anodes in marine sediments	1 500	-0.95
Zn based anodes in sea water	780	-1.0
Zn based anodes in marine sediments	700	-0.95

Table B-14 Recommended sacrificial anode utilisation factor

Anode type	Anode utilisation factor, u
Long slender stand –off L ≥ 4r	0.90
Short slender stand-off L < 4r	0.85
Long flush mounted L ≥ width and L ≥ thickness	0.85
Short flush-mounted, bracelet and other types	0.80

Table B-15 Electrochemical characteristics of impressed current anodes (Ref. /3/)

Anode material	Consumption rate[1] g/A	Maximum current density A/m²	Maximum voltage V
Platinised titanium	0.0012 to 0.004	500 to 3 000	8[2]
Platinised niobium	0.0012 to 0.004	500 to 3 000	50
Platinised tantatium	0.0012 to 0.004	500 to 3 000	100
Mixed metal oxide on titanium substrate	0.0006 to 0.006	400 to 1 000	8[2]

[1] The life of the anode will be influenced by the resistivity of the electrolyte. Further the life will be influenced by the ripple on the direct current power supply. A ripple frequency less than 100 Hz should be avoided.

[2] The oxide film on titanium may be broken down at voltages exceeding 8 V.

Table B-16 Recommended anode resistance formulas for CP design calculations

Anode Type	Resistance Formula
Long slender stand-off [1] L ≥ 4r	$R_a = \dfrac{\rho}{2 \cdot \pi \cdot L}\left(\ln\dfrac{4 \cdot L}{r} - 1\right)$
Short slender stand-off [1] L < 4r	$R_a = \dfrac{\rho}{2 \cdot \pi \cdot L}\left[\ln\left\{\dfrac{2L}{r}\left(1+\sqrt{1+\left(\dfrac{r}{2L}\right)^2}\right)\right\} + \dfrac{r}{2L} - \sqrt{1+\left(\dfrac{r}{2L}\right)^2}\right]$
Long flush mounted [2] L ≥ width	$R_a = \dfrac{\rho}{2 \cdot S}$
Short flush-mounted, bracelet and other types	$R_a = \dfrac{0.315 \cdot \rho}{\sqrt{A}}$

[1] The equation is valid for anodes with minimum distance 0.30 m from protection object. For anode-to-object distance less than 0.30 m but minimum 0.15 m the same equation may be applied with a correction factor of 1.3.

[2] For non-cylindrical anodes: $r = C/2\,\Pi$, where C(m) is the anode cross section periphery.

Table B-17 Impressed current anodes: Calculation of potential at shield edge	
Shield Geometry	*Equation for calculation of potential at the edge of the anode shield, E_{as} (V)*
Circular anode and shield I = Anode current, A ρ = Resistivity in SW, ohm cm D = Diameter of shield, cm E_c = General hull potential, V	$$E_{as} = E_c - \frac{\rho \cdot I}{D \cdot \pi}$$
Rectangular anode and shield I = Anode current, A ρ = Resistivity in SW, ohm cm A = Length of shield, cm B = Width of shield, cm L_{a} = Length of anode, cm E_c = General hull potential, V	Rectangular shield with: $B^2 > (A^2 - L_a^2)$ $E_{as} = E_c - ((\rho \cdot I)/2 \cdot \Pi \cdot L_{a}) \cdot \ln((A + L_{a}/(A - L_{a}))$ Long strip rectangular shield with: $B^2 < (A^2 - L_a^2)$ $E_{as} = E_c - ((\rho \cdot I)/2 \cdot \Pi \cdot L_{a}) \cdot \ln((X + L_{a}/(X - L_{a}))$ $X = (L_a^2 + B^2)$
The equations for rectangular anodes have been developed by P. Singh and W. H. Thomason,ConocoPhillips (2005). This derivation is similar derivations done previously by E. D. Sunde and others The equation for "rectangular shield" and "long strip rectangular strip shield" are equal when: $A^2 = L_a^2 + B^2$ The two equations "rectangular shield" are equal to the equation for the "circular shield" when: A = B and L_a is very small	

| Table B-18 CP in service: Potential monitoring and action requirements	
Measured potential (mV) Ref. Ag/AgCl/SW	*Action required*
More negative than -1 000	Check "set" values for ICCP- system (This potential range will not occur with a SA-system)
More negative than -900	"Leave"-no action required
More positive than -900	Monitor and plan for retrofit of anodes (or increase ICCP-anode current output)
More positive than -800	Replace anodes immediately (or increase ICCP-anode current output)

B.2 Figures
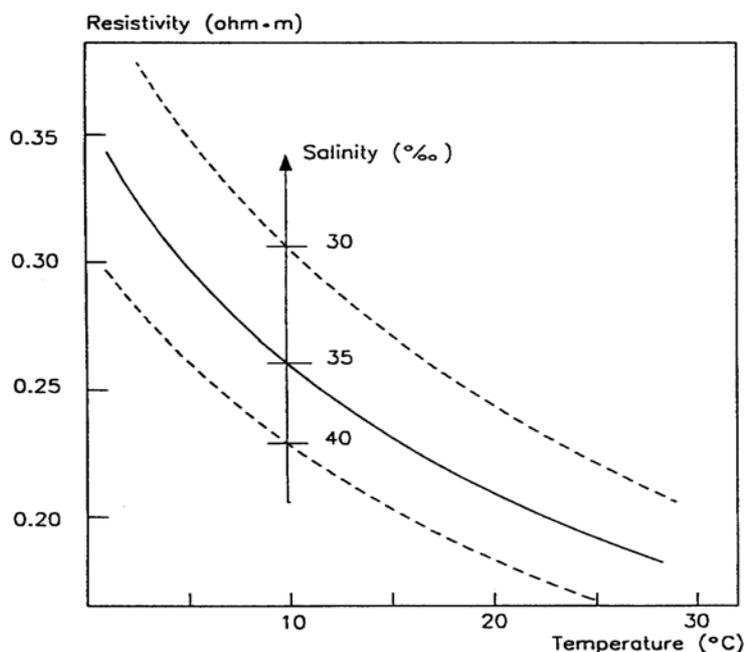
Figure B-1
Seawater resistivity as a function of temperature for the salinity range 30 to 40 ‰.